NORTHERN ARIZONA UNIVERSITY

Department of Mechanical Engineering
Spectral Forest
ME 486C – 001

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Subject: Finalized Testing Plan - ME486C

Design Requirements Summary (10pts)

The customer requirements are as follows: durable (CR1), semi-constant internal conditions (CR2), ease of access (CR3), environmentally sound (CR4), spectral range between 400-1000nm (CR5), as light as possible (CR6), as small as possible (CR7), drone mountable in operation (CR8), and ambient operating range of 0-50°C (CR9).
The engineering requirements are as follows: long lifespan (ER1), internal temperature control with vents (ER2), easy to access data in EE side (ER3), water and dust proof (ER4), optics designed for full range (ER5), drone can fly while carrying (ER6), fits within drone payload space (ER7), and optics secured during flight (ER8).

Top Level Testing Summary (20pts)

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

Detailed Testing Plans (30pts)

Ex 1: Laser Alignment

During this test, the major design requirements are that the optics must use the range required (400-1000nm) as well as being drone mountable in operation and be resilient to temperature changes within the working range of 0-50°C. The requirement of the optics meeting CR5 (400-1000nm range) is predetermined from the Zemax calculations so long as the lenses and gratings are aligned according to plan. It will be looked at that the alignment is long lasting in the variety of working conditions expected (drone vibrations, minor drops, and temperature fluctuations). To ensure this, we must examine the stability of each mount and how easily the mounts can become unaligned.

To perform this test. We will be 3D printing a jig for a laser that shall align it centered on the optic entrance and we can align via that. We will print this mount out of PLA (already have). The only other thing needed to purchase for this test will be the laser. This is something we can get from THORLABS or a variety of other sources. Before purchasing we need to research wavelength preferences and power and laser safety class of the ideal laser.

The variable we will be testing here is how off-center the laser is at each point of the lenses. In this procedure we will work in a progression starting with the initial line up of the entrance and then working through the internal mounts. We will be measuring each lens alignment in mm in both the horizontal and vertical directions. If the laser we select has a beam diameter of 3.5mm we can assume that we can get it with 0.5mm of center for each one. The benefit is each lenses error is compounding so we can easily fine tune the earlier lenses later during the test.

The first step is to determine a laser to use (factors include beam width, power, wavelength, and safety class (how dangerous/harmful the laser is)). Once decided upon, this will need to be purchased. Then we can build a CAD design that centers the laser onto the optic entrance. This will involve mounting this bracket onto the sides of our current enclosure. We can then print and begin iterating the adjustment of the mounts. This is convenient as the 3D printed bracket will allow for reuse as a realignment will need to happen someday in the future, ideally not very often but optic mounts are known for wiggling and becoming not aligned over time.

For results, we can expect that we can get the laser within 0.5mm of center, if not closer. We are looking for precision and stability in this alignment.

This test is critical to the success of our reflectance optical spectrometer as without the alignment in place, the light reaching the chip will be unpredictable and therefore unreadable. This test will be a muti-step process that can be completely (theoretically) in 10 hours including print time. This may be extended as aligning optics can be very tricky and elusive, even to professionals.

Ex 2: Heat test

The major question being answered here is how the enclosure responds to heat increase/decrease externally and what does that cause internally. It is required that the internal components do not experience drastic temperature changes (ER2). This requires that the enclosure be durable and maintains semi-constant internal temperatures (CR1 and CR2). This will look like gradual temperature changes with no damage in each chamber. This will be completed via the vents and the heat transferring through the walls of the enclosure (ER2). It is also required that the enclosure be environmentally sound, which involves being adaptable to temperature changes (CR4). With this in a similar vein, the lifespan of how it deals with heat must be lengthy, at least longer than our predicted 5-year lifespan (ER1).

The equipment needed for this test is three thermocouples and the necessary Arduino/cables to record the data collected by the thermocouples. Of course, the software that is needed for this recording will be needed too. Perhaps LabVIEW. To control the temperature, we will use items easily available to use, these items being a standard house oven (set on super low) and a standard fridge/freezer.

The variable isolated and measured during this test will be temperature in degrees Celsius compared to time.

Use the complete enclosure with all vents and gaskets in place. Wire in a thermocouple into the optic chamber, the electronic cavity, and one outside of the enclosure to record ambient temperatures of the heating/cooling units. Once all is set up to record, the enclosure will be placed in an oven (low temperature but greater than naturally will occur and then also placed in a fridge/freezer. Waiting long enough to see how the seals/vents and the polycarbonate print material.

This test is critical to the functionality of the spectrometer because if there is too much heat change quickly, the optics will be more likely to un-align themselves and the electronics are likely to fail. Quick and large changes in temperature will also take a toll on the battery, shortening its life.

Overall, this test will only affect active use a small amount but shall tell us many things about the overall lifespan of the spectrometer.

Ex 3: 3D printed fits

The question being answered in doing this test is to ensure all components fit in their respective spots and line up correctly. The CR's hit on this test are ease of access and as light as possible (CR3 & CR6 respectively). The ER hit on this test is securing the optics during flight (ER8).

The equipment needed for this test is the Bambu Lab X1 Carbon printer that is currently set up in our lab and a computer to edit the CAD, slice the model, and send it to be printed.

There will be no variables isolated in this test as does it fit is all that is being observed and planning based on that answer.

First, using a computer a member of the team will make the necessary cuts to the model to isolate the feature of interest and export it as a STEP file to be sliced by the Bambu Studio slicer software. Second, using our printer, we will print the features of interest to test how the vents, glands, mounts, optics, and hardware will interface with the print material and other components to ensure flush fits, a sealed final enclosure, and all parts are lining up correctly. Making cuts to the model will allow testing of certain fits without printing the entire model which saves time, filament, and money.

The expected results are it fits, or it does not fit, either way information about the quality of the model is gained and forward progress is made. There are no equations related to testing fits of components or if a 3D printed hole lines up with the respective hole on the mount.

To recap, this test will drive the design of our enclosure by testing how the components will physically fit and align together since the CAD model will only go so far on the functionality. Printing section of the model and trying to screw the parts together sheds much light on if the design will work or not and is imperative to the functionality of the enclosure.

Ex 4: Flight/drop for optics

The objective of the flight/drop test is to assess the survivability rate of the optics inside the enclosure when experiencing a drop from an existential height. The design must be durable enough to withstand the impact of the fall and environmentally resistant to the outside while maintaining a small size and being easy to access when working with the internal components (CR1, CR4, CR6, and CR7). This test will ensure that the design can have a long lifespan where it can stay resilient to outside factors such as water or dust while maintaining the optic layout during operation (ER1, ER3, and ER8). The equipment needed for the drop test, is the fully sealed enclosure with the optic layout secured inside and a tape measurer for measuring the height of the platform the drop will be happening from. The variables being isolated in this test are the impact resistance and survivability of optics as well as the environmental resistance of the enclosure.

To start the test, the team must first prepare the sealed enclosure with optics securely positioned inside and measure/record the height of the platform from which the drop will occur. Then the enclosure can be positioned on the platform and release to simulate a drop from a specified height. This test will be repeated using a variety of heights to ensure reliability of the results. The results the team wants to see from this test is the optics remaining intact and undamaged after the drop as well as the enclosure maintaining its structural integrity and environmental resistance. This test will also be used to find any potential weaknesses or areas for improvement in the design. An anticipated range of results can be calculated using equations related to impact force, material properties, and environmental factors. For instance, the impact force can be calculated using the equation F = ma, where 'm' represents the mass of the enclosure and 'a' represents the acceleration due to gravity.

This test plays a crucial role in validating the design's robustness and longevity in real-world scenarios, informing further improvements if necessary. The flight/drop test serves to evaluate the viability of optics within the enclosure when subjected to a significant drop. It aims to ensure the design's durability and environmental resilience while maintaining compactness and accessibility.

Ex 5: Destructive test on enclosure

This destructive test aims to answer questions regarding the durability and resilience of the designed enclosure, aligning with the customer requirements of durability, being environmental sound, ease of access, and minimal size (CR1, CR4, CR6, and CR7). The engineering requirements being tested include ensuring a long lifespan, water and dust-proof design, and securing optics during flight (ER1. ER4, and ER8)

The equipment that will be required for this test is a completed enclosure. A measuring tape will be used to accurately determine the falling distance of the enclosure. In the case of the parking garage, it will be estimate based upon number of floors up.

The focus of this test is to understand the systems resistance to impacts and how it will react to natural drops from handling as well as in flight. There is not an obvious variable to record this,

The procedure is straight forward. We will simulate a series of drops starting from a mild height of a few feet. Then progress to a table drop (simulating it knocked off a table). Then a standing drop (roughly 6ft). and finally, an in-flight simulation drop test, this will be performed at the San Francisco parking garage. We will drop from the top story after ensuring the landing area is completely clear. As we step through each of these tests, we will document (pictures and brief written blurbs) the damage as visible after each drop. This will cause compounding damages but that will be realistic to actual use.

The enclosure should be durable enough to withstand impacts from reasonable heights without significant damage. The seals holding the box together should remain intact, preventing water and dust from getting in the enclosure. The optics should remain secured within their respective mounts during impacts. Optics are extremely sensitive so any height of fall will likely cause some misalignment issues but in worst case scenario it will be good to know what it can and cannot survive. The ideal result from a fall is the optics get misaligned and can then be realigned later but worst case is the optics become dislodged from the mount and are then ruined.

The theoretical results can be calculated using equations related to impact resistance, material properties, and environmental factors. For instance, impact force can be calculated using Newton's second law (F = ma), and material stress limits can be compared against expected impact forces to predict potential damage. The max allowable force the material can withstand can be obtained, and the max force experienced by a fall from a reasonable height and landing the corner to create the highest stress can be found.

The destructive test will give insight into the weaknesses of the design and show what needs to be improved and the limits of the design.

Ex 6: Seal/vent test upon submersion

For this test, we are focusing on the ability of the enclosure to adequately protect the internal cavities from the weather and environmental factors it will endure during application. The enclosure must protect the internal components from temperatures, water, and dust (CR2 and ER2). The rating we are stiving to accomplish is IP54M, but we will test it to greater amounts. For example, this rating only includes the splashing of water whereas we will be testing our seal and vents via submersion. We will also test against intense exposure to sand/dirt/dust to ensure our rating is actively true. By reaching this rating (or beyond) we can confirm that the enclosure is environmentally sound and will be water and dust proof to the extent we need it to be (CR4 and ER4)

For this test, we will need a plastic tub (will use the one we are currently storing some parts in), paper, and water of course. This should be self-explanatory. We will fill the tub full of water, enough that we can fully submerge the enclosure. The paper is to put inside of the enclosure to measure the water ingress. We will put a little bit of food dye in the water and use white paper, so it is quite easy to tell exactly how much water entered the enclose. The test will be done in stages starting with very short-term submersion and extending into longer periods of time (30 minutes) which is harsher of an environmental setting than our predicted scenarios. The second step of the test will involve sand and/or sandy dirt that we will blow of the enclosure to measure the ingress of dust. This will be done outside using a leaf blower. This is again rougher conditions than expected.

Ingress of water producing any amount of harmful damage. This will be considered via how much water (if any) is absorbed by the paper bits inside the enclosure. As well as the ingress of any harmful damage from dust/sand/dirt particles. It is critical to the operation of the device that none of these items enter the enclosure.

This is a two-step test, first being the submersion test and then also a sand/dirt/dust contact test. Stated above, the enclosure will endure water submersion and dust blown at it. This involves putting white paper inside while the water will be dyed slightly. The water portion will be done in stages starting with very short-term submersion and extending into longer periods of time (30 minutes) which is harsher of an environmental setting than our predicted scenarios. The second step of the test will involve sand and/or sandy dirt that we will blow of the enclosure to measure the ingress of dust. This will be done outside using a leaf blower.

The results we will be looking at is the ingress of any amount of water and dust/sand/dirt that will cause harmful damages to the enclosure and especially the internal components.

This comprehensive and extensive test will go beyond what is required and will tell us exactly how these systems will work in protecting the internal equipment as it is exposed to the environmental conditions that we expect it to be exposed to.

Ex 7: Spectrum tube color adjust

NOTE: The ME team will not perform this test. We will be assisting and helping provide equipment so the EE team can calibrate the chip for a variety of wavelengths that will allow us to build a wavelength density and location curve which will allow the spectrometer to become fully operational.

The major question to answer here is what kind of wavelengths show where on the chip and at what density based off predictable light sources. Of course, during this test, it will confirm that there are semi-consistent internal conditions (CR2). Showing that the alignment and calibration can be regarded as accurate. This test very explicitly shows that the spectral range of 400-1000nm is successfully transmitted upon the CCD (charge coupled device) detector (CR5 and ER5). This customer requirement is the most important design requirement as without this succeeding the entire device will be useless regardless of how long it lasts. During this alignment we will ensure that the optics are aligned at more than just room temperature (20°C). This is important to ensure functionality in all operating conditions, mostly regarding the variety of temperatures experienced. (CR9). Just like our optic alignment test, this test will be important to pay attention to how secure the lenses and mounts are (ER8).

Basic distance measuring equipment, spectrum tubes (can borrow these from the physics department and their lab demo section (already organized and got permission) and our completed spectrometer including EE parts.

The procedure is yet to be determined exactly. It will involve the use of the spectrum tubes and either pointing the spectrometer directly towards it or using them to reflect off a flat source before observation via the spectrometer. Regardless of the setup we would then calibrate the electronic pick up of these predictable wavelength emission peaks. Building a calibration curve for all data collected based on the wavelength and location on the chip and the intensity of the lights and wavelengths received.

During this test, the main goal is to get a mostly predictable calibration curve for wavelengths. A test to finalize the effectiveness and ensure the usability of the spectrometer. Must be completed with the EE team as this calibration focuses on finalizing their data retention and chip accuracy.

Specification Sheet Preparation (30pts)

Customer Requirement	CR met? (yes or no)	Client Acceptable (yes or no)
CR 1: Durable		
CR 2: Semi-constant internal conditions		
CR 3: Ease of access		
CR 4: Environmentally Sound		
CR 5: Spectral Range Between 400-1000nm		
CR 6: As Light as Possible		
CR 7: As Small as Possible		
CR 8: Drone Mountable in Operation		
CR 9: Ambient Operating Range of 0-50°C		

Engineering Requirement	Target	Tolerance	Measured/ Calculated Value	ER met? (yes or no)	Client Acceptable (yes or no)
ER 1: Long Lifespan	5 years	+/- 1 year			
ER 2: internal temperature control with vents	°C	+/- 5% of initial			
ER 3: easy to access data in EE side	Time in seconds (s) (to enter)	<1 minute			
ER 4: Water and dust proof	Harmful damage	Harmful damage			
ER 5: optics designed for full range	nm	+/- 10 nm			
ER 6: drone can fly while carrying	lbs	+/- 0.5 lbs			
ER 7: fits within drone payload space	in*in*in	+/- 1 in^3			
ER 8: optics secured during flight	hertz	+/- 50 Hz			

QFD (10pts)

The QFD provided below, highlights the correlation between the engineering requirements (ER) and customer requirements/needs (CR) during the testing phase of the project. The customer needs are weighted according to their importance in the design with the spectral range of 400-1000nm and the box being environmentally sound. To ensure these requirements are met, laser alignment of the lenses by the ME team and a spectrum tube color adjustment test conducted by the EE team will occur along with a variety of physical environmental testing for box's resilience. Most of the CRs that weighed higher tended to come from the design and functionality of the box while the ones that were weighted lower related more to potential changes in the internal or external environment. The CRs are then rated on a scale ranging from 0-10 for their relationship to each ER. With these correlation values, absolute technical importance calculations are done to evaluate the relative importance of each ER. Each ER comes with its own technical unit and target that the team must be aware of to use as a tolerance when testing. The highest-ranking ER for technical importance and correlation to the CRs was the design being water and dust proof with controlling the internal temperature of the box and having no changes in humidity, pressure or temperature tying for second. This means that there should be more attention towards the heat and submersion testing of the design. The ER with the least correlation and importance to CRs ended up being the design having a long lifespan. This ER will still be tested through the drop and destructive testing but will not have a significant focus. These relationships between the CRs and ERs can be better visualized in the top section of the QFD where the correlations from are marked with positive or negative symbols to show their level of correlation. If there are two positives or negatives, this means there is a strong correlation while a singular symbol represents a moderate one. A legend is provided for better understanding.