Spectral Forest

Initial Design Report Template

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Fall 2023-Spring 2024

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DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

This is Report 1 for Team 10: Spectral Forest from the capstone group of Fall '23 – Spring '24. Our project is a shared capstone project, we are teaming up with an EE capstone team and working on different areas of the project that will join in the finished product. This project has two purposes, one for each of our clients. Alexander (Allie) Shenkin wants to use this device for ecology in a stationary position on the forest floor and while attached to a drone. While in either of these two situations the device will collect light data through a small aperture then after bouncing off of a few mirrors it will be directed into a linear array that can decipher the light and display it to a computer. Once the computer has the data a user can run the data through various software's that can use the given data and compare it to previous data sets, run it though simulation models to predict health of the forest, and view water concentrations in the soil, leaves, and trunks. Our other client, Carlo da Cunha, will use this device in a lab setting to look at semiconductors and how they absorb or reflect light and how the light energy is transferred across and through the surfaces. The EE team is designing a custom PCB used to collect data and store it on an on-board SIM card. They are going through the entire process of selecting resistors, capacitors, LEDs, and a battery. They are also tasked with selecting an appropriate linear array that is sensitive to the wavelengths that our client is interested in. The wavelength range that our clients are interested in is 350-1000 nm which is a little bit of UV, all the visible, and some of the IR. Our main task as the ME team is to protect all these components from the outside environment by creating a robust, waterproof, and spectrally intelligent enclosure that will keep all ingress out to the degree that a NEMA 3X rated enclosure would accomplish. A robust design will be simple as our device will not experience much stress under normal operation, but we must design for a fall to occur before drone flight take off and ensure the integrity of our device will not be compromised. We have not decided on any specific strategy yet, but a promising option is adding small holes in the inner sides of the walls where we can add a type of insulation material like foam that will act as a shock absorber throughout the walls of the enclosure. Material selection for the enclosure will be crucial to its strength and life in the field. We have decided on Onyx and carbon fiber reinforced nylon that has great strength capabilities and we can 3D print it on campus at the engineering building. Waterproofing to the standard of a NEMA 3X enclosure will just require the accurate 3D printed dimensions of the top and bottom pieces of our design to mate smoothly together and implement a high-quality O-ring to provide the seal to block anything from entering at that access point. The other access points will be the USB-C port and the aperture. The USB-C port will be equipped with a rubber sealing door that will block dust and water from entering the device. As for the aperture, the design has not been finalized but we anticipate using a circular hole covered by a cosine corrector that in our case will be a short cylinder of silica-quarts glass sealed along its edge with industrial grade structural epoxy or silicone to provide a weather resistant seal. When it comes to designing a spectrally intelligent enclosure what is meant by that is something that only allows the light we want to reach the linear array and the light we don't want never enters or is caught in a light trap inside the device. Our preliminary design concept that we are working on at the moment is a mirror-based design with a single aperture, followed by a tiny slit to allow only a small beam of light to enter the device as light will expand in beam width as it travels. After entering and expanding the beam will bounce off a collimating mirror which forces the beam to act like a column and have a consistent width by stopping it from expanding further. Then the bean will bounce off a diffraction grating which is a collection of thousands of tiny prisms that will split the light up by wavelength and create a rainbow, the same function that a prism provides but a diffraction grating is cheaper and easier to insert in a small space. Then the light bounces off a focusing mirror, through a beam splitter, and into our two linear arrays that are used to capture the entire spectrum that we are interested in. These two linear arrays will be mounted on the custom PCB along with all the other EE components and mounted to the inside of the box. The box will also be equipped with a balloon-based pressure equalization system that employs a strain relief clamped around a piece of tube that is open to the air on one side and the balloon in on the inside the box, attached with cable ties. The balloon will increase and decrease volume with the change in altitude therefor changing the volume in the box and equalizing the internal pressure.

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1 BACKGROUND

In the background section of this report the project description will be summarized based on the proposal that was provided by the client at the beginning of the semester, along with the preliminary meetings that we had with the sponsor to gain insight to their vision and desired outcome of this project. Why the project is important, along with the budget we are provided with, and the fundraising that we will conduct will be discussed. Secondly, the major deliverables that have been completed up to this point will be described, including the Team Charter, Presentation 1, and Presentation 2. Lastly, a success metrics will be shown describing how the team will be successful and how they will prove it will calculations, tests, and design requirements.

1.1 Project Description

The purpose of this project is to build a robust spectrometer housing to protect the internal components of the spectrometer. The range of wavelengths of light that the client is interested in is 350-1000 nm, this product could help change the trajectory of forests research and conservation efforts. Insights into plant health, leaf makeup and thickness, water concentrations in soil and in trees, temperature differences due to water conspiring up the tree, this data will be put into prediction models to analyze the forests' health. The unit will be placed in a specific understory position to continuously monitor a location. Later the device will be attached to a drone and can analyze the forest from above. The lab application is to view the optical and energy properties of semiconductors like energy transfer and light reflection and absorption. The use of a single aperture with mirrors to direct the light into the linear array being used to decipher the light and collect the data. The budget allotted to us for this project is $500 for each sub team, so $1000 total combined between the EE and ME teams. It was made clear that this money can be moved around to accommodate higher costs on the ME side of things. On the fundraising front, we are required to raise 10% of the budget ourselves and with that number only being $50 dollars, our fundraising is essentially complete as we can donate the money ourselves and have it to pay for prototyping to avoid the slow process of paying for it with the allotted budget.

1.2 Deliverables

Team Charter: within is the team purpose, team goals, members personalities, roles, and responsibilities, ground rules, and potential barriers combined with coping strategies were discussed.

The team purpose has been described above, the team goals that were stated at the beginning of the semester are as follows: create a final product that is functional and successful in its role. We would like to exceed the clients' expectations, produce a quality item, and continue the expectation of excellence that is produced from NAUs undergraduate engineers.

As for the team members personalities, roles, and responsibilities, Tyler: My personality style leads to me being organized and conservative. I will take things slow and make sure they are done right but that could take an extra hour which is why I like to start tasks early so there is plenty of time to make sure everything is right. I am also very logical and diplomatic so I will get the opinions of others and collaborate before acting. This style will make me a good Team Manager because I pay close attention to detail and will be the last one to look over documents before submission to ensure the highest quality, if time allows. Along with Team Manager I will also take part in the test, manufacturing, CAD engineer positions as well. Since we are a team of three, we will all share these three roles. Torrey: My personality style is a strong inner motivation to create and implement innovative ideas, coupled with assertiveness, pressure-handling abilities, and a drive for excellence or perfection. I excel in innovative thinking, problem-solving, and keeping high standards in my pursuits. My resilience under pressure and how I approach challenges make me effective in demanding situations. A fault I have is I often strive for perfectionism which is not always best in every situation. These traits lead me to be successful in the role of financial manager. The major points necessary for the role are effective communication and attention to detail. Paired with this role we will be splitting the roles of test, manufacturing, and CAD engineers amongst ourselves as needed throughout the year. We are all equally qualified to complete the tasks that come with the roles and so we have decided it to be most effective to split them evenly. Derrick: My personality style reflects a generally diligent worker that works well within a team and can help implement creative ideas/strategies to improve the teams' overall quality of work. When working within a team, I can effectively communicate and cooperate with each team member to make sure everyone is on board with what tasks need to be completed as well as how efficiently the team can complete said task. This makes me a suitable candidate as the Logistics Manager who oversees internal and external communications (clients, stakeholders, professor, etc.) for the team. In addition to this role, I will also contribute towards the test, manufacturing, and CAD engineer positions to accommodate for the team having less members, sharing these roles between my team members and me.

Next, ground rules were laid out, we will start by planning for the coming week and decide if an additional meeting is needed, which can also occur later in the week if workloads pile up from other classes. Communication is of the utmost importance as it will be hard to accommodate if no one speaks up if they are struggling or need help. We will decide on a case-by-case basis if we need to meet in-person or remotely, remotely is more convenient and will be the preferred method, but it is up to the discretion of the team. Before presentation, a goal of the team is to ensure each member holds the same understanding of what is being presented and to practice the whole presentation together at least 2-3 times and give feedback to each other and ask questions before presenting to the class. To be successful during this year long project consistent participation is required if someone is busy with classes, work, extracurriculars, and living their life it must be made known so the rest of the team can accommodate and plan. As for accountability, the team will employ the honor system as we are college students and really have no power over each other, other than threats but we would prefer not to resort to that.

Lastly, potential barriers and coping strategies, disagreements are bound to happen and when they do the team plans to have a meeting to hash them out and come to a collective decision that ideally satisfies both parties. Each member will give their opinions and then as a group we will discuss the possible pros and cons of each idea with supporting evidence and proper justification. Then if a consensus is not reached, propose a combination of the two ideas. If members are still not satisfied, will we begin brainstorming fresh solutions and propose those. If the disagreement persists, narrow the options down to two then we will assign each choice to either heads or tails and flip a coin to avoid any more wasted time. When working within a team, the most common potential barrier to occur are extracurricular activities. This can come down to a variety of things such as individual sports, work, and personal matters as well. Each team member has their own set of extracurriculars that they must tend to over the course of a day, and this can cause distraction as well as lack of communication over the obligations needed to be withheld for the team. In relation to this, overall time management also plays a significant role in how well the team produces its' work. In past experiences with other groups, individuals would wait until the last minute to work on team assignments and cause the team progression to slow down throughout the project. Along with this came potential issues in quality of work, since there was more emphasis on getting the work done rather than getting it done well.

Extracurriculars and delays in the project are sometimes unavoidable and to be able to work as an effective team we must devise strategies to overcome these barriers. Team members will have different schedules throughout the day and working around them can prove to be difficult. However, with better communication between the team and better management of time, the team can conquer these challenges and work more efficiently and productively. Getting the work started ahead of time and cooperating as a team will allow for each member to be on the same page about the project in addition to giving time for revisal for work of the highest quality.

Presentation 1: The first presentation was all about defining our customer needs/ requirements and engineering requirements. Other sections that were included were project description, background & benchmarking, literature review, math modeling, budget, and schedule. All of which are linked to a different section of this report where it is gone into more detail.

Presentation 2: The focus of the second presentation was concept generation and evaluation. The other notable sections include project description, functionals decomposition, black box model, engineering calculations, Pugh chart, decision matrix, schedule, BoM, and budget updates.

1.3 Success Metrics

This project will be a success if we create a spectrometer for less than $500, it can withstand typical outdoor weather by continuing normal operation, the internal components are easily accessible and adjustable, and the device accurately takes light data. The budget will be accessed by the team's budget liaison in the second semester towards the end when we are getting closer to making our final purposes and if we are under, at, or just over $500 that is a win. We will test the functionality of the sealing of the box by running water over it and then letting it completely dry then opening it up and seeing if there is any water present. We will do this with a scale version, so it is cheaper. Making the internal components easily accessible is the easy part, that is accomplished by simply adding a door with screws that come out and designing the internal mounting to be located on the door, so it all comes out together and is easy to see everything. Making the device easily adjustable will be slightly more difficult but that can be done by adding small adjustment screws on either side of the mounting plate for the mirrors so the user can adjust the mirror angles if they become out of alignment during use. The goal of the device accurately taking light data is partially on the EE side but we are responsible for aligning the mirrors and linear arrays in a way that it is repeatable and also adjustable so it can be calibrated and tuned.

2 REQUIREMENTS

Contained in this second chapter are the requirements laid out by our client in the form of customer requirements which are goals that the client would like to achieve with this device. Along with constraints due to the nature of components that are necessary to include. The customer requirements are then translated into engineering requirements and are worded in such a way that they are quantifiable and testable so we can verify that our design does in fact meet that requirement. These two styles are then compiled into a House of Quality and the technical requirements are ranked based on how well they meet each customer's requirements. Their goals, values and units are shown in the HoQ as well.

2.1 Customer Requirements (CRs)

- Protect internal instruments – Design a shell for the design to incase all the internal components from outside factors and prevent them from moving or interfering with one another.
- Resilient to temperature fluctuations - The inside components could produce heat when operating which can cause problems in the functionality of the design. There are also temperatures (both high and low) from the outside that can affect the model and must be accounted for.
- Protection against humidity and water entering the unit – In colder temperatures, humidity can build up inside the unit, causing the internal components damage and possible failure. There can also be outside rain or snow that can possibly get inside so the team must seal the design to be waterproof.
- UV resistance - The only light that should be reflected into the unit should be the light above the aperture. This means that the rest of the box should resist light so that the light can be focused and reflected on the cosine corrector to record the spectral data. This can be done by simply making the outside color of the box white.
- Proper venting – When taking the design to different altitudes, there can be pressure built up within the unit, causing it to expand or collapse slowly if not properly ventilated.
- Compatible design to accommodate all electronic components with ease of install – The shell should allow for easy accessibility to the internal components in case of possible damage or failure in the design. It should also be made to properly fit and in case any new components if added.
- Integrated cable management – The design must contain ports for outside cables and hard drives to be connected. These ports will be used to withdraw data from the system as well as possibly power it if needed.
- Gimbal mounting system - In some cases, the design will need to be mounted to a drone for surveillance over harder to reach regions. Therefore, a gimbal mount is a great solution for a mounting system because most drones have gimbals for cameras such as a GoPro.
- Small and Light– When creating the design, the client wants it to be as light and as small as possible in order for easier portability and mounting.

2.2 Engineering Requirements (ERs)

- Long life – The device should last 5 years or more
- Stable internal Temp – We want the internal temperature and the external temperature to vary no more than 2 degrees in either direction.
- Tight tolerances – The tight tolerances are essential because then the top and bottom halves will connect seamlessly and there will be no gap
- Waterproof – The device should be waterproof to the degree of a NEMA 3X which is rated for rain, sleet, and ice. No water should be present when exposed to these conditions
- Small – The size we must fit into is a 100x120x200 mm area (0.0024m^3) that is constrained by the dimensions of the drone that our client will be using to fly the device around with
- Lightweight – The weight must be less than 3.3 lbs at a maximum as that is the max payload that the drone can carry but we will shoot for less than 2 lbs.

2.3 House of Quality (HoQ)

The House of Quality is represented by our team's system QFD below in Figure 1. In the QFD, the technical, engineering, and customer requirements are all weighted and compared according to their significance in the design. Each technical requirement is provided with a target that the team wants to be under or meet and consists of their own units. The three pre-existing state of the art (SOTA) designs were then ranked according to the customer needs. This step is useful in concluding which requirements are more valuable than others. As well as getting a baseline on how to test which design concepts are better or worse. This process can be redone in the future with later designs or iterations as well as individual components.

System QFD

Project:	Spectral Forest
Date:	Fall 2023

Correlation Legend	
++	Strong positive
+	Moderate positive
-	Moderate negative
--	Strong negative

Legend	
A	APEX Imaging
B	ASD FieldSpec 4
C	NASA HyMap

1	Long Life						
2	Stable internal Temp	++					
3	Tight tolerances	+	+				
4	Waterproof	++	++	-			
5	Small	+	+	+	+		
6	Lightweight	-	--	-	-	++	

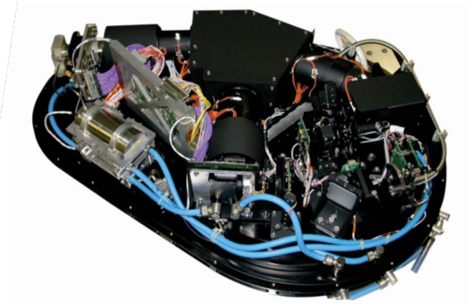
			Technical Requirements						Customer Opinion Survey				
	Customer Needs	Customer Weights	Long Life	Stable internal Temp	Tight tolerances	Waterproof	Small	Lightweight	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
1	Durable	5	9			9	3					AB	C
2	Vents ensure semi-constant conditions	4	3	9		9	1				B	A	C
3	1 central aperture	5		3	9	3	3					BC	A
4	Unit is sealed	5	9	3	9	9						AB	C
5	Ease of access	3		1		1	9				C		AB
6	Reliable	3	3	3	3	3	9	3			B	AC	
7	UV resistant	3										ABC	
8	Ambient operating range of 0-50 °C	3.5	3	9			9					AB	C
	Technical Requirement Units		Years	°F	in	water	mm	lbs					
	Technical Requirement Targets		5	F +/- / sec	+/- 0.01	0	.0024m^	<2					
	Absolute Technical Importance		121.5	109.5	99	153	119.5	9					
	Relative Technical Importance		2	4	5	1	3	6					

Figure 1: QFD

3 Research Within Your Design Space

3.1 Benchmarking

To begin the design process, the team must first consider the pre-existing models and consider how they function as well as the subsystems contained within each. The state of the art (SOTA) designs being presented utilize spectrometers that capture spectral data ranging from 350-2500 nm. The 3 pre-existing models use remote sensing to study forest ecosystems through biophysical and biochemical variables.



Design 1: Airborne Prism Experiment (APEX) Imaging Spectrometer

The APEX imaging spectrometer records hyperspectral data in 300 bands with a spectral range of 380-2500 nm and at a spatial ground resolution of 2-5 m. It is also able to be mounted on drones.

Design 2: ASD FieldSpec 4 Standard-Res Spectroradiometer

The ASD FieldSpec 4 is a portable, handheld spectrometer with a spectral range of 350-2500 nm. It comes with a plethora of interchangeable contact probes and mug lights for recording data by hand.

Design 3: NASA HyMap Sensor

The NASA HyMap Sensor utilizes four spectrometers in the interval of 450-2450 nm. The design consists of two major atmospheric water absorption windows and an on-board bright source calibration system. This model is used in planes and helicopters when surveilling different environmental variables over large regions.

3.2 Literature Review

3.2.1 Tyler Lerew

[1] NEMA Enclosure Types - Website

This website describes the ratings for what environments electrical enclosures can safely be used in. They are based on the amount of ingress allowed to enter the enclosure, meaning dust and water. We must match the rating to the conditions that our unit will be experiencing. The rating that matches our operating conditions is the NEMA 3X.

[2] Electronic Enclosures, Housings and Packages, Woodhead Publishing, Chapter 4 - Book

This book chapter contains information about operating conditions, aesthetics, safety, internal fits, structural robustness, materials, maintenance. This information about these important topics will help us design a robust housing that conforms to the industry standards for electronic housings designed for external use when exposed o strong UV, rains, wind, sleet, and ice.

[3] Electronic Enclosures, Housings and Packages, Woodhead Publishing, Chapter 6 - Book

This book chapter contains information about IP ratings (Ingress protection), condensation, corrosion, gaskets, and extreme conditions. This information will help us with designing our enclosure in a way so it will not fail in the field under extreme conditions when exposed to harsh weather conditions. And it will help us design in a way to avoid or at least limit corrosion and condensation on an in our enclosure.

[4] Geometric optimization of an accurate cosine correcting optic - Paper

This peer reviewed paper discussed insights about optimizing the cosine corrector, so all the light that enters into our devices makes its way to the chips in the correct orientation. This will help us in our design because it is essential that the light is as spectrally flat as possible, so we get an accurate reading from the linear array

[5] Multispectral bidirectional reflectance of northern forest canopies with the advanced solid-state array spectroradiometer (ASAS) - Paper

This peer reviewed paper discusses the use of a linear array inside of a spectrometer used to survey the forest. This will aid in the design because this is exactly what we are trying to achieve, and the information presented here will help move us in the correct direction to achieving this task.

[6] Micro actuators for aligning optical fibers - Paper

This peer reviewed paper explains potential solution to misalignments of optical fibers during transit and data collection. There is technology that will mechanically adjust the optical fibers to ensure they are always perfectly aligned but this technology is of course very expensive. Still, it is very interesting and if we receive one of the large grants that we applied for this could be relevant but with our current budget allotment, it is not possible.

[7] Understanding Fiber Optic Splitters and How They Work - Website

This website aids in understanding how fiber optic splitters work so we can accurately design around it for optimal performance. Since we are taking a single aperture and splitting it into 3 chips we will use this information to help us split the light effectively. It is very interesting and if we receive one of the large grants that we applied for this could be relevant but with our current budget allotment, it is not possible.

[22] How did they make iPhone waterproof - Website

This Google search yields a few websites and videos that take iPhones apart and describe how they are sealed so well and can remain submerged at a depth of 6 meters for a claimed 30 minutes. This time limit has been proven to be much longer by independent users. This will help us in our design because we can use the same strategies that Apple uses to seal their products and implement those strategies into our device as well.

[23] The Benefits of Fused Silica & Quartz - Website

This webpage shows the versatility and usability of fused silica and quarts glass in spectral application. This will help us in our design because with their large range of transmissibility their application in optical situations is unmatched.

[24] Spectrometer Introduction, Tear-down, and Data Analysis for Plant Phenotyping - Website

This YouTube video shows the internal structure of a spectrometer that uses a linear array. This video is what we will be basing our initial design off of has been a good source of inspiration for design.

3.2.2 Torrey King

[8] Handbook of Optical Design - Book

The handbook is a valuable resource in the field of optical design. It covers a wide range of topics related to optical design, making it an essential reference for professionals and researchers in the field of optics and optical engineering. The book explores various aspects of optical design, including principles, techniques, and applications, providing in-depth knowledge for those working on optical systems and optical device design.

[9] Fiber Optic Sensors: Fundamentals and Applications - Book

This book provides a detailed exploration of the fundamental principles of fiber optic sensors. It offers an extensive examination of the theory and practical aspects of fiber optic sensor technology, covering their design, operation, and applications in various fields, including spectrometry. This book dives farther into this topic than necessary for this project. The book serves as an invaluable resource for researchers, engineers, and anyone seeking a deeper understanding of fiber optic sensors.

[10] UAV-based Measuring Station for Monitoring and Computational Modeling of Environmental Factors - Paper

This paper presents a UAV-based measuring station designed for the monitoring and computational modeling of environmental factors. The authors discuss the utilization of UAVs equipped with advanced spectroscopic sensors for various environmental monitoring applications, such as vegetation analysis and pollution detection. The paper offers insights into the innovative use of UAV technology to collect essential data for environmental research, demonstrating its potential to contribute to the fields of environmental science and remote sensing.

[11] Research and application of UAV-based hyperspectral remote sensing for smart city construction – Paper

This journal article explores the research and application of UAV-based hyperspectral remote sensing in the context of smart city construction. Hyperspectral imaging, a form of spectroscopy capable of capturing a wide range of wavelengths, is a central focus of the study. The paper examines the various applications of UAV-based hyperspectral imaging in fields that are separate but conceptually comparable to the project at hand. It delves into how this technology can be harnessed for enhancing urban planning, environmental monitoring, and the development of smart cities, offering valuable insights into the potential integration of hyperspectral remote sensing in urban development and management.

[12] UAV-based multispectral remote sensing for precision agriculture: A comparison between different cameras - Paper

This journal article provides a comprehensive comparison of various cameras used in UAV-based multispectral remote sensing for precision agriculture. The study focuses on optimizing crop management through the application of UAVs and spectroscopic sensors. It offers insights into the benefits and limitations of different camera technologies in the context of precision agriculture. The research findings contribute to the enhancement of agricultural practices, enabling more efficient and sustainable crop management by harnessing the capabilities of UAVs and multispectral remote sensing.

[13] 1x4 Polarization-Maintaining Fiber Optic Splitters at Thorlabs - Website

Thorlabs, Inc. offers 1x4 Polarization-Maintaining Fiber Optic Splitters, which were considered for application. However, their suitability may be affected by cost constraints and the potential need for adjustments based on chip type changes.

[14] Cosine Correctors at Ocean Insight - Website

Ocean Insight is a reputable manufacturer offering a diverse range of cosine correcting lenses, essential for optimizing light filtration prior to its entry into the fiberoptic and chip components. This source serves as a potential vendor for procuring these essential items.

3.2.3 Derrick Doan

[15] Imaging Spectrometry for Soil Applications, in Advances in Agronomy - Book

This book shows how spectrometers work and how they detect differences in soil through biophysical and biochemical properties such as light, precipitation, temperature, etc. This will aid the team in understanding how a spectrometer functions in different applications as well as the properties being recorded.

[16] Designing Plastic Parts for Assembly – Book

This book provides an overview of the design and manufacturing process of plastic parts within an assembly. Some key information that is included within the book is the process of material selection, fasteners, hinges, and techniques for assembling the model. The team can use this information when having to decide on different methods of design or selection over parts for the model and have references to previous designs.

[17] eoPortal - Online

This website provides pre-existing designs, specifications over parts, sub-units/subsystems, and figures to demonstrate how the models operate as well as record various types of data. The team can use this website for comparison over designs and reference for internal subsystems.

[18] Malvern Panalytical - Online

This website offers pre-existing design comparison and provides key applications, specifications, and accessories such as probes and lights. The team can use these models in state-of-the-art reviews and benchmarking of the current design.

[19] “Fusion of imaging spectrometer and LIDAR data over combined radiative transfer models for forest canopy characterization” - Paper

This peer reviewed journal covered remote sensing signal of imaging spectrometry and large footprint LIDAR to derive comprehensive canopy characterization of forests. This paper can be used to understand the different imaging methods and provides previous tests results to help base our design on.

[20] “Remote sensing of forest biophysical variables using HyMap imaging spectrometer data” - Paper

This peer reviewed paper demonstrates hyperspectral image data using HyMap sensor and linear predictive vegetation models. These models and recorded data are used to predict future outcomes in plant life in specific regions. This paper can be used to show methods of

[21] “Simulating imaging spectrometer data: 3D forest modeling based on LiDAR and in situ data” - Paper

This peer reviewed paper provides information on key biophysical and biochemical variables as well as insight on photosynthetic processes, plant health, plant functional types, and species composition.

3.3 Mathematical Modeling

3.3.1 Free fall off a table - Tyler Lerew

The equations that were used in this mathematical modeling were the impact for a falling object $F = \frac{mgh}{d}$ [25] and the stress equation $\sigma = \frac{F}{A}$. The total force incurred by the box from the fall is 120 N found by a height of 1.8 m, a mass of 0.34 kg, and a bounce distance of 50 mm. The stress was found to be .5 MPa by the force of 120 N and an area of 253 mm^2. The ultimate strength of the material of choice, Onyx, is 69 MPa so there will be no yielding to worry about, but the shifting of internal components will be of some concern.

3.3.2 FEA on mounting system - Tyler Lerew

There were no equations used when analyzing the mounting system because I used FEA through the cloud-based software, Sim Scale. I set up the boundary conditions and force locations and ran the simulation and analyzed the results. There was only one place with a high stress concentration and that was because of the sharp corner that resulted in a tiny area and caused a super high stress to occur there. This is because there was a gap between the sleeve nut and the casement. When constructing this there will be some type of fastening glue to connect these two locations so the area will be large and the stress small.

3.3.3 Electronic and Environmental Heat Disbursement - Torrey King

One major design constraint that must be overcome is the temperatures the housing unit and internal electronic components may be exposed to. Major concerns stem from a few sources. First, the heat produced by the variety of electronics must have a way to dissipate and not overheat itself. The second major cause will be from the sun when operated during the daytime in the field. The third major concern is the overall external environment temperature that the unit will be operating in. To do some brief calculations for these there are some equations. Fourier's law of heat conduction which defines the heat transfer due to conduction through materials specifically temperatures within the internal environment to the external environment. Essentially exploring the heat transfer of produced heat inside to how it will cool off depending on some different materials we are looking into and simple guesses at proposed geometry of the unit. That equation is as follows $Q = -k \cdot A \cdot \frac{\Delta T}{\Delta x}$. Assuming the final design will contain an air vent to assist in pressure differentials during flight we can use that to assist in keeping the internal components cool. Newtons Law of cooling can assist in that: $Q = h \cdot A \cdot (T_s - T_a)$. For the radiation from electronics and the sunlight. Stefan-Boltzmann equation helps represent that: $Q = \varepsilon \cdot \sigma \cdot A\,(T_s^4 - T_o^4)$. This is just a rough breakdown and more exact calculations will be done later as the project scope narrows.

3.3.4 Vent Flow and Temperatures - Torrey King

To continue calculations on the topic of heat transfer and general material transfer through a vent to assist in dealing with pressure differentials and temperatures that may harm the sensitive electronics within the unit there are two general equations and an example of a potential vent. The vent chosen to estimate what can be achieved in the final design was a general vent that gore produces. It's a "weather-resistant" vent that allows 4000 ml/min at 70 mbar. Using the mass flow rate equation: $\dot{m} = \rho AV$ and the ideal gas law: $\rho = \frac{P}{RT}$ it can be calculated that the chosen option of a vent will work plenty fine per our assumptions. Based off these equations, this level of vent will be more than adequate for the final design.

3.3.5 Forces applied when mounted to a drone - Derrick Doan

When mounting the design to a drone, it will be faced with the same forces as the drone itself. These forces include mass (m), acceleration (a), gravity (g), thrust (F) and weight (W). The mass was estimated by adding the mass of a drone, 2 kg, and the approximate mass of the design, 0.34 kg, to get 2.34 kg. The acceleration was also estimated using the average speed that drones travel, 45 mph or 20.13 m/s. With these variables we can calculate the thrust (F) using the equation $F = ma$ to be 47.1 kg-m/s and weight (W) using $W = mg$ to get 22.93 kg-m/s^2. Putting the variable thrust over weight, we get the ratio $\frac{F}{V}$ which represents acceleration and climb rate. The higher the ratio, the higher acceleration and climb rate the design will experience. In our example the calculated ratio was 2.05 which means it will experience high levels of forces. It is important to understand these forces to not allow for the design to fail when facing them.

3.3.6 Cosine Correction - Derrick Doan

Cosine correction is needed in the design because the light aperture needs to be spectrally flat to produce even data across the spectrum. Without it, most apertures can only see approximately 25 degrees of the area exposed and can receive a plethora of energy levels when coming in at different angles. Cosine correction also expands the view of the aperture, allowing for a full 180-degree spectrum that emits light evenly across. This is based off Lambert's Law: $L_{\theta} = L_0 \times cos\theta$, which states the light intensity on the reflected surface times the cosine of the angle being reflected is the light intensity being received on the other end. The top angle reads as 0 degrees and goes down to 90 from all sides because light becomes more intense as the angle becomes more obtuse.

4 Design Concepts

4.1 Functional Decomposition

The design is simple with minimal moving parts and limited function per se. It is helpful to confirm this and clarify the functions of the housing unit and internal parts. For the housing unit, based on the design criteria which come from technical requirements. These are the following in no particular order: long life, stable internal temp, tight tolerances, waterproof, small, lightweight, durable, one central aperture, unit is sealed, ease of access, reliable, UV resistant, ambient operating temp of 0-50 degrees Celsius. Some of these criteria are more critical than others which helps in ranking design qualities. However, they are all used in determining necessary functions. This list generated the following black box model.

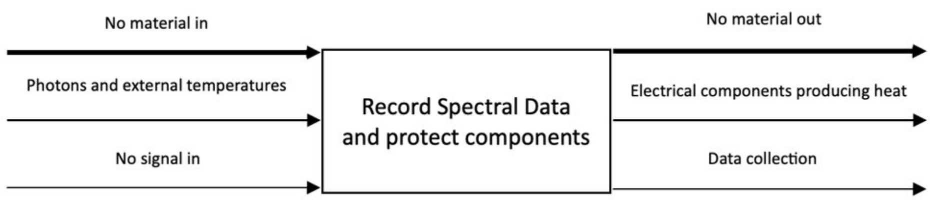


Figure 2: Black Box Model

In this black box model, it states that there is no material change in or out of the unit at any point during the process of the unit being used. There is also no signal input, and the only output signal is internally in the process of data collection as well as a USB port that allows for the off-loading of the data collected to be analyzed afterwards. Energy transfer is a little more complicated as there are photons entering the aperture and then also radiation. This causes the production of heat to occur as well as the electrical components to do their thing.

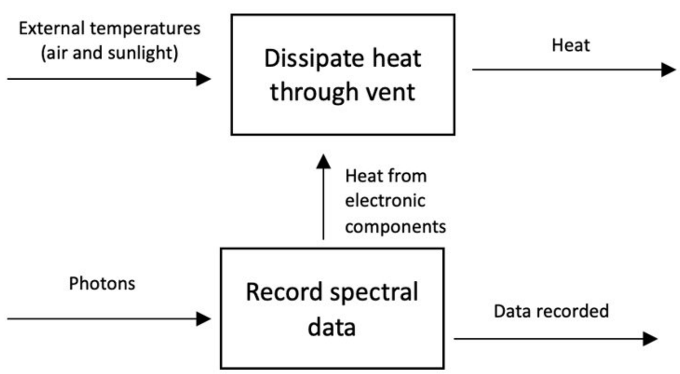


Figure 3: Functional Model

The Functional model is the same concept as the black box model and in the example of this project it's just about as simple. It shows the breakdown of what is happening and where within the system it occurs in a more coherent way than. It is important that the unit can reliably and easily dissipate heat in order to protect the internal electronics. It has to do this within the constraints of size and weight to allow it to be drone mounted. The functional model for the internal electronic components would be much more interesting and robust, however the EE sub-team will be handling all of that portion of the design.

4.2 Concept Generation

Sub System	1	2	3
Optics	Linear Array ✓	Fiber Optic	Camera
Shape	Rectangular Prism ✓	Cylinder	
Cosine Corrector	Silica glass ✓	PTFE Film	Microscope Slide
Pressure Equalizer	Inside / Outside Balloon ✓	Inside / Outside Vent	Inside / Outside Hole
O-ring	Rubber	Fluorocarbon ✓	FFKM
Material	ABS	Onyx ✓	Polycarbonate

Figure 4: Morph Matrix

The main subsystems that the ME team is concerned with are the optics, shape of the enclosure, cosine correction, pressure equalization inside the box with outside of the box, O-ring selection, and the material of the enclosure.

Optics is how the light will be turned into data that can be read by a computer and then analyzed by the user. The 3 options are a linear array, fiber optics, and a camera. The pros for the linear array are that it is cheaper and easy to use. The cons are that it is subject to shifting and will result in inaccurate results as it requires the use of mirrors to transform the light into a rainbow because its array of pixels is set up in such a way that each one can only read the light at a certain wavelength. The pros of a fiber optic cable are that there is no need for mirrors, and it will yield consistent results. The cons are that it is very expensive and difficult to mount to chips without blocking the light fiber. The camera pros are that it is very cheap and easy to use. The cons are that it is bulky so it will increase the size of the enclosure and it requires modification to remove filters to it can accept more ranges of light.

Shape concepts are the geometry of our enclosure and will govern how everything on the inside will integrate together. The 2 options for the shape of our enclosure are rectangular prism and a cylinder. The rectangular prism's pros are that it is easy to manufacture/ 3D print and it will integrate easily with most drones and mounting systems. The cons are that it has sharp edges but that can be avoided with filleting in CAD. The cylinder has no pros as it is just an awkward shape and is difficult to make.

The Cosine corrector will make the light entering our device spectrally flat meaning the light entering will be transmitted through the cosine corrector at a consistent percentage, preferably around 90%. There are 3 options, fused silica quarts glass, PTFE film, and a microscope slide. The fused silica quarts glass has pros of high transmissibility and ease of access. The cons are that it will have to use some fastening glue to attach it to the box and it could be easily removed if a force is applied to a side face. The PTFE film's pros are once it is fastened it will be more secure because it is flush to the surface because it is a film. The cons are that it is difficult to attach to the box as it is very thin and makes it susceptible to punctures and it has lower transmissibility. The microscope slide has pros of high transmissibility and cons of weak strength.

The pressure equalizer is what will keep the box stable in temperature and pressure by allowing either allowing air to enter or using a clever balloon system to achieve this. The 3 options are a balloon, a purchasable vent, and a hole. The pros for the balloon are that it is a very simple strategy to equalize the pressure and will not let any ingress or air enter the enclosure. The cons are that it will take up more space than other options because it has 4 components, and it could get pricy if we cannot find the right balloon readily available. The vent pros are it is only one piece and will be easy to install. The cons are it could leak and let ingress enter unless we spend a large portion of our budget on an expensive vent rated for submerging. The hole is not considered as it is open directly to the outside and anything can enter the enclosure.

The O-ring is what will seal the largest entry point of our enclosure off from the outside, so it is very important that its selection is taken seriously. The three options are rubber, fluorocarbon, and FFKM. The rubber is not considered as it is the cheapest but will not offer much is resistance to corrosives and irritants. The fluorocarbon O-ring pros are that it is resistant to outdoor weather and most irritants. The cons are that it can be semi-pricy for an O-ring. FFKM's pros are that it is specifically resistant to weather exposure and sunlight and a broadband of chemicals and acids. The cons are also the price. [26]

Material selection is of the upmost importance as this will take the brunt of the weathering and sun exposure. The three options for material are ABS, Onyx, and Polycarbonate. The pros of the ABS are the high glass transition temperature at 100 C which is the temperature that the 3d printed thermoplastic starts to become gooey. It is also cheap and readily available. The cons are that is has a lower melting temperature at 190 C, and it is not the best looking when completed. The pros of Onyx are the smooth final product, readily available, very strong, and a high melting point at 220 C. The cons are it is semi-pricy, it has to be printed on campus by students so the quality of product might vary, and the glass transition temp is lower than ABS at 70 C. [27] Polycarbonate has pros of high strength, it has strong outdoor ratings, and it looks good. The cons are that it is super expensive and will have to be injection molded.

4.3 Selection Criteria

Long life, stable internal temp, tight tolerances, waterproof, small, and lightweight the engineering requirements that drove the concept selection as being the criteria that all of the selection decisions were based on. Each of these requirements are quantifiable as shown in the house of quality in Figure 1 and in the engineering requirements section. A summary of those quantities is a long life of 5 years, found by waiting that long and checking back or by running a cyclic loading simulation to simulate a lifetime worth of vibration and calculating how many years it will theoretically last. Stable internal conditions are desired to be plus or minus 2 degrees Fahrenheit difference between the inside and outside. This can be tested by inserting thermal couples connected to a computer and reading the temperature data and calculating the difference after putting the device in a freezer. Tight tolerances can be tested by reading the specs on the 3D printer used and measuring the gap present on the device after printing in an area that should have been flush. Waterproof is based off of the NEMA 3X rating that is rain proof so we can simulate rain and then after drying open the device and inspect it for water inside. Small is testable by measuring the dimensions after printing. Lightweight is also testable by weighing the device with a scale after assembly is complete.

4.4 Concept Selection

Each design shown in a morph matrix in Appendix B Figure 12 was ranked based on how well it stacked up against the datum based on customer requirements. These designs were all ranked based on industry standards shown in order of viability for our application, ranging from green being the best to orange being the worst. Only the top three were drawn out as shown in Appendix B Figures 9-11. We changed our design, so the CAD is outdated as shown in Appendix B Figures 13-15. The preliminary revised CAD is shown in Appendix B as well in Figure 16.

The team went through a comparison phase, in which subsystems were either supported or ruled out in designs and began working towards drawing potential concept designs shown in the Pugh chart in Appendix A. These concept designs were then narrowed down and ranked using a decision matrix in Figure 6 based on the engineering requirements, in which a top design was decided on shown in Figure 7. Since then, a rough Bill of Materials has been made, listing all the items being considered as well as their quantities and costs. This figure can be seen below in Appendix A. With the materials laid out and an idea of what is being designed, the team has begun working towards creating the model for the 1st prototype demonstration along with its virtual demonstration.

5 CONCLUSIONS

The purpose of this project is to build a robust spectrometer housing to protect the internal components of the spectrometer. The range of wavelengths of light that the client is interested in is 350-1000 nm, this product could help change the trajectory of forests research and conservation efforts. Insights into plant health, leaf makeup and thickness, water concentrations in soil and in trees, temperature differences due to water conspiring up the tree, this data will be put into prediction models to analyze the forests' health. The unit will be placed in a specific understory position to continuously monitor a location. Later the device will be attached to a drone and can analyze the forest from above. The lab application is to view the optical and energy properties of semiconductors like energy transfer and light reflection and absorption. The use of a single aperture with mirrors to direct the light into the linear array being used to decipher the light and collect the data. This report begins with a disclaimer and an executive summary stating the info in this report is of academic student origin and an overall summary of the entire report within the executive summary. The background section of the report contains the project descriptions, re-stated here, the deliverables submitted up to this point, and the success metrics describing what it will take for this project to be successful. The requirements section contains the customer and engineering requirements, and the house of quality with the CR and ER correlations and rankings. The research within your design space discusses the benchmarked products, the literature review, and math modeling that each member completed and what was learned from each. The design concepts section went into how the team generated, evaluated, and selected concepts. The use of Pugh charts, Morph matrices, decision matrices, and advantages and disadvantages tables were helpful in this section. Finally, this conclusion is followed by the references and appendices containing all the figures, and tables used throughout this semester up to this point.

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7 APPENDICES

7.1 Appendix A: Table of Figures

System QFD

Project:	Spectral Forest
Date:	Fall 2023

Correlation Legend	
++	Strong positive
+	Moderate positive
-	Moderate negative
--	Strong negative

Legend	
A	APEX Imaging
B	ASD FieldSpec 4
C	NASA HyMap

		Long Life	Stable internal Temp	Tight tolerances	Waterproof	Small
1	Long Life					
2	Stable internal Temp	++				
3	Tight tolerances	+	+			
4	Waterproof	++	++	-		
5	Small	+	+	+	+	
6	Lightweight	-	--	-	-	++

			Technical Requirements						Customer Opinion Survey				
	Customer Needs	Customer Weights	Long Life	Stable internal Temp	Tight tolerances	Waterproof	Small	Lightweight	1 Poor	2	3 Acceptable	4	5 Excellent
1	Durable	5	9			9	3					AB	C
2	Vents ensure semi-constant conditions	4	3	9		9	1				B	A	C
3	1 central aperture	5		3	9	3	3					BC	A
4	Unit is sealed	5	9	3	9	9						AB	C
5	Ease of access	3		1		1	9				C		AB
6	Reliable	3	3	3	3	3	9	3			B	AC	
7	UV resistant	3										ABC	
8	Ambient operating range of 0-50 °C	3.5	3	9			9					AB	C
	Technical Requirement Units		Years	°F	in	water	mm	lbs					
	Technical Requirement Targets		5	F +/- / sec	+/- 0.01	0	.0024m^	<2					
	Absolute Technical Importance		121.5	109.5	99	153	119.5	9					
	Relative Technical Importance		2	4	5	1	3	6					

Figure 1: QFD

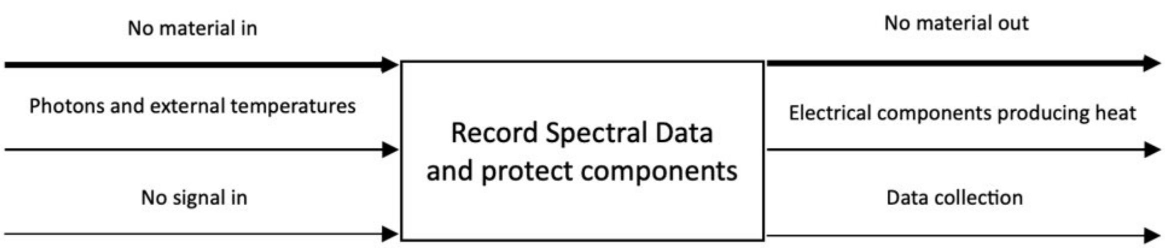

Figure 2: Black Box Model

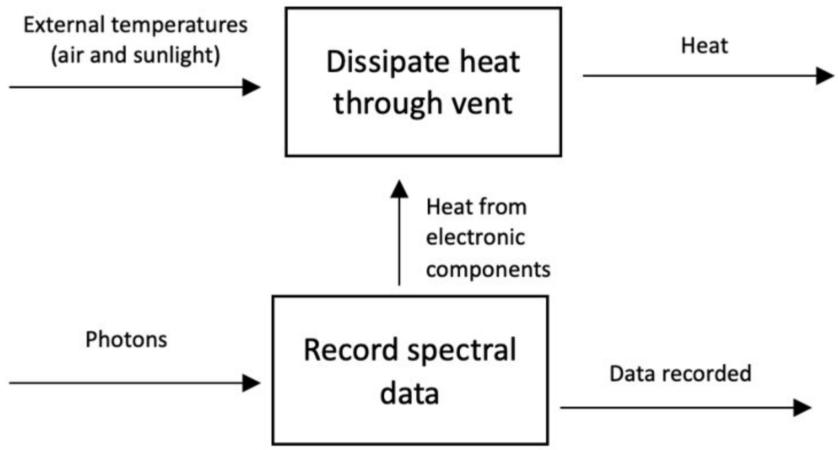

Figure 3: Functional Model

Pugh Chart						
Criteria	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
Durable	-	=	=	=	D	-
Vents ensure semi-constant conditions	+	=	+	+	A	=
Unit is sealed	-	=	-	=		=
Ease of access	-	+	-	=	T	+
Reliable	-	+	-	+		=
UV resistant	-	=	+	=	U	=
Affordable	+	-	-	-	M	=
S+	2	2	2	2		1
S-	5	1	4	1		0
S=	0	4	1	4		6

Figure 5: Pugh Chart

Design #:	-	Design # 2		Design # 4		Design # 5	
Criteria	Weight	Unweighted	Weight	Unweighted	Weight	Unweighted	Weight
Durable	0.15	85	12.75	90	13.5	80	12
Vents ensure semi-constant conditions	0.15	90	13.5	100	15	90	13.5
Unit is sealed	0.2	95	19	95	19	95	19
Ease of access	0.05	100	5	50	2.5	50	2.5
Reliable	0.2	95	19	100	20	90	18
UV resistant	0.2	90	18	90	18	90	18
Affordable	0.05	0	0	100	5	90	4.5
Total	1	Sum	87.25	Sum	93	Sum	87.5
Relative Rank	N/A	3		1		2	

Figure 6: Decision Matrix

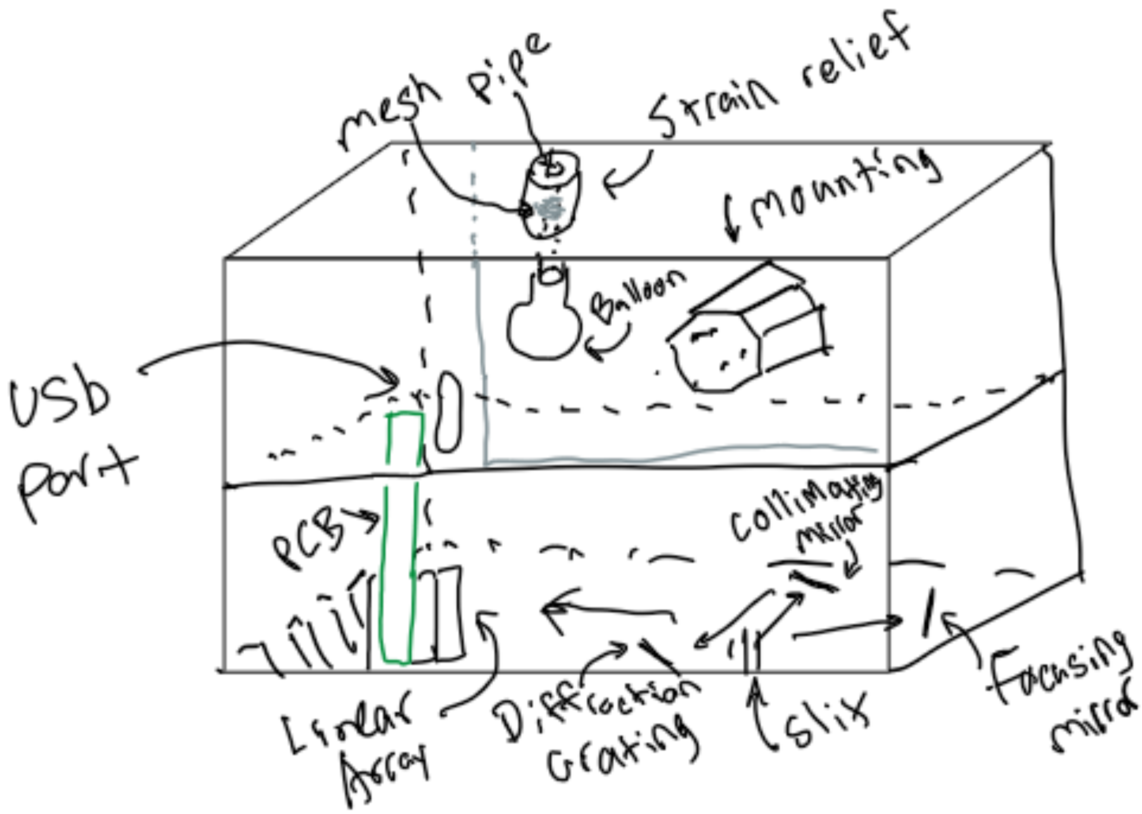

Figure 7: Current Final Design Concept

Item #	Item	Item Description	Vendor	Quantity	Cost $	Cost Per unit $
1	Onyx filament	Micro carbon fiber filled nylon (12 m)	Markforged	1	96	.24/cm^3
2	Fasteners	Han-compact fixing screw	DigiKey	8	1.20	.15
3	O-ring	Fluoropolymer sealing ring	DigiKey	1	.47	.47
4	Cosine Corrector	CC-S-DIFFUSE Spectralon Diffuser	OceanInsight	1	75	75
5	Diffraction Grating Film	LAPPING FILM SIL CARBIDE 11X8.5"	DigiKey	2	5.94	2.97
6	Silicone	Chip Quik Electronic Grade Silicone	DigiKey	1	4.95	4.95
7	PCB with Components	UNIVERSAL PROTO-BOARD PCB 6CM	DigiKey	1	1.95	1.95
8	USB-C Rubber Seal	Würth Elektronik CONN COVER FOR USB-C	DigiKey	1	.63	.63
9	Conductive Silver Tape	Electrical Shielding Tape Conductive Acrylic Adhesive Silver 1/4" X 180'	DigiKey	1	3.94	3.94
10	Black Oxide Paint	Golden® Fluid Acrylics, Carbon Black 1 oz.	Michaels	1	8.49	8.49

Figure 8: Bill of Materials

7.2 Appendix B: Designs and Subsystems

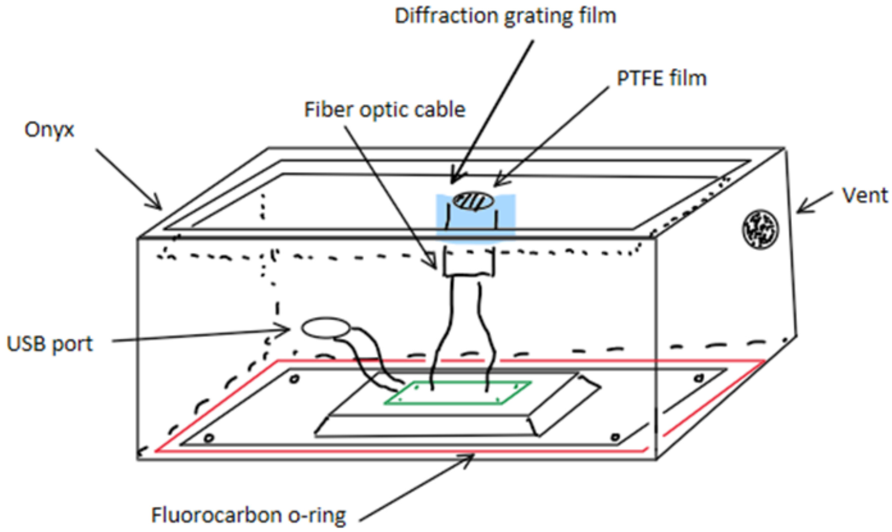

Figure 9: Old design 1

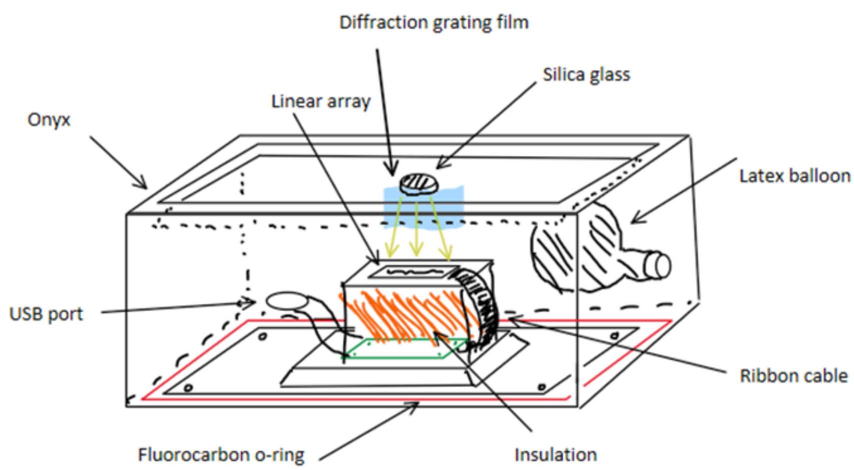

Figure 10: Old design 2

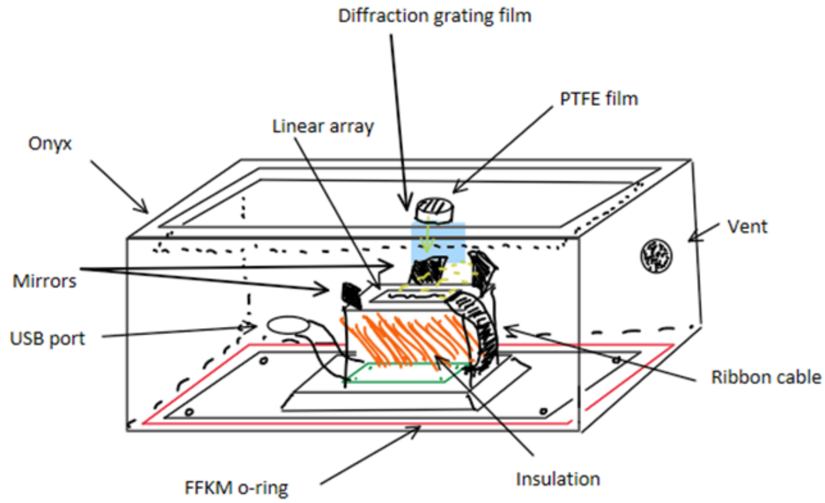

Figure 11: Old design 3

Morph Matrix						
Subsystem	1	2	3	4	5	6
optics	Linear array	fiber optic	camera	linear array	linear array	linear array
shape	cylinder	ectangular prisı	Cone	rectangle	rectangle	rectangle
cosine corrector	ilica/quarts glas	PTFE film	Aicroscope slid	silica glass	PTFE film	silica glass
pressure equilizer	latex balloon	vent	hole	nverted balloo	vent	vent
o-Ring	rubber	flurocarbon	FFKM	flurocarbon	FFKM	rubber
material	ABS	Onyx	Polycarbonate	onyx	onyx	onyx
insulation	yes	no	yes	yes	yes	no
mirrors	yes	no	yes	no	yes	no

Figure 12: Old Morph Matrix

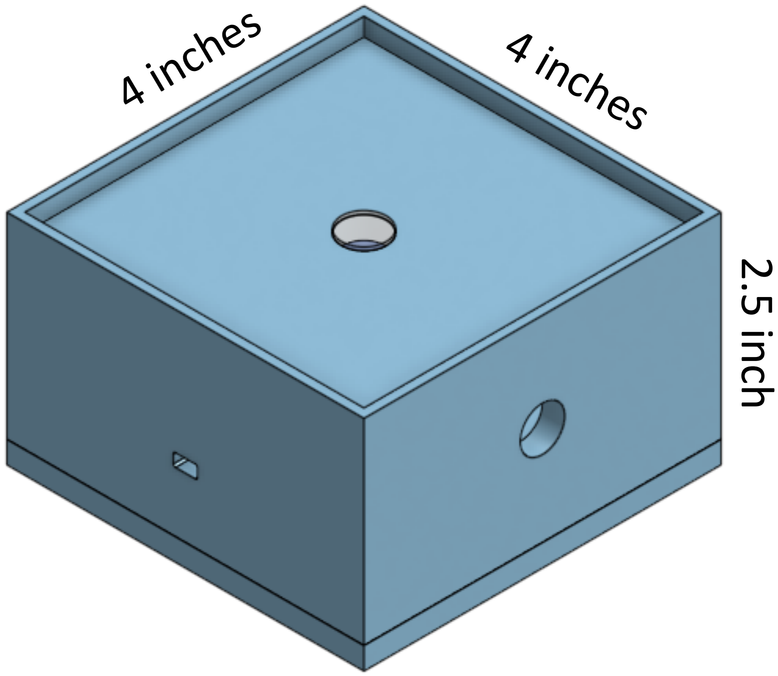

Figure 13: ISO CAD View (OLD)

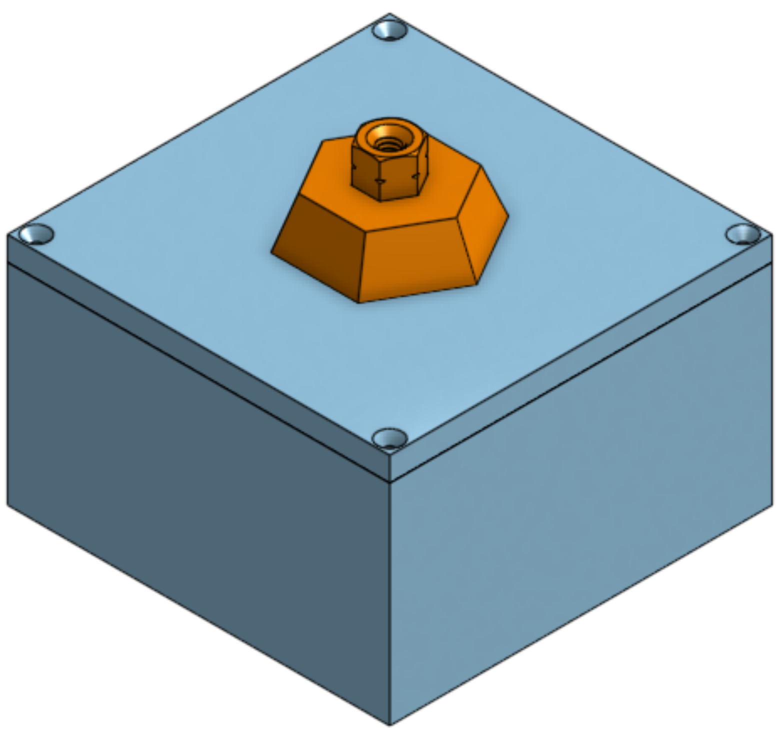

Figure 14: Bottom ISO CAD View (OLD)

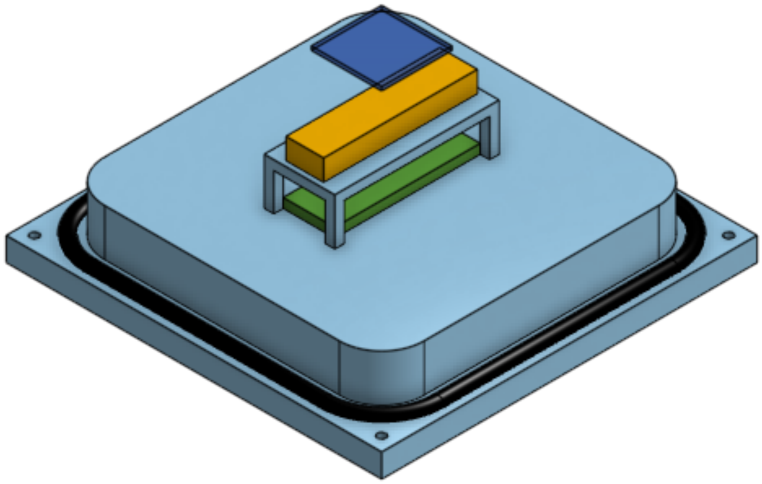

Figure 15: Internal CAD View (OLD)

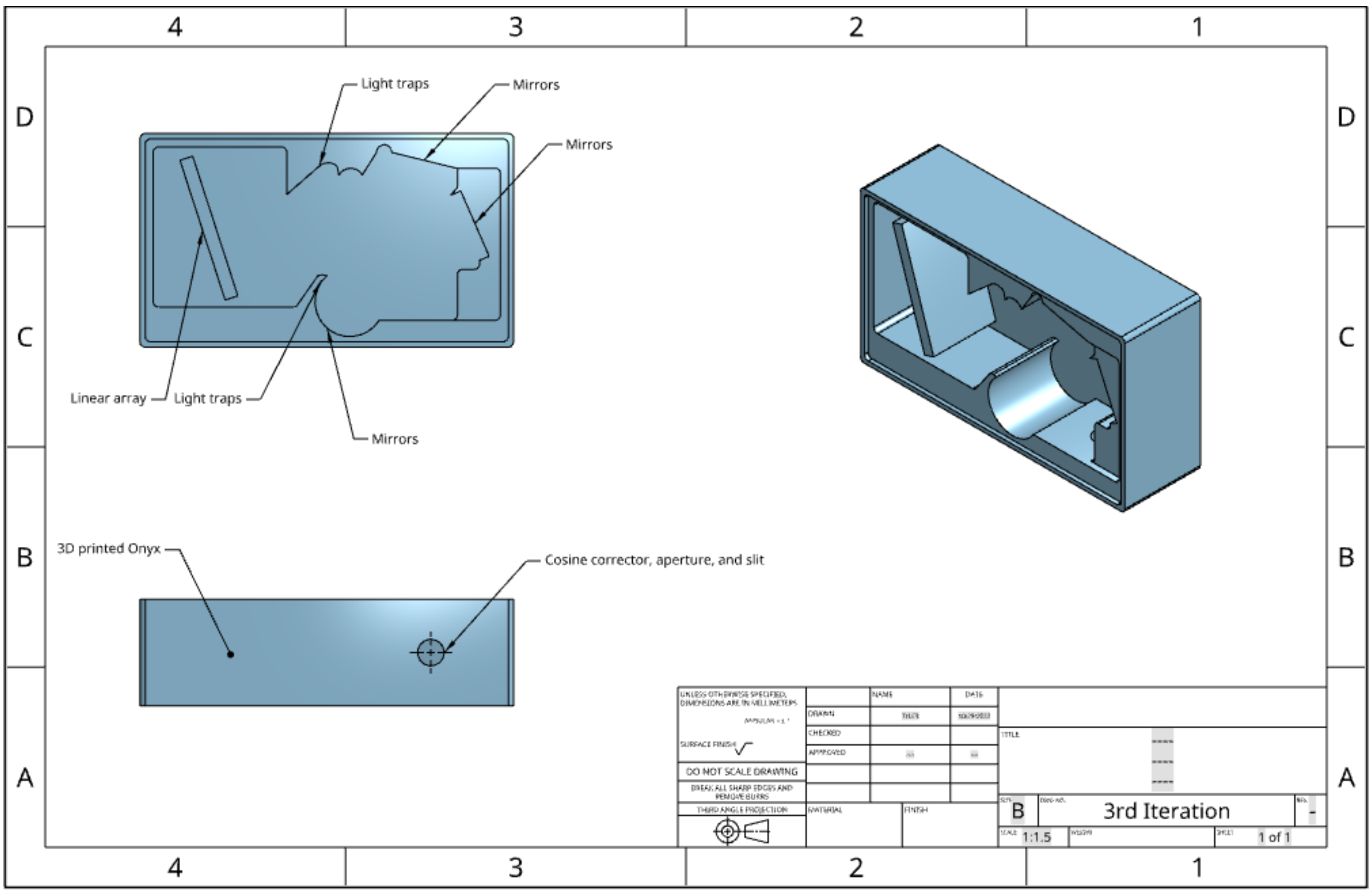

Figure 16: Revised CAD