Department of Mechanical Engineering
Spectral Forest
ME 486C – 001

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Date: 1/26/2024

Subject: Engineering Model Summary Report

Top Level Design Summary

The problem being solved is poor forests research and conservation efforts. This device provides insights into plant health, leaf makeup and thickness, water concentrations in soil and in trees and temperature differences due to water conspiring up tree trunks. Using the device to collect data about all these different areas of a forest with modern prediction models will change the trajectory of the research done in the forest and corresponding conservation efforts.

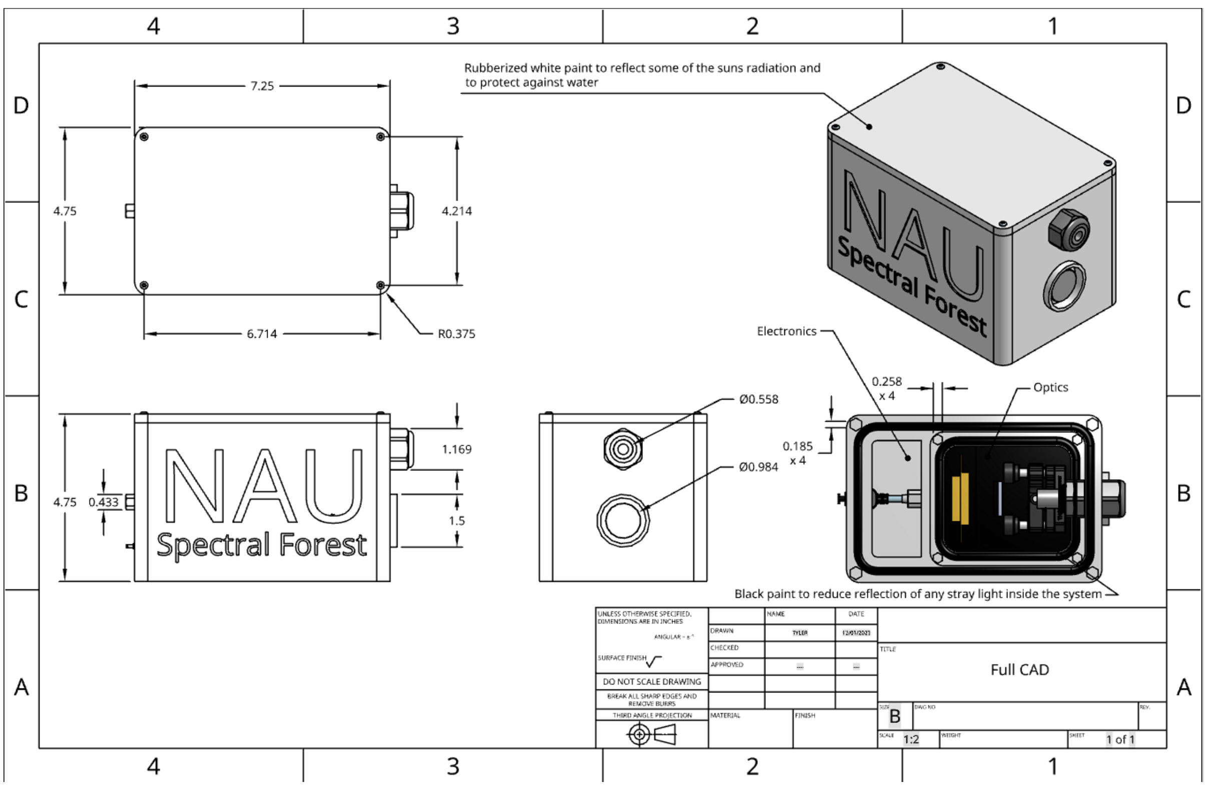

Figure 1: Optics sub-system

The three main sub-systems are the optics, pressure equalization, and the electronics. All three of which can be seen in Figure 1. The optics shown in Figure 2 will take in light from the outdoors through a small opening in the side of the box. The light will be directed through a series of lenses that will expand, contract, and bend and the light into a detector. The detector will record what wavelength it is seeing and send it to an onboard SIM card.

The pressure equalization system seen in Figure 3 is made of a PVC pipe, a cable gland, foam stuffed inside the PVC pipe, and a balloon on the inside. This system is in place to keep the device in equilibrium with the external conditions to avoid a negative pressure differential. It achieves this by having an open end on the outside and a balloon attached on the inside, so when the pressure outside decreases the balloon contracts and therefor increase the volume inside the box and in turn decreasing the pressure.

The electrons side of the device is handled by the EE sub-team that is working on this project simultaneously. The main role of the EE team is to create a custom PCB to record the data at a specified interval and keep the device running for as long as possible with the size constraints.

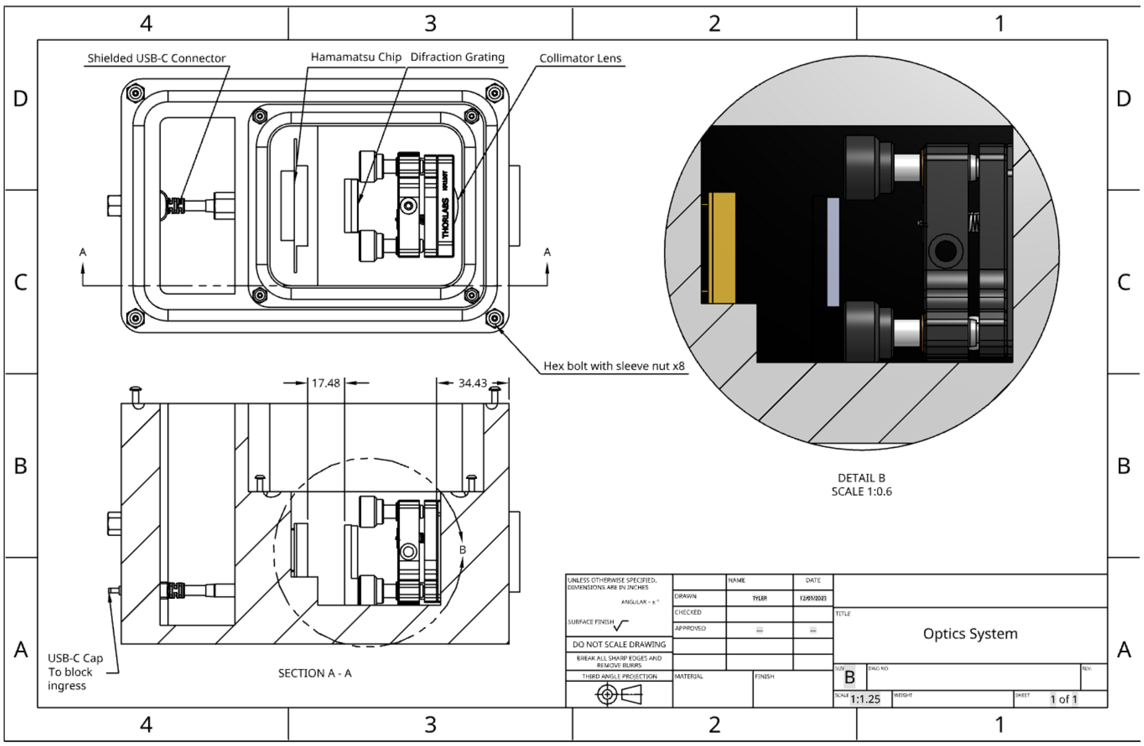

Figure 2: Optics sub-system

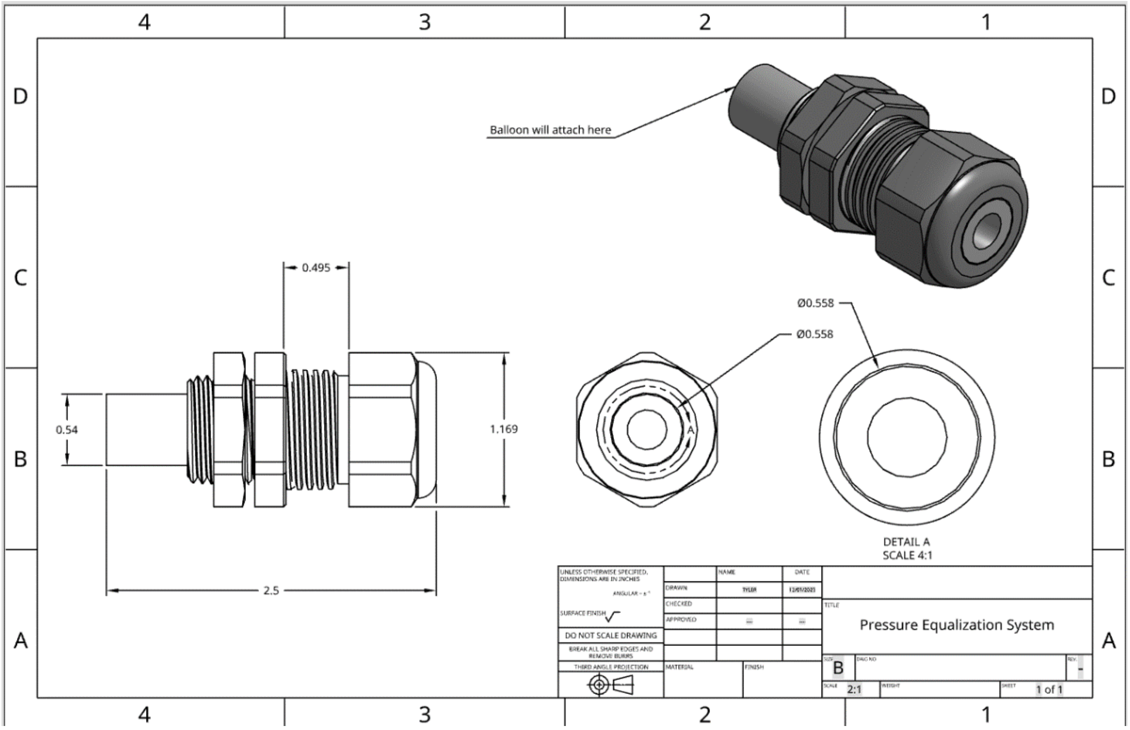

Figure 3: Pressure equalization sub-system

System QFD

Project:	Spectral Forest
Date:	Fall 2023

Correlation Legend

++	Strong positive
+	Moderate positive
-	Moderate negative
--	Strong negative

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

Legend	
A	**APEX Imaging**
B	**ASD FieldSpec 4**
C	**NASA HyMap**

	Customer Needs	**Customer Weights**	**Long Life**	**Stable internal Temp**	**Tight tolerances**	**Waterproof**	**Small**	**Lightweight**	*1 Poor*	*2*	*3 Acceptable*	*4*	*5 Excellent*
			Technical Requirements						**Customer Opinion Survey**				
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 +/- / mi	in	water	in^3	lbs					
	Technical Requirement Targets		5	2	+/- 0.01	0	<331	<2					
	Absolute Technical Importance		121.5	109.5	99	153	119.5	9					
	Relative Technical Importance		2	4	5	1	3	6					

Figure 4: QFD

Customer Requirements (CRs)

- Durable: the device is robust and can survive outside for multiple days
- Vents ensure semi-constant conditions: pressure equalization system keeps the device at constant conditions
- 1 central aperture: only one entry place for light to enter the device
- Unit is sealed: no ingress can enter the unit as the mirrors and electronics are sensitive
- Ease of access: the internal components of the unit are accessible for calibration and updating if needed
- Reliable: the device should not fail before multiple years of use
- UV resistant: the device will spend a lot of its light exposed to the sun so it should not degrade
- Ambient operating range of 0-50 °C: the device can operate without change in a large range of temperatures

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 – Tight tolerances are essential because the top and bottom halves must connect seamlessly with no gap to prevent outside interference.
- 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.

Summary of Standards, Codes, and Regulations

NEMA ratings

The NEMA 3X rating is for non-hazardous outdoor use. It protects against water, rain, snow, sleet, exterior ice formation, windblown material like dust, and corrosive agents. The NEMA 3X rating will be satisfactory for this application.

Summary of Equations and Solutions

Device falls from above head height and lands on a corner – Tyler

The device weighing 3 pounds (1.4 kg), falling from a height of 8 feet (2.4 meters), onto a corner with an area of 0.4 square inches (253 square millimeters). From the equations below a stress of 2.5 MPa resulted. The UTS of polycarbonate is 60 MPa which yields a factor of safety of 23.7. There will be no issue of the box yielding but the components inside will be misaligned.

$$F = \frac{mgh}{d}$$

$$\sigma = \frac{F}{A}$$

$$FoS = \frac{F_{fail}}{F_{allow}}$$

Heat transfer though the walls of our device using MATLAB – Torrey

The code is shown in Appendix A

As for assumptions:

Onyx: k=0.9 rho=500 Cp=1000

Air: k=26.3 P=1.1614 Cp=1.007 mu=184.6 v=15.89 alpha=22.5

Conditions to test: initial temperature range -10°C to 60°C both of which are extreme cases, all testing was done with increments of 5°C. Assuming a convective heat transfer coefficient of 100. And used a wall thickness of 1/4 inch as well as 1/8 inch.

As for heat produced by battery in the electronics system:

Battery capacity= 2600 mAh

Voltage = 11.1 volts

Airmass = 0.001213 kg

specific heat capacity of air = 1005 J/(kg*k)

Vent Flow and Temperatures – Torrey

It is a "weather-resistant" vent that allows 4000 ml/min at 70 mbar.

Using the mass flow rate equation: m. = ρAV and the ideal gas law: ρ = PRT

it can be calculated that the chosen option of a vent will work fine per our assumptions.

Based off these equations, this level of vent will be more than adequate for the final design.

Forces applied when mounted to a drone – Derrick

Forces on the drone: 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/s2. Putting the variable thrust over the weight variable, we get the ratio 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 acceleration and upward force. It is important to understand these forces to not allow the design to fail or be damaged when facing them.

Cosine Correction – Derrick

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, L_0, times the cosine of the angle, $\cos\theta$, being reflected is the light intensity being received on the other end, L_θ. 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.

Calculations involved with the stress during liftoff – Tyler

$$Thrust = Thrust\ to\ Weight\ Ratio * Total\ drone\ weight$$

Aurelia X4 Standard

Payload up to 3.3 lbm

Total weight of drone with battery and housing attached = 10.68 lbs

Thrust to weight ratio = 2:1

Thrust = 21.36 lbf

Stress according to FEA = 5.5 x 10^3 psi (Figure 6)

Strength of sleeve nut is 105 x 10^3 psi

FoS = 5.5/105 = 19.1

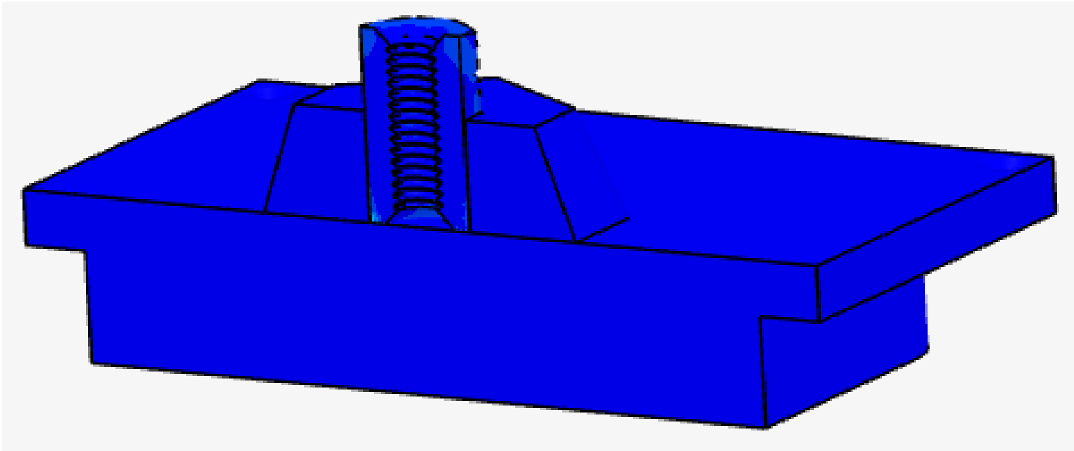

Figure 5: FEA Solution Field

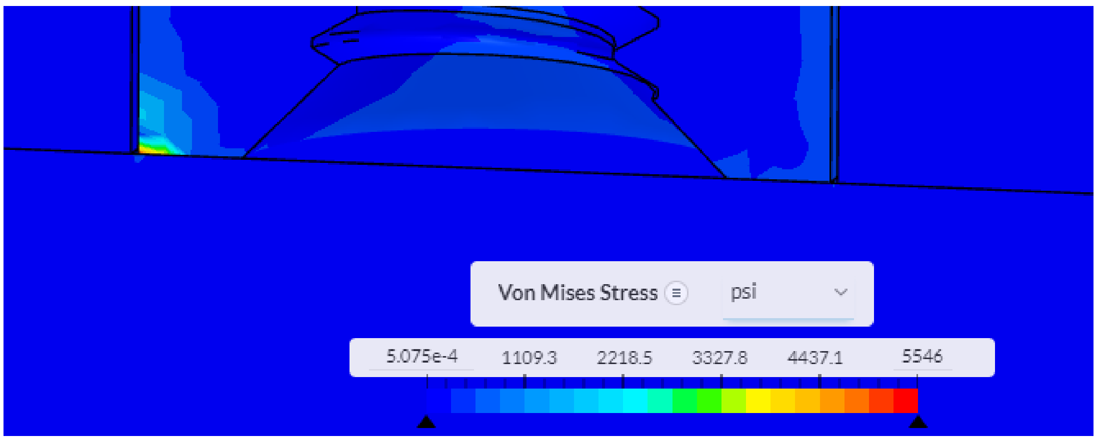

Figure 6: Highest stress concentration

Calculations of O-ring diameter – Tyler

Using the perimeter of the O-ring groove by selecting the outer most line in the track in OnShape gave the total perimeter. Considering that perimeter to be the circumference and using the circumference of a circle equation to back solve for diameter. Given the radius an O-ring can be selected from a supplier.

$$C = \pi * d$$

$$d = \frac{C}{\pi}$$

The main O-ring had a perimeter measurement of 19.6 inches and using the equation above a diameter of 6.24 inches is needed to achieve the required perimeter. Similarly, the O-ring for the optics side is a circumference of 13.2 inches and yields a diameter of 4.2 inches.

Total weight of 1 unit – Tyler

Using the datasheet or specs table given on the webpage the weight of each unit was obtained. Summing them all up yields the total weight of the device. After summing all the found weights the approximate weight of one unit is 2 pounds and 5 ounces.

Drone attachment can be seen in Figures #5-6

Table 1: FoS Table

Sub-system	Part	Load Case Scenario	Material	Minimum FoS
Drone attachment	¼-20 sleeve nut	Lift off when attached to drone	Zinc-Plated Steel	19.1
Device	Exterior of device	Device falls on its corner from head height	Polycarbonate	23.7

These calculations confirmed the hypotheses that were assumed. Now the numbers back up the assumptions and it is known that the device has a certain weight that the drone can carry, the mounting system will not fail during flight, if dropped on the ground it will not break, the heat transfer inside the box due to an external source is very minimal, the calculated cosine angles are consistent with what the datasheets for the lenses say, and the O-ring size required can easily be found.

Flow Charts and other Diagrams

The design of the spectrometer box proves to be minimalistic in function and operation but still undergoes internal as well as external factors that must be accounted for. This is done to ensure the spectral data is being collected and distributed efficiently within the system as well as lengthening its' longevity. To analyze and better understand these various factors that can affect the system's functionality, a black box model as well as a functional model were developed.

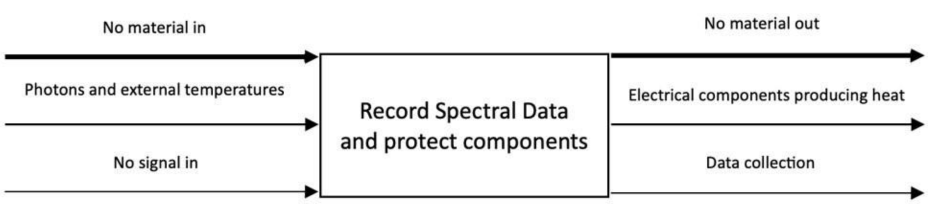

Figure 7: Black Box Model

In the black box model provided in Figure 7, we can see that there should be no material properties going in or out of the system while in operation. When working with electrical equipment and transferring energy to the design, there can be constant heat radiation emanating inside as well as photons entering the system from direct sunlight. This can cause the electrical components to produce heat, which should be accounted for within the design of the box. There can also be seen that there is no signal input, however there is data that will be outputted from the device using a USB port that will allow the user to collect and analyze the spectral data observed.

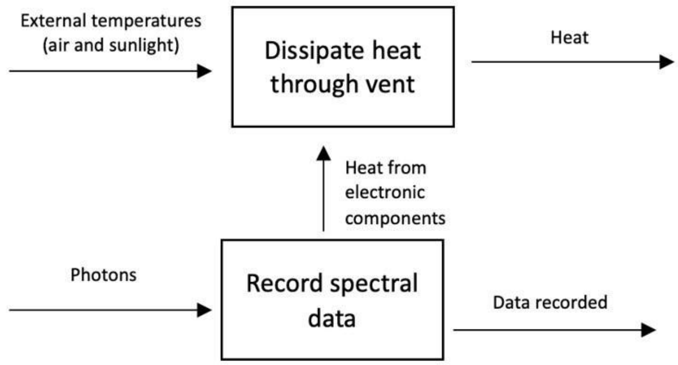

Figure 8: Functional Model

The functional model, found in Figure 8, closely resembles the black box model, and utilizes the same concepts found within. It is used to break down what occurs inside the system and how parts subsystems correlate to one another. From the model we can see that when the system is operating and recording the spectral data, photons enter the aperture and energy is transferred causing heat to radiate from the internal components. This heat is then dissipated through a vent system that is also used to regulate the temperature from external factors such as sunlight or air. The design must be able to properly dissipate the heat within the system to protect the internal components from being damaged or failing. It is important to note that this functional model only corresponds to the design of the box since the EE team will be more heavily focused on the internal electrical components.

Moving Forward

Going forward the CAD needs to be updated to accommodate the new lens orientation found from the Zemax files. Then the weight of the device needs to be recalculated using OnShape. The overall cost to create 1 device needs to be calculated as well since we are buying multiples of everything the purchase request will be a large amount more than the cost to make one unit. Reevaluating the FEA on the mounting system with respect to a friction fit and the small amount of glue inside the sleeve that the sleeve nut will be installed in.

Appendix A: MATLAB Code for Heat Calculations

```
% Constants
specificHeatAir = 1005; % Specific heat capacity of air in J/(kg·K)
batteryCapacity = 2600; % mAh
voltage = 11.1; % Volts
time = 60*60; % seconds
airMass = 0.001213; % kg

HLpercent = 1:1:100; % heat loss

% Convert battery capacity from mAh to Ah
batteryCapacity = batteryCapacity / 1000;
for i = length(HLpercent)
tempRise = (HLpercent * batteryCapacity * voltage) / (time * airMass * specificHeatAir);
end

%fprintf('Estimated temperature rise: %.2f degrees Celsius\n', tempRise);

plot(HLpercent, tempRise);
xlabel('Heat Loss Percentage (%)');
ylabel('Temperature Rise (degrees Celsius)');
title('Temperature Rise vs Heat Loss Percentage');
grid on;
```

```
%INPUTS

k = 0.9; % Thermal conductivity of onyx by markforged (W/m*K)

thickness_in = 0.25; % Thickness of the box walls (in)

thickness = thickness_in*0.0254; %convert thickness to meters

A_in = 35; %area of wall to transfer heat (in^2)

A = A_in*0.00064516; %convert to (m^2)

% Define parameters

tMax = 60; % Maximum time (s)

Nx = 60; % Number of spatial nodes

Nt = 10000; % Number of time steps

rho = 500; % Density (kg/m^3)

Cp = 1000; % Specific heat (J/kg*K)

alpha = k / (rho * Cp); % Thermal diffusivity (m^2/s)

% Define initial conditions
```

```
T0 = 20; % Initial temperature (°C)
T = T0 * ones(Nx, 1); % Initial temperature distribution
% Define boundary conditions
T_inside = 100; % Inside temperature (°C)
T_outside = 25; % Outside temperature (°C)
h_inside = 100; % Inside convective heat transfer coefficient (W/m^2*K)
h_outside = 100; % Outside convective heat transfer coefficient (W/m^2*K)
% Define spatial grid
x = linspace(0, A, Nx);
% Preallocate temperature matrix
T_matrix = zeros(Nx, Nt);
% Time-stepping loop
dt = tMax / Nt;
for i = 1:Nt
% Calculate new temperature distribution using finite difference
for j = 2:Nx-1
d2T = (T(j+1) - 2*T(j) + T(j-1)) / (x(j+1) - x(j))^2;
q_inside = h_inside * (T_inside - T(j));
q_outside = h_outside * (T_outside - T(j));
dT = alpha * d2T * dt - (q_inside + q_outside) / (rho * Cp) * dt;
T(j) = T(j) + dT;
end
% Apply boundary conditions
T(1) = T_inside;
T(Nx) = T_outside;
% Store temperature distribution
T_matrix(:, i) = T;
end
% Plot the temperature distribution over time
figure;
imagesc(linspace(0, tMax, Nt), x, T_matrix');
%x1 = axes('top');
%x2 = axes;
```

```
xlabel('Time (s) at inside');
xlabel('Time (s) at outside');
ylabel('Position (m)');
title('Temperature Distribution Over Time');
colorbar;
```