Spectral Forest Presentation 3

ME 476C Section 02

Team: Tyler Lerew, Torrey King, & Derrick Doan

Project Description

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

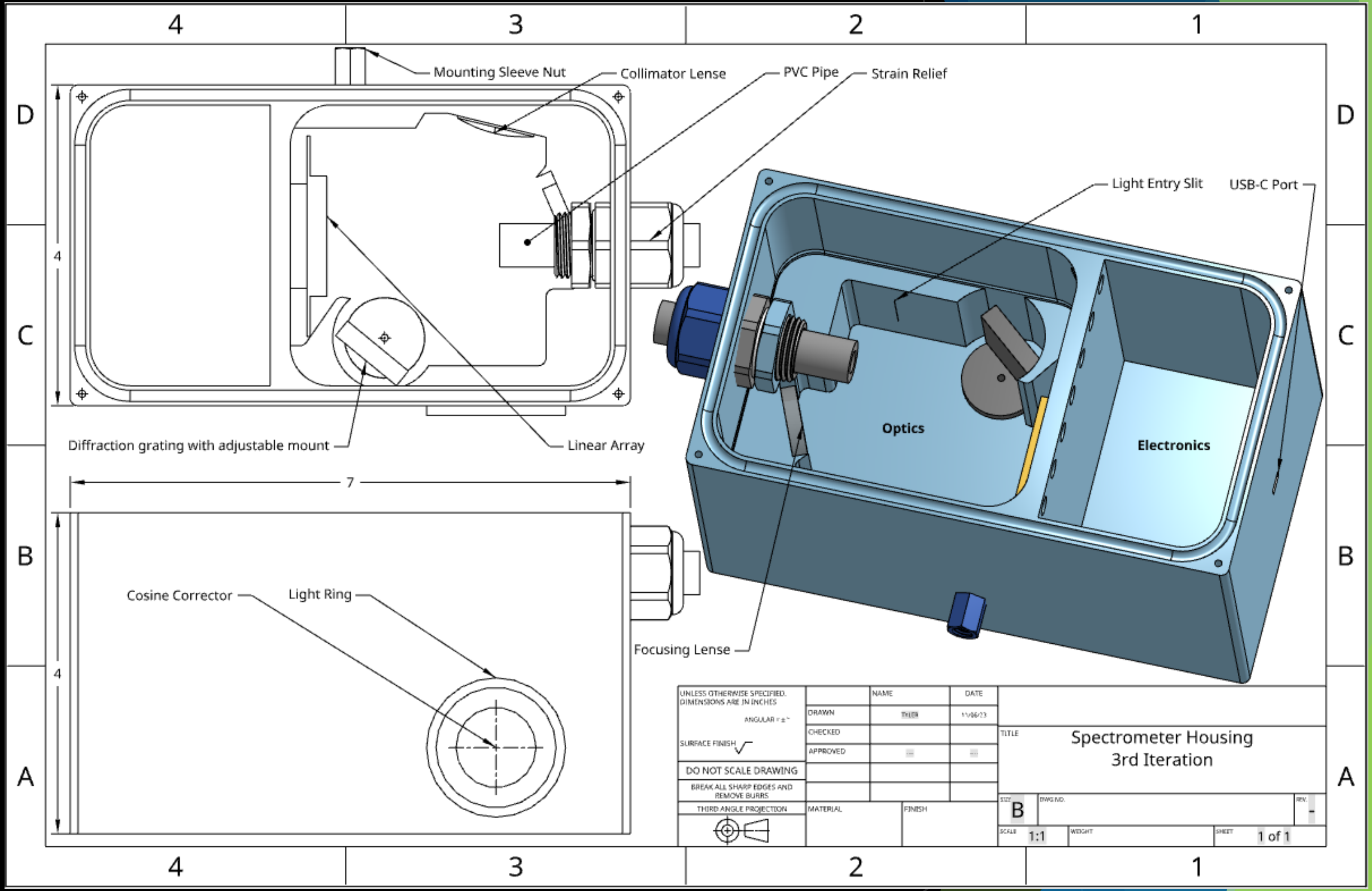
The unit will be placed in a specific understory position to continuously monitor a location. Later the device will be attached to a drone and can analyze the forest from above. The lab application is to view the optical and energy properties of semiconductors like energy transfer and light reflection and absorption

Use single aperture with or without mirrors to direct the light into the linear array being used to decipher the light and collect the data

Sponsors: Alexander Shenkin (Assistant Research Professor) and Carlo da Cunha (Assistant Professor) - SICCS

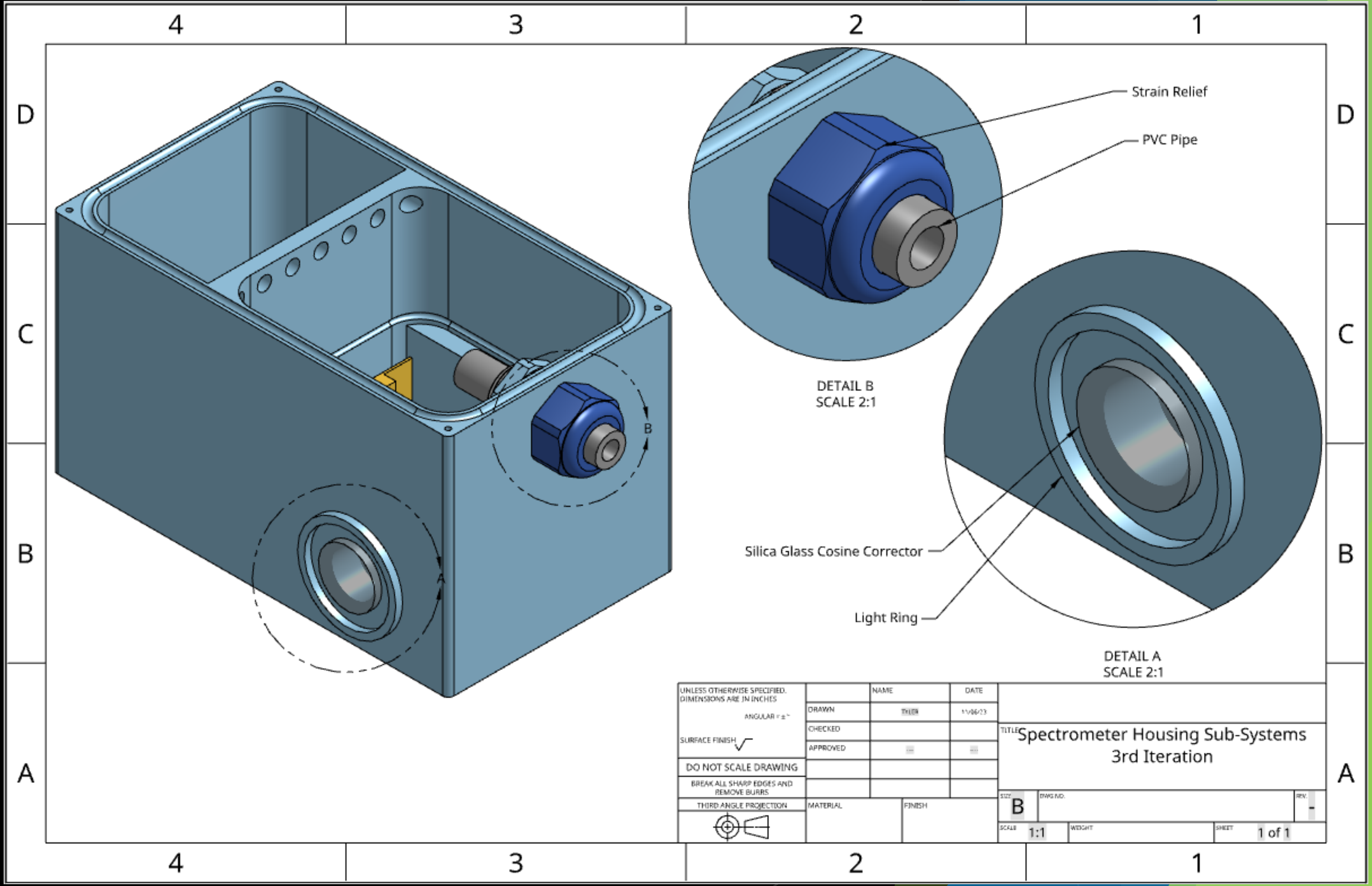
Design Description

- 3 major sub-systems: The electronics (EE), the optics (ME), and the pressure equalization (ME)
- Optical system function:
- Light enters through the slit
- The light then reflects off the collimator mirror which stops the light from expanding
- Then off the diffraction grating which separates he light by wavelength, creating a rainbow
- Then off a focusing mirror which will concentrate the light onto the linear array which will read the data and give a graph with the help of a program



Design Description

- Detail B: Pressure equalization system
- One end of the PVC pipe is open to the outside air
- The other side of the pipe has a latex balloon fastened to it with two cable ties
- The inside of the pipe is filled with foam so air can pass through but nothing else
- The balloon will expand and contract when the temperature and elevation change, therefor changing the volume in the box and equalizing the pressure
- Detail A: Light Ring
- Stops low angle light from entering the cosine corrector



Design Requirements - QFD

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

	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 +/- / sec	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					

Design Requirements – CR

- 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 very 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

	Customer Needs	Customer Weights
1	Durable	5
2	Vents ensure semi-constant conditions	4
3	1 central aperture	5
4	Unit is sealed	5
5	Ease of access	3
6	Reliable	3
7	UV resistant	3
8	Ambient operating range of 0-50 °C	3.5

Design Requirements – ER

- Long Life: 5 years relates to reliable and durable
- Stable internal Temp: $\pm \frac{2^{\circ}\mathrm{F}}{second}$ relates to some constant conditions
- Tight tolerances: +/- 0.01 on all dimensions relates to sealing and reliability
- Waterproof: Zero water can enter the unit due to rain per spec of a NEMA 3X enclosure relates to sealing and reliability
- Small : The volume of our box must be less than 256 in^3 (4 x 8 x 8)", constrained by the drone undercarriage size (4.41 x 8.66 x 8.66)" relates to the semi constant conditions
- Lightweight: The device must weigh less than 2 pounds, constrained by the drone payload capacity relates to the reliability and durability of the device

Technical Requirements

Long Life	Stable internal Temp	Tight tolerances	Waterproof	Small	Lightweight
9			9	3	
3	9		9	1	
	3	9	3	3	
9	3	9	9		
	1		1	9	
3	3	3	3	9	3
3	9			9	
Years	°F +/- / se	in	water	in^3	lbs
5	2	+/- 0.01	0	<331	<2
121.5	109.5	99	153	119.5	9
2	4	5	1	3	6

Engineering Calculations – Tyler Lerew

- **Balloon size increase**
- $V = V_0 \left(\frac{T1}{T0}\right) * e^{(-c*y)}$ & $c = \frac{\rho * g}{P_0}$
- Rho being density in Flagstaff, which is assume to be: 0.062 $\frac{lb}{ft^3}$
- Y being altitude and assumed to be a maximum of 330 ft
- V_0 being the volume of the deflated balloon, found by $V_0 = 4/3 * \pi * r^3$ with r being assumed to be 0.75in
- T0 will be assumed to be 68 °F and T1a to be 122 °F (50 C) and T1b to be 32 °F (0 C)
- Finally, gravity = 32.174 $\frac{ft}{s^2}$ & P0 = 11.3 psi (@ 7000ft)
- Plugging everything in, at T1a the volume of the balloon is 3.17 in^3
- At T1b the volume is 0.832 in^3
- Back solving to get the radius, they are 0.91 in & 0.583 respectively
- We need at least 3-3.5 cubic inches of space for the balloon, the current design has 14.25 cubic inches

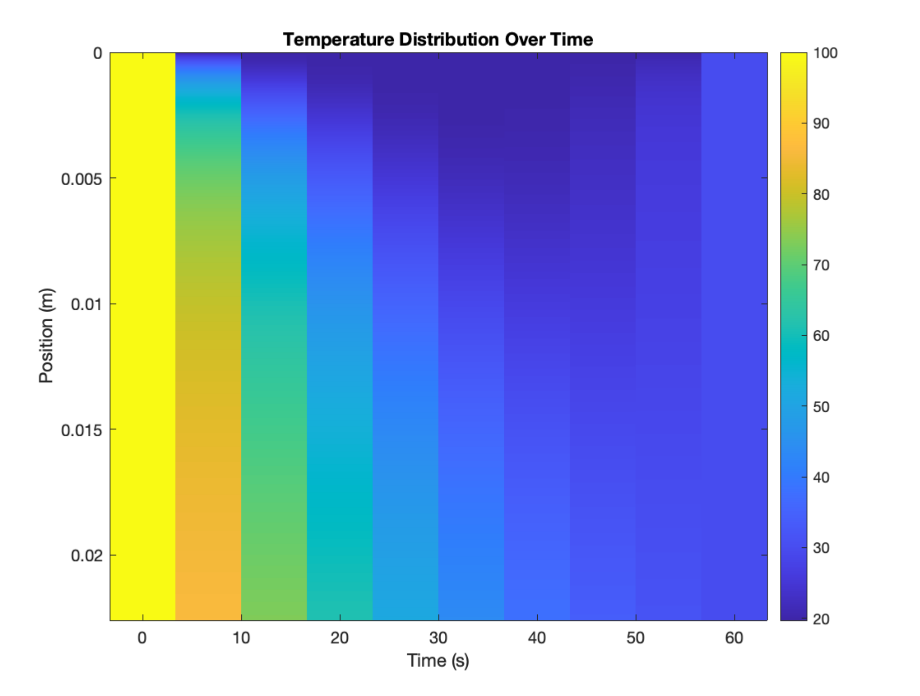
Engineering Calculations – Torrey King

$$\rho * Cp * V * \frac{\partial T}{\partial t} = \nabla * (\mathrm{k} * \nabla \mathrm{T}) + h_1 * A_1 * (T_1 - T) +* h_2 * A_2(T_2 - T)$$

A heat equation from "fundamentals of heat and mass transfer"

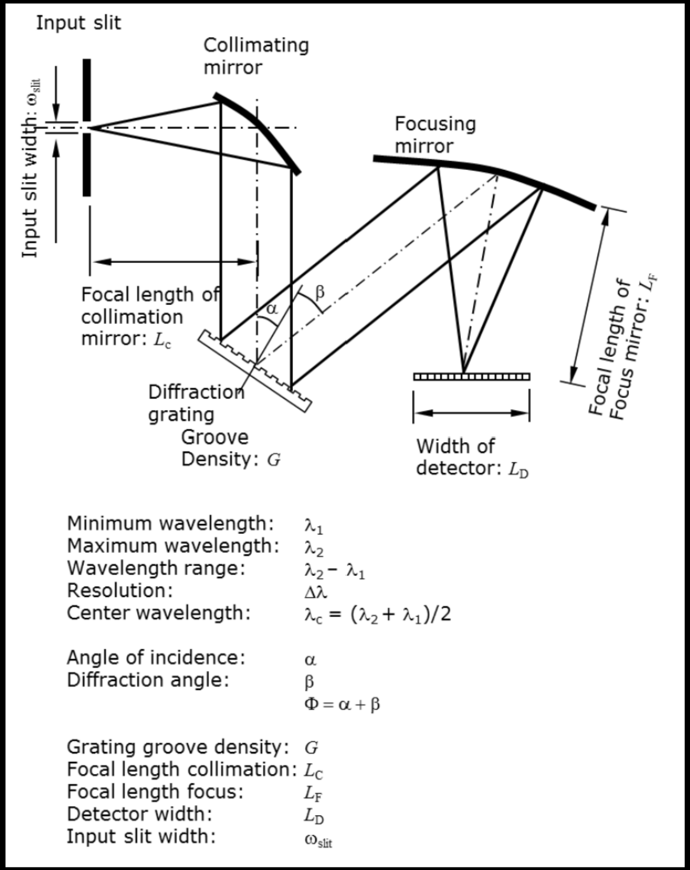
- T refers to temperatures, either in wall or in surrounding fluids
- ρ is the density of the wall
- Cp is the specific heat of the wall material.
- V is the volume of the wall.
- k is the thermal conductivity of the onyx material by markforged.
- H is the convective heat transfer coefficients for the surrounding fluids.

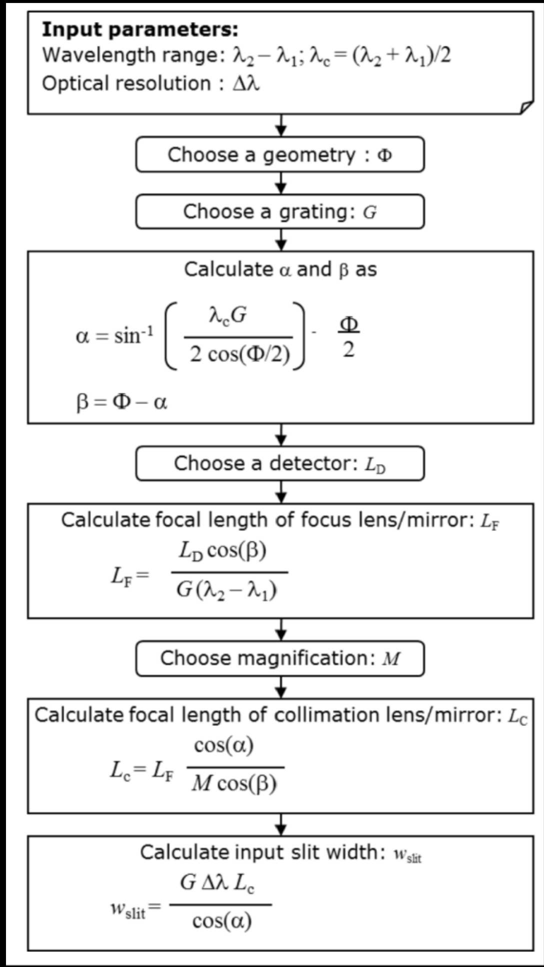
Using this equation and MATLAB iterations, its calculated that going from 100°C inside and 30°C outside we will still transfer heat away from the electronics within 60 seconds as shown in the plot



Engineering Calculations – Derrick Doan

Czerny-Turner:





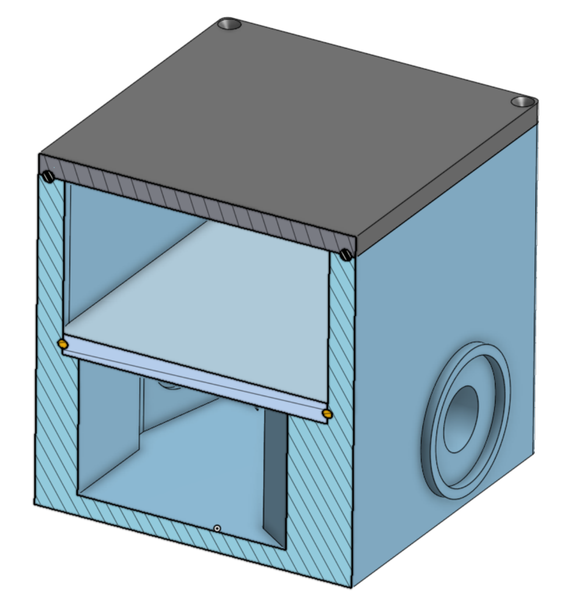
Solutions:

- Wavelength range: 350-1000nm
- Center Wavelength: 675 nm
- Geometry Angle: 90 degrees
- Angle of incidence: 26.7 degrees
- Angle of Diffraction: 63.3 degrees
- Detector Length: 3 in
- Focal length of focus mirror: 2.3 in
- Focal length of collimation mirror: 2.3 in
- Slit width: .56 in

Design Validation - Seals

Product Name **Spectral forest Spectrometer**		Development Team				Page No of			
System Name **Housing**						FMEA Number **1**			
Subsystem Name **Door Sealing**						Date **11/7/23**			
Component Name	**Seals**								
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
2 Fasteners (Holds model together)	Corrosion, Breaking	Improper sealing and mounting	3	Weather conditions, improper usage	1	FEA force anaylsis and	3	9	Compare different materials and sizes
3 O-ring (Seals Model)	Breach in O-ring	Electronics fail	5	puncture during installation	1	Seal box and submerge while empty	2	10	Perform test(s), inspect O-rings for damage
5 O-ring (Seals Model)	Breach in O-ring	humidity and dust form on mirrors	5	pressure is not adequately equalized	1	Seal box and submerge while empty	2	10	Perform test(s), inspect O-rings for damage
6 Silicone (Sealent)	Breach in Silicone	outside conditions effecting mirrors and correction	5	Outside conditions, pressure, temp	1	Seal box and submerge	2	10	Perform test(s), inspect for damage
8 USB-C Rubber Seal (Seals ports)	Breach in port	Failure to power and extract data	4	Weather conditions, not resealing	1	Insert seal into port and submerge	2	8	Perform test(s), inspect for damage

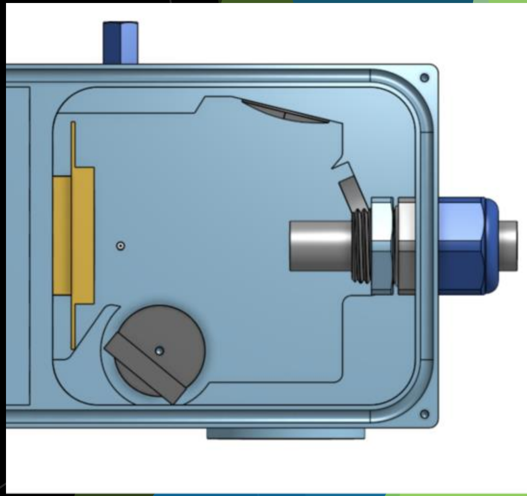
- Failure to seal the housing correctly or a breach in one of the walls will likely cause catastrophic failure if incident occurs when the unit is isolated in the forest
- Water -> humidity -> fog on mirrors
  - Water gets on electronics and ruins them
- Dust -> clouds mirrors
- Added an extra door that covers the mirrors with an O-Ring as a second layer of defense
- Increase cost of overall product for extra protection
- Testing: seal the box fully but with not components installed and submerge in water and watch for bubbles. Install thermistors and move the box to extreme temperatures and monitor the changes
- Equipment and resources: Table, tub, freezer (can use personal one), thermistors, Arduino to read thermistors,



Design Validation - Optics

Product Name **Spectral forest Spectrometer**		Development Team				Page No of			
System Name **Housing**						FMEA Number **1**			
Subsystem Name **Optics**						Date **11/7/23**			
Component Name	**Mirrors**								
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
2 Fasteners (Holds model together)	Corrosion, Breaking	Improper sealing and mounting	3	Weather conditions, improper usage	1	FEA force anaylsis and	3	9	Compare different materials and sizes
4 Cosine Corrector (Spectrally flat)	Correction failure, Spectral Data Distribution	Incorrect data being transmitted	5	Covered aperture: humidity, dust, etc	3	Zemax software: light distribution test	3	45	Clear aperture, test model, replace if needed
6 Silicone (Sealent)	Breach in Silicone	outside conditions effecting mirrors and correction	5	Outside conditions, pressure, temp	1	Seal box and submerge	2	10	Perform test(s), inspect for damage
7 PCB (Data collection and storage)	Mechanical Failure	Incorrect data, chip failure	7	Heat, humidity build up, insufficient powering	2	Data collection, Zemax, physical	5	70	Test(s) for functioning, light distribution and replace if needed
11 Mirrors (Reflect Light)	Light diffraction	Incorrect wavelength range, light distribution	6	Improper angling, focal lengths, damage to box	2	Zemax software: light distribution test	4	48	Perform Zemax test, configure mirrors to fits requirements

- The optics in the system dictate whether the spectrometer records the proper spectral data according to the client's requirements.
- Weather Conditions (Internal and External)
  - Humidity, dust, heat, pressure, etc.
- Improper Mounting
  - Incorrect spectral range, loss of light distribution, PCB not detecting light
- Testing: Light distribution test(s), configuring angles and focal lengths to meet requirements.
- Equipment and resources: Zemax software, USB-C data collection, Czerny-Turner method,



Schedule

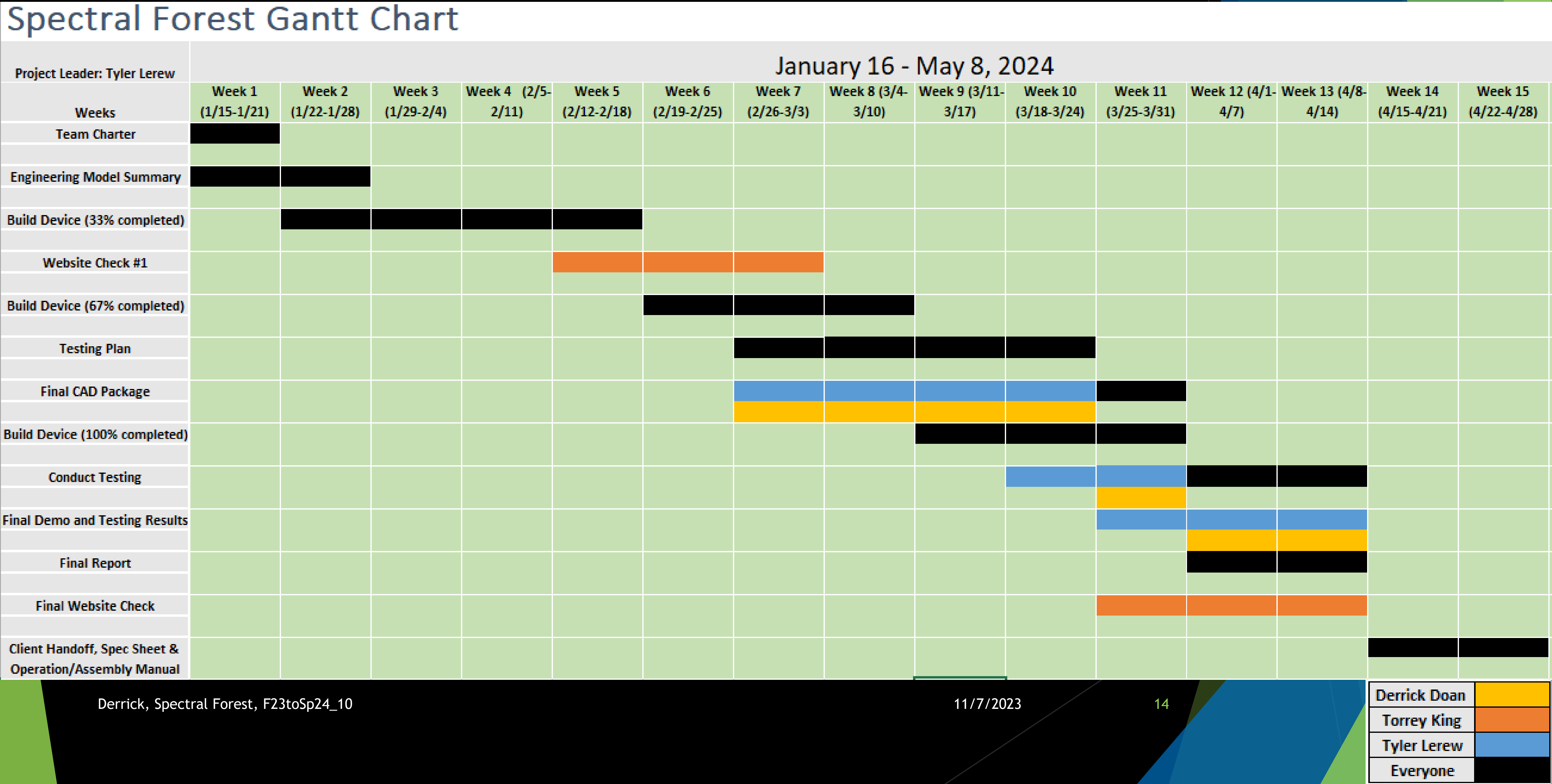
Fall Semester

- On Schedule
- Designated roles for upcoming weeks
- Torrey working on website
- Derrick and Tyler on prototyping and CAD modeling
- Collaborate on Reports and Presentations

Spring Semester

- Gantt Chart on next slide
- Website Check #1 done by end of February
- Testing plan done by 3rd week of march
- Final CAD and Device built by 1st week of April
- Testing results done by mid April
- Final Report and Website Check done by 3rd week of April
- Present end of April
- Handoff device to client 1st week of May

Gantt Chart – Spring Semester



Budget

- $500 for each ME and EE teams $1000 total, can be moved around
- Anticipated expenses:
  - Prototyping ($50), Linear Array ($30-$200), final product parts ($150-200), misc. ($50)
  - Total according to BOM: $198.57 or $200
- Total expenses to date: None
- Total balance: $500
- We will raise $50 ourselves, which is 10% of the allotted budget
- Chris Edwards' Space Grant Consortium (>$5K)

Budget=	+$500
Expenses (BOM approx.) =	-$200
Total:	$300

Thank you!

Questions?

References

- [1] "Spectrometer Design Guide," Ibsen Photonics, https://ibsen.com/resources/spectrometer-resources/spectrometer-design-guide/
- [2] "Calculating Balloon Volume Change with Altitude," Physics Forums: Science Discussion, Homework Help, Articles, Sep. 05, 2005. https://www.physicsforums.com/threads/calculating-balloon-volume-change-with-altitude.87604/#
- [3] "Air - Altitude, Density and Specific Volume," Engineeringtoolbox.com, 2019. https://www.engineeringtoolbox.com/air-altitude-density-volume-d_195.html