Spectral Forest

"Drone Mountable Enclosure and Optics for Eco-Sensing Optical Spectrometer"

ME 486C Section 01

Team: Tyler Lerew, Torrey King, & Derrick Doan

Project Description

Build a robust hyperspectral VIS-NIR (Visible to near infrared wavelengths) spectrometer housing to record wavelengths of light reaching forest floor ranging from 400-1000 nm, it 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

It will be 3D printed with stainless steel hardware inserted, 45-degree FOV, under 3lbs, fits within a 10x5x10in space, mountable onto a drone, weather resistant, operation range of 0-50 degrees C, and adequately protects sensitive internal components.

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

Initial budget was $500, this was later increased and will be discussed shortly

Tyler Lerew

Deliverables

- Fall Semester:
- Initial design presentations, reports, and calculations
- Spring Semester:
- Hardware status updates - 33%, 67%, and 100% checkpoints to keep us on track
- Finalized testing plan, Initial and final testing results presentations
- Registering and submitting our poster and presentation to UGRADs
- Final CAD packet – collection of the entire CAD for the project
- Website checks
- Operation/ assembly manual – to inform the client on how to use the device

Success Metrics

- The device survives typical weather experienced in nature
- Protects the optics and electronics
- The accepted light range is 400-1000nm
- Within the drone’s weight capacity of 3.6 lbs and can be mounted to a drone
- Operates from 0-50 °C

Customer Requirements

Customer Requirement	CR Met	Client Acceptable
CR1 - Durable	✓	✓
CR2 - Semi-constant internal conditions	✓	✓
CR3 - Ease of access	✓	✓
CR4 - Environmentally sound	✓	✓
CR5 -Spectral range between 400-1000nm	✓	✓
CR6 - As light as possible	✓	✓
CR7 - As small as possible	✓	✓
CR8 - Drone mountable in operation	✓	✓
CR9 - Ambient operating range of 0-50°C	✓	✓

Engineering Requirements

Engineering Requirement	Target	Tolerance	Measured/Calculated Value	ER Met?	Client Acceptable
ER1 - Long lifespan	5 years	± A few months	PC has a life of 10-20 years, everything else can be replaced/re-aligned	✓	✓
ER2 - Internal temperature control with vents	0-50 ℃	± 5 ℃	Ambient = 50C, Internal Ambient = 48.26 C	✓	✓
ER3 - Easy to access data	<5 sec	0 sec	Just plugs in, USB (needs 3 tries to get correct orientation)	✓	✓
ER4 - Water and dust proof	0 ml/ 0 mg	±0.01 ml/ 0.01 mg	Ingress after 10 sec of full submersion	✓	✓
ER5 - Optics designed for full range	400-1000 nm	± 0 nm	Based on Zemax Calculations, 400-1000nm fit within the CCD chip space	✓	✓
ER6 -Drone can fly while carrying	<2 lbs	+1lb	2lb 7oz	✓	✓
ER7 -Fits within drone payload space	10in*10in*5 in	+ 0.5in	9.976in*8.238in*4.5in	✓	✓
ER8 - Optics secured	0 in of movement	0 in	Per greater than 5 ft drop, it moves. Will fix upon next iteration	✓	✓

Derrick Doan

House of Quality

System QFD

Project:	Spectral Forest
Date:	Spring 2024

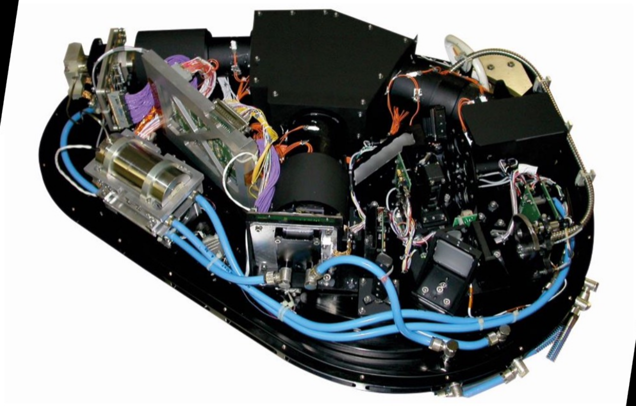
Correlation Legend	
++	Strong positive
+	Moderate positive
-	Moderate negative
--	Strong negative

Legend	
A	APEX Imaging
B	ASD FieldSpec 4
C	NASA HyMap

#	Technical Requirement	1	2	3	4	5	6	7	8
1	Long Lifespan	++							
2	Easy to access data in EE side	--	++						
3	Water and Dust Proof	+	--	++					
4	Optics Designed for Full Range	-	--	+	++				
5	Drone can fly while carrying	-	-	--	-	++			
6	Fit within drone payload space	-	+	--	+	+	++		
7	Optics Secured During Flight	+	-	+	-	+	+	++	
8	Internal Temperature Control with Vents	+	--	+	-	-	-	-	++

#	Customer Needs	Customer Weights	Long Lifespan	Easy to access data in EE side	Water and Dust Proof	Optics Designed for Full Range	Drone can fly while carrying	Fit within drone payload space	Optics Secured During Flight	Internal Temperature Control with Vents	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
1	Durable	4.5	9	2	5				8					AB	C
2	Semi-constant internal conditions	3.5			6					8			B	A	C
3	Ease of access	4		9	4			5					C		AB
4	Environmentally Sound	5			9					7				AB	C
5	Spectral Range Between 400-1000nm	5			5	9		2	6	3			B	AC	
6	As Light as Possible	4.5					9						C	A	B
7	As Small as Possible	4.5				2		9					C	A	B
8	Drone Mountable in Operation	3.5					8	8	9				BC		A
9	Ambient operating range of 0-50 °C	3.5			7					9				AB	C
	Technical Requirement Units		years	time in sec (to enter)	mL	nm	lbs	ins*ins*ins	Hertz	°C					
	Technical Requirement Targets		5	<60	0	400-1000	<2	<331	+/- 50	0-50					
	Absolute Technical Importance		40.5	45	154	54	68.5	98.5	97.5	109.5					
	Relative Technical Importance		8	7	1	6	5	3	4	2					

Derrick Doan

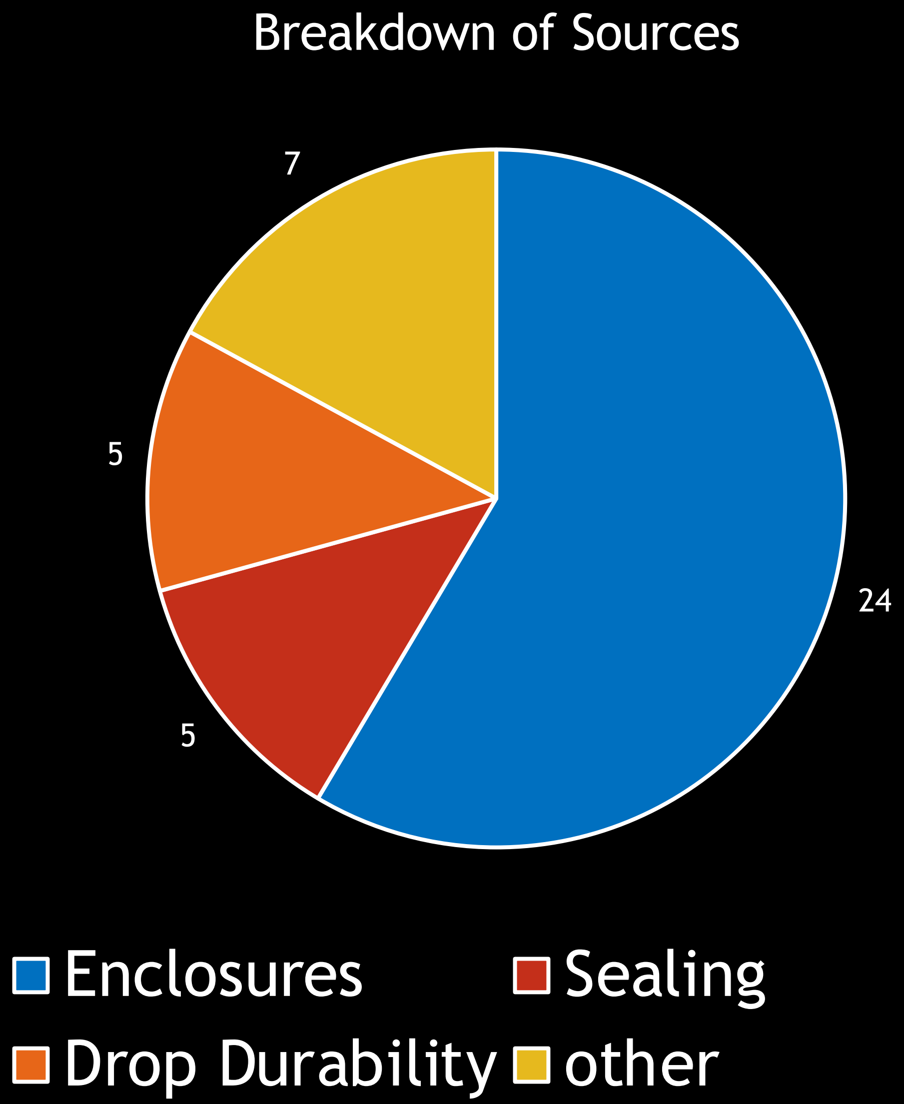


Benchmarking

The state of the art (SOTA) designs, depicted on the left, 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.

SOTA Design	Description
Airborne Prism Experiment (APEX) Imaging Spectrometer	Attached to drone, hyperspectral data in 300 bands, spectral range of 380-2500 nm and at a spatial ground resolution of 2-5 m.
ASD FieldSpec 4 Standard-Res Spectroradiometer	Portable, handheld, spectral range of 350-2500 nm, interchangeable contact probes and mug lights
NASA HyMap Sensor	Four spectrometers in the interval of 450-2450 nm, 2 major atmospheric water absorption windows, on-board bright source calibration system

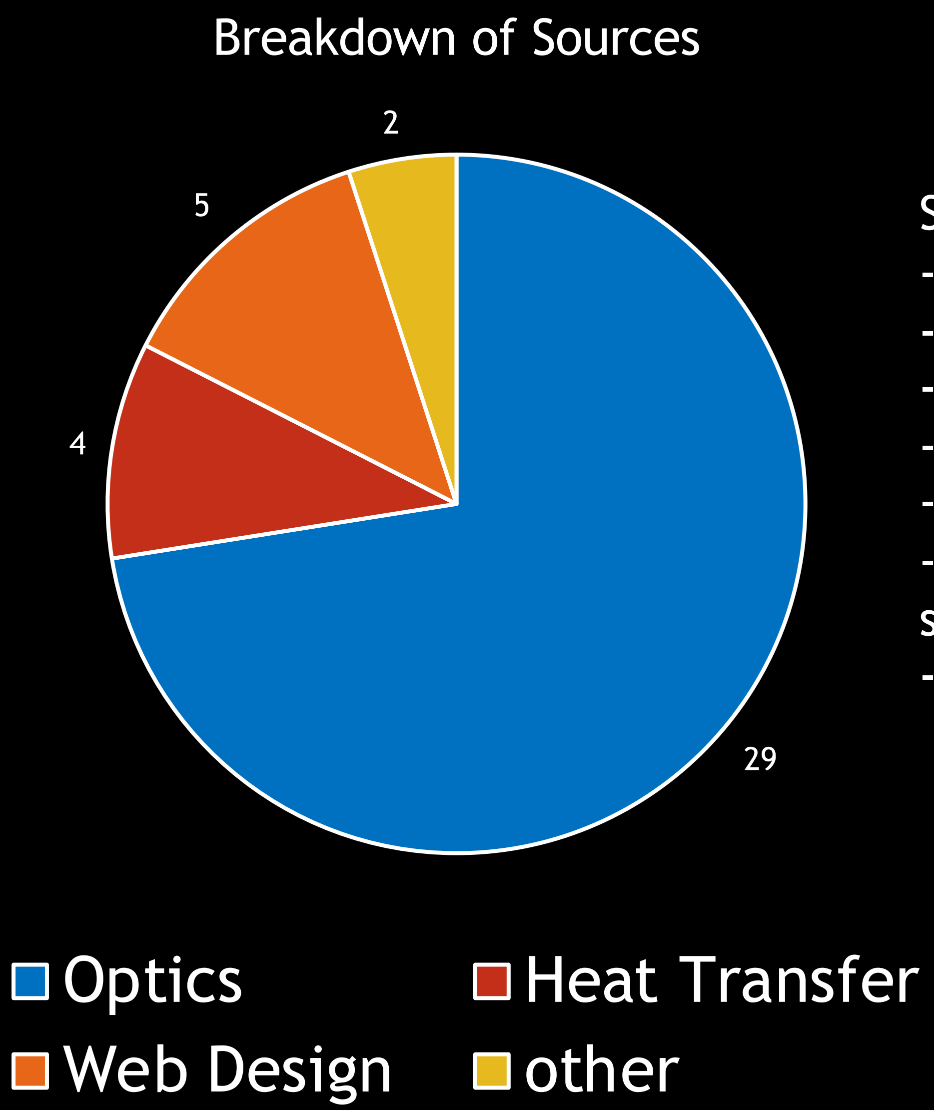
Tyler Lerew Literature Review



Sources list:

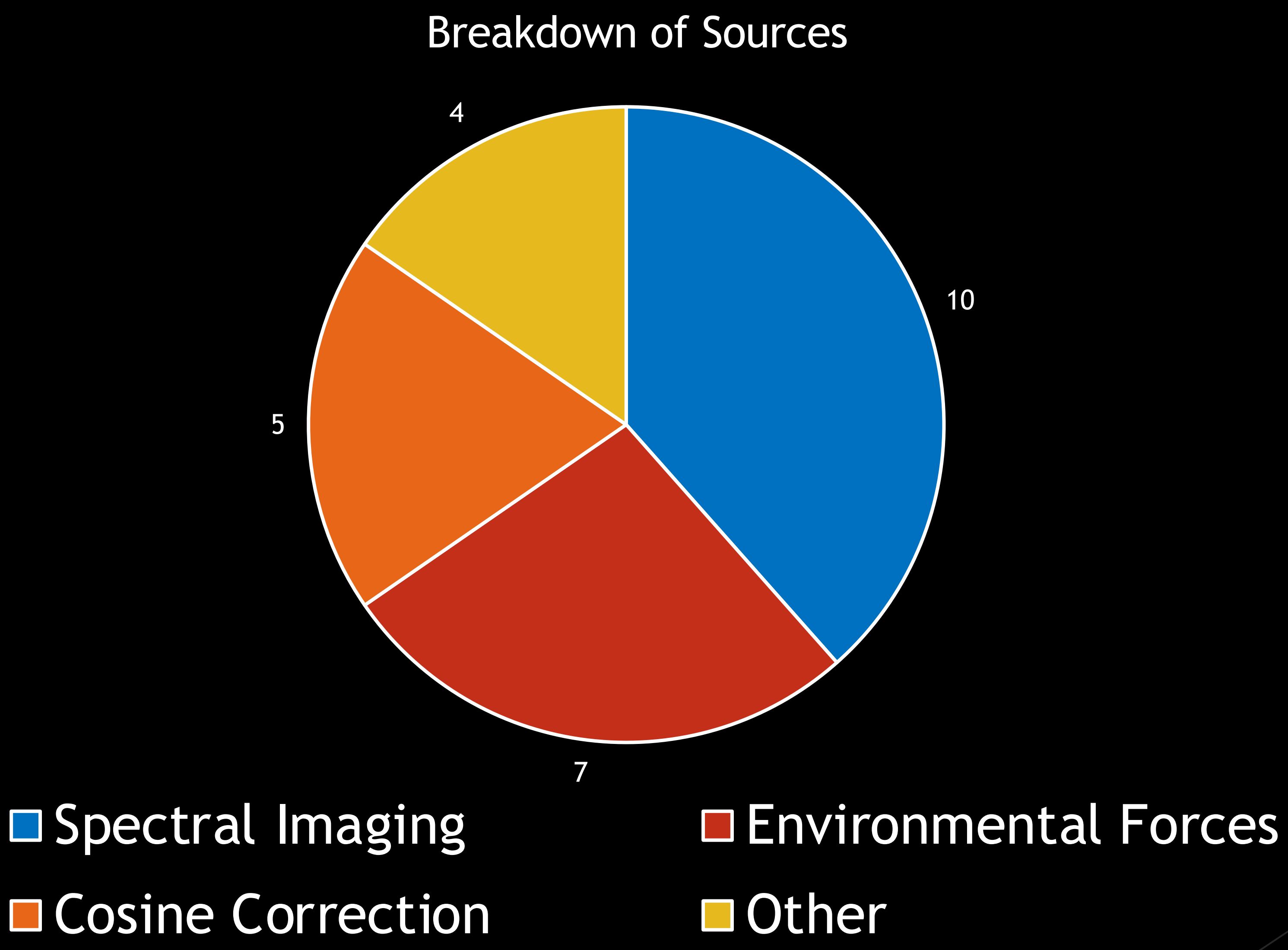
-NEMA Enclosure Types
-IP ratings
-ONYX Material properties
-Best filament for outdoor use
-PETG vs. PC
-All filaments
-Filament densities
-O-Ring Groove (Gland) Design Guide
-Nothing Gets In: Waterproof Enclosure Design 101 (and IP68)
-AS568 O-ring Size Chart
-How to Calculate Force of Impact
-Impact Force Calculator

Torrey King Literature Review



Some of these sources:
-Edmund optics how to pages
-Zemax support and guidance forum
-UofA zemax course material
-UofA optic mounting procedure
-UofA lab laser safety
-UAV-based hyperspectral remote sensing paper
-Mozilla Developer Network:
    -html and css and javascript

Derrick Doan Literature Review



Sources list:

- Spectral Imaging
  - LiDAR 3D forest modeling
  - Linear predictive vegetation models
- Environmental Forces
  - Biophysical and Biochemical properties
- Cosine Correction
  - Lambert’s Law
- Other
  - Pre-existing designs
  - Specifications and subsystems

Mathematical Modeling

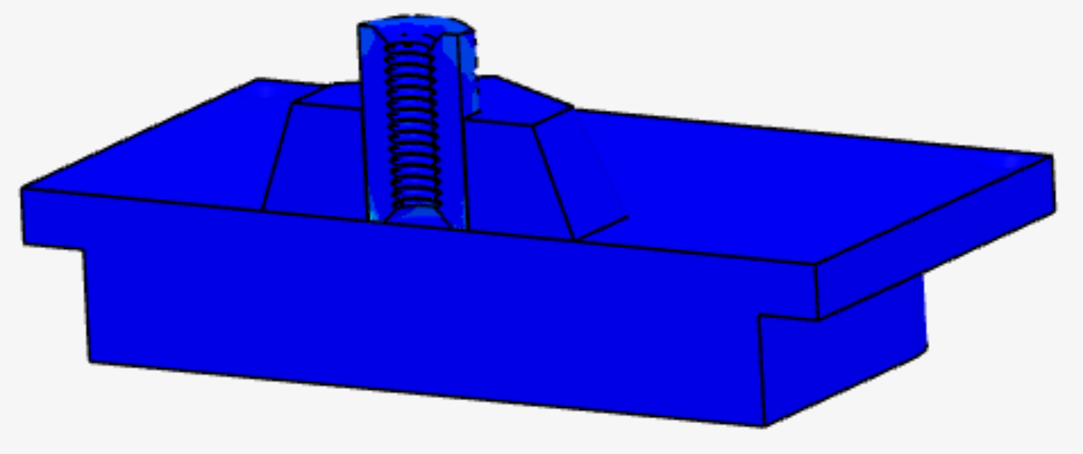
Tyler Lerew	Torrey King	Derrick Doan
• Free fall off table • FEA on Mounting System	• Heat Disbursement • Vent Flow • Optic Path	• Force on Mounting System • Cosine Correction

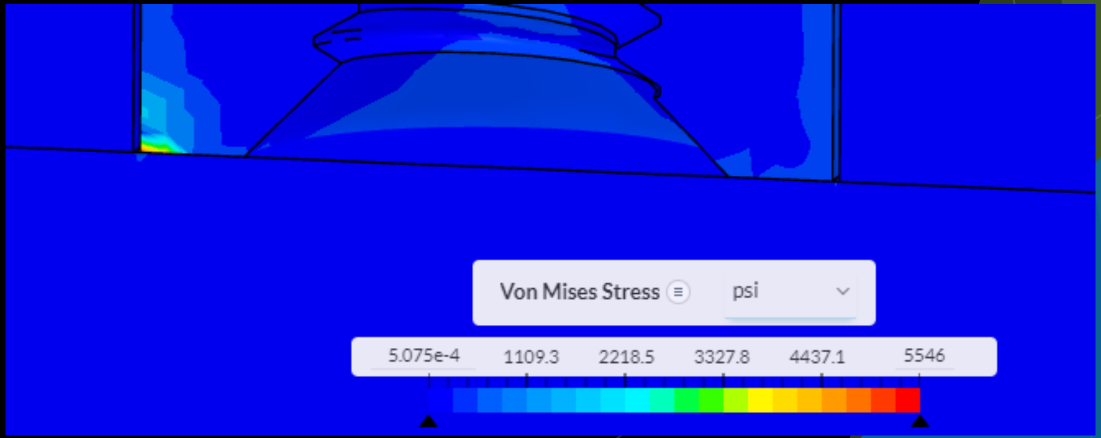
Mathematical Modelling Tyler

- Impact force and stress on housing if the unit is dropped, ensure no fracture to housing
  - Preliminary nylon housing mass estimate (101.6mm x 101.6 mm x 50.8mm): ~ 0.34 kg
  - Height of fall: 1.81 m
  - Height of bounce: 50.5 mm
  - Governing equation (Impact from a falling object): $F = \frac{mgh}{d}$
  - Stress equation: $\sigma = \frac{F}{A}$
  - **Total force: 120.4 N**
  - **Stress: 0.5 MPa**
  - **Ultimate Strength: 69 MPa**
- Can use this calculation later in the design process in FEA to ensure the unit is intact after a fall and design around this force to ensure internal components do not shift during impact

Engineering Calculations -Tyler

- FEA on camera mount attached to housing
- Purpose: design the housing to easily be attached to a standard camera mount and it will not fail when attached
- 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
  - Strength of sleeve nut is 105 x 10^3 psi

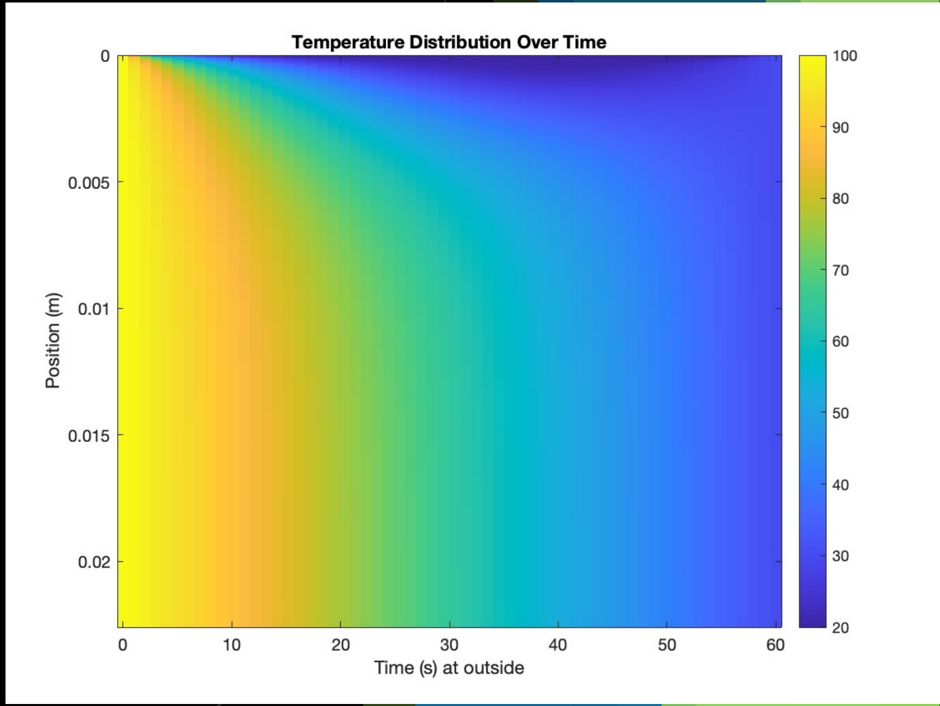




Mathematical Modelling Torrey

- Electronics heat disbursement and internal temperature status
  - Using knowledge from: Bergman, T. L., & Lavine, A. (2017). Fundamentals of heat and mass transfer. John Wiley & Sons.
- Looking at edge case internal and external temperature states with over assumption of electrical and radiation inputs for the system.
- Found that in worst scenario designed for, internal chamber returns to operating temp. in roughly 40 seconds

- Assumptions:
- Print Material: 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
- Battery capacity= 10050 mAh
- Voltage = 3.7 volts
- Airmass = 0.001213 kg
- specific heat capacity of air = 1005 J/(kg*k)
- In-fill ignored, assuming a double wall system of print material



Engineering Calculations - Torrey

- Diffraction Grating Angle
  - Maybe most important of the optic placement and alignment calculations
- The grating is what isolates each wavelength and allows for the detector to read location/intensity and not wavelength.
- Equation from Thorlabs, the company we sourced our grating from.

$$m\,\lambda = d\sin(\theta)$$

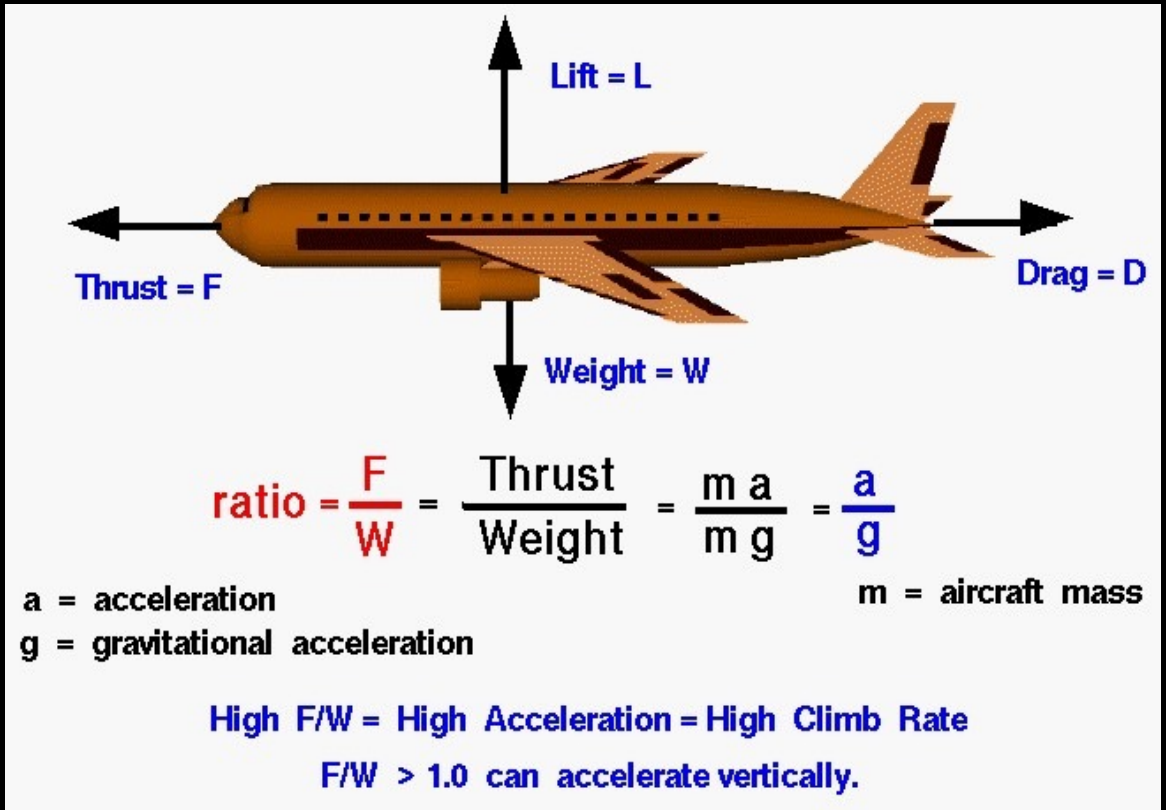
$$\theta = sin^{-1}(\frac{\lambda}{2d})$$

$$\lambda = \frac{1-0.4}{2} = 0.3$$

$$d = 1.66$$

$$\theta = 0.2124\,rad = 12.1718°$$

Mathematical Modelling Derrick



- Forces Applied When Flying
  - Mass estimate (m): Drone (2kg) + Design (.34kg) = 2.34 kg
  - Avg. Drone Speed (a): 45 mph = 20.13 m/s
  - Gravity (g): 9.8 m/s^2
  - Thrust (F): 47.1 kg-m/s or N-s
  - Weight (W): 22.93 kg-m/s^2 or N
  - Ratio (F/W): 2.05 = High Climb Rate
  - Measurements to be used when creating housing for system to resist movement from these forces (material, fasteners, hinges, etc.)

Derrick Doan

Engineering Calculations - Derrick

- Cosine Correction – Making light spectrum spectrally flat across all arrays (Ex: eyes)

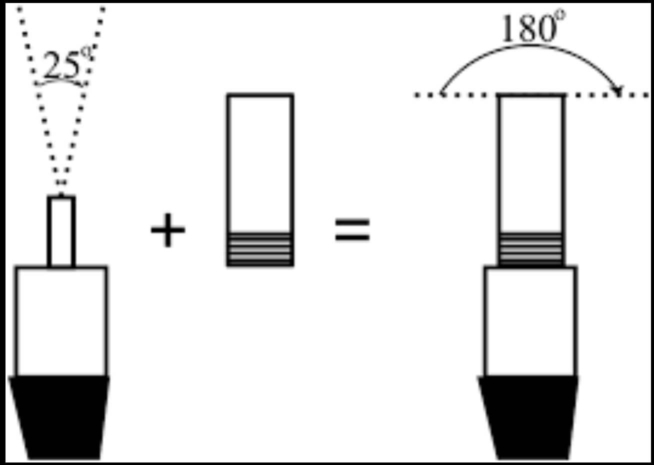


Figure 5: Cosine Corrector Example

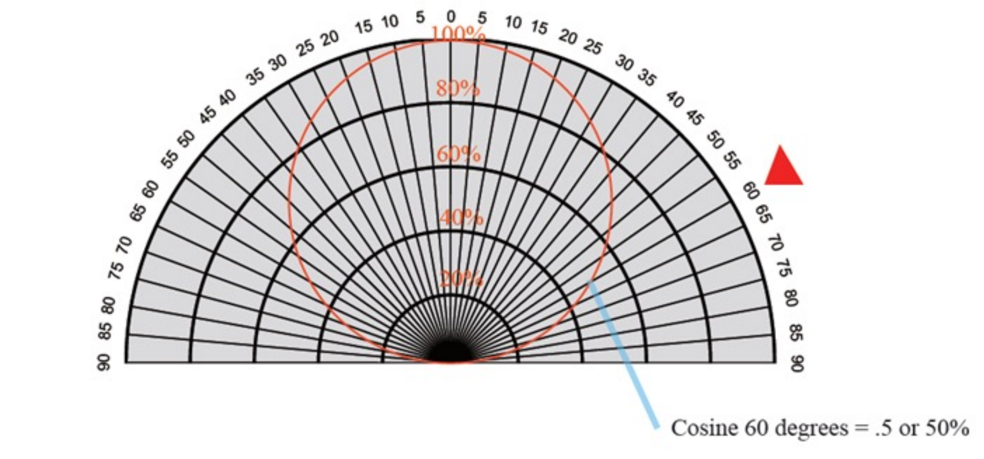


Figure 6: Cosine Correction for Oblique Angle Light

Lambert's Law:

$L_\theta = L_0 \times \cos\theta$

Light Intensity at Angle θ = Light Intensity on Reflected Surface x Cosine of Oblique Angle θ

Concept Generation and Selection

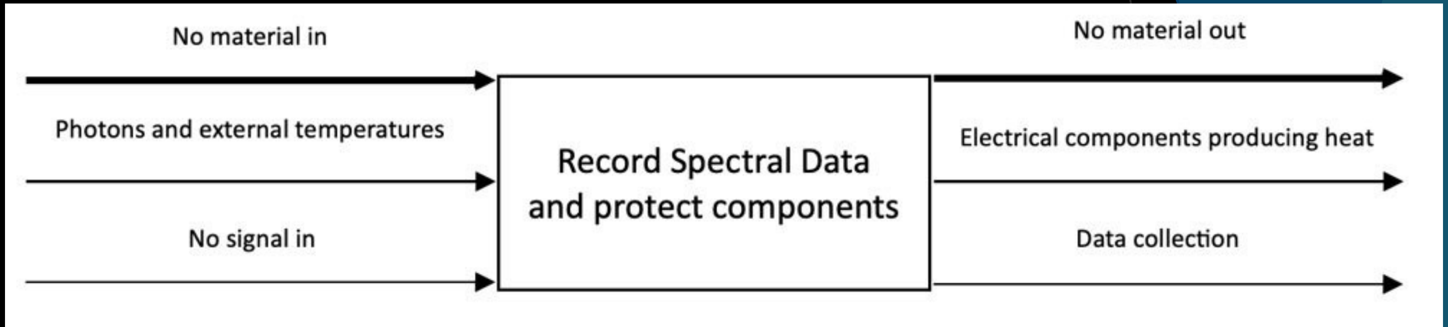
Functional Decomposition

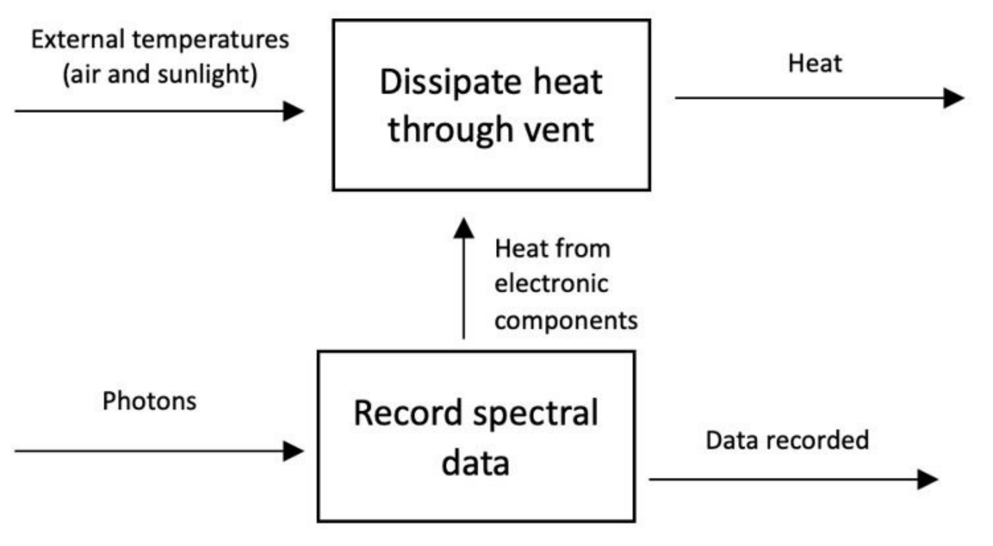
Black Box Model

- No material change in or out of the unit at any point during the process of the unit being used
- 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 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.

Functional Model

- Uses same energy transfer method described in Black Box Model for recording spectral data
- It is important that the unit can reliably and easily dissipate heat to protect the internal electronics. It must do this within the constraints of size and weight to allow it to be drone mounted





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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 ✓

Selection Criteria

Detector	Enclosure	Aperture

• Linear Array
  • Cheapest with highest quality
	• Rectangular
	  • Easy to mount internal components
		• Wide FOV Entrance Lens
		  • Allows largest amount of light in

Selection Criteria cont.

Pressure Equalization

- Vent
  - Ultrasonically welded filter membrane
  - IP67, 68. NEMA 3R, 4, & 4X
  - Max airflow: 16.6 LPM/3.7cm^2 at 13.5 psi

O-ring

- Neoprene 70A, 1.39% stretch, 79% groove fill, 27% compression

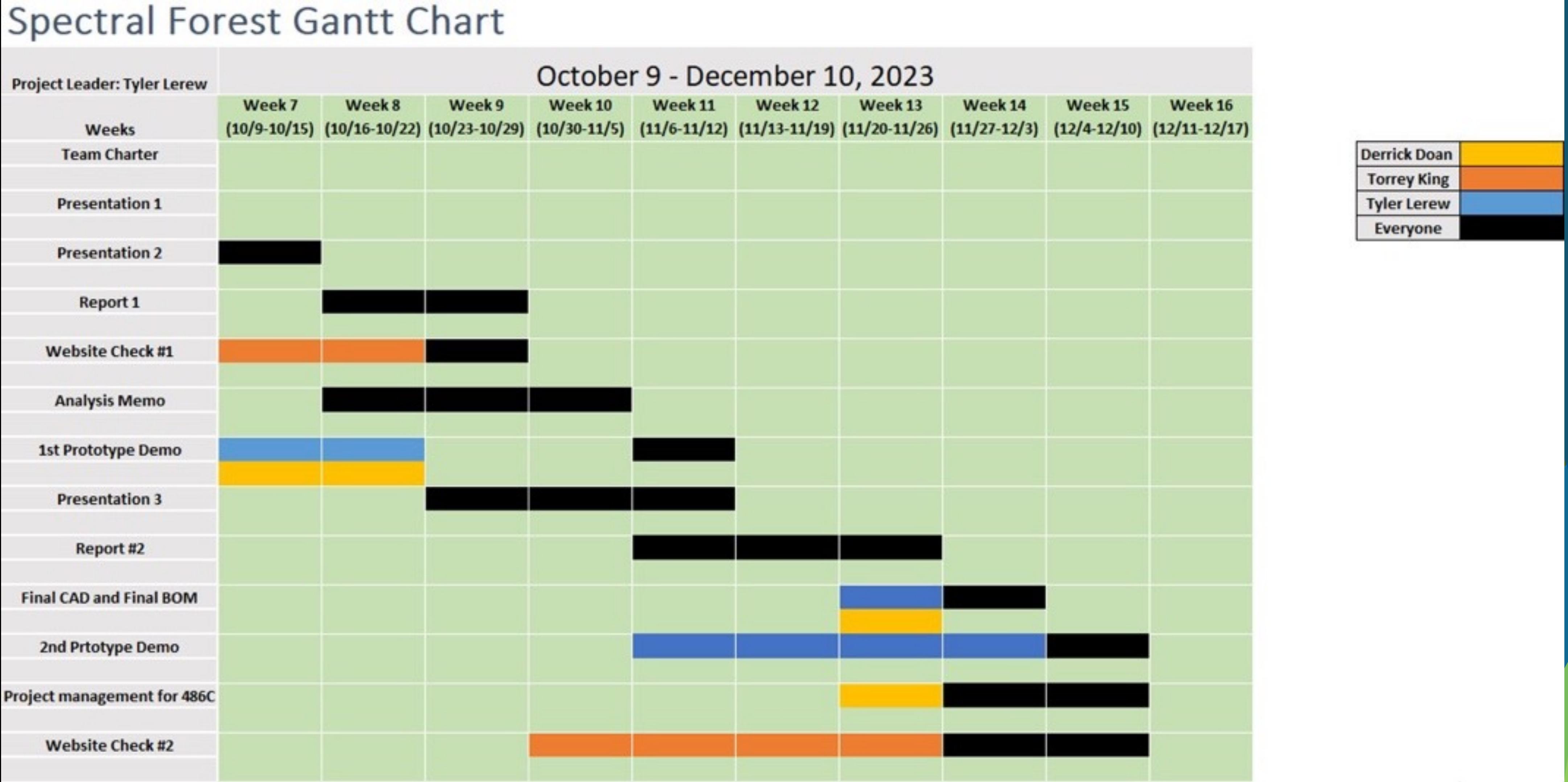
Material Selection

- Polycarbonate
  - UV resistance
  - Strong
  - 3D printeable
  - 10-20 year life

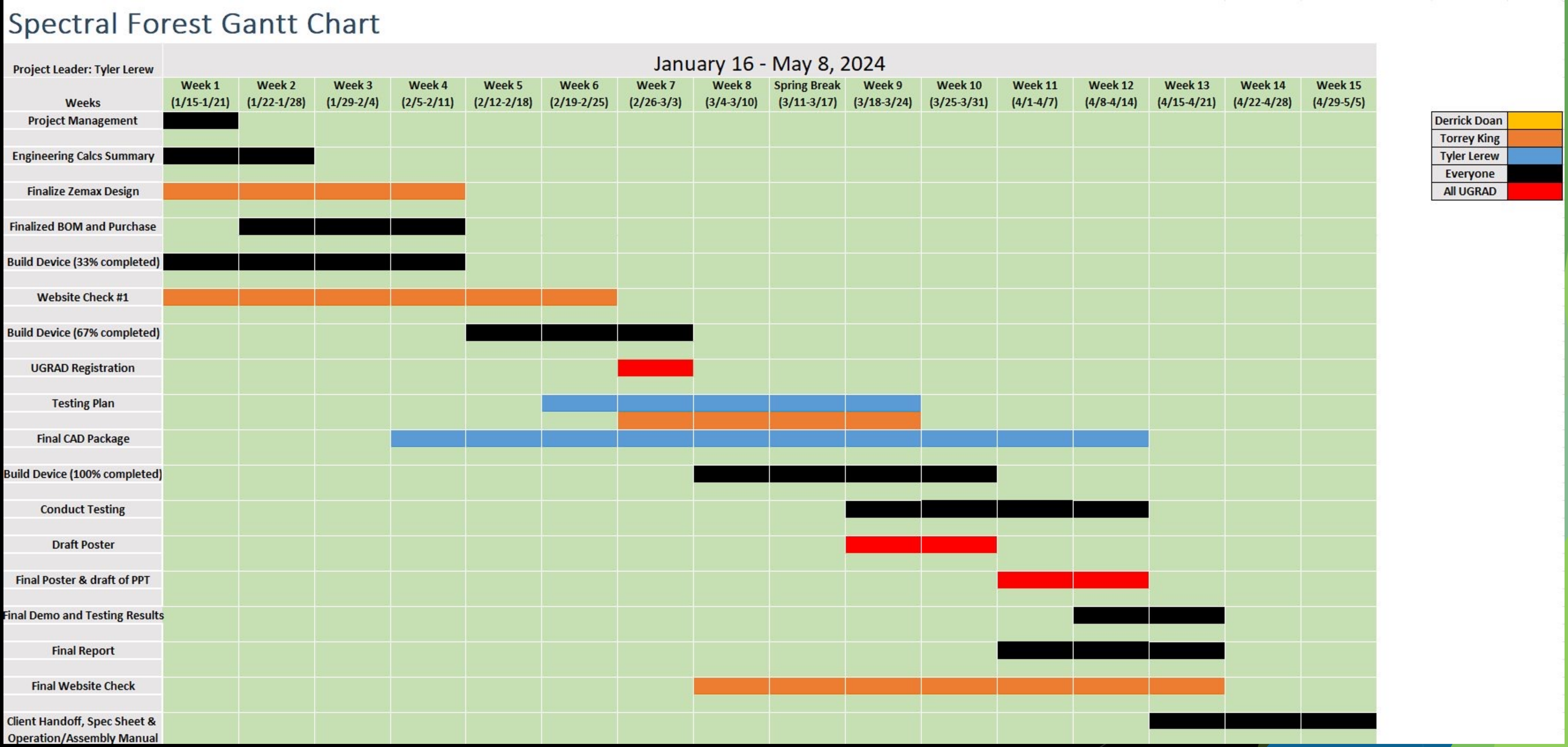
Tyler Lerew

Project management – Schedule

Fall Semester Schedule



Spring Semester Schedule



Budget

- Total budget: $5600
- Total spent on components: $5323.41
- Total leftover: $276.59
- We self-funded ~2% or $102.75
- Chris Edwards' Space Grant Consortium funded ~98% of the project
- Any individual item under $5000 can be purchased by the Space Grant

- Without this grant this project would be reduced to a DIY weekend project with the back of a CD used as a diffraction grating inside of a black carboard box

Tyler Lerew

Bill of Materials (BoM)

Bill of Materials: Purchased Items									
Item #	Item	Item Description	Vendor & Part #	Quantity	Cost $	Cost Per unit $	Purchase or Manufact	Weight [oz]	to buy
1	Polycarbonate CF filament	Filament that is used to print our device	Amazon	3	$ 136.77	$ 45.59	Purchase	N/A	yes
2	Amazon Basics TPU 3D Printer Filament, 1.75 mm, Red, 1 kg Spool (2.2 lbs)	Filament for vibration dampening	Amazon	1	$ 30.70	$ 30.70	Purchase	N/A	yes
3	M4-0.7x10mm Stainless Steel Pan Head Phillips Drive Machine Screw 2-Pieces	For grating mount	Home Depot	2 pk (2)	$ 2.50	$ 1.25	Purcahse	0.1	yes
4	M4-0.7 x 20 mm. Internal Hex Button-Head Cap Screws (12-Pack)	For lens mounts	Home Depot	1 pk (12)	$ 6.99	$ 6.99	Purchase	0.1	yes
5	18-8 Stainless Steel Button Head Torx Screws M4 x 0.70 mm Thread, 10mm Long	For door	McMaster-Carr #90991A122	1 pk (100)	$ 6.64	$ 6.64	Purchase	0.1	yes

Bill of Materials (BoM)

6	Phillips Rounded Head Thread-Forming Screws for Plastic, 18-8 Stainless Steel, Number 1 Size, 1/8" Long	For PCB standoffs	McMaster-Carr #99461A605	1 pk (50)	$ 15.65	$ 15.65	Purchase	0.1	yes
7	Medium-Strength Steel Coupling Nut	Zinc-Plated, Grade 5, 1/4"-20 Thread Size	McMaster-Carr #90977A130	1	$ 5.67	$ 5.67	Purchase	0.25	no
8	Plastic Submersible Cord Grip NPT Threads, for 0.39"-0.55" Cord OD, 1/2 Knockout Size	For pressure system	McMaster-Carr #69915K57	5	$ 24.95	$ 4.99	Purchase	1	yes
9	UV-Resistant Thick-Wall PVC Pipe for Water 4 Feet Long, 1/4Pipe Size	For pressure system	McMaster-Carr #5066K38	1 (4ft long pc)	$ 13.60	$ 13.60	Purchase	1	yes
10	303 Stainless Steel Tapered Heat-Set Inserts for Plastic M4 x 0.7 mm Thread Size, 7.92 mm Installed Length	for screwing screws into	McMaster-Carr #97163A153	5 pk (10)	$ 38.90	$ 7.78	Purchase	5	yes

Tyler Lerew

Bill of Materials (BoM)

11	165 Neoprene O-Ring, 70A Durometer, Round, Black, 6-1/2" ID, 6-11/16" OD, 3/32" Width (Pack of 5)	To seal the door	Amazon	1 pk (5)	$ 8.42	$ 8.42	Purchase	0.1	yes
12	Cosine Corrector	25.4mm Dia., 3mm Thick, ISP Optics CaF_2 Infrared (IR) Diffuser	Thor Labs WG41050	2	$ 136.12	$ 68.06	Purchase	1.06	yes
13	Diffraction grating	Richardson Gratings 600 Grooves, 25 x 25mm, 400nm, Plane Ruled Reflection Grating	Thor Labs GT25-06V	2	$ 254.18	$ 127.09	Purchase	0.96	yes
14	Collimator	25.4mm Dia. x 25.4mm FL, VIS-NIR Coated, Plano-Convex Lens	Edmund optics #62-599	7	$ 346.50	$ 49.50	Purchase	3	yes
15	entrance lens	25mm Dia., 0.66 Numerical Aperture Uncoated, Aspheric Lens	Edmund optics #47-729	2	$ 520.00	$ 260.00	purchase	N/A	

Bill of Materials (BoM)

16	Round Lens Mount	SM1-Threaded Kinematic Mount for Thin Ø1" Optics	Thorlabs KM100T	4	$ 741.24	$ 185.31	Purchase	19.2	yes
17	Kinematic Rectangular Optic Mounts	Kinematic Mount for 1/2" Tall Rectangular Optics, Right Handed, 8-32 Tap	Thorlabs KM05S	2	$ 225.14	$ 112.57	Purchase	3.36	yes
18	Silicone	Mildew-Resistant Silicone Sealant	McMaster-Carr #7545A611	1	$ 36.62	$ 36.62	Purchase	0.5	yes
19	USB-C Rubber Seal	Würth Elektronik	Digi Key #732-11387-ND	5	$ 3.15	$ 0.63	Purchase	0.1	no
20	USB-C Panel Mount Connector	Panel-Mount USB Cord	McMaster-Carr #4872N19	2	$ 26.34	$ 13.17	Purchase	4	no
21	Plasti Dip	11 oz. White General Purpose Rubber Coating Spray	Home Depot	2	$ 17.96	$ 8.98	Purchase	0.5	yes
22	Black paint	12 oz. Black Matte Interior/Exterior Spray Paint and Primer in One Aerosol	Home Depot	1	$ 6.98	$ 6.98	Purchase	0.5	yes

Bill of Materials (BoM)

23	Foam	Fill PVC pipe so only air can pass through and nothing else	McMaster-Carr #1298N4	1 (3ft pc)	$ 14.69	$ 14.69	Purchase	0.1	yes
24	Latex balloon	Will be attached inside box to PVC pipe	Walmart	5	$ 5.00	$ 1.00	Purchase	0.1	yes
25	Silica pellets	Will be inside box to absorb any moisture in the air	McMaster-Carr #2189K16	2 (pk. 10)	$ 17.68	$ 8.84	Purchase	0.21	yes
26	3D printer	Used to print the final product	Bambu Lab	1	#########	$ 1,449.00	Purchase	N/A	yes
27	0.4mm Hardened Steel Backup Nozzel	Used to print the CF filament	Bambu Lab	2	$ 29.98	$ 14.99	Purchase	N/A	yes
28	Disposable Nitrile Gloves	To handle lenses and to paint box	Home Depot	1 pk (10)	$ 2.98	$ 2.98	Purchase	N/A	yes
29	KN95 5 Layer Respirator Mask	To stop breath from landing on lenses	Home Depot	1 pk (10)	$ 2.50	$ 2.50	Purchase	N/A	yes
30	2 in. Flat Chip Brush	To paint the inside and outside of the box	Home Depot	2	$ 2.94	$ 1.47	Purchase	N/A	yes
31	Canned Air	To remove dust from lenses if any	Staples or Walmart	1	$ 7.88	$ 7.88	Purchase	N/A	yes
32	Vent	Equalize pressure	PolyCase PART#: UA-006	5	$ 19.45	$ 3.89	Purchase	0.01	yes

Tyler Lerew

Bill of Materials (BoM)

33	8 in. UV Resist Zip Ties	To hold balloon on pipe	Home Depot	1 pk (20)	$ 3.31	$ 3.31	Purchase	0.05	yes
34	Slit Assembly	Allows the light to enter the device	Xometry. Purchaser: Send your email to ttl58@nau.edu to gain access to the quote	3	$ 65.22	$ 21.74	Purchase	4	yes
35	14-In-1 TORX Multi-Bit Screwdriver	Used to install tamper-proof screws	Home Depot	1	$ 17.97	$ 17.97	Purchase	N/A	yes
36	Glue Stick	For bed of printer	Walmart	1	$0.97	$ 0.97	Purchase	N/A	yes
37	Heat Set Insert Tool	Used to heat set screw inserts	Amazon	1	$ 59.99	$ 59.99	Purcahse	N/A	yes
38	Prototype device #1	Will be used for testing purposes	Travis	1	$ 20.00	$ 20.00	Purchase	18.25	no
39	First Demo ME 476C	Used to prove concept and test fits	Jake Draper (Friend)	1	$ 10.00	$ 10.00	Purchased	19.2	no
40	EE Fund	Money the EE team needs	Space Grant	1	$ 900.00	$ 900.00	Purchase	N/A	yes

Design Validation and Prototyping

Failure Modes and Effects Analysis (FMEA)

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

6.1.1 Door Sealing

- 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,

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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	

6.1.2 Optics

- The optics in the system dictate whether the spectrometer records the proper spectral data per 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,

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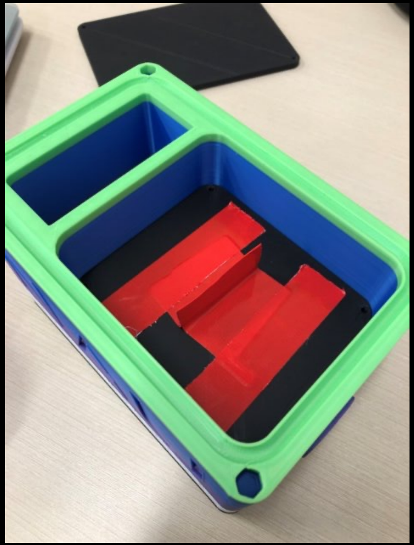
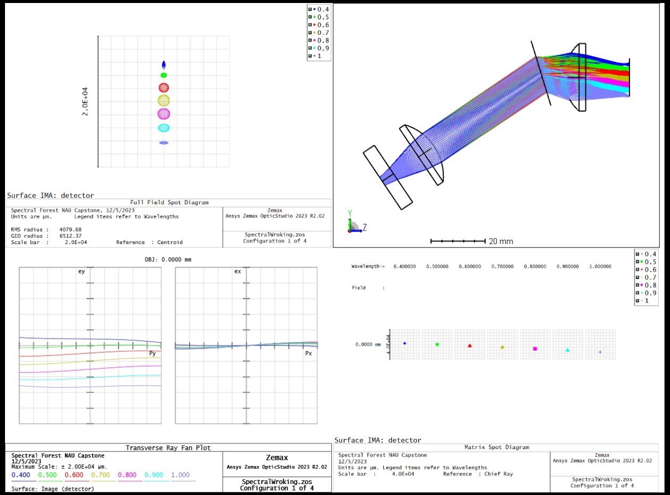
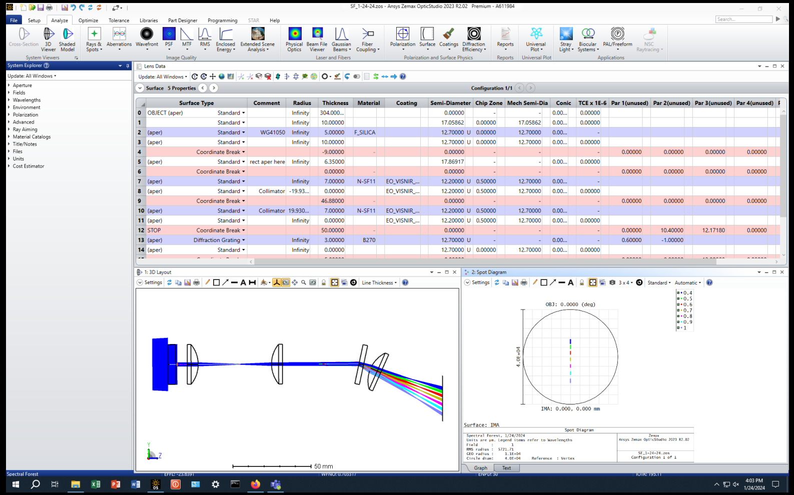
Initial Prototyping







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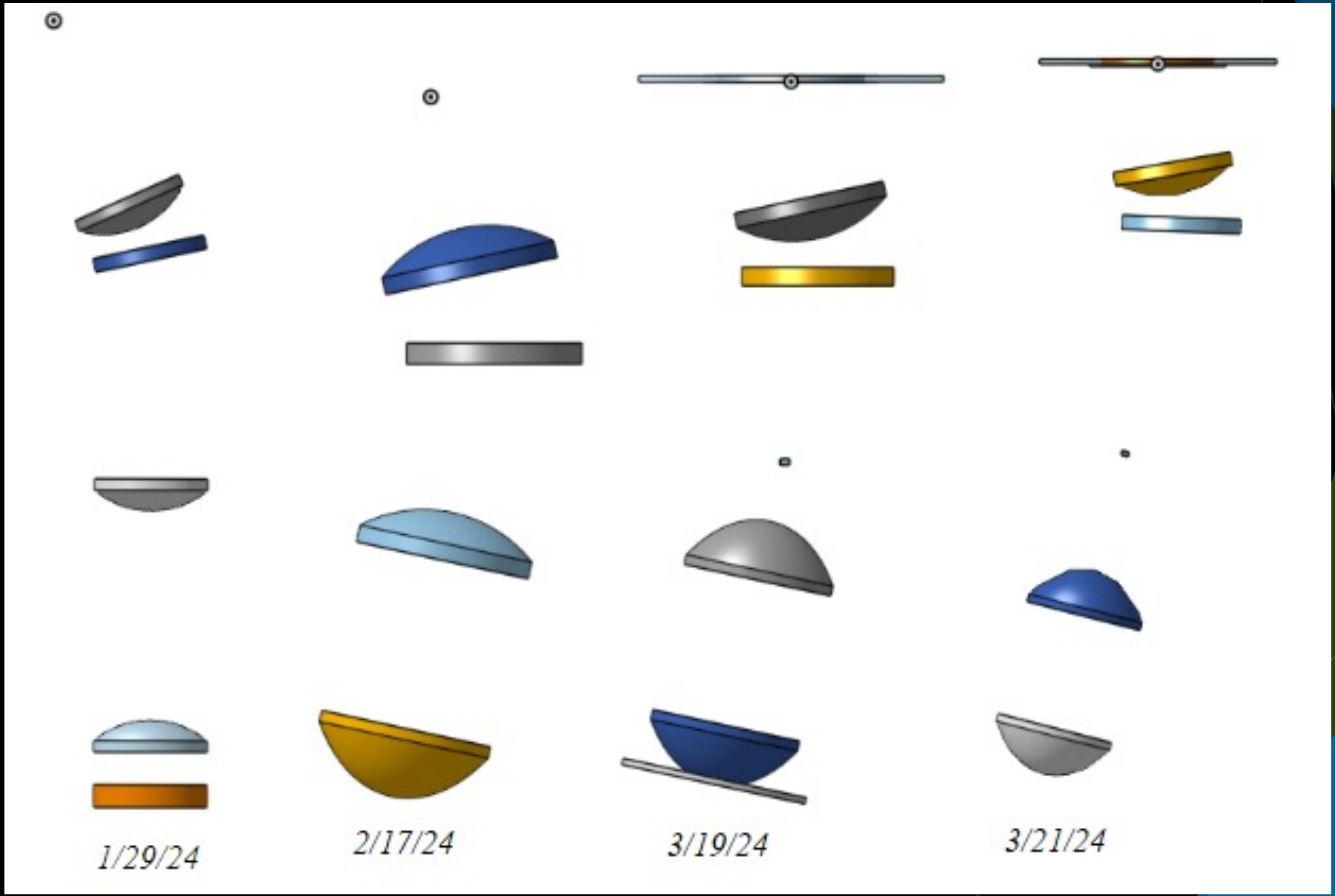
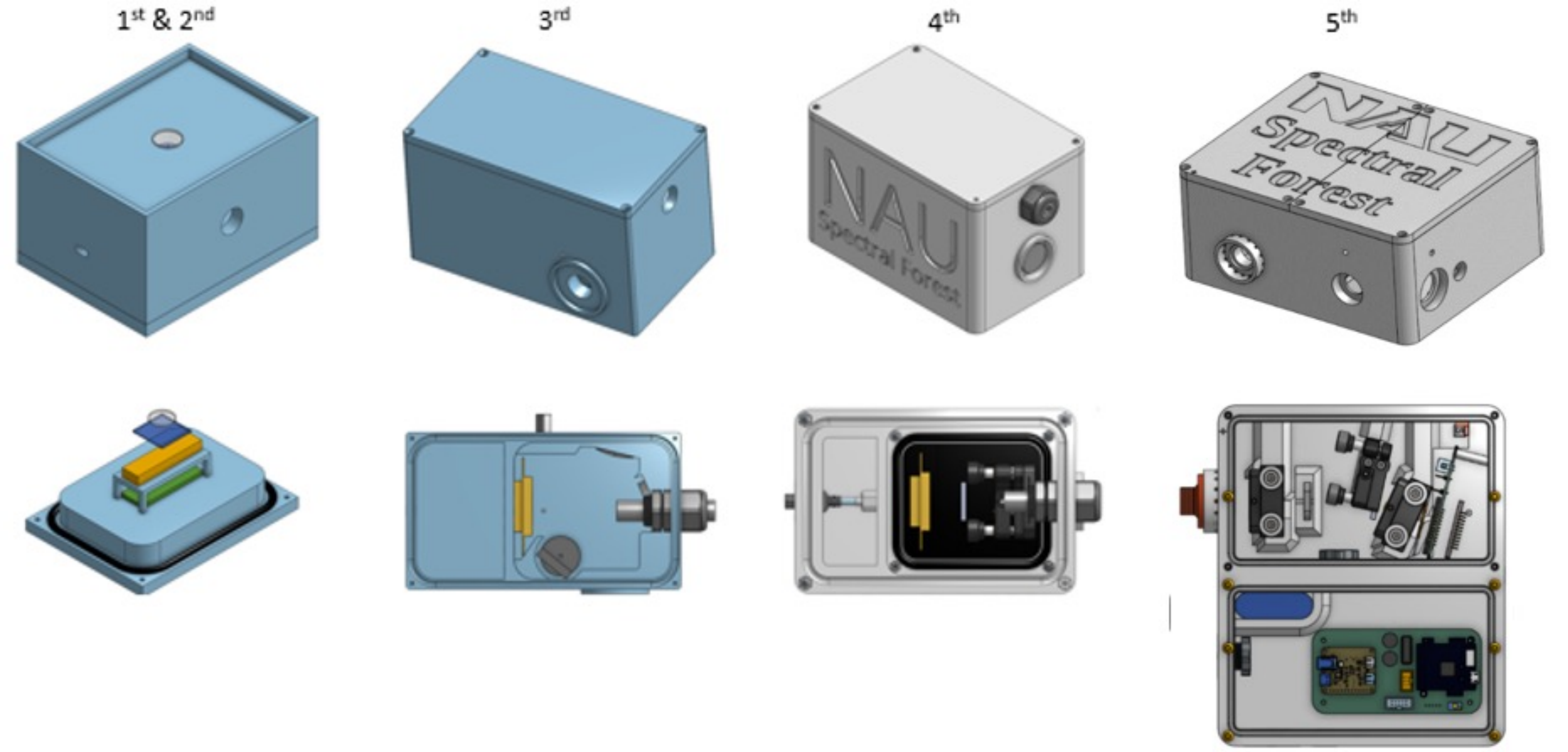
Optical Iterations



Enclosure Iterations



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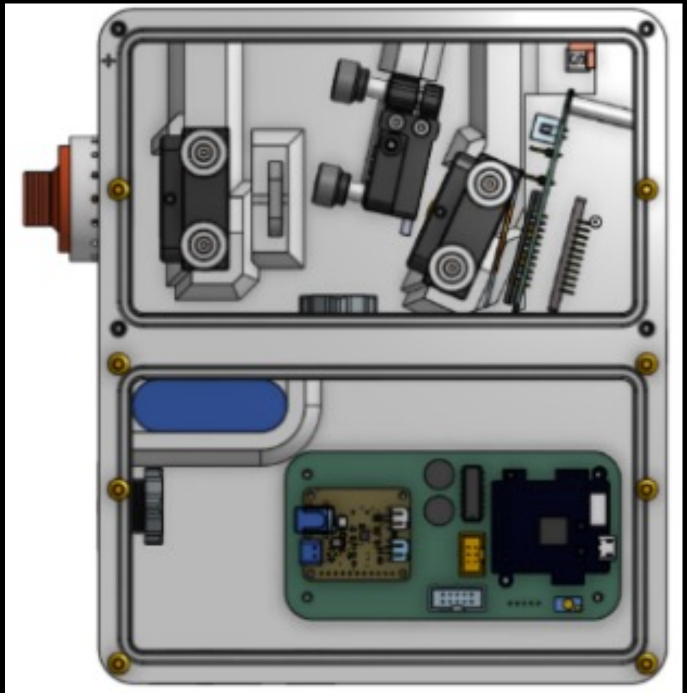

Final Hardware

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Final Testing

Top level Testing Summary Table

Experiment/Test	Relevant DRs
Ex 1: Laser Alignment	CR5, CR 8, CR9, ER1, ER5, ER8
Ex 2: Heat test	CR1, CR2, CR4, ER1, ER2
Ex 3: 3D print mount connection	CR3, CR6, ER8
Ex 4: Flight/drop for optics	CR1, CR4, CR6, CR7, ER 1, ER4, ER8
Ex 5: Destructive test on enclosure	CR1, CR4, CR6, CR7, ER 1, ER4, ER8
Ex 6: Seal/vent test upon submersion	CR2, CR4, ER2, ER4
Ex 7: Spectrum tube color adjust	CR2, CR5, CR9, ER5, ER8

Test 1: 3D Printed Fits

Relevant DRs
CR3: Ease of access
CR6: As light as possible
ER8: Optics Secured

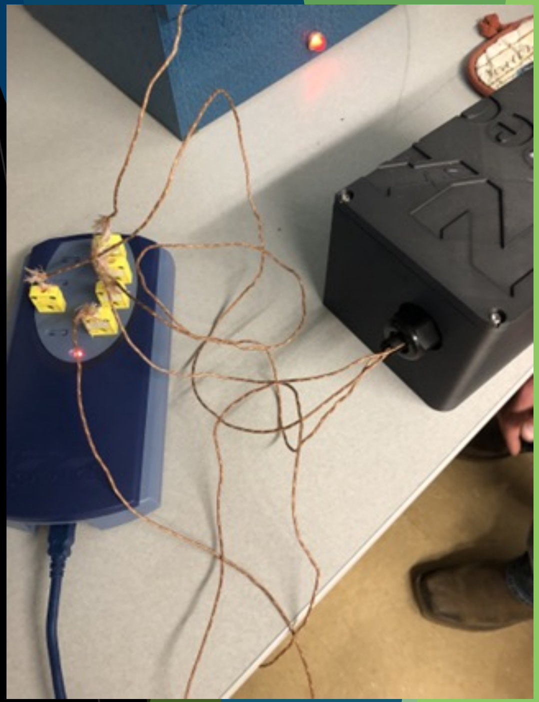
- Procedure:
  1. Use Bambu Lab X1 Carbon printer to print features of interest, such as vents, mounts, and hardware, based on CAD models.
  2. Make necessary cuts to isolate features for testing without printing the entire model.
  3. Assess how components fit and align together, ensuring flush fits, sealed enclosure, and proper alignment.
  4. Record observations regarding the quality of fits and any necessary adjustments.
- Results:
  - Upon 1-2 iterations we could find the correct fit for each purchased and manufactured parts
  - Inform design decisions based on fitment observations.

Test 2: Laser Alignment

Relevant DRs
CR5: Spectral Range of 400-1000nm
CR8: Drone mountable in operation
ER1: Long lifespan
ER5: Optics designed for full range
ER8: optics secured

- Procedure:
  1. Select a laser (Thorlabs PL252 4.5mW 639nm class 3R 3mm dia
  2. Design a CAD model to center the laser onto the optic entrance and 3D print a mount using PLA.
  3. Measure the off-center alignment of the laser at each lens point, both horizontally and vertically.
  4. Progress through alignment steps, starting with the optic entrance and moving to internal mounts.
  5. Iterate adjustments of mounts as necessary for precision alignment.
  6. Record measurements and adjustments made during the alignment process.
- Results:
  - Laser aligned to correct location on detector
  - Some reflections but manageable

Test 3: Heat Test



Relevant DRs
CR1: Durable
CR2: Semi-constant internal conditions
CR4: environmentally sound
ER1: Long lifespan
ER2: Internal temp. controlled w/ vents

- Procedure:
  1. Install three thermocouples to measure temperatures in the optic chamber, electronic cavity, and ambient temperature outside the enclosure.
  2. Use a standard house oven set to low temperature and a refrigerator/freezer to induce gradual temperature changes.
  3. Monitor temperature changes over time and observe the response of seals, vents, and polycarbonate material.
- Results:
  - Assess the enclosure's ability to withstand and regulate temperature changes.
  - Ensure minimal impact on optic alignment and electronic functionality.
  - Insights gained will inform the spectrometer's lifespan and performance under varying environmental conditions.

Test 4: Seal/Vent Test upon Submersion

Relevant DRs
CR2: Semi-constant internal conditions
CR4: Environmentally sound
ER2: Internal temp. controlled w/ vents
ER4: Water and dust proof

- Procedure:
  1. Submerge the sealed enclosure in water for varying durations, from short-term to longer periods.
  2. Assess water ingress by placing white paper inside the enclosure and observing any wetness.
  3. Test the enclosure's resistance to dust and sand by exposing it to blowing sand/dirt using a leaf blower.
  4. Evaluate the ingress of dust/sand/dirt and any potential damage to internal components.
- Results:
  - Submersion for roughly 10 seconds
  - Rain and dust are more than alright for success

Test 5: Flight/Drop for Optics

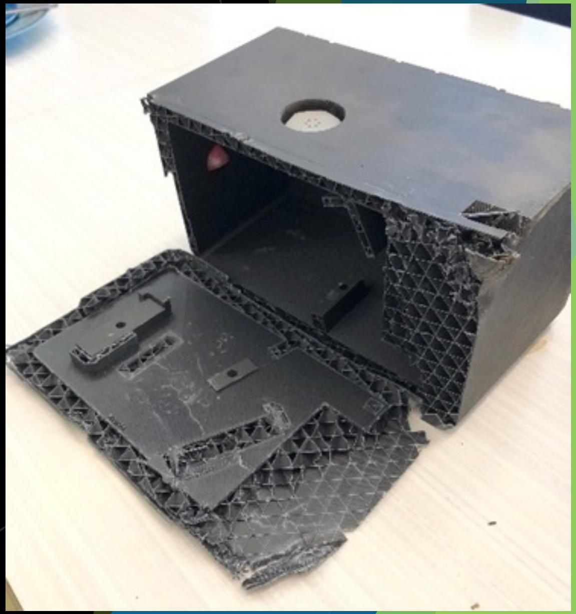
Relevant DRs
CR1: Durable
CR4: Environmentally sound
CR6: as light as possible
CR7: as small as possible
ER1: Long Lifespan
ER4: Water and dust proof
ER8: Optics secured

- Procedure:
  1. Prepare a sealed enclosure with optics securely positioned inside.
  2. Measure and record the height of the platform from which the drop will occur.
  3. Position the enclosure on the platform and release to simulate drops from specified heights.
  4. Repeat the test using different heights to ensure reliability.
  5. Assess the condition of optics and enclosure after each drop, noting any damage or weaknesses.
  6. Anticipate a range of results using equations related to impact force, material properties, and environmental factors.
- Results:
  - Shaking is survivable for lenses and mounts
  - For mid to high drops found errors in mounting technique, iterated and late found new design to be able to withstand expected drops.

Test 6: Destructive Test on Enclosure

Relevant DRs
CR1: Durable
CR4: environmentally sound
CR7: as small as possible
ER1: Long lifespan
ER4: Water and dust proof
ER8: Optics secured

- Procedure:
  1. Simulate drops from different heights, starting with mild heights and progressing to more severe drops.
  2. Assess the damage to the enclosure after each drop, documenting any weaknesses or failures.
  3. Evaluate the enclosure's ability to withstand impacts and maintain structural integrity.
  4. Use theoretical calculations to predict potential damage based on material properties and impact forces.
- Results:
  - Withstands drops of table height and 6ft
  - Flight drops are unreliable in survival, may or may not succeed



Torrey King

Test 7: Spectrum Tube Color Calibration

Relevant DRs
CR2: Semi-constant internal conditions
CR5: Spectral range of 400-1000nm
CR9: Ambient operating range of 0-50$°C$
ER5: Optics design for full range
ER8: Optics Secured

- Procedure:
  1. Use spectrum tubes to emit predictable wavelengths and calibrate the spectrometer chip accordingly.
  2. Build a calibration curve for wavelength density and location on the chip.
  3. Ensure optics alignment is accurate at different temperatures to maintain functionality.
  4. Collaborate with the EE team to finalize chip accuracy and data retention.
- Results:
  - To be determined

Future Work

REQUIRED

- Calibrate CCD chip wavelength alignment via spectrum tube test

Would Be Nice

- Extend optic wavelength range into the infrared range by stacking another optic system with focus on the range 1000-2000nm
- Conduct study on replacing adjustable mounts with 3D printed holders to reduce overall weight

Thank you!

Questions?