Oceallus Design Packet

ME 189B

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Executive Summary

The purpose of this project was to develop a camera system for observing marine animal populations on the seafloor. In the case of the project's sponsors, this specifically means clams and lobsters in the Santa Barbara area. While products that accomplish this already exist on the market, they can be prohibitively expensive for researchers to acquire. This project aimed to create a solution that can be reproduced by any research group using off-the-shelf and 3D-printed parts for a fraction of the price of an existing camera setup.

The challenges addressed in the project include ensuring the system's stable deployment on uneven seafloor surfaces, reliable waterproofing at 30m depth, extended power management for four-week operation, protection against corrosion from prolonged exposure to saltwater, optimized image quality and field of view (FOV), ease of reproduction by other researchers, and price optimization. The team's solution includes the following: a specialized tripod design to stabilize the camera on uneven terrain, pressure-proofed housings with watertight seals, corrosion-resistant materials such as marine-grade 316 stainless steel, PVC, and ABS, implementing efficient power control with the Raspberry Pi Zero, and additionally including adjustable mounting height and the ability to swap camera lenses to achieve the required FOV and image clarity for effective data capture.

The system's frame is highly adjustable and stable on the seafloor. This is because the seafloor can be uneven and rocky, and currents can push the system around. The other reason for the adjustability is that this project was developed to observe multiple types of animals that require different setups for optimal image capture. The solution is a tripod constructed from PVC pipes, where each leg can be individually raised and lowered in any desired increment. The legs will be allowed to fill with water, while custom pipe plugs control the rate of water ingress, so that the frame does not immediately fill with water when thrown in the ocean and subsequently sink to the seafloor. All of the pipe joints and fittings are custom parts 3D-printed out of ABS. The joints making up the main frame of the tripod have attached rings to add ballast to the system, for weight and stability. PVC and ABS were chosen due to their corrosion resistance and ease of use.

Waterproofing was achieved by the use of BlueRobotics underwater enclosures. The camera enclosure is a waterproof acrylic cylinder with an inner diameter of 2 inches and a length of 11.8 inches, rated for a depth of 100 m. The camera enclosure has an attached pressure relief valve, cable pass-throughs for powering the lighting through the same batteries and for sending signals to the lighting, and a waterproof switch. The switch is used to turn on and off a display that is inside the camera enclosure; this monitor displays what the camera sees for precise placement. The enclosure houses 8 2600 mAh batteries, enough for 4 weeks of deployment while taking a photo once every 5 minutes. The camera uses a custom PCB put together by an outside vendor, a Raspberry Pi Zero, and a camera module that faces out of a flat acrylic end cap. Everything in the enclosure is secured by a custom 3D-printed internal mounting structure.

The lighting system is fully adjustable independent of the camera. When viewing lobsters on the seafloor, for example, the camera may need to be several feet away from the animals while the light is directly above them, pointing into a crack in a rock. This challenge was solved by attaching the lighting to the camera frame via a highly adjustable arm. The lighting uses infrared lights to avoid disturbing or attracting animals because most animals cannot see it. The overall construction is a custom PCB with LEDs facing toward the end of a 2 inch diameter, 3.9 inch long cylindrical enclosure with a flat acrylic end cap. The enclosure is similar to the camera enclosure, but smaller. The enclosure has a pressure-relief valve and cable pass-throughs.

Power needs to be conserved wherever possible. The system is operational for up to 4 weeks at a time; any longer is unnecessary due to biofouling requiring the camera to be cleaned. The system runs on rechargeable 18650 batteries, and to save power, the Raspberry Pi Zero will be kept in low-power mode and woken up every 5 minutes to take a photo. A photoresistor determines whether the infrared lights are needed; they will not activate when sufficient sunlight is present. The lights will be allowed to turn on, the photo will be taken, and then the lights and camera will turn back off until needed again. Also, the display can be turned off by a switch in order to conserve power

Introduction, Background, and Research Summary

Introduction & Background

The goal of this project was to design and develop an adjustable underwater camera system for observing clams and lobsters at depths of up to 30 meters. We needed to make sure it was a cost-effective and replicable tool that other researchers can build using off-the-shelf and 3D-printed components.

Existing underwater camera systems are too expensive or lack necessary specializations, limiting research applications. Our system addresses this gap by balancing research-grade functionality with affordability.

Key challenges considered in the design include:

- Long-term deployment (4 weeks) while managing power efficiency
- Reliable waterproofing and corrosion resistance
- Minimizing disturbance to marine life through infrared lighting
- Tripod adjustability to accommodate uneven seafloor terrain

Our solution integrates a Raspberry Pi Zero, an infrared-based lighting system, and a highly adjustable tripod mount to achieve these objectives. This modular approach ensures that researchers without an engineering background can quickly adapt and replicate the setup for various marine studies.

Research Summary (Technical Details & Implementation Focus)

To ensure stability on uneven seafloor surfaces, the camera system is mounted on a tripod with individually adjustable legs, allowing precise positioning. Each leg is extendable, ensuring minimal displacement from ocean currents. The frame is constructed from schedule 40 PVC pipe, offering high corrosion resistance while remaining lightweight, accessible and easy to assemble.

The camera and lighting system are housed in separate BlueRobotics 2-inch diameter watertight enclosures, rated for depths of 100+ meters. The enclosures feature a pressure relief valve, waterproof cable pass-throughs, and an external waterproof switch to control essential components. The flat acrylic end ensures optimal image clarity and durability against underwater conditions.

The system utilizes 940 nm infrared LEDs to minimize disturbance to marine life, as this wavelength is beyond the visual sensitivity of clams and lobsters. The lighting unit is mounted on a fully adjustable arm, enabling precise positioning independent of camera positioning. A reflective backing within the enclosure enhances light distribution, ensuring clear image capture in low-light conditions.

The system operates on high-capacity rechargeable 18650 lithium-ion batteries, with a Raspberry Pi Zero acting as the system’s controller. The Pi remains in low-power mode, waking up every 5 minutes to capture an image. A photoresistor automatically triggers the infrared lights, preventing unnecessary power usage in well-lit conditions.

An external waterproof monitor displays a live feed from the camera to assist researchers in precisely aiming it. This monitor can be toggled on or off via an external waterproof switch, ensuring power efficiency when the system is not being repositioned.

Final Specifications

Product Definition

The goal of this product was to develop an advanced underwater camera, light, and mounting system capable of operating for extended deployments of up to four weeks. This system is designed to function reliably at an operating depth of 30 meters while capturing high-quality images at a resolution of 1080p. It takes photos at a consistent rate of one image every five minutes, ensuring thorough monitoring of the underwater environment. The system accommodates various focal lengths within a field of view ranging from 0.3 x 0.3m to 1 x 1m.

Features and Specifications

The camera system is designed to function continuously for up to four weeks without requiring maintenance or intervention. To meet the requirements, the system is equipped with an infrared light operating at 940 nm, enhancing visibility in low-light underwater conditions; and a monitor is included, allowing for real-time image review. The system also includes video capability, expanding its functionality beyond still image capture. For stability and secure placement, ballast mounting points are incorporated into the design. The mount heights are adjustable, ranging from approximately 0 to 1 meter, offering flexibility in positioning for optimal data collection. The entire setup maintains a compact and efficient physical footprint of 1 m × 1 m, ensuring ease of deployment. The total cost to build the system is $799, making it a cost-effective solution for extended underwater monitoring.

Specification	Value
Infrared light	850 nm
Operating time	Up to 4 weeks (projected)
Display included	Yes
Operating depth	30 m
Field of view	Variable
Capture rate	Variable
Resolution	1080p
Ballast mounting points	3
Mount heights	~0 m to ~1 m

Price	$799
Video capability	-
Physical footprint	1 m x 1 m

Table 1. Features and Specifications

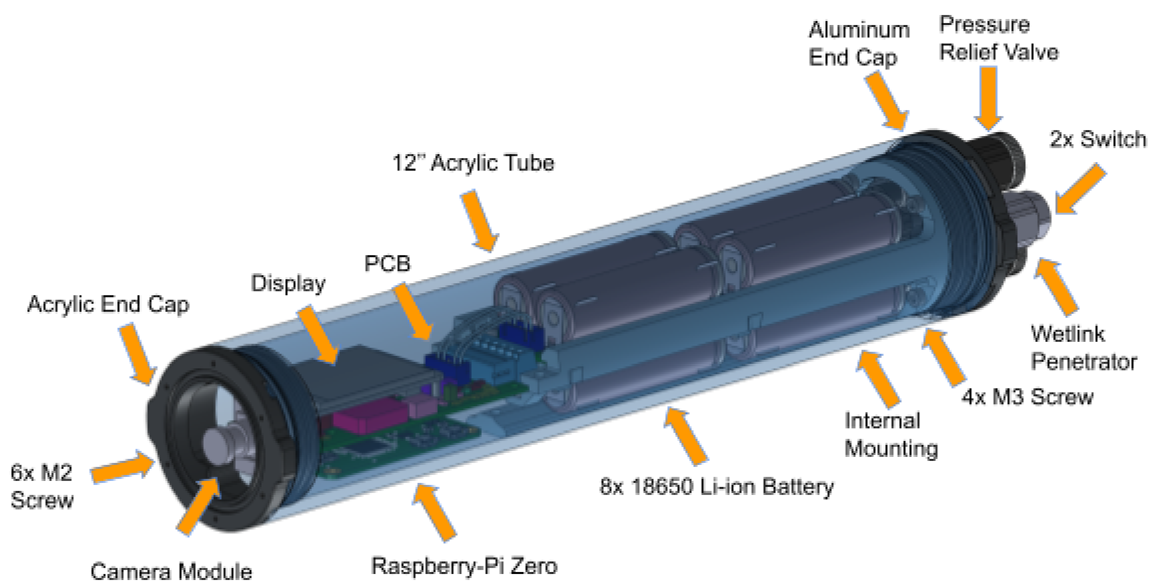
Description of the Design

Camera

Our underwater camera system is housed in a BlueRobotics 3-inch acrylic tube, designed to withstand pressures at depths of 30 meters while keeping internal components completely dry. The enclosure is sealed using an aluminum end cap on one side and an acrylic dome cap on the other, providing structural integrity and a transparent optical window for the camera.

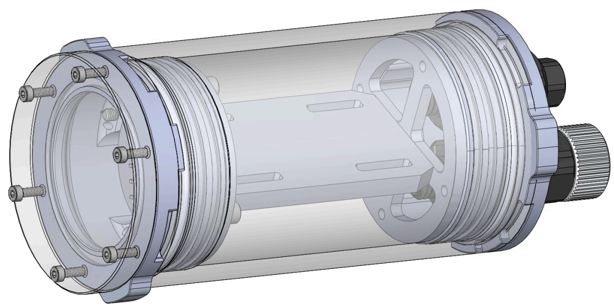
Inside, the camera module, Raspberry Pi Zero, and display module are mounted on a custom 3D-printed bracket(not shown in this rendering) to keep everything securely in place. Power comes from eight 18650 lithium-ion batteries, arranged for efficient space use and long-term operation of up to four weeks. A pressure relief valve prevents vacuum buildup, while WetLink penetrators allow for waterproof cable pass-throughs.

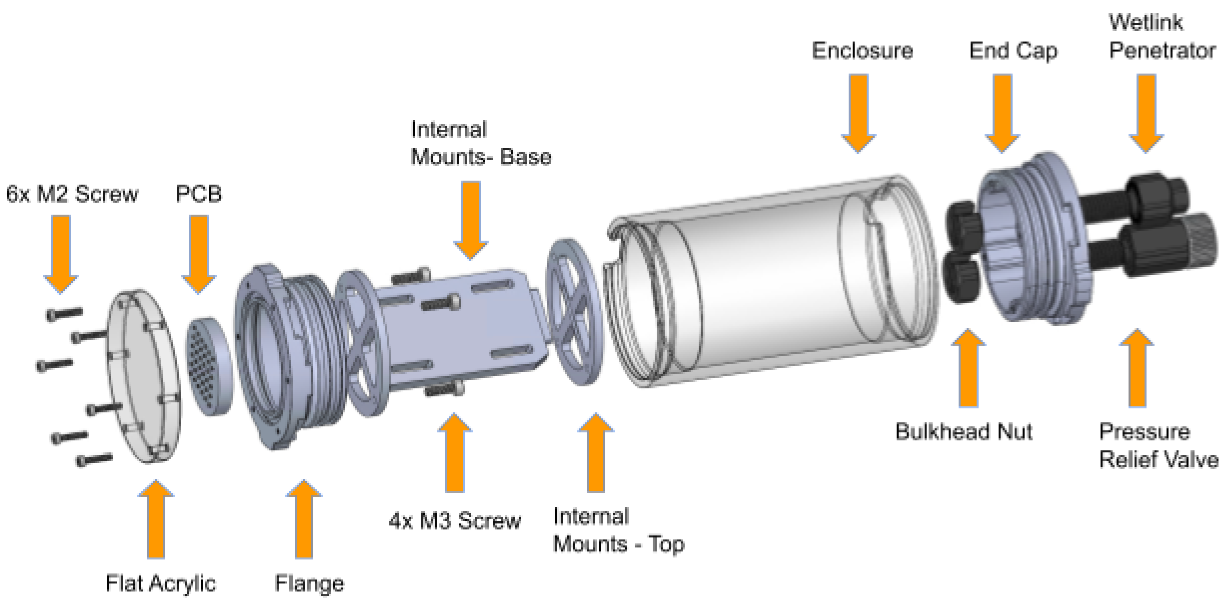
To make operation easier, we added an external electronic switch, so researchers can power the system on and off without opening the enclosure. The display module provides real-time visual feedback, making camera positioning more precise. To handle the harsh saltwater environment, we used 316 stainless steel screws and bulkhead nuts, ensuring corrosion resistance and long-term durability.



Lighting

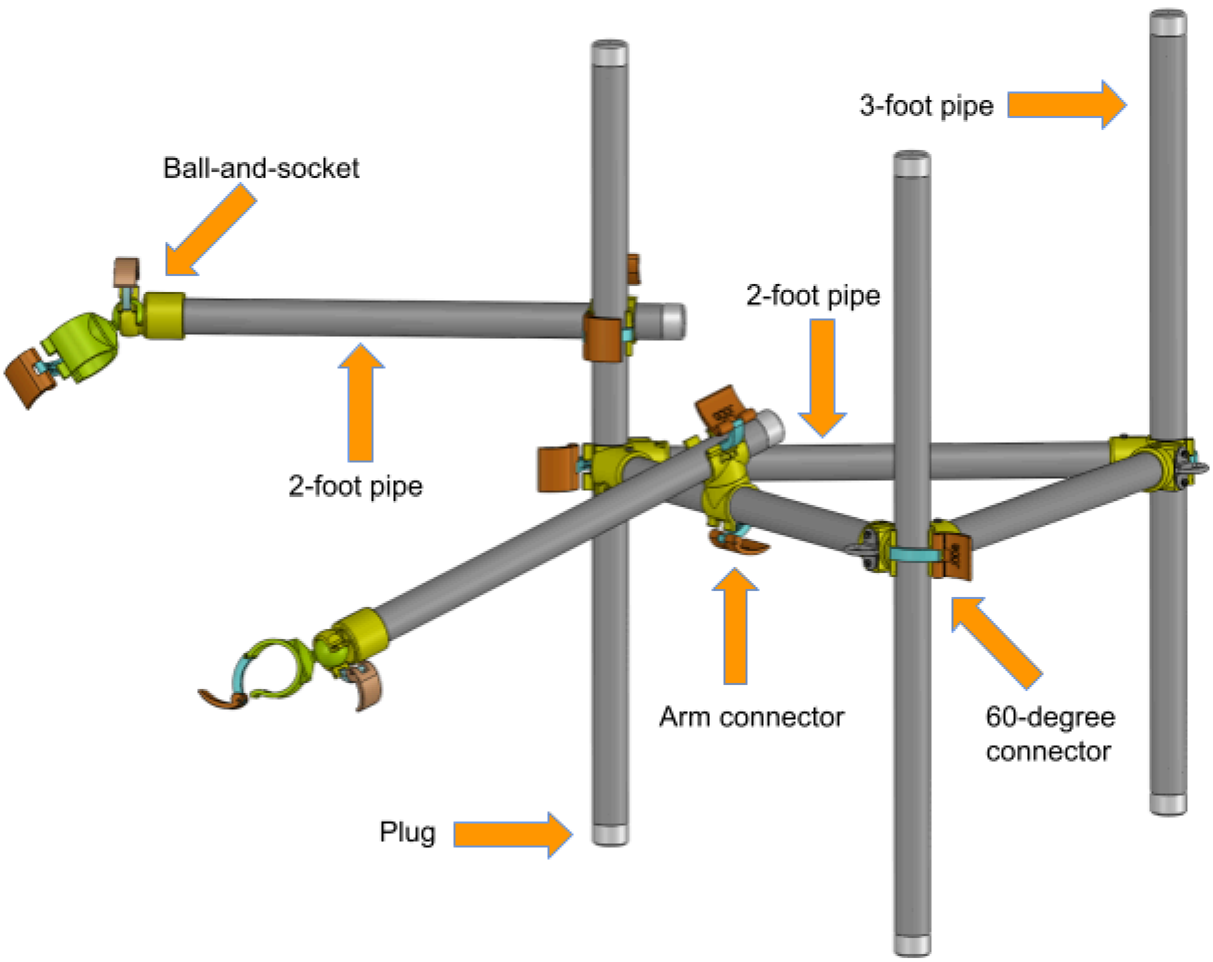
The lighting system consists of a printed circuit board (PCB) equipped with infrared (IR) LEDs, providing illumination for the underwater camera. This PCB is connected to the camera system using a marine cable, ensuring reliable power and signal transmission in submerged conditions. The entire lighting assembly is securely mounted on a 3D-printed mechanical support structure, which is designed for stability and durability. These mounts are then firmly attached to the enclosure using screws, ensuring a secure and rigid installation capable of withstanding underwater environments.





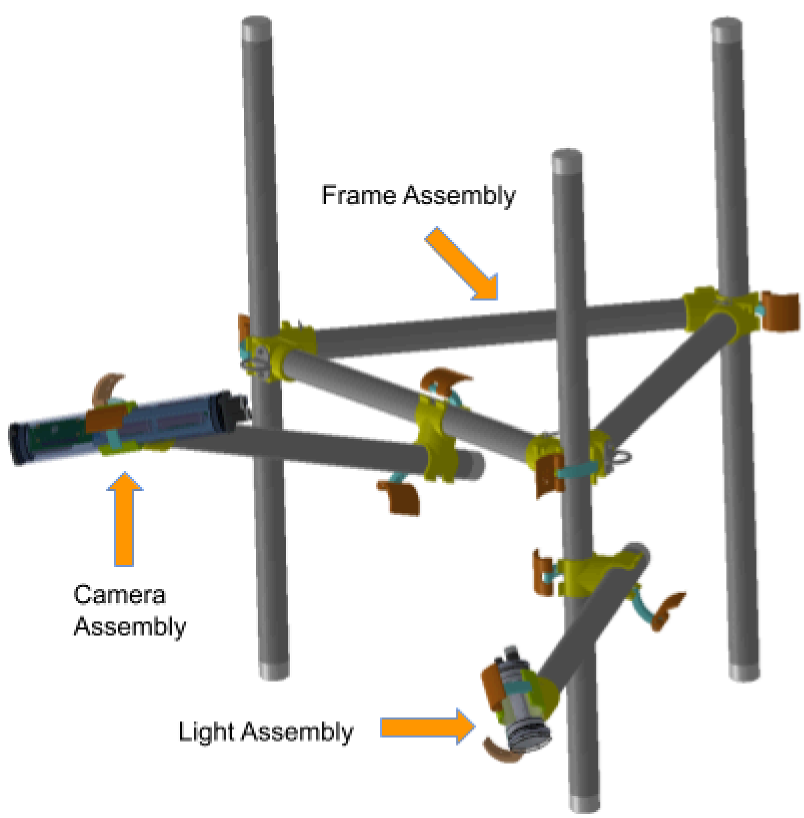
Frame

The system's frame is a highly adjustable tripod made of PVC pipes and 3D-printed ABS joints. Three 2-foot pipes in the plane of the ground form a triangle. Each corner of the triangle has a custom 3D-printed joint holding it together, as well as an eccentric latch for holding a leg. Each of three legs can be adjusted up and down independently of each other, up to 3 feet, to accommodate for any terrain. The fittings holding the legs also have an attachment point for ballast. Another eccentric latch connector is used to attach each of two 2-foot arm pipes. These arm pipes are used to hold the camera and lighting enclosures, and can be moved around to any pipe on the frame as desired. The arms also have a 3D-printed ball-and-socket at the end that allow a wide range of movement so that the camera and lighting can be pointed at various angles. All pipes are allowed to fill with water, with water ingress rate being controlled by a pipe plug with a small hole. All joints and fittings are either press-fits or held with a cotter pin and clevis pin.



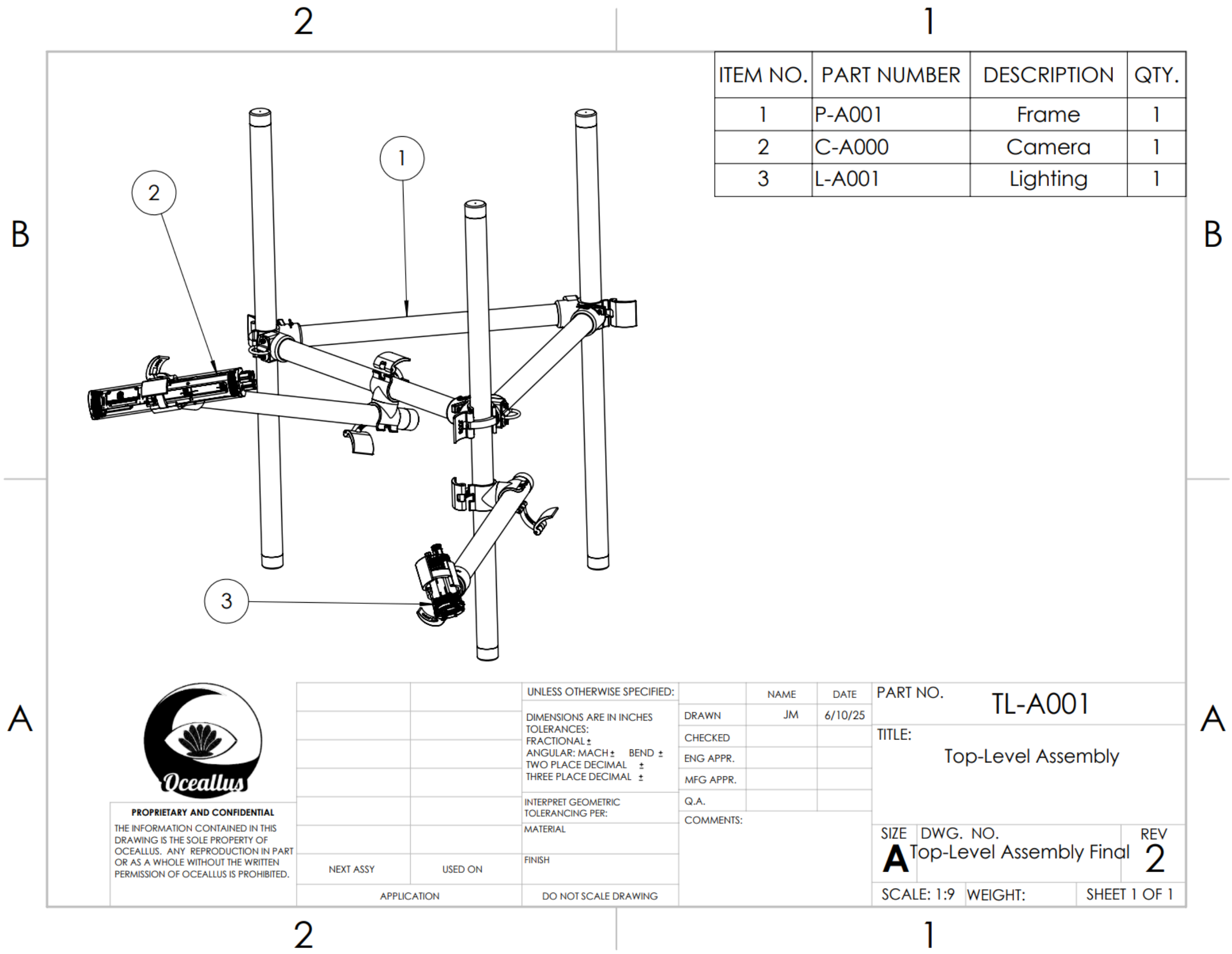
Top-Level

The overall assembly consists of three main sub-assemblies, which includes the camera assembly, the lighting assembly, and the frame assembly. The frame assembly includes 3D printed joints, such as the arm connector, ball and socket joint, and 60 degree connector. 3D printed components were chosen in order to accommodate the request for the entire assembly to be easily reproducible by separate research groups with no engineering background. 3D printing also allowed the use of a triangular platform, since 60 degree PVC joints could not be found commercially. Both the camera and lighting assemblies are held by 3D printed ball-and-socket joints, which allow for an extra degree of adjustment with a wide range of configurations depending on the research subject. Each joint uses an eccentric latch locking mechanism, which allows for quick adjustments without the use of tools. The camera and lighting assemblies were kept as separate bodies to allow for various lighting needs such as near the camera for subjects close to the camera and near the subject for subjects far from the camera, as well as to reduce internal glare from having the lighting in the same enclosure as the camera. The eccentric latch on the connectors allows the arms to be connected to whichever pipe section best suits the deployment needs. A highly variable system was desired in order to make the system applicable to a wide range of researchers, who may need different configurations. In addition, the ability of each connection to be removed also helps with reducing the footprint of the device for storage purposes.



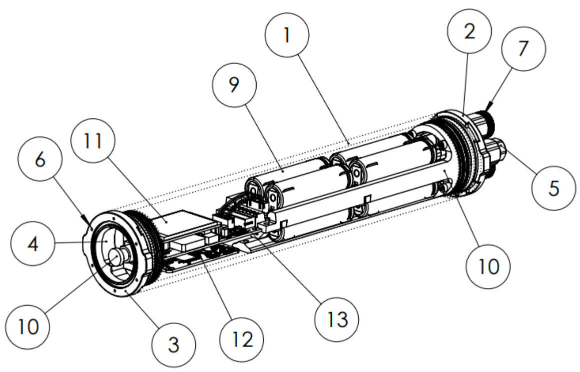
Drawings

Top-Level Assembly



Sub-assemblies

Camera



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	BR001	Watertight Enclosure	1
2	BR004	4 x Hole Endcap	1
3	BR005	Aluminum Flange	1
4	BR006	Acrylic Endcap	1
5	BR007	Pressure Valve	1
6	BR008	Stainless Steel Screws	6
7	BR009	Waterproof Switch	2
8	BR010	Cable Penetrator	1
9	C001	2600 mAh Battery	8
10	C002	Camera Module	1
11	C003	Display	1
12	C004	Raspberry Pi Zero	1
13	C005	Main PCB	1
14	C006	Battery PCB	1
15	C007	Internal Mounting	1

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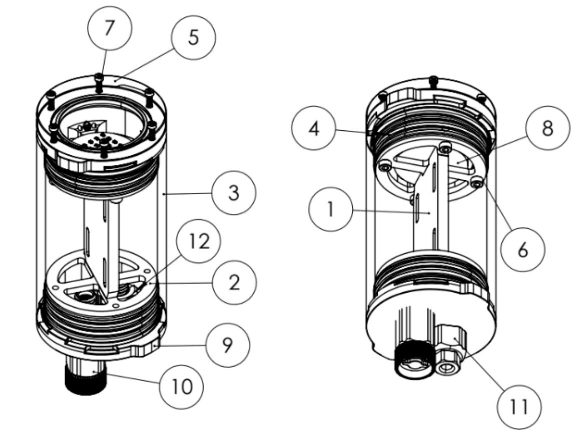
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	JM	6/10/25
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

PART NO. C-A000
TITLE: Camera
SIZE A | DWG. NO. FullCameraV2 | REV 2
SCALE: 1:3 | WEIGHT: | SHEET 1 OF 1

Lighting



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	L002	Lighting-Internal Mounts-Base	1
2	L001	Lighting-Internal Mounts-Top	1
3	BR002	Blue Robotics - Enclosure - 3.9"	1
4	BR005	Blue Robotics - Flange	1
5	BR006	Blue Robotics - Flat Acrylic	1
6	L003	Lighting - Screw	4
7	BR008	Blue Robotics - Screws	6
8	L004	Lighting - PCB	1
9	BR003	Blue Robotics - End Cap - Aluminum 2-Hole	1
10	BR007	Blue Robotics - Pressure Relief Valve	1
11	BR010	Blue Robotics - WetLink Penetrator	1
12	BR012	Blue Robotics - Bulkhead Nut	2

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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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DRAWN	AG	2/28/25
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ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

PART NO. L-A001

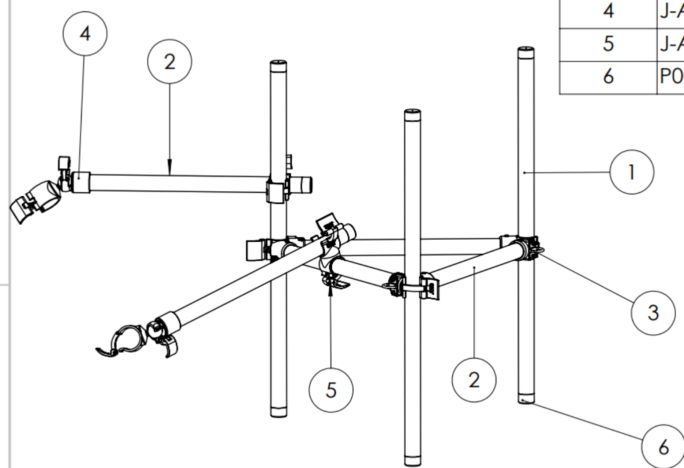
TITLE: Lighting

SIZE A | DWG. NO. LightingAssembly | REV 1

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

Frame

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	P003	3 Ft Pipe	3
2	P002	2 Ft Pipe	5
3	J-A001	60 Degree Connector Assembly	3
4	J-A003	Ball and Socket Assembly	2
5	J-A002	Arm Connector Assembly	2
6	P001	Pipe Plug	8



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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

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DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	JM	6/10/25
CHECKED		
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MFG APPR.		
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COMMENTS:

PART NO. P-A001

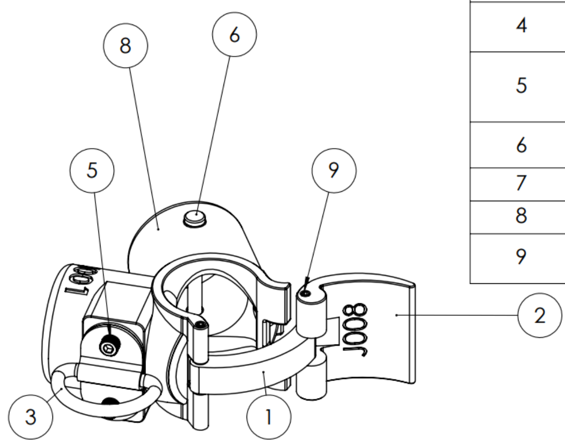
TITLE: Frame

SIZE A | DWG. NO. Frame Assembly | REV 2

SCALE: 1:12 | WEIGHT: | SHEET 1 OF 1

Joint - 60 Degree

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	J007	Latch Bar	1
2	J008	Latch Lever	1
3	J006	Tie-Down Ring	1
4	J006-1	Super-Corrosion-Resistant 316 Stainless Steel Hex Nut	2
5	J006-2	Super-Corrosion-Resistant 316 Stainless Steel Socket Head Screw	2
6	J010	316 Stainless Steel Clevis Pin	1
7	J011	Hairpin Cotter Pin	1
8	J001	60 Degree Body	1
9	J009	316 Stainless Steel Slotted Spring Pin	2



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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	JM	6/10/25
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

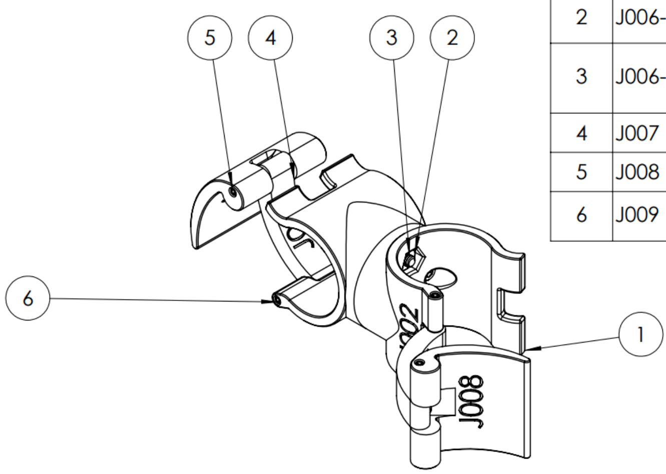
PART NO. J-A001

TITLE: 60 Degree Connector

SIZE A | DWG. NO. 60 Degree Connector Assembly | REV 2

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

Joint - Tee Connector



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	J002	TeeConnector	2
2	J006-1	Super-Corrosion-Resistant 316 Stainless Steel Hex Nut	4
3	J006-2	Super-Corrosion-Resistant 316 Stainless Steel Socket Head Screw	4
4	J007	LatchBar	2
5	J008	LatchLever	2
6	J009	1050-1095 Spring Steel Slotted Spring Pin	4

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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AG	6/10/25
CHECKED		
ENG APPR.		
MFG APPR.		
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COMMENTS:

PART NO. J-A002

TITLE: Arm Connector

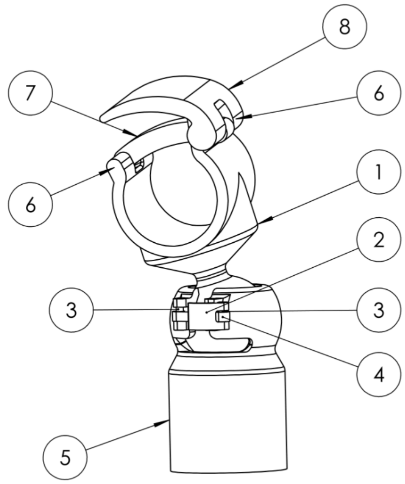
SIZE A | DWG. NO. Arm Connector Assembly | REV 2

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

Joint - Ball-and-Socket

2 1

B



ITEM NO.	PART NUMBER	Description	QTY.
1	J003	Socket Connector Body	1
2	J005	Socket Connector Lever	1
3	J010	12mm Pin	2
4	J011	Socket Latch Bar	1
5	J004	Socket Connector Body	1
6	J009	50mm Pin	2
7	J007	Main Latch Bar	1
8	J008	Main Latch Lever	1

B

A

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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	DK	2/28/25
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

PART NO. J-A003

TITLE: Joints - Ball-and-Socket

SIZE A | DWG. NO. BallAndSocket | REV 1

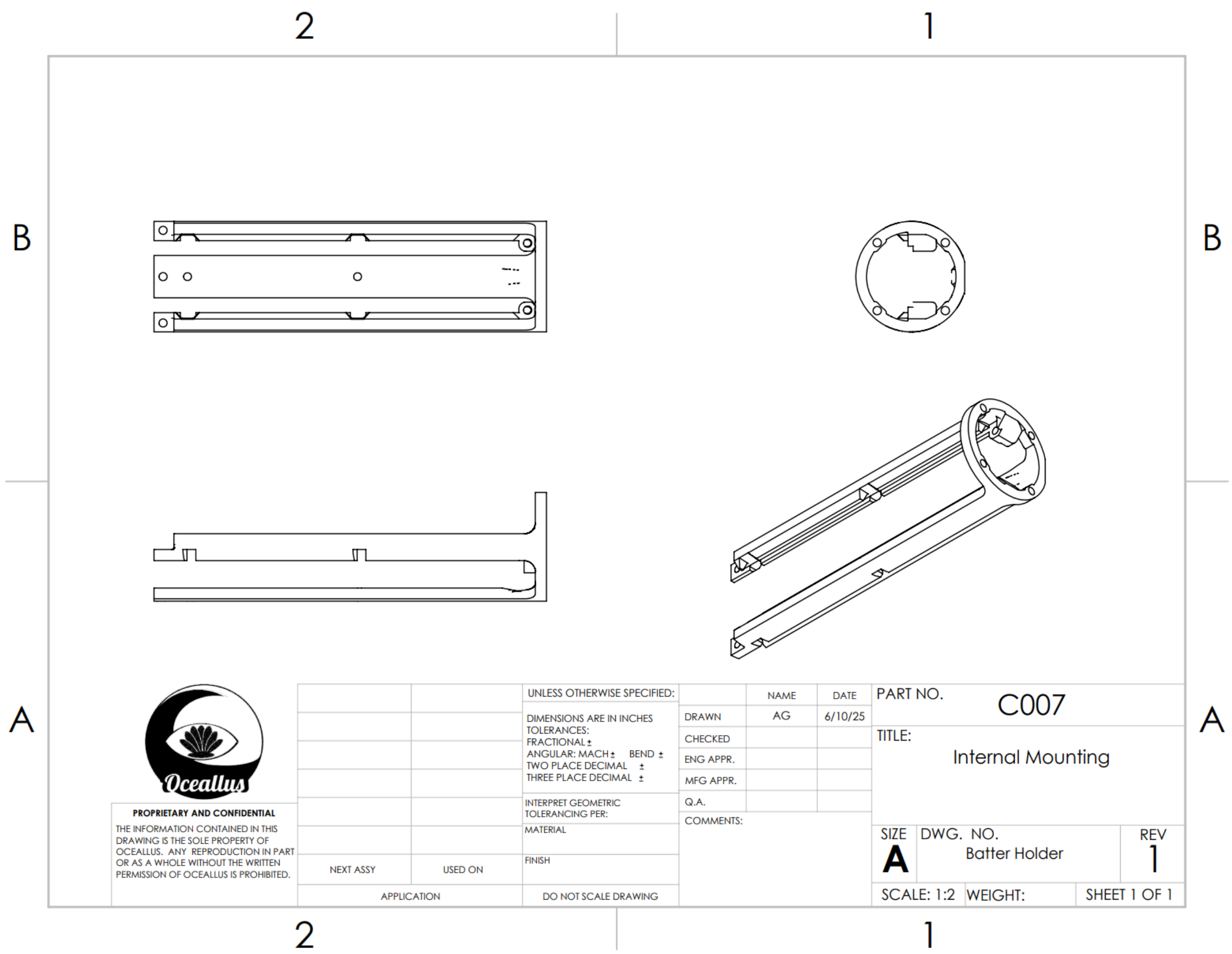
SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

A

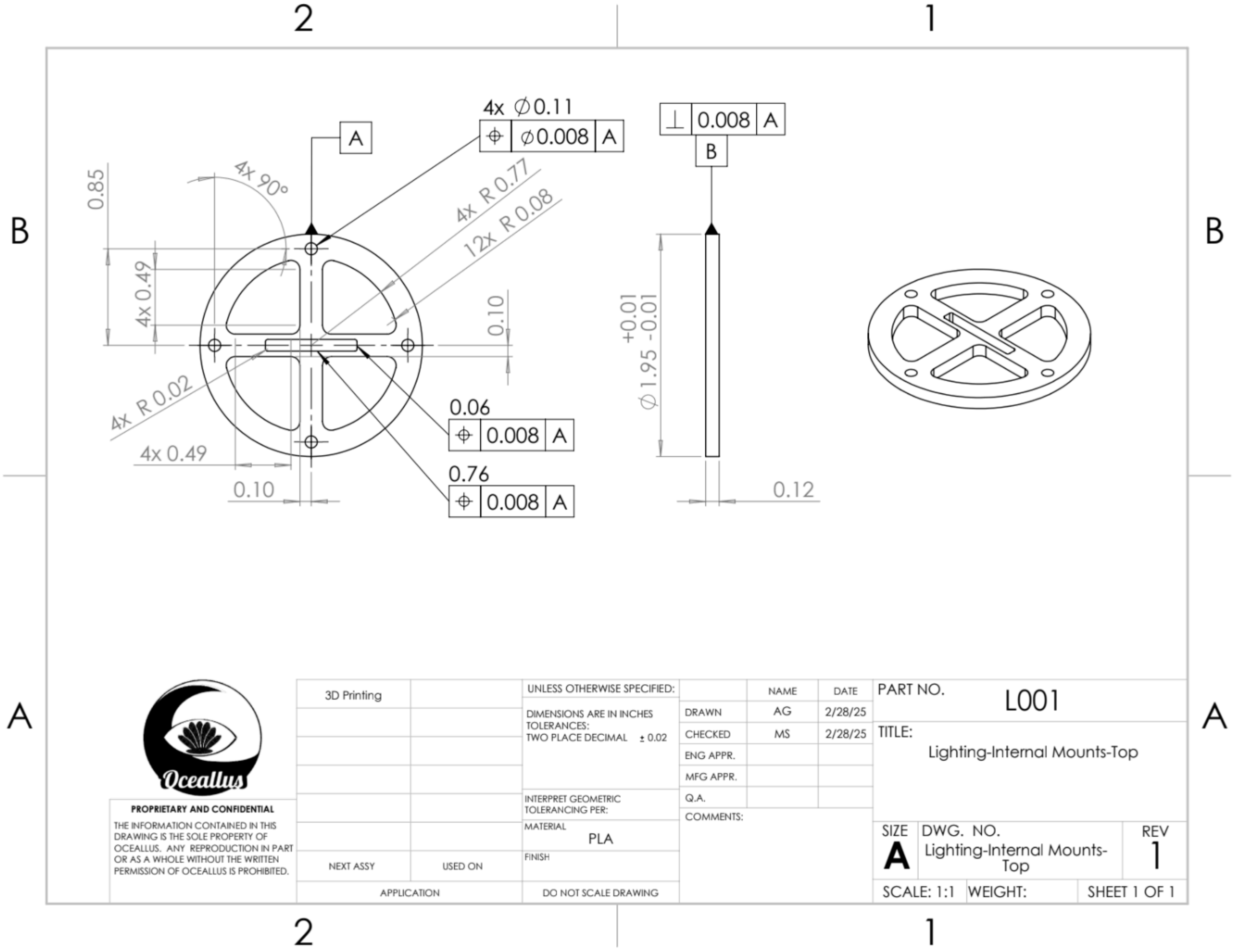
2 1

Working Drawings

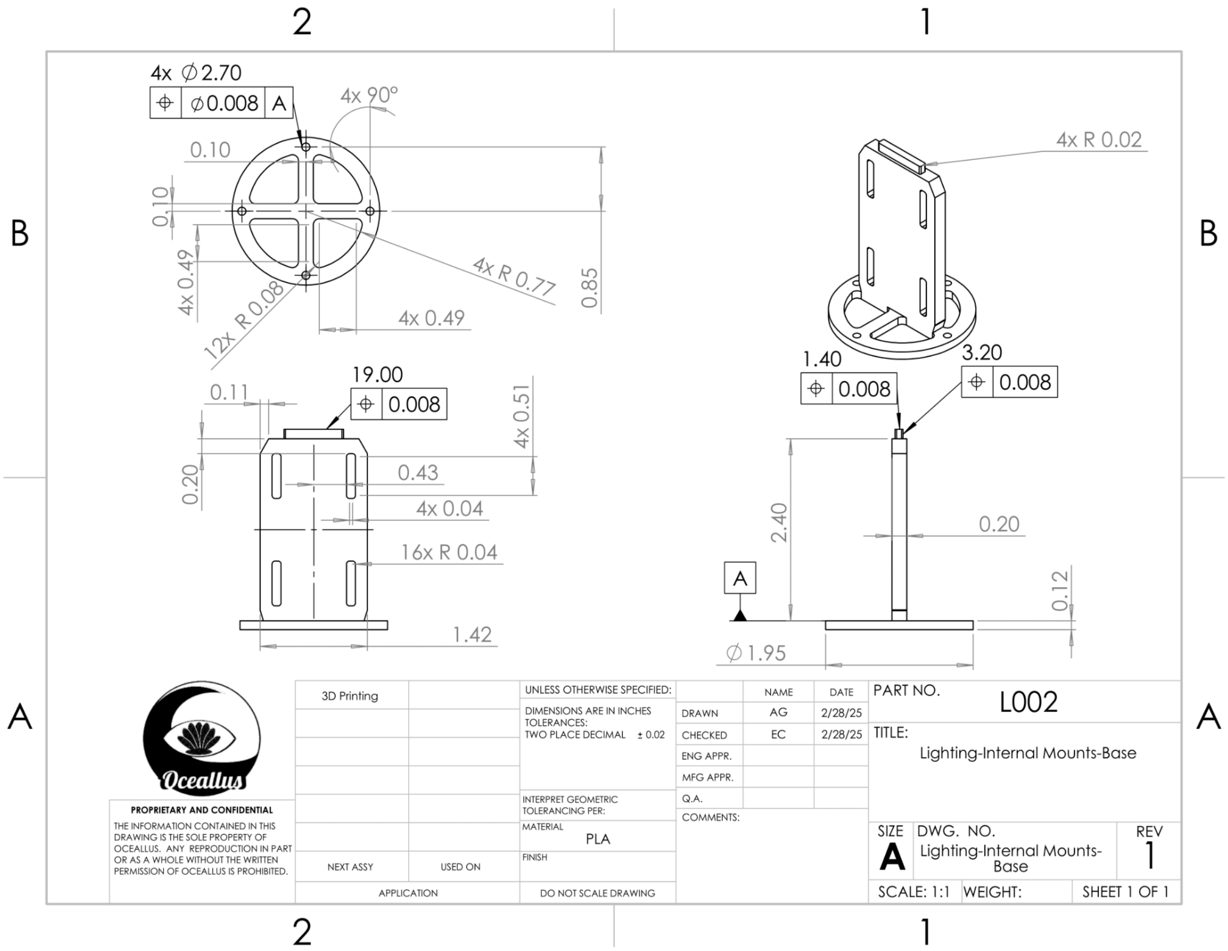
Camera - Internal Mounting



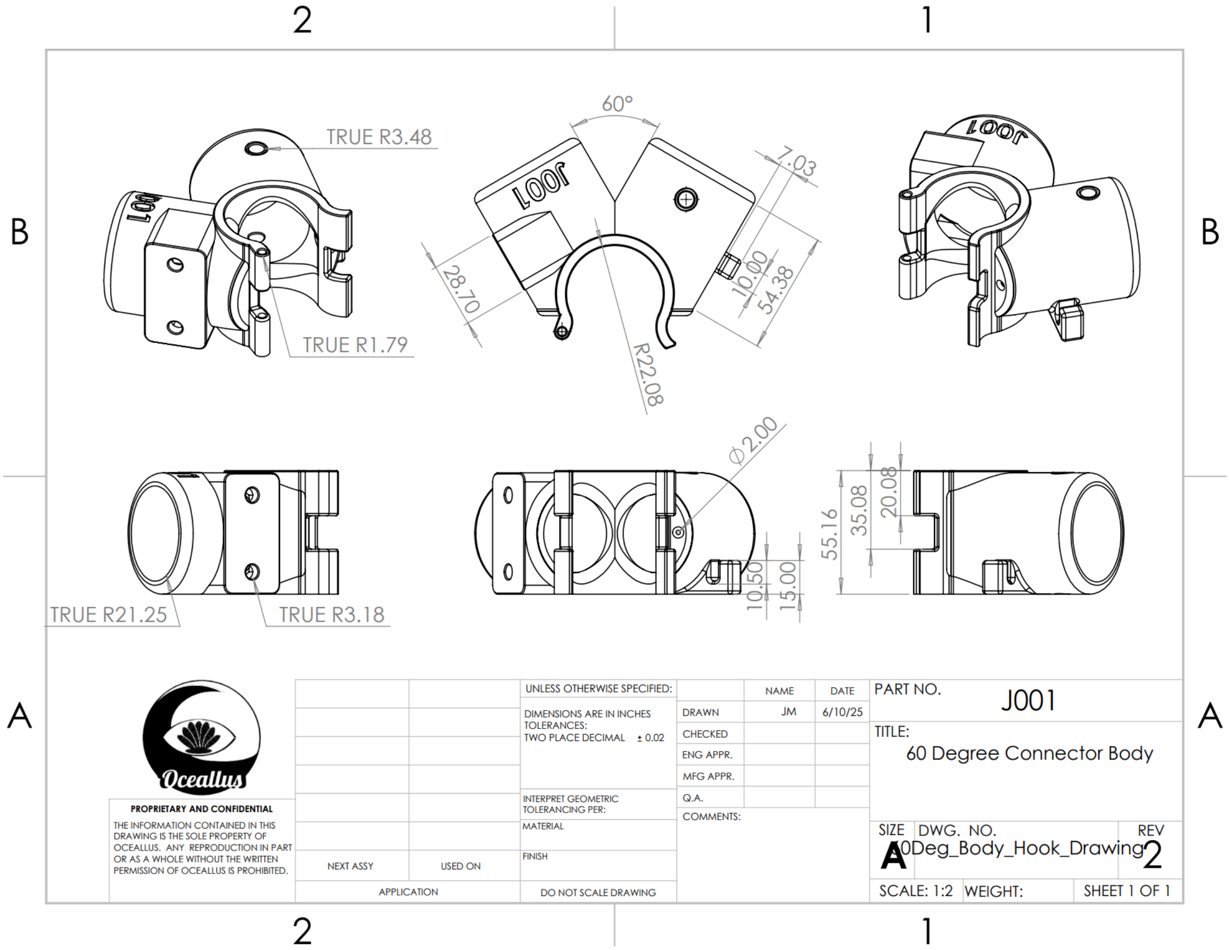
Lighting - Internal Mounting - Top



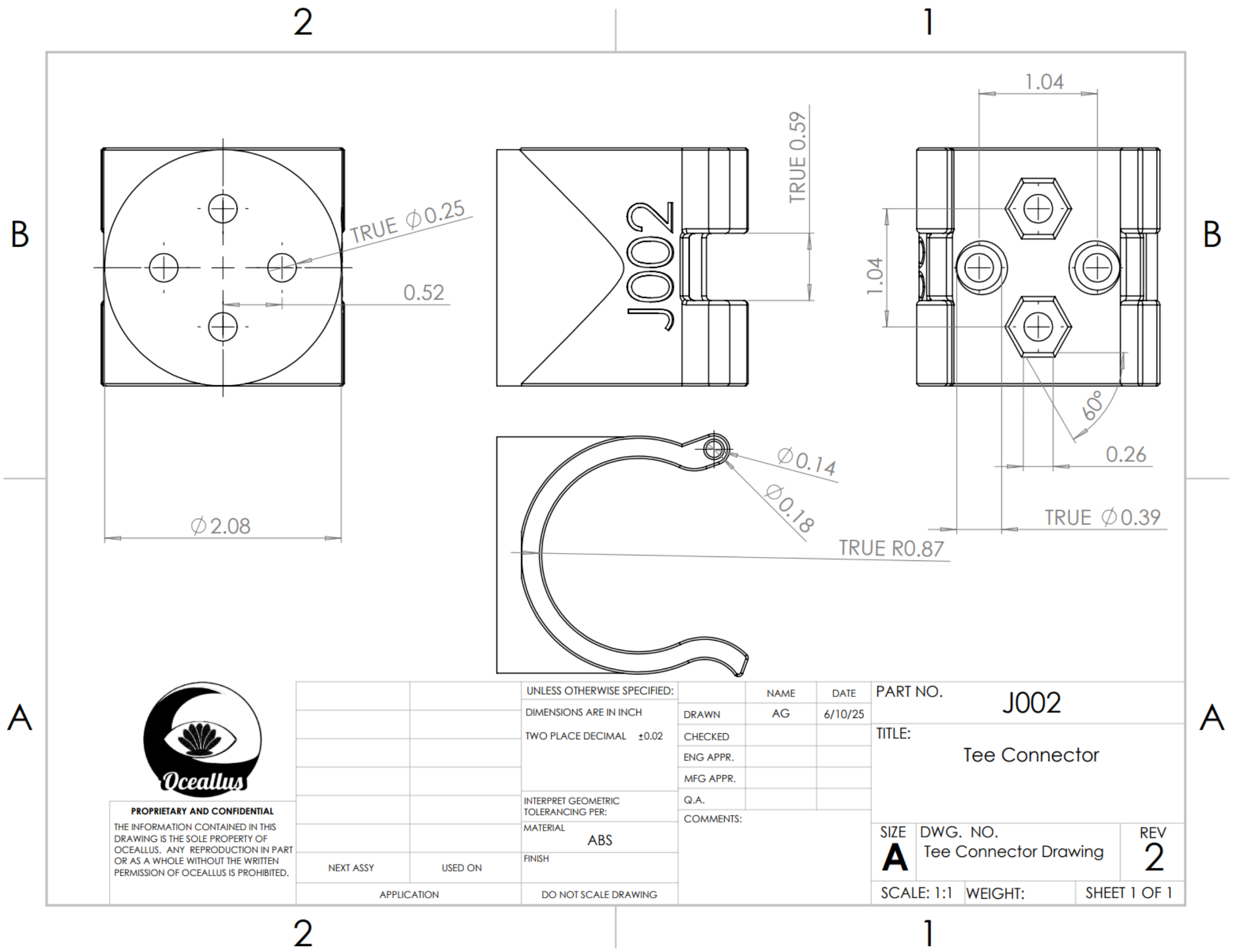
Lighting - Internal Mounting - Base



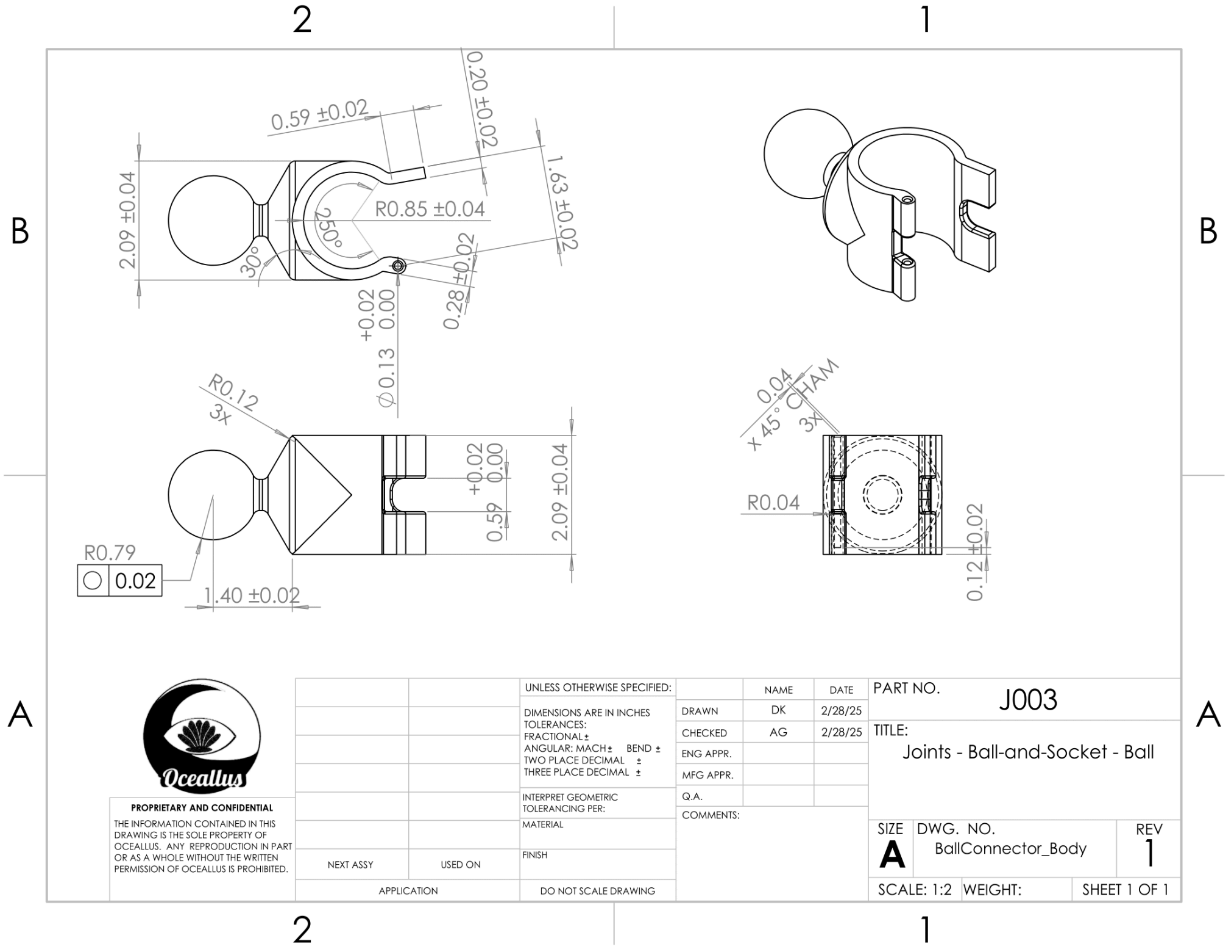
Joints - 60 Degree - Body



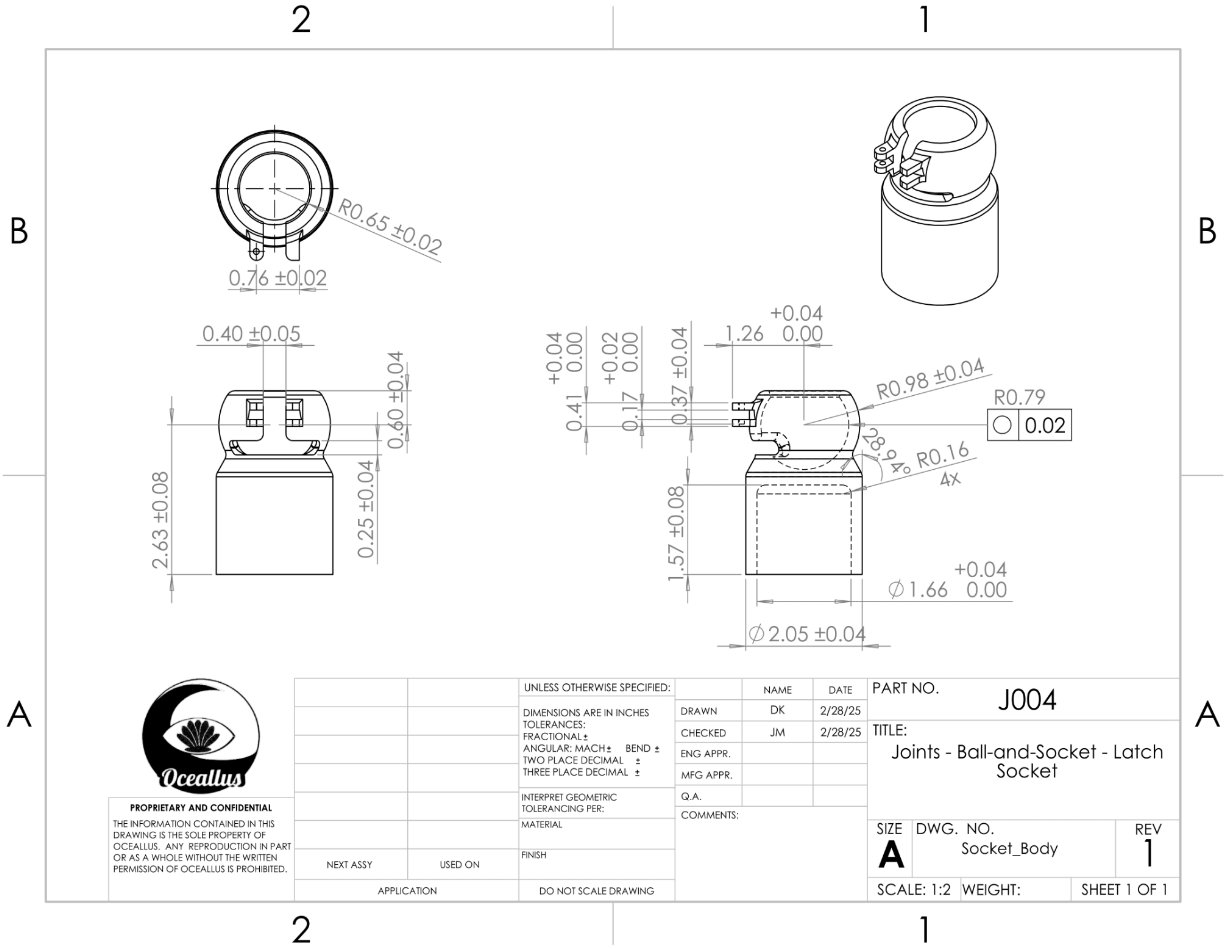
Joints - Tee Connector - Body



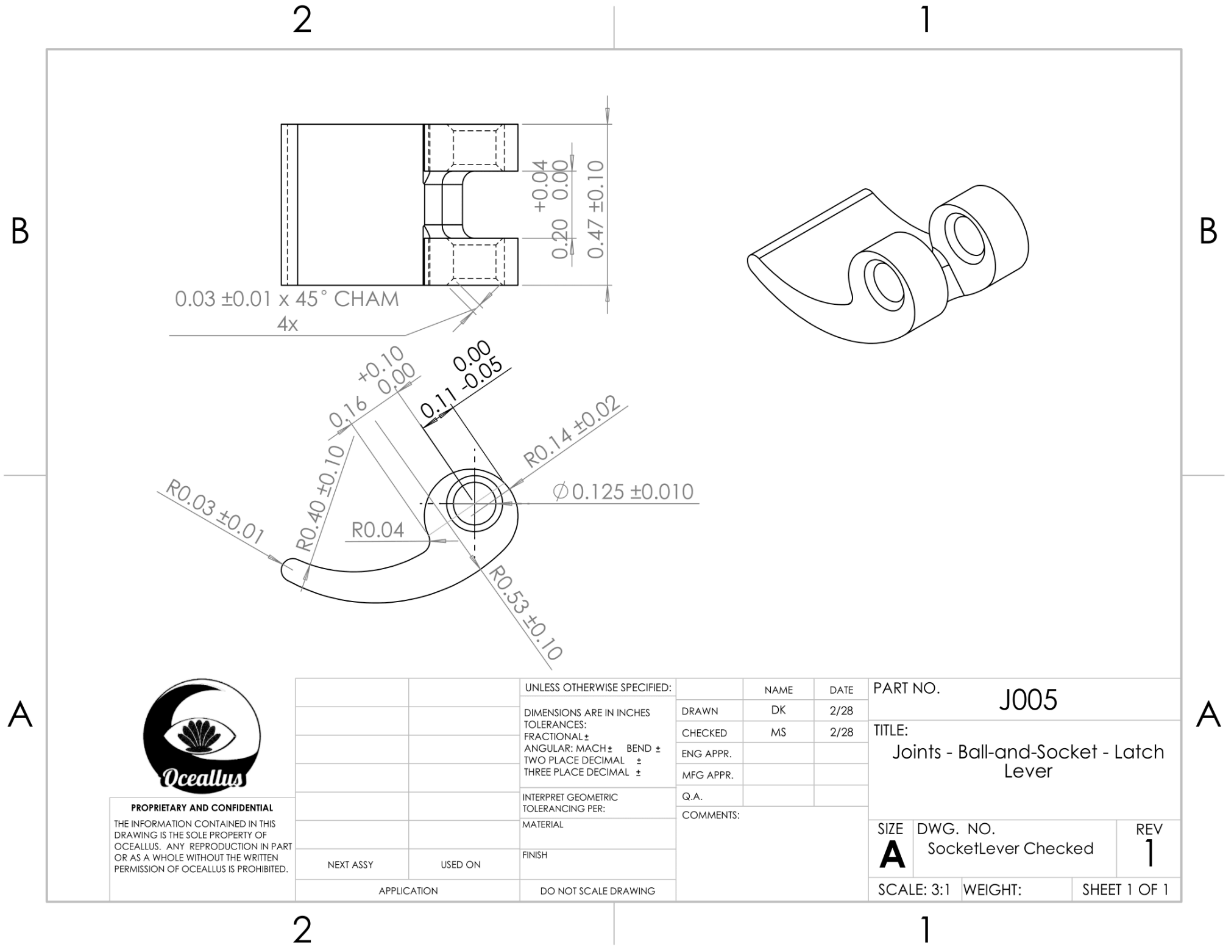
Joints - Ball-and-Socket - Ball Body



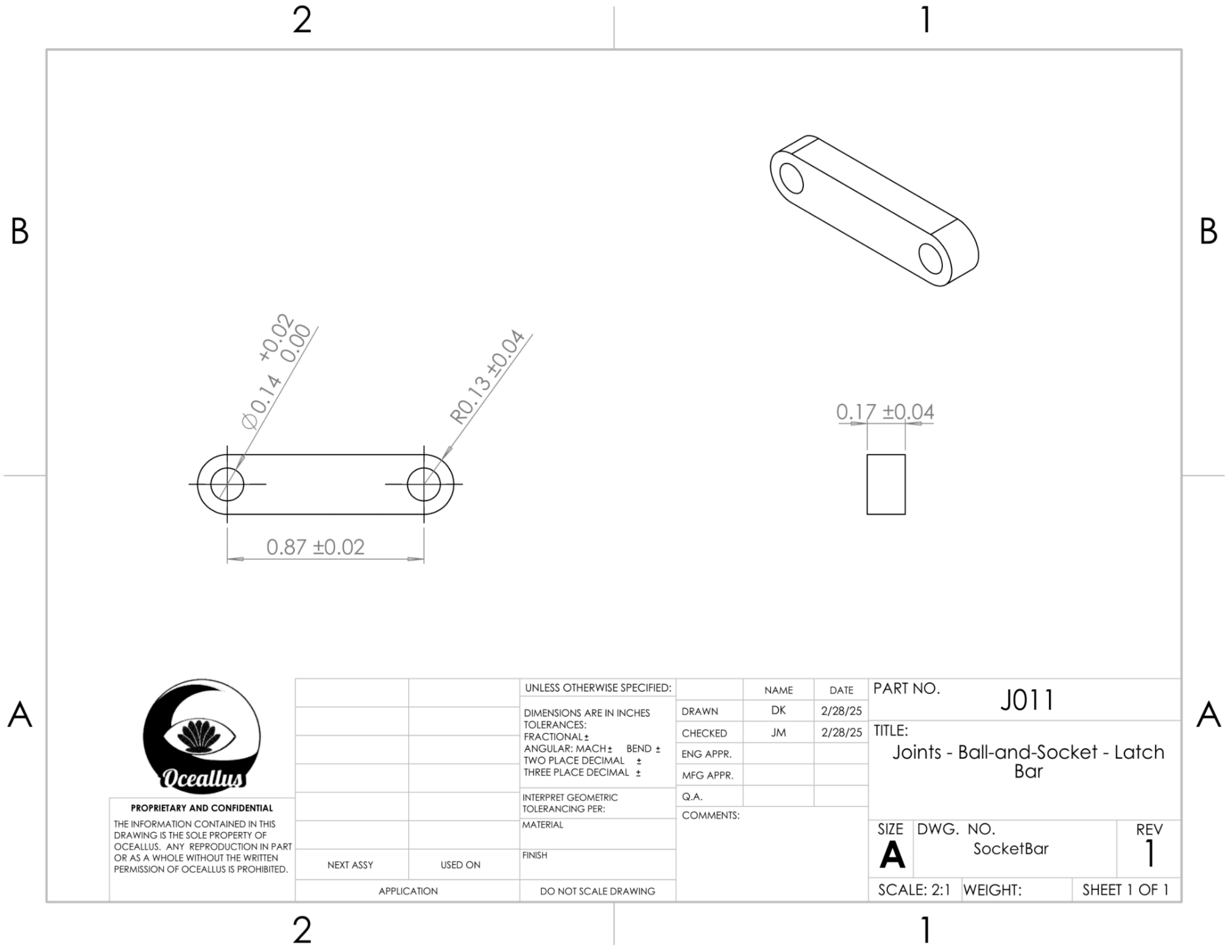
Joints - Ball-and-Socket - Socket Body



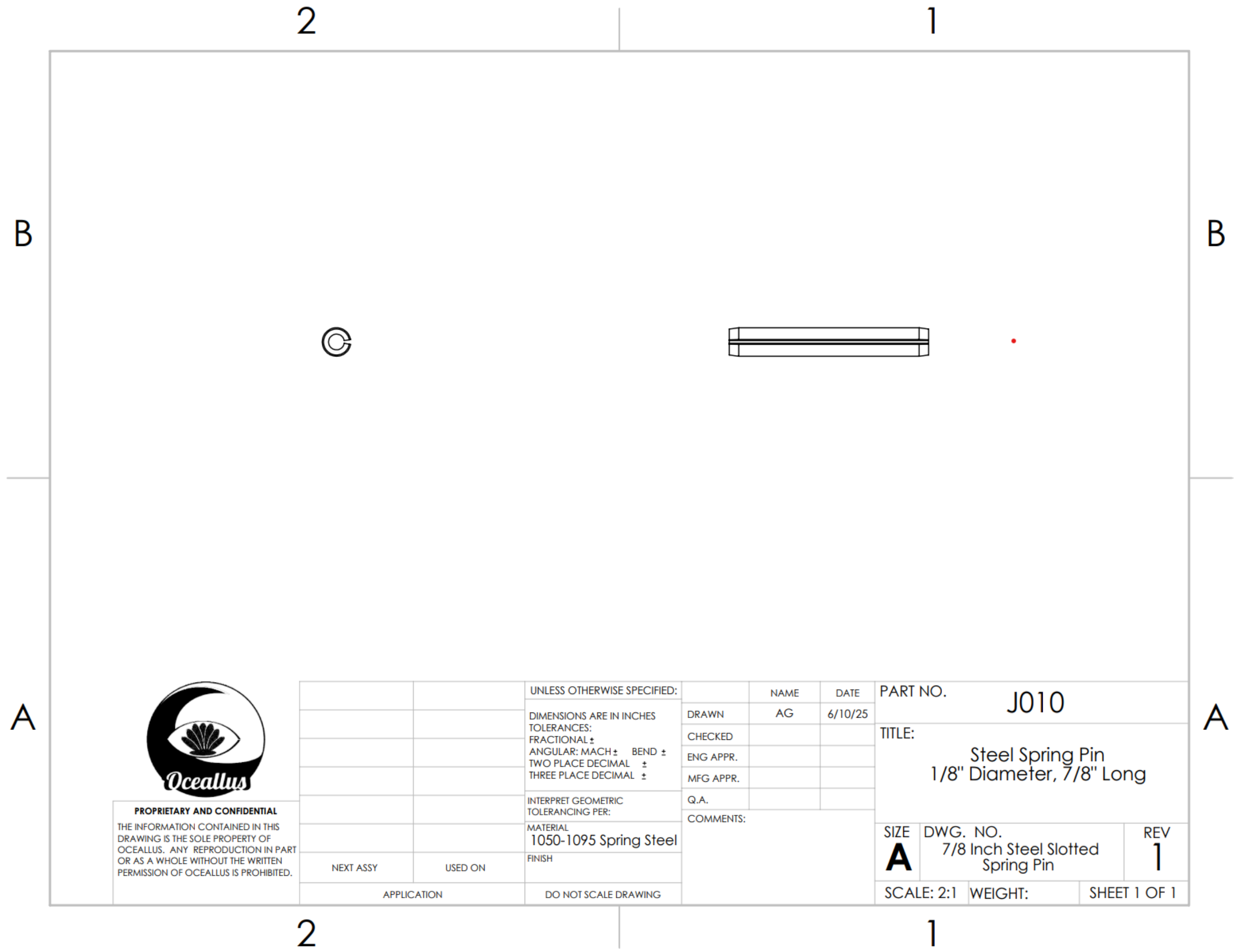
Joints - Ball-and-Socket - Latch Lever



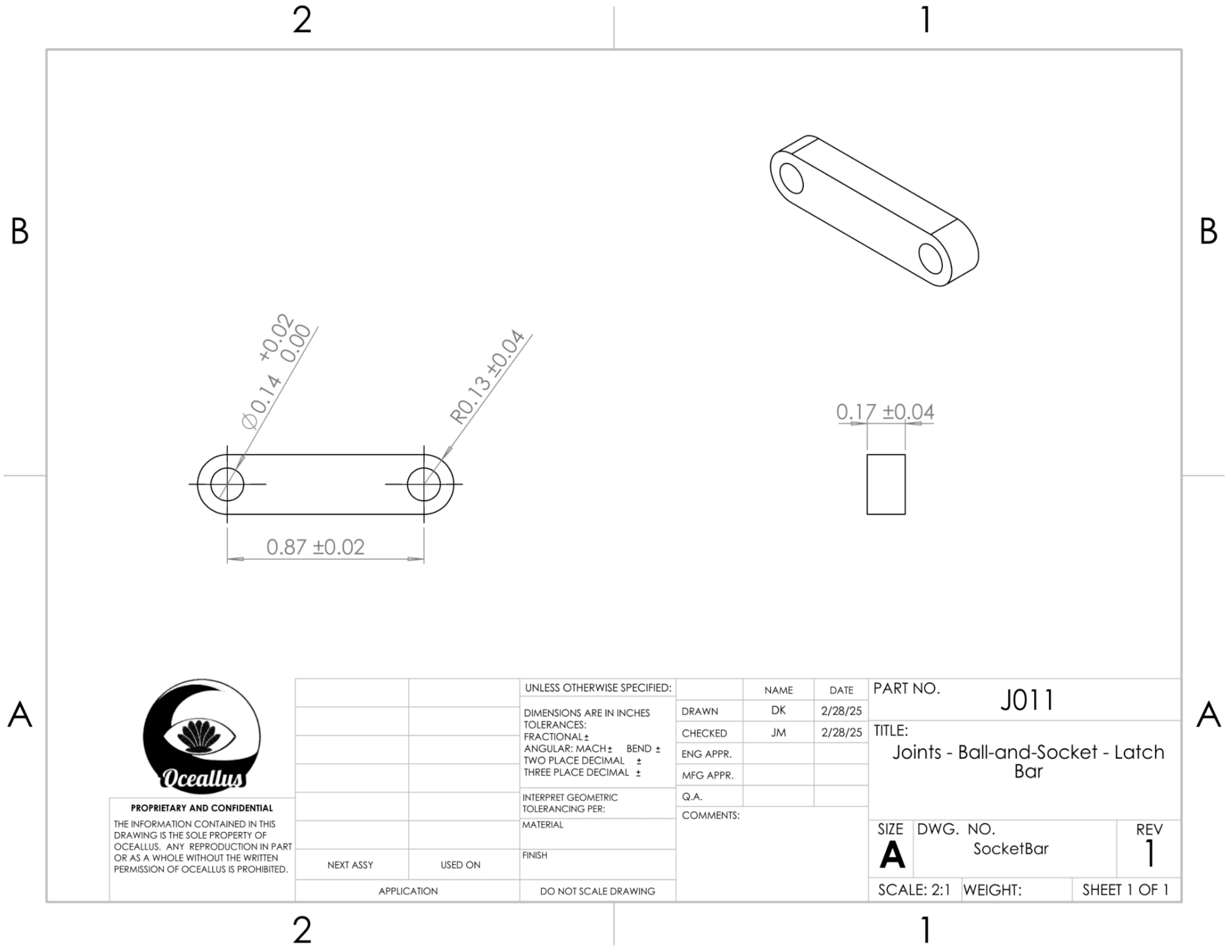
Joints - Ball-and-Socket - Latch Bar



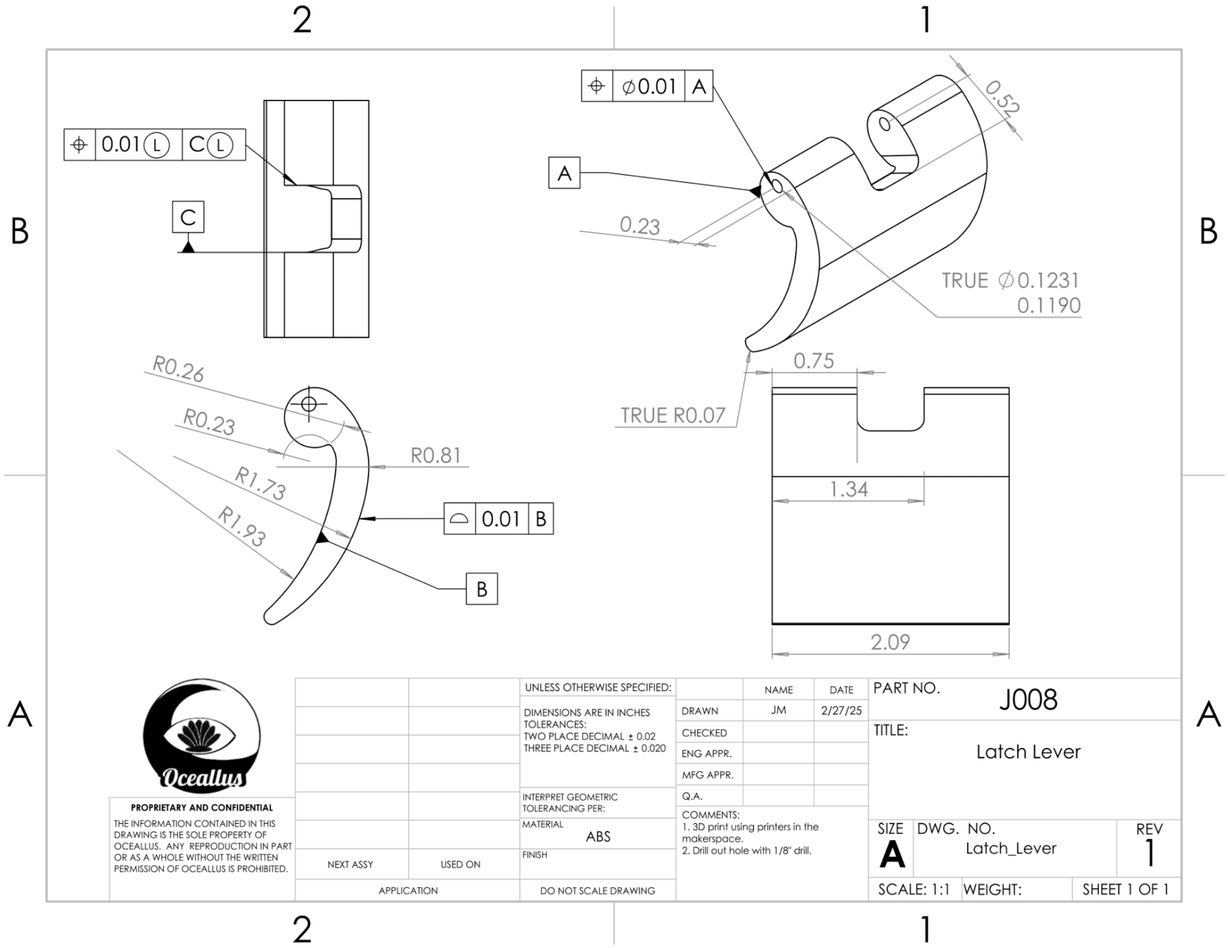
Joints - Ball-and-Socket - ⅞ Inch Sping Pin



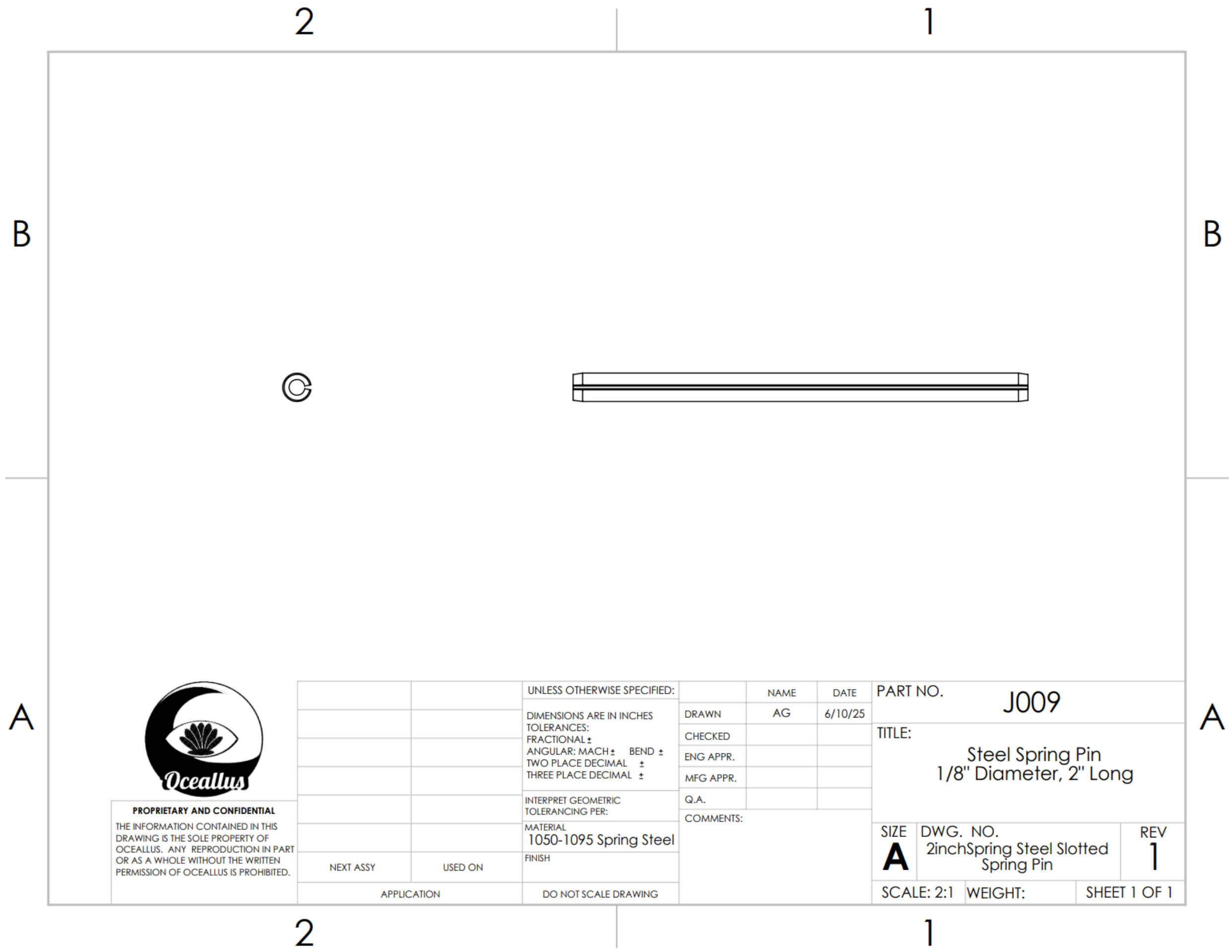
Joints - Latch Bar



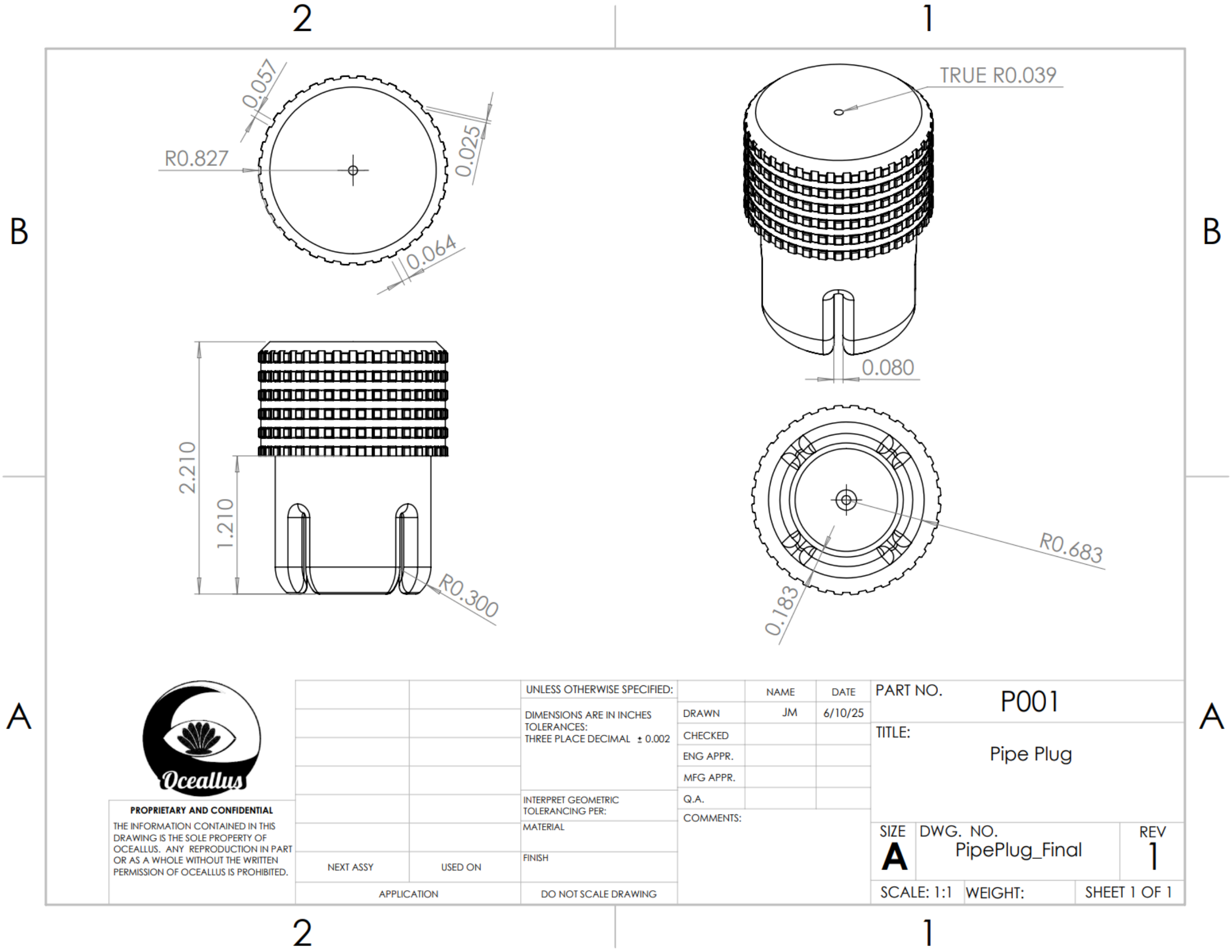
Joints - Latch Lever



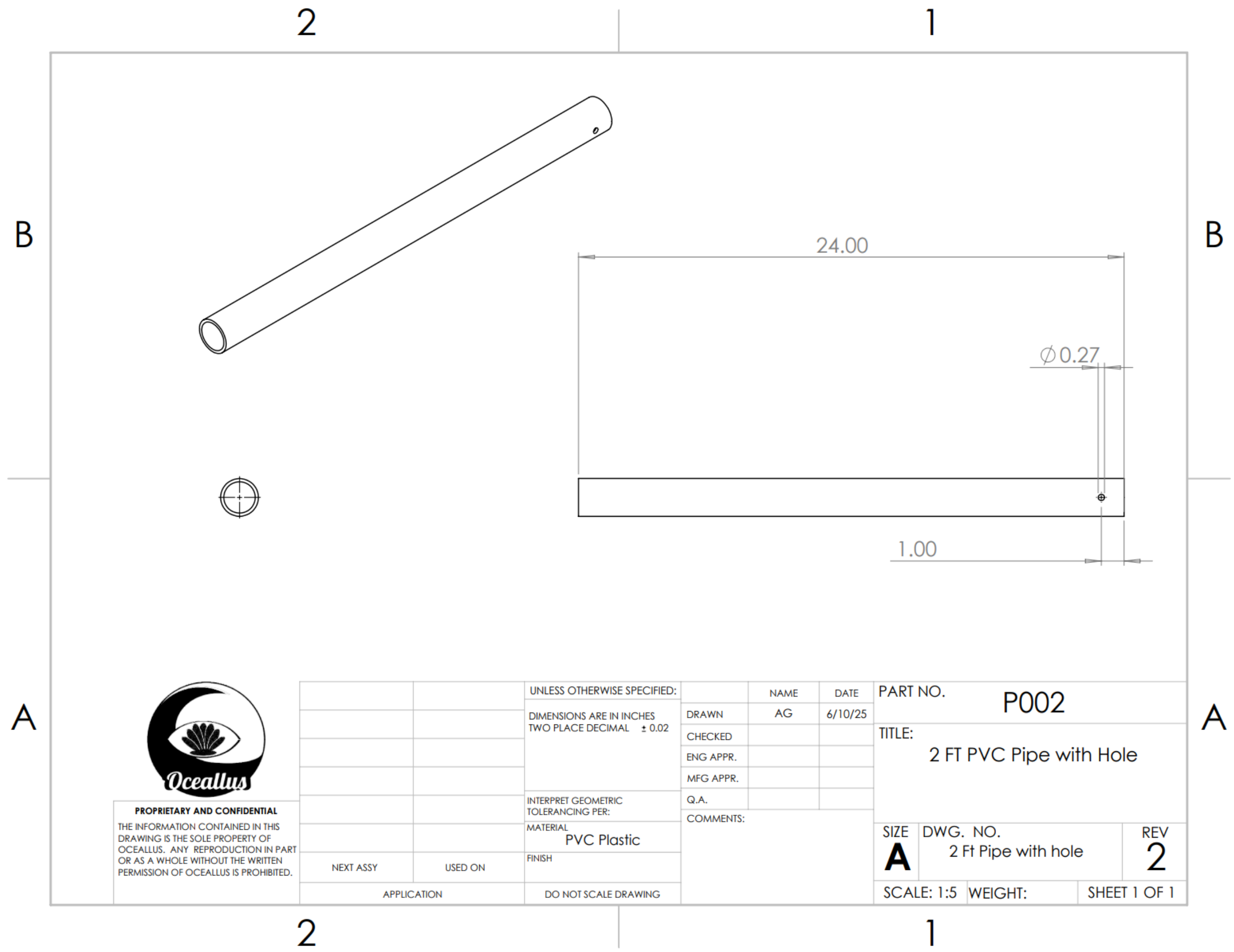
Joints - 2 Inch Spring Pin



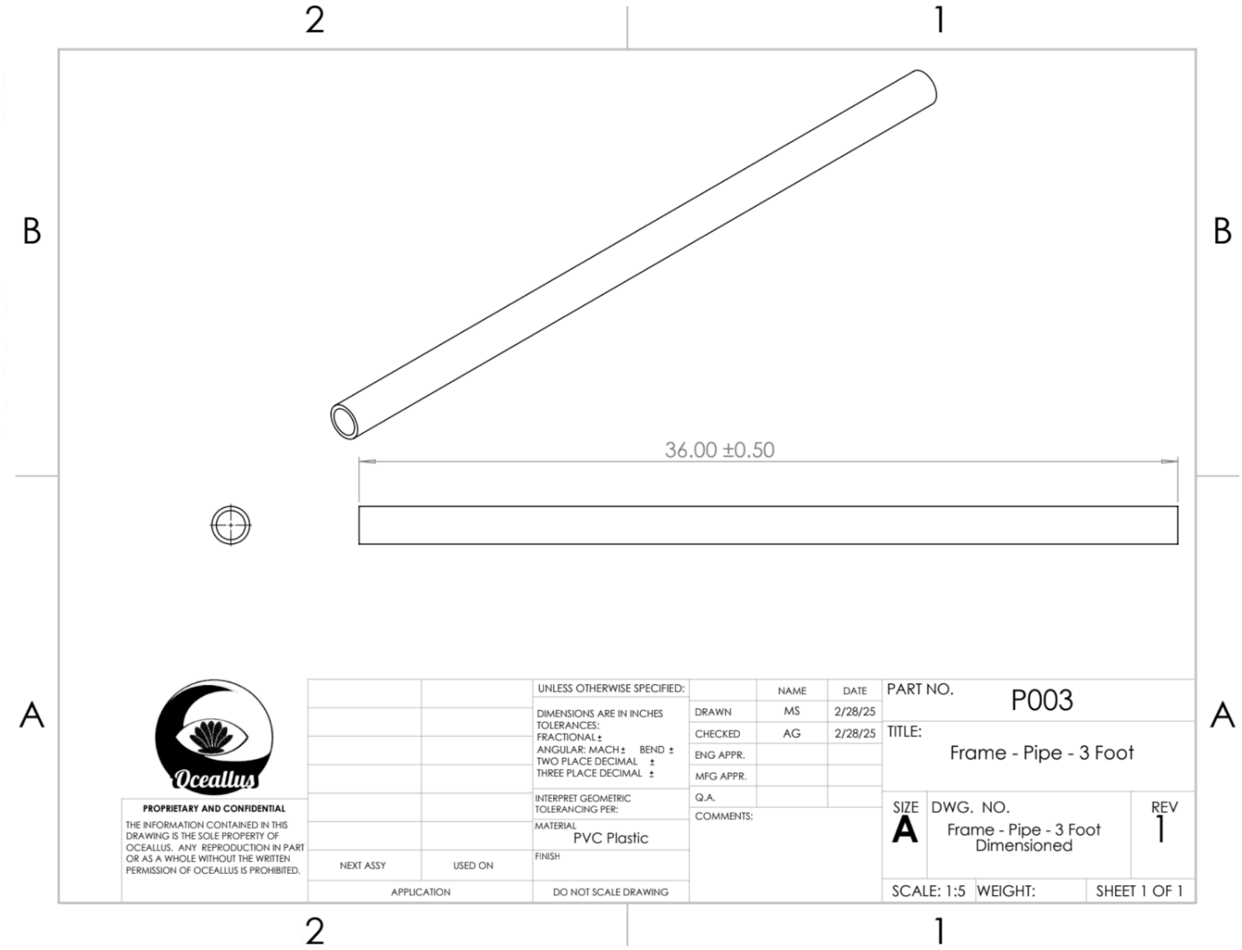
Frame - Pipe Plug



Frame - Pipe - 2 ft

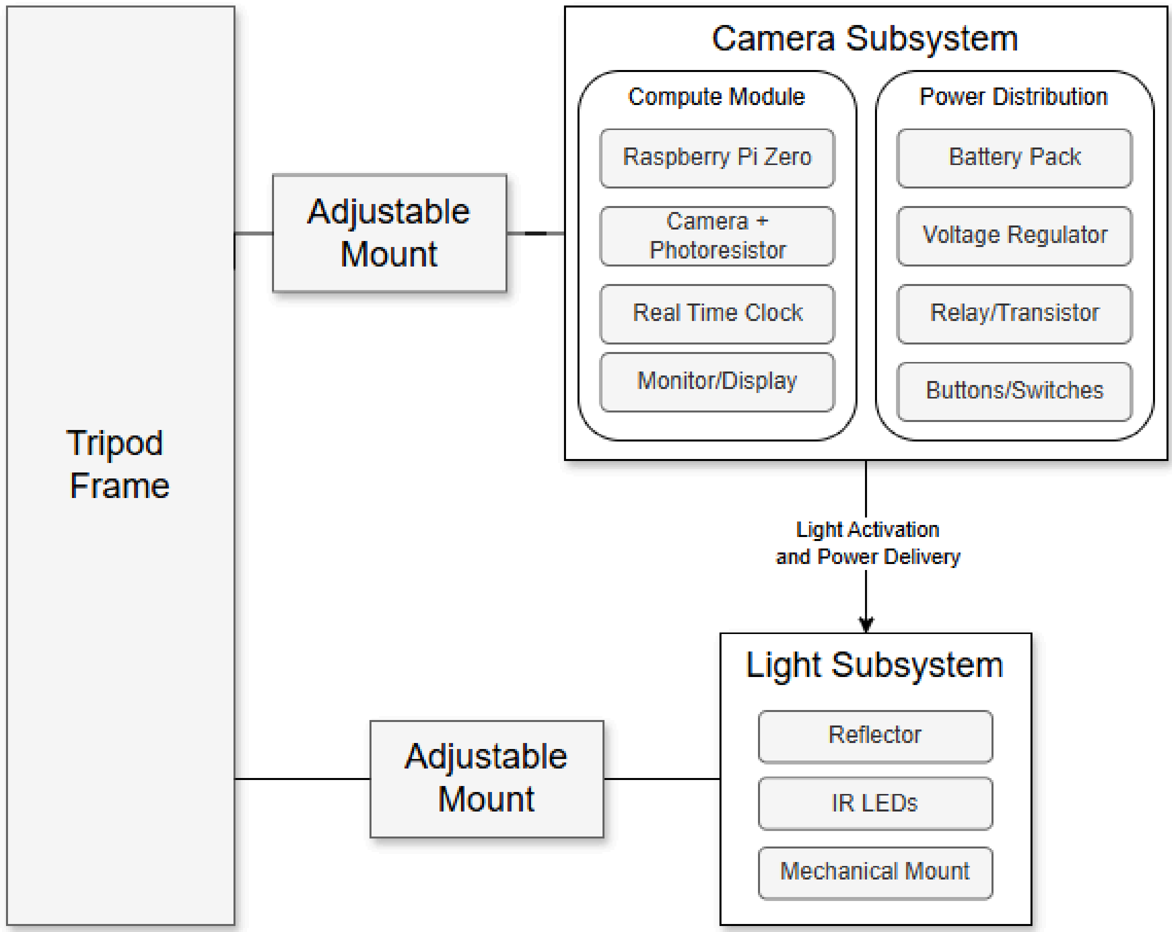


Frame - Pipe - 3 ft



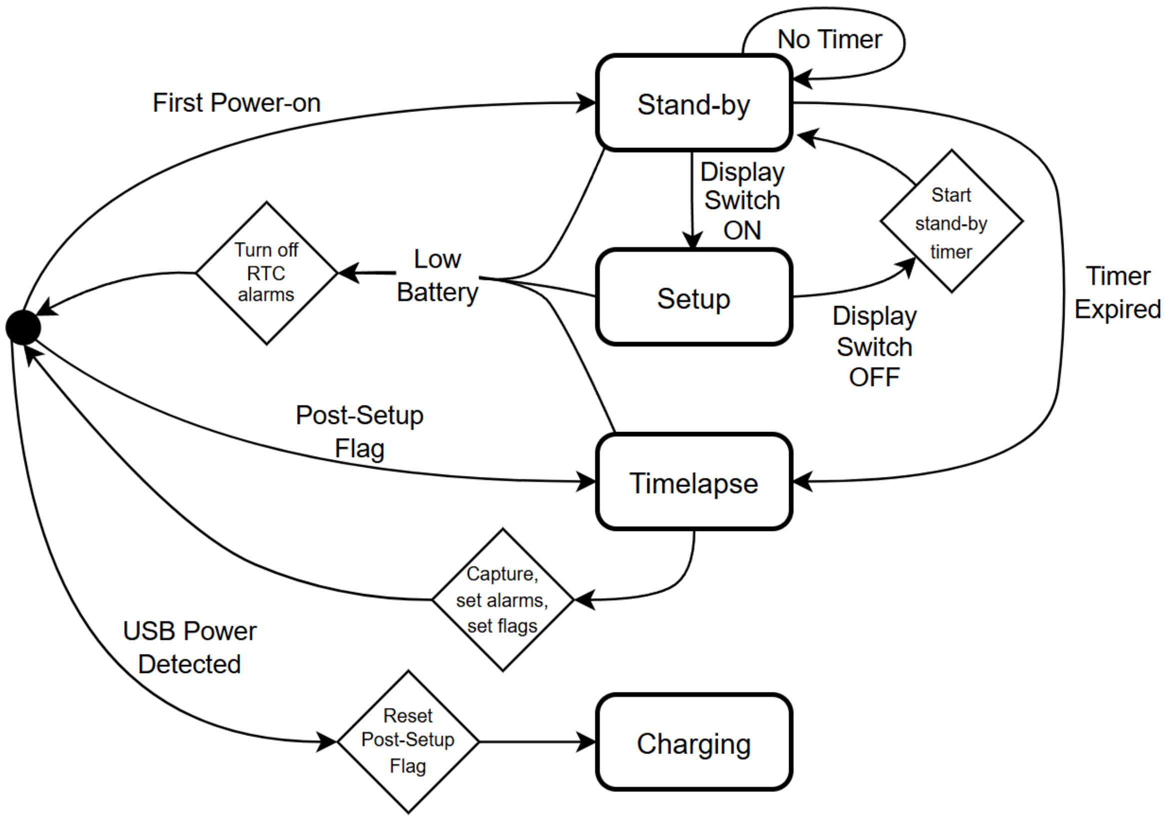
System and Subsystem Block Diagrams

Full system block diagram:



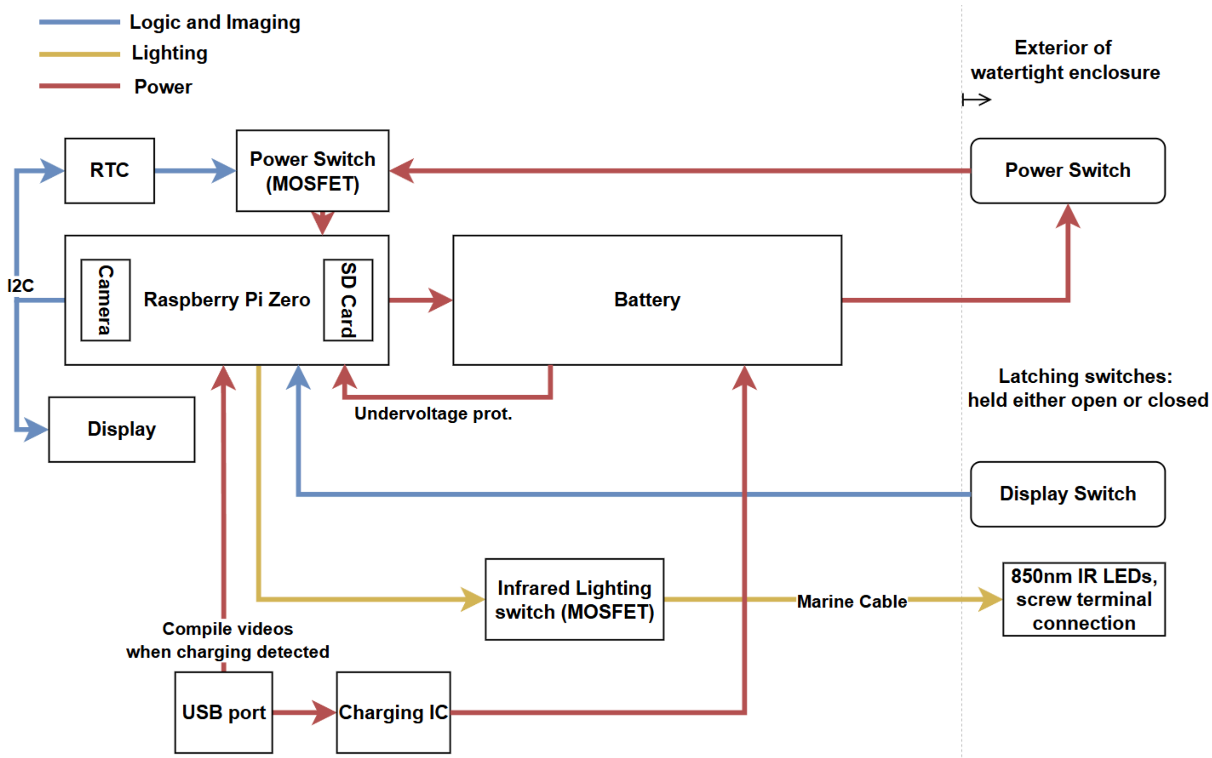
Operational Flowcharts

Software state machine flowchart:

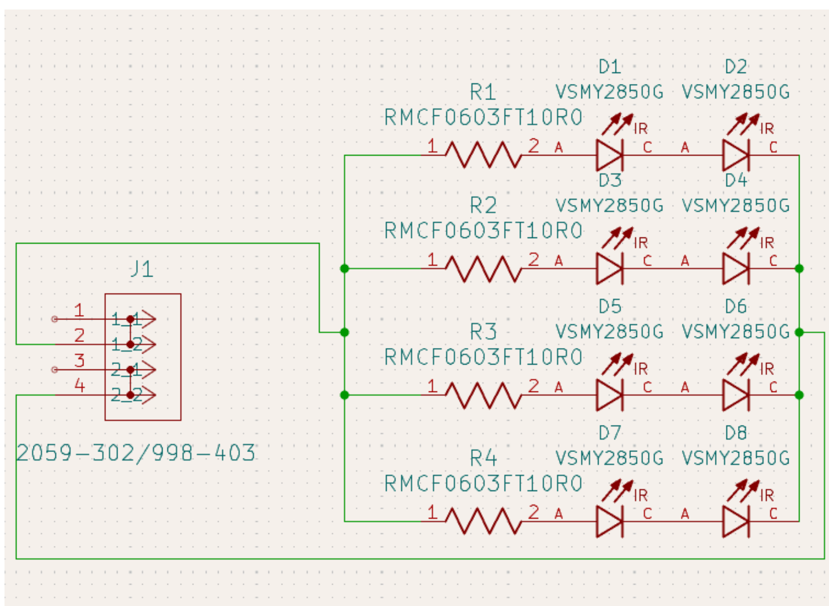


Circuit Schematics and Wiring Diagrams

Camera subsystem schematic:



Lighting subsystem schematic:



Bill of Materials

Item	Price ($)	# of Items	Total Price ($)
Raspberry Pi Zero WH	16	1	16
TFT RGB 2" Display	8.74	1	8.74
5mm Infrared LEDs - 25 count	7.95	1	7.95
18650 Lithium Battery	5.33	8	42.64
5 MP Raspberry Pi Camera Module	17.99	1	17.99
4 Pin Display Cable	4	1	4
Micro SD Card	7	1	7
PCB for camera	250	1	250
ABS Filament 1 kg	19.93	2	39.86
PVC Pipe - 1 1/4 in, 10 ft, Schedule 80	8.86	2	17.72
316 Stainless Steel D-Ring, 210 lb	8.58	3	25.74
316 Stainless Steel Screw, 12", 12-24, x 10	4.92	2	9.84
316 Stainless Steel Hex Nuts, 12-24, x 50	9.44	1	9.44
Watertight Enclosure - Camera	34	1	34
Watertight Enclosure - Lighting	24	1	24
Blank Acrylic Endcap	15	2	30
O-Ring Sealing Flanges	32	2	64
4 x M10 Hole Aluminum Flange Cap	36	1	36
2 x M10 Hole Aluminum Flange Cap	34	1	34
Waterproof Switch	26	2	52
Pressure Relief Valve	28	2	56
WetLink Penetrator - M10 4.5 mm HC	12	2	24
Fathom Cable (by m)	3.5	2.5	8.75
Total (Excluding Blue Robotics)			456.92
TOTAL			**819.67**

Budget / Total Expenditures

Item	Price ($)	# of Items	Total Price ($)
Raspberry Pi Zero WH	16	1	16
DS33231 Real-Time Clock	14.95	1	14.95
Witty Pi Real-Time Clock	33	1	33
Breadboard 32650-W	2.7	1	2.7
TFT RGB 2" Display	10.82	1	10.82
5mm Infrared LEDs - 25 count	7.95	1	7.95
18650 Lithium Battery	5.33	8	42.64
6 Bay 18650 Battery Charger	16.98	1	16.98
3 Cell 18650 Battery Holder	0.6	2	1.2
18650 Battery Holder	0.3	8	2.4
5 MP Raspberry Pi Camera Module	17.99	1	17.99
Wires - Female to Female	3.95	1	3.95
Wires - Female to Male	3.95	1	3.95
Wires - Male to Male	3.95	1	3.95
Photoresistor	0.84	1	0.84
ABS Filament	12.59	2	25.18
PVC Pipe - 1 1/4 in, 10 ft, Schedule 80	30.62	2	61.24
PVC Pipe - 1 1/2 in, 10 ft, Schedule 80	33.64	2	67.28
PVC Pipe Cap Fitting	1.61	6	9.66
316 Stainless Steel D-Ring, 210 lb	8.58	6	51.48
316 Stainless Steel Screw, 12", 12-24, x 10	4.92	2	9.84
316 Stainless Steel Hex Nuts, 12-24, x 50	9.44	1	9.44
Grainger 10 ft Schedule 80 1 1/4 PVC Pipe	24.57	2	49.14
18650 Battery Pack	26.44	1	26.44
Oatey Purple Primer	9.27	1	9.27
Oatey Green Cement	9.25	1	9.25
Sand - 50 lb	4	1	4
Epoxy	7.78	1	7.78
4 pin display cable	4	1	4
PCB for camera	60	1	60

SMD PCB Terminal Block	1.23	1	1.23
Operating Tool	1.25	1	1.25
Breadboard SMD Plated	5.13	1	5.13
Emitter IR 940 nm SMD	0.592	10	5.92
Resistor 220 ohm 1/4 W	0.018	10	0.18
Watertight Enclosure - Camera	34	4	136
Watertight Enclosure - Lighting	24	3	72
Blank Acrylic Endcap	14	4	56
Blank Acrylic Endcap (Price Increase)	15	2	30
O-Ring Sealing Flange	29	4	116
O-Ring Sealing Flange (Price Increase)	32	2	64
4 x M10 Hole Aluminum Flange Cap	34	2	68
4 x M10 Hole Aluminum Flange Cap (Price Increase)	36	1	36
2 x M10 Hole Aluminum Flange Cap	32	2	64
2 x M10 Hole Aluminum Flange Cap (Price Increase)	34	1	34
Waterproof Switch	25	4	100
Waterproof Switch (Price Increase)	26	2	52
Pressure Relief Valve	28	4	112
Pressure Relief Valve (Price Increase)	30	2	60
Wetlink Penetrator Blank - M10	6	2	12
WetLink Penetrator - M10 4.5 mm HC	12	6	72
Fathom Slim Tether (by m)	3.5	13	45.5
Molykote 111	32	1	32
Tef-gel	33	1	33
WetLink Bulkhead Wrench	16	1	16
Hand Operated Vacuum Pump	98	1	98
Backfill Adapter	11	1	11
Boards	180	1	180
Digikey parts	180	1	180
Tariffs	360	1	360
Amazon 3/7/25	180.01	1	180.01
McMaster Carr 4/8/25	48.62	1	48.62
Digikey 4/8/25	103.68	1	103.68
Flexcard 4/15/25	40.58	1	40.58
McMaster Carr 4/28/25	56.55	1	56.55

Digikey 5/7/25	290.43	1	290.43
Robotshop 5/12/25	102.89	1	102.89
Digikey 5/19/25	122.05	1	122.05
Amazon 5/21/25	99.65	1	99.65
TOTAL			**3581.34**

Prototypes and Testing

Tests

Electronics and Software Feasibility Testing

The current prototype (see prototype section) has been tested and confirmed feasibility:

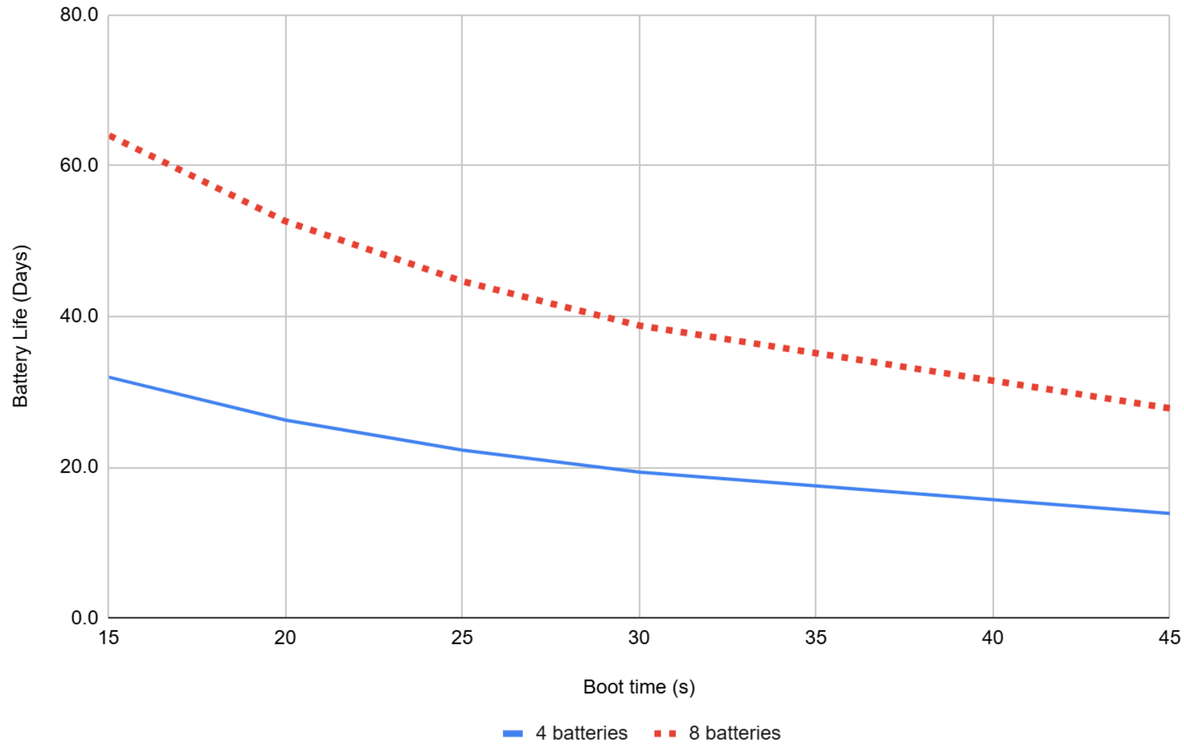
- All necessary electrical connections are physically possible.
- The selected components are compatible and fit within the enclosure.
- Core functionalities have been validated.

Operating System and Software A lightweight operating system has been selected and successfully installed on the Raspberry Pi, ensuring optimized performance within the hardware constraints.

- **Image Capture & Timelapsing:** Basic image capture functionality and time-lapse photography have been implemented and verified.
- **Scheduled Booting:** The system is being optimized for scheduled boot operations, reducing active power consumption to maximize deployment duration.
- **Peripheral Communication:** Development is ongoing for I2C and other peripheral interaction scripts to integrate display, lighting control, and user interface elements.
- **Data Transfer & Automation:** Data transfer over wired and wireless connections has been achieved. Efforts are now focused on improving ease of use and automation for streamlined data retrieval.
- **Boot Time Optimization:** Current boot time averages 45 seconds, which is a significant factor in overall power consumption. We aim to reduce boot time to 25 seconds, leveraging known optimizations that have achieved 8–12 second boot times in similar configurations.

Power Consumption and Deployment Planning Once the final hardware configuration is established, comprehensive power consumption testing will be conducted to refine energy management strategies. Preliminary estimates suggest that:

- The image capture script runs for fewer than 5 seconds per duty cycle.
- Sleep mode or power-off states will dominate the duty cycle, significantly extending deployment duration.
- Initial calculations indicate that a four-week deployment may be achievable with four 18650 batteries, though eight may be required, see plot below.
- If eight batteries are necessary, a larger, slightly more expensive enclosure will be required. While this increases cost, the difference is marginal and ensures extended operational reliability.



With continued development in hardware integration, power optimization (See Analysis section), and system automation, the final prototype will be capable of long-term underwater operation with minimal manual intervention, maximizing efficiency and reliability.

Lighting Brightness and Feasibility Testing

To evaluate the effectiveness of the lighting prototype, we will conduct two primary tests: brightness and coverage and power consumption and efficiency.

Brightness and Coverage

One of the primary goals of this prototype is to ensure that the infrared LEDs provide sufficient illumination for the camera to capture clear images at depths of up to 30 meters. To assess this, the lighting system will first be tested in a controlled dark water tank, simulating the low-light conditions of deep-sea environments. The camera will capture images with and without the reflective backing in place to determine its impact on brightness and light distribution.

Additionally, we will evaluate light coverage over distance by positioning the lighting 3-4 feet away from the camera, mimicking real deployment scenarios. The intensity and uniformity of illumination will be measured at various distances to ensure that the infrared light effectively covers the required field of view. This prototype will also be compared directly to the original breadboard LED array, highlighting improvements in brightness and coverage.The success of this test will be determined by whether the SMD LED system can illuminate the scene sufficiently for the camera to capture usable images. The light must be evenly distributed, avoiding excessive shadowing or glare, and the separate housing must allow for flexible positioning without compromising illumination quality.

Power Consumption and Efficiency

Another critical aspect of this prototype is ensuring that it operates efficiently within the system's four-week power budget. Given that the lighting will be deployed for extended periods without manual intervention, it must consume power conservatively while maintaining stable brightness output.

To evaluate this, we will measure the current and voltage draw of the SMD LED PCB, ensuring that it aligns with the expected Vf = 1.4V, If = 70mA specifications. By calculating the total power consumption across all LEDs, we will determine whether the system remains within acceptable energy limits.A battery drain simulation will also be conducted, running the lighting system in intermittent operation mode to mimic real-world usage. This will allow us to estimate how long the lighting can function before requiring a recharge. The lighting system must last the full four-week deployment without draining excessive power. Additionally, the LEDs should activate only when necessary, conserving battery life by adjusting based on ambient light conditions.

Watertight Enclosure Long-Term Stability

The BlueRobotics waterproof enclosure is designed to withstand prolonged submersion at depth, ensuring complete protection of internal electronics for our 4-week deployment at 30 meters. The enclosure components were selected based on their high depth ratings and significant safety factors, making them highly reliable under extended pressure conditions.

Our system includes:

- Cast Acrylic Tube (2" diameter, 11.8" length) – Rated for 100m, providing a 3.33× safety factor at 30m.
- Acrylic End Cap – Rated for 500m, offering an over-engineered 16.67× safety factor at 30m.
- Aluminum Flange Cap & O-Ring Sealing Flange—Both are rated for 1000m, giving us a 33× safety factor at 30 m with a watertight seal under extreme pressure.

Blue Robotics Enclosures

Component	Weight (g)	Depth Rating	Justification
Cast Acrylic Tube - 11.8", 2" diameter	238	100m	**Rated for 100m, providing a 3.33× safety factor at 30m**
Acrylic End Cap Blank - 2" diameter	17	500m	**Over-engineered with 16.67× FoS at 30m**
O-Ring Sealing Flange	41	1000m	**33× safety factor at 30m, watertight seal under extreme pressure**
Aluminum Flange Cap - 4 x M10 hole, 2" diameter	58	1000m	**33× safety factor at 30m, watertight seal under extreme pressure**

[9]

Planned Waterproofing Testing

We are conducting a two-phase testing approach to verify the enclosure's performance before full deployment.

1. <u>*Phase 1*</u> – **Controlled Submersion Testing**
    - We will first use a small water tank/container in our lab to test for leakages, seal failures, and enclosure integrity. This controlled environment allows us to identify and address potential weak points before field testing.
    - The tank will be filled with saltwater from the seawater tap on campus, ensuring a realistic marine environment rather than just fresh water.

2. *Phase 2* – **Open Water Testing**
    - Once the enclosure successfully passes the tank submersion tests, we will coordinate with our sponsors to arrange full-scale sea testing at the required 30-meter depth.
    - This will allow us to assess the enclosure's performance under actual deployment conditions, including wave motion, varying pressure levels, and long-term exposure to actual ocean currents.

Expected Performance

With proper sealing and pre-deployment testing, the enclosure is expected to maintain full integrity at 30 meters, preventing internal electronics from water damage or pressure-induced failures. The multi-stage testing approach ensures that potential issues are identified and resolved in a controlled setting before field deployment, increasing the system's reliability and longevity.

Frame Submersion

The PVC frame subsystem is intended to withstand hydraulic pressures at depths up to 30m and support the necessary ballast for deployments up to 4 weeks. The frame will need to withstand the ballast required to keep the system anchored to the ocean floor, and be able to support it while the system is being lifted back out from the water after deployments.

Our system includes:
- 1-¼" diameter PVC pipe (both 2 and 3 foot long sections)
- 3D Printed end caps to allow connectors to fully slide off of pipe sections
- 3D Printed connectors to connect cantilever arms to the frame and the horizontal section to the vertical section

Planned Submersion Testing
Through testing, we plan on answering the following design questions:

- Do the rubber cement seals on the end caps keep water out of the interior of the frame?
    - This will be checked by monitoring the frame connections, especially at the end caps and the horizontal connections, which would indicate water is entering the frame.
- Does the frame withstand the weight of ballast when being retrieved?
    - We expect to use ballast of up to 50 pounds during testing, which means we will need to retrieve the frame with the ballast attached to it. While hoisting the frame out of the water, the connections and seals will need to be able to withstand the ballast without breaking apart.
- Can the frame remain sturdy after deployment?

    - External events in the ocean could affect the integrity of the deployment, so we would like to ensure that the addition of ballast and implementation of other methods such as filling the pipes with foam will resist these external events.

Our testing will follow three phases, a shallow water pool submersion, a deep water pool submersion, and a full deployment.

1. *Phase 1* - **Shallow Water Pool Submersion**
    - In the half-moon area of the recreation center pool, we will work with water depths that will fully submerge the frame, but not come much higher than that above the frame.
    - This will be to verify the integrity of the seals used to connect the end caps and the connectors, and also to quickly test the retrieval system, while it is at a depth that is accessible without diving.
2. *Phase 2* - **Deep Water Pool Submersion**
    - In the diving tank area of the recreation center pool, we will work with water depths that fully submerge the frame, but also increase the height of water above the top of the frame. This will allow us to test at a higher pressure than the shallow area.
    - The increased depth will allow us to check that the ballast is sufficient to keep the frame stable, and also give us the opportunity to retrieve the frame while loaded with ballast. Ideally the shallow water testing will verify that the system works before we attempt to remove the frame using this method.
3. *Phase 3* - **Full Deployment Testing**
    - With verified seal integrity and ballast support, we would move on with full deployment at desired depths chosen by the sponsors. All subsystems will be tested during these tests, under real world conditions for power consumption, pressure values, and possible interference.

After testing the systems in the pool, testing at depth will verify the frame is viable at the desired depth scales.

Expected Performance

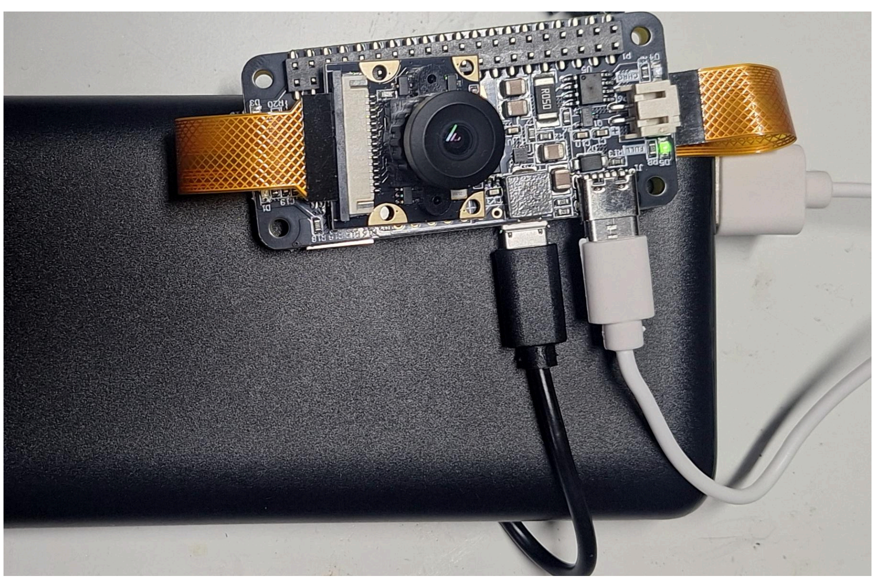
Similar PVC based systems have withstood deployments at these depths, but the addition of ballast might complicate things. We have conducted an analysis that suggests the chosen parameters will be able to hold up under the expected conditions. Before moving to the full deployments, each of the problem areas will be verified using the first two phases of the testing, which should ensure a more reliable system being tested in open water.

Prototypes

Camera

Electronics Hardware The current prototype for our underwater camera system integrates off-the-shelf and custom-designed electronic components to achieve a compact and efficient design suitable for long-term deployment.

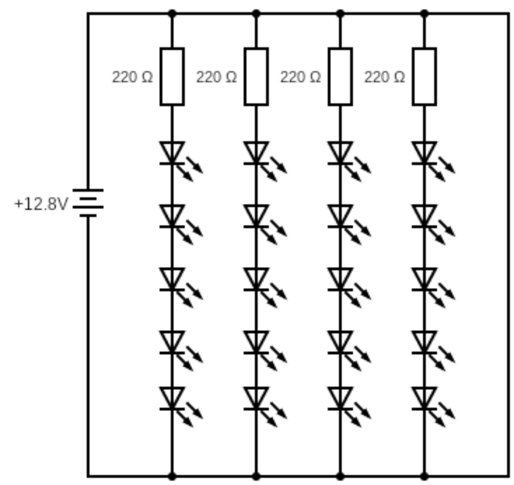
- **Processing Unit:** A Raspberry Pi Zero serves as the primary computing unit, chosen for its low power consumption and sufficient processing capability for image capture and data management.
- **Power Management:** The system utilizes an off-the-shelf HAT that handles power distribution, time tracking, and scheduled booting functionality.
- **Imaging System:** A camera module with a swappable lens is used, allowing flexibility in focal length and image quality optimization.
- **Storage:** Captured footage, as well as the operating system, are stored on an SD card, providing sufficient space for high-resolution image sequences over extended deployments.
- **Battery System:** The prototype currently employs a commercial power bank. However, we plan to transition to a 3.7V battery pack composed of 18650 rechargeable batteries. Due to the lack of suitable pre-assembled battery packs in our required capacity and form factor, we are designing a custom solution with the help of outsourced PCB manufacturing.
- **Peripheral Connectivity:** I2C expansion is necessary for integrating a display and additional peripherals such as switches and a lighting system. However, finding a non-invasive method to break out I2C lines without soldering remains a challenge. A custom PCB is under development to either function as a Raspberry Pi hat incorporating these features or as an interfacing board to supplement the existing hat.



Lighting

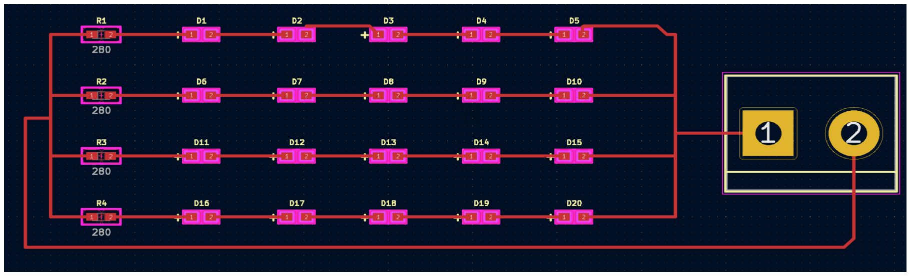
The lighting system will be housed in a separate enclosure, allowing for flexible placement up to 3-4 feet away from the camera.The lighting prototype is essential for ensuring that the underwater camera captures clear images in low-light conditions without disturbing marine life. The initial prototype focused on testing basic LED functionality, while later iterations explored ways to optimize brightness and power efficiency within the constraints due to the size of the waterproof enclosure.

Prototype 1 (Breadboard LED Array)
The first lighting prototype was a simple infrared LED array on a breadboard. This was built to quickly test whether basic infrared lighting was sufficient for underwater imaging. The breadboard LED array did not produce enough light for clear image capture in complete darkness, as the enclosure size limited the number of LEDs that could be installed, making it necessary to find a more compact and powerful solution. Based on these results, we decided to transition to a custom PCB with SMD LEDs for improved brightness and efficiency.



Prototype 2 (SMD LED on PCB)
The second lighting prototype was developed in response to the shortcomings of the initial breadboard LED array, which failed to provide adequate brightness for capturing clear images in dark conditions. The primary issue was that the limited space within the waterproof enclosure restricted the number of through-hole LEDs that could be installed, making it impossible to generate sufficient infrared illumination. To address this, the second prototype features Surface-Mount Device (SMD) LEDs mounted on a custom Printed Circuit Board (PCB), designed to maximize brightness while maintaining energy efficiency.

SMD LEDs offer higher light output per unit area compared to traditional through-hole LEDs, allowing for a more compact yet powerful lighting system. By mounting the LEDs on a PCB, we can precisely control their arrangement, ensuring optimal light distribution while minimizing wasted space within the enclosure. Additionally, the PCB design allows for improved thermal management, preventing overheating and ensuring consistent brightness throughout the system's four-week deployment.



Pipe Fittings

Overview As part of our frame construction, we are developing a set of custom 3D-printed pipe fittings to interface with PVC pipes. These connectors serve multiple purposes, ensuring structural stability, modularity, and ease of adjustment in the field. Renders of each connector will be provided for visualization.

Connector Types and Functionality

- **60-Degree Connectors (3x)**
  - Permanently join two PVC pipes at a fixed 60-degree angle.
  - Provide an adjustable, clamped connection for a third, perpendicular pipe.
  - Utilize an eccentric latch mechanism with 316 stainless steel pins for axles.
  - The latch applies pressure to the PVC pipe for secure locking while allowing for easy repositioning to accommodate different terrains.
  - Include attachment points for D-rings, enabling ballast weight connections.
- **90-Degree "Tee" Connectors (2x)**
  - Serve as structural joints to attach cantilevered camera and lighting arms to the tripod frame.
  - Provide a rigid and stable interface between components while maintaining ease of assembly.
- **Ball and Socket Connectors (2x)**
  - Allow for flexible positioning of camera and lighting subassemblies.
  - Enable fine-tuned angle adjustments for optimal imaging and illumination.

Testing and Evaluation

- **Fitment and Assembly**
  - Ensuring connectors fit securely with standard PVC pipe diameters.
  - Evaluating ease of assembly and disassembly for field deployment.
- **Printing Reliability**
  - Assessing consistency and accuracy of 3D prints.
  - Identifying any warping, print defects, or tolerance issues.
- **Mechanical Functionality**
  - Testing latch tolerances and clamping forces for secure yet adjustable connections.
  - Verifying ball and socket joints provide adequate range of motion and holding strength.

Material Selection and Optimization

- Current prototypes are printed in PLA for rapid prototyping.
- Final production will transition to ABS for improved marine durability.
- Sealing methods will be applied to enhance water resistance and longevity.
- Strength optimization and material reduction strategies will be implemented to improve cost-effectiveness.

Future Testing and Feedback

- **Sponsor Hands-On Testing**
  - The prototype fittings will be provided to sponsors for real-world handling and feedback.

- User experience will inform refinements in design, strength, and usability.

By refining our designs through iterative testing and optimization, these custom fittings will ensure a robust, adaptable, and cost-effective solution for the underwater camera frame system.

Frame

The frame prototype that we plan on building will include PVC pipe sections, custom 3D printed connectors, and custom 3D printed endcaps. We intend to connect the full system together for submersion tests to ensure the strength of the frame and its connections.

Materials

- 1-¼" diameter PVC pipe
- 3x 3' sections
- 5x 2' sections
- 3D Printed endcaps
- 3D Printed connectors
- 60 degree connectors for horizontal plane
- Tee connectors to for cantilever arms
- Rubber Cement

Testing Plan

We intend to verify multiple areas with the proposed frame prototype:

- Strength of overall frame using 3D printed connectors
- Ability of frame to withstand possible disturbances in the water
- Adjustability of frame
- Ease of set up

Strength of Overall Frame using 3D printed connectors

Using pool testing, ballast will be added to the connectors at the designated connection points. In both shallow and deep pool water, the ability of the frame to withstand the weight of the ballast will be checked, particularly when it comes to retrieving the frame from the water, which will require the horizontal parts of the frame to also withstand the bending due to the ballast.

Ability of Frame to withstand possible disturbances in the water

Full scale deployment will likely be needed to fully establish this, but shallow water tests can be used to verify that small scale disturbances will not affect the frame.

Adjustability of Frame

The 3D printed end caps were specifically designed to allow the connectors to slide off of the vertical pipe sections in order to allow for the full collapse of the frame for storage purposes. Testing will verify that the clearance between the end cap and the connector will allow for the connector to slide off and be placed back on without difficulty.

Ease of Set Up

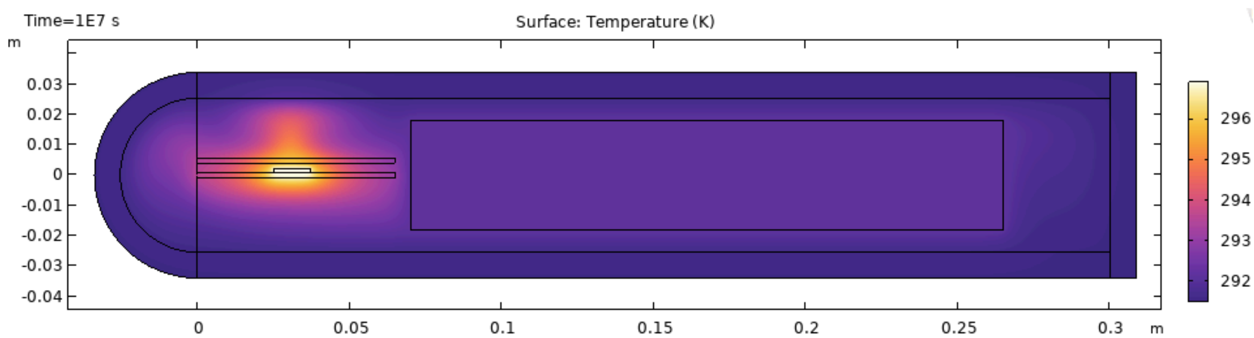
In order to verify that the frame is not too difficult to deal with, we intend to present the prototype to the sponsors in order to make sure that we can give set-up directions that are thorough enough for them to be able to put the frame together on their own.

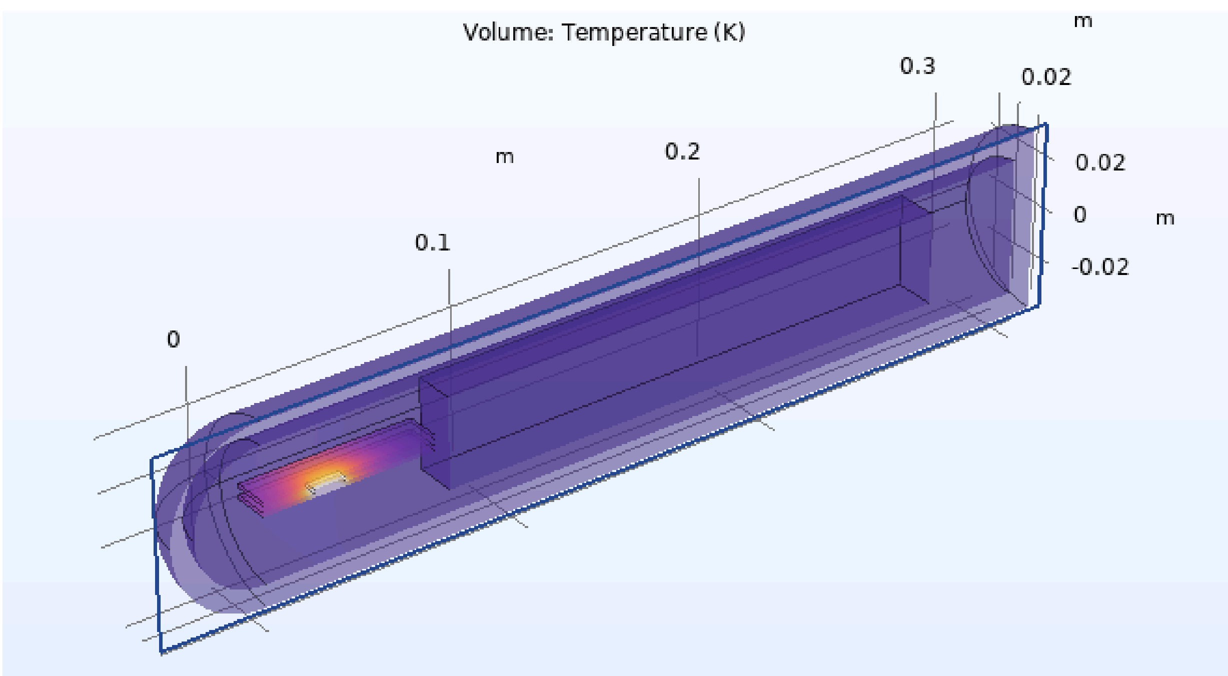
Analysis and Modeling

Electronics Cooling

Multiphysics Simulation for Thermal Stability Verification

To ensure thermal stability of the camera subsystem, we conducted multiphysics simulations using both a simplified 2D model and a basic 3D model. With known material properties, estimated power draw, and heat generation from current, we simulated heat transfer within the enclosure, convection of internal air, and dissipation to the surrounding ocean, factoring in average sea floor currents near Santa Barbara.

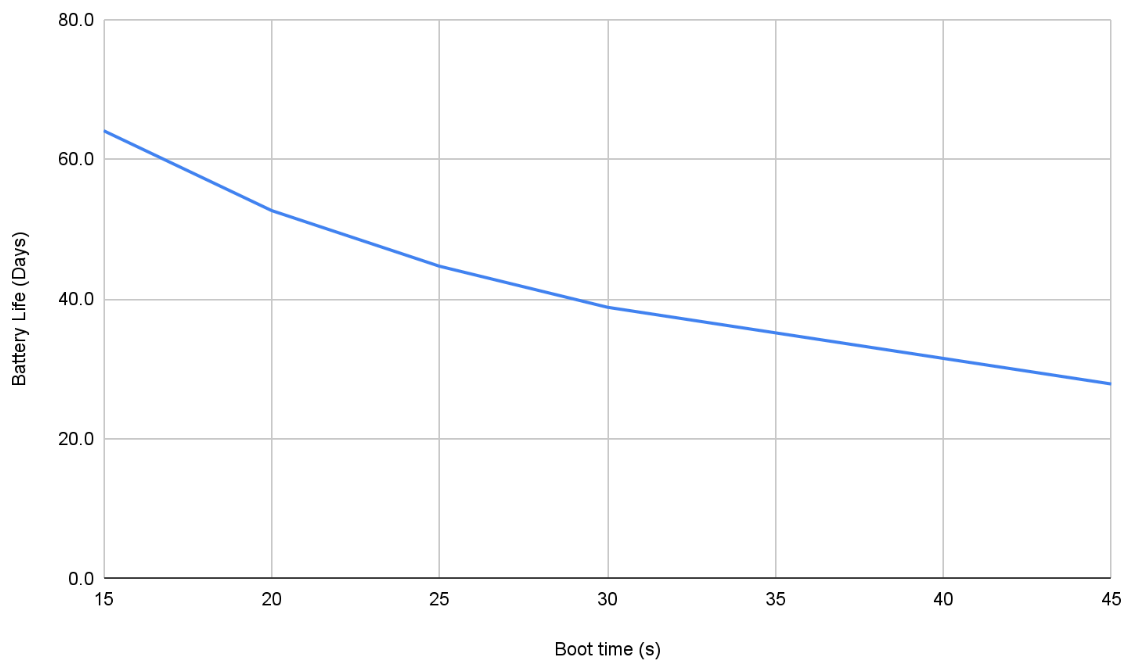




Results confirmed no thermal concerns for our planned operational modes. However, at maximum possible power draw sustained over extended periods (days to weeks), thermal runaway is theoretically possible. This is naturally mitigated by battery limitations, as the system would exhaust its charge before overheating becomes an issue. Notably, if another research group were to adapt our design for continuous video capture with maximum illumination, they would likely need to integrate active cooling solutions, such as fans, to maintain safe operating temperatures.

Camera Power Consumption and Battery Life

To maximize deployment duration, we analyzed power consumption across the camera's duty cycle. The setup operates in distinct phases: high-power consumption during boot-up, very high but brief spikes during image capture and lighting activation, and near-zero draw while powered off or in sleep mode between frames.



Using a battery capacity constraint, we modeled the total number of achievable cycles and generated a plot illustrating battery life under different duty cycle scenarios. This analysis highlights boot time as the primary optimization target, as it represents a medium power draw over a significant portion of each cycle. Reducing boot time will yield the greatest improvement in overall efficiency, extending deployment duration without requiring larger battery capacity.

Lighting Power Consumption

For the PCB lighting prototype, ensuring long-term energy efficiency is critical, as the system must function continuously for four weeks while operating on battery power. The lighting follows an intermittent activation cycle, turning on for 1 second every 5 minutes, totaling 4.8 minutes of operation per day. This low-duty cycle significantly reduces overall power consumption compared to continuous operation, allowing for extended deployments.

The circuit consists of 8 surface-mount LEDs arranged in 4 parallel branches, each with 2 LEDs in series and a 10 Ω resistor. The system operates on a 4.2 V power supply. Under this configuration, the total power draw during activation is approximately 0.4 W. With the brief daily runtime, energy use is about 0.03 Wh per day, totaling around 0.84 Wh over four weeks.

The system is powered by 8 lithium-ion batteries, each rated at 1500 mAh and 3.2 V, connected in series to provide 25.6 V. The four-week deployment only consumes about 2.2% of the total 38.4 Wh energy capacity, so power availability will not be an issue.

Pipe Characteristics

In order to inform the team's choice of pipe size for the frame, analysis was performed on four pipe characteristics: collapse pressure, cantilever bending stress, static deflection, and vibrations.

Collapse Pressure

The collapse pressure of a pipe is determined using the formula,

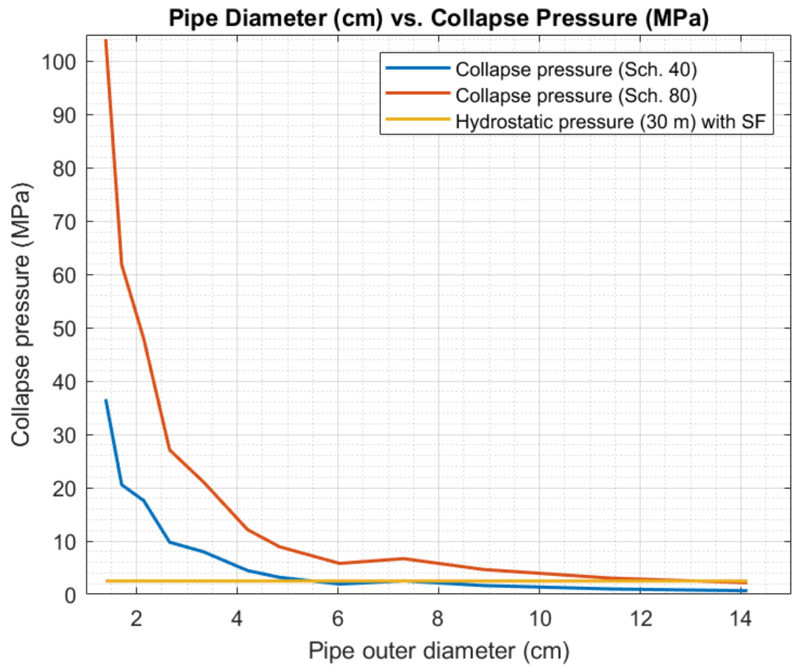
$$P_c = \left(\frac{2E}{1-\nu^2}\right)\left[\frac{1}{\left(\frac{d_o}{t}\right)\left(\frac{d_o}{t}-1\right)^2}\right],$$

where E is Young's modulus, *v* is Poisson's ratio, d_o is the outer diameter, d_i is the inner diameter, and t is wall thickness.

The results were compared to the hydrostatic pressure that the pipes will actually experience underwater, which was determined by the hydrostatic pressure formula,

$$P_h = \rho g h,$$

where ρ is density of the seawater, g is the acceleration due to gravity, and h is the depth. A depth of h = 30 m was used, as this is the project's maximum target depth. The following plot shows the results, where the hydrostatic pressure has been multiplied by a safety factor of 5.



Cantilever Bending Stress

The bending stress experienced by the cantilever pipe that holds the camera was determined by first calculating all of the forces on the pipe. These forces are: buoyancy, weight, and drag from currents. Each of these forces occur twice; once distributed along the pipe itself, and once on the end of the pipe due to the camera, giving six total forces.
Buoyancy force was determined through the formula,

$$F_b = \rho V g \, ,$$

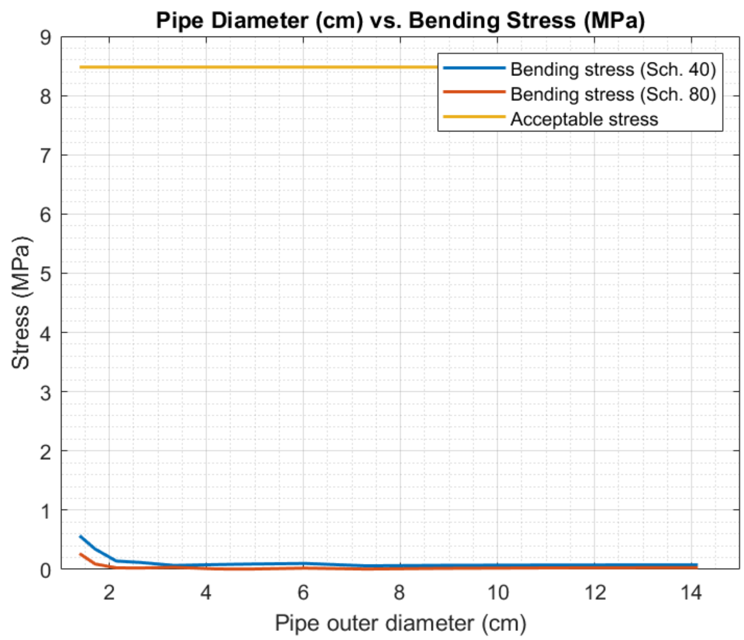
where V is the volume of displaced water.

The formula for drag force is:

$$F_D = \frac{1}{2}\rho C_D A v^2 \, ,$$

where C_D is the drag coefficient for the relevant object, A is the maximal cross-sectional area of the object, and v is velocity of the currents. A velocity of v = 0.2 m/s was used, as research indicated this is the upper end of current velocities on the seafloor at this depth.

The end forces were added together to get $F_{end,total}$, and the distributed forces were added together to get $F_{distributed,total}$. These forces were used to calculate two separate internal bending moments, and the two bending moments were added together to get *M*. This *M* was then used to calculate the total bending stress in the pipe. The results were then compared with the yield stress of the material. This comparison is shown in the following plot, which has yield stress divided by a safety factor of 5, demonstrating that bending stress is not an issue.



Static Deflection

The maximum deflection due to the end load was calculated using the formula,

$$\delta_{\text{max, end}} = \frac{PL^3}{3EI} ,$$

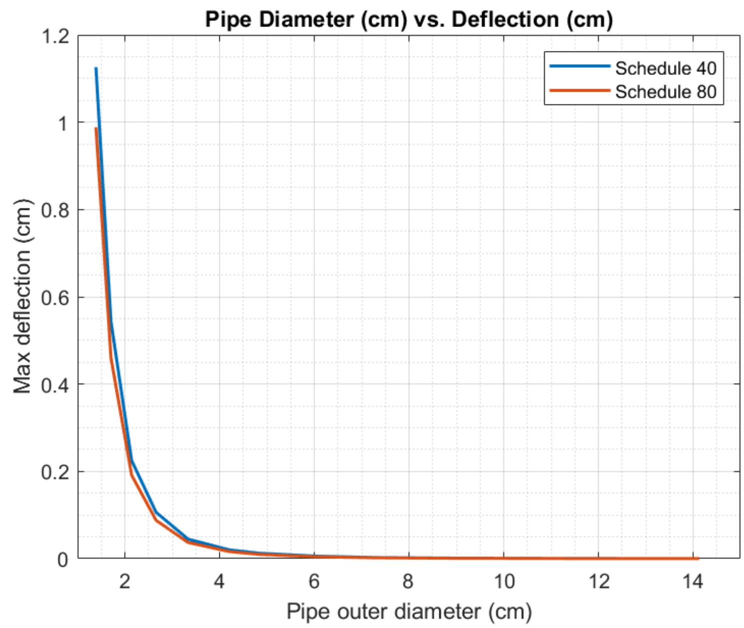
where P is the end load, and I is the second moment of inertia for a pipe.
The maximum deflection due to the distributed load was calculated using the formula,

$$\delta_{\text{max, distributed}} = \frac{wL^4}{8EI} ,$$

where w is the distributed load.

The two values were added to attain a total static deflection.

The maximum deflection for each pipe size is shown in the next plot. From the plot, it was observed that the deflection levels off around a diameter of 5 cm.



Vibrations

The natural frequency of the cantilever pipe was calculated using the formula for a cantilever beam of non-negligible weight with an end load,

$$f_1 = \frac{1.732}{2\pi}\sqrt{\frac{EIg}{WL^3 + 0.236wL^4}},$$

where W is the end load and w is the distributed load.

This was compared to the vortex shedding frequency,

$$f_{vortex} = \frac{St \cdot v}{d},$$

where St is the Strouhal number (0.2 for a cylinder), v is the current velocity, and d is the diameter of the object.

This was also compared to the wave frequency. This was determined using NOAA data to find the average period of waves in the Santa Barbara area, then taking the reciprocal of the period. The results are shown in the following table.

Size	Natural Freq 40 (Hz)	Natural Freq 80 (Hz)	Vortex Shedding, Pipe (Hz)	Vortex Shedding, Cam (Hz)	Wave Freq (Hz)
0.25	1.4954	1.5999	2.8796	0.7874	0.12821
0.375	2.1527	2.3481	2.3439	0.7874	0.12821
0.5	3.3512	3.6514	1.8664	0.7874	0.12821
0.75	4.8637	5.3859	1.5043	0.7874	0.12821
1	7.4789	8.3082	1.1999	0.7874	0.12821
1.25	11.082	12.535	0.95082	0.7874	0.12821
1.5	14.007	16.039	0.82613	0.7874	0.12821
2	20.057	23.536	0.66308	0.7874	0.12821
2.5	30.249	35.219	0.54776	0.7874	0.12821
3	41.04	49.046	0.44994	0.7874	0.12821
4	59.323	73.373	0.34996	0.7874	0.12821
5	78.849	100.61	0.28311	0.7874	0.12821

Further vibrational analysis is planned, including looking for a way to calculate the natural frequency for modes beyond the first mode, and vibrational analysis within SOLIDWORKS.

Pipe Analysis Conclusion

The results from the three preceding sections are shown in the following table:

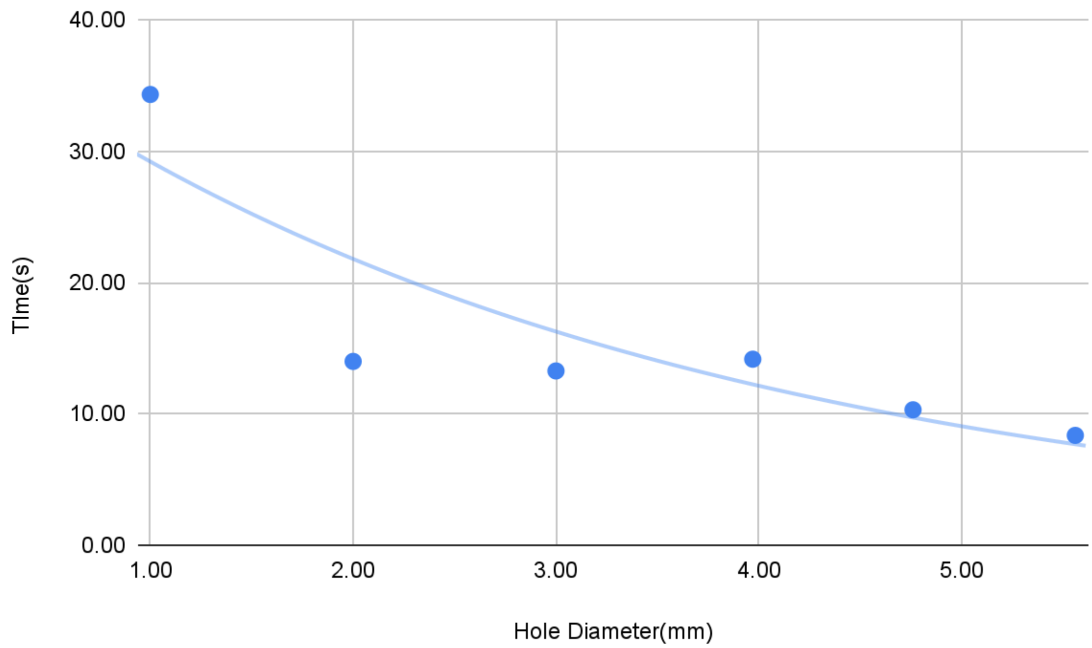
Size	Price 40 ($)	Deflection 40 (um)	SF Collapse 40	SF Stress 40	Price 80 ($)	Deflection 80 (um)	SF Collapse 80	SF Stress 80
0.25	28	4919	73.217	74.481	31.08	3592.3	208.24	158.3
0.375	37.14	2394.1	41.126	122.65	46.16	1516.6	123.62	459.01
0.5	18.58	912.81	35.175	299.8	20.92	479.23	95.946	1611.6
0.75	20.86	486.9	19.553	363.45	29.54	206.89	54.141	1817.1
1	32.58	212.86	15.941	630.28	43.08	56.955	42.078	1187.1
1.25	40.86	140.44	8.9158	520.02	61.24	36.627	24.243	5071.5
1.5	48	115.37	6.3786	471.7	67.08	32.402	17.835	7707.9
2	65.72	88.981	3.857	420.42	94.46	28.142	11.6	1955
2.5	107.42	43.034	5.0422	702.36	155.08	9.5213	13.394	6510.5
3	130.28	37.479	3.3032	611.9	190.16	11.558	9.3205	2364.3
4	177.72	30.038	2.0139	565.03	272.62	11.511	6.0717	1553.2
5	358.58	24.306	1.3575	552.97	437.24	10.249	4.3586	1341.5

These results were used to choose size 1 ¼ schedule 40 pipe for the frame, due to its combination of low static deflection, high collapse safety factor, avoidance of natural frequency, and most importantly, its low price per unit produced.

Final Test Results

The testing phase of the camera system was crucial for validating its design and operational capabilities under both simulated and real-world conditions. A series of targeted evaluations were conducted to ensure that all subsystems functioned as intended, with particular emphasis on core functionalities such as waterproofing, mechanical stability, and power efficiency.

Initial validation focused on characterizing the descent dynamics of the underwater frame through water ingress testing. This was achieved using 1-foot-long, 1 1/4-inch Schedule 40 PVC pipes sealed with end plugs, one of which contained precision-drilled holes of varying diameters. These plugs were intentionally designed to be non-hermetic to allow controlled flooding. The objective was to ensure the frame would sink gradually rather than abruptly, enabling safe, diver-assisted deployment. Results revealed a nonlinear relationship between hole diameter and fill time, indicating that small variations in orifice size produce significant changes in ingress rate due to flow resistance and hydrostatic pressure. By selecting appropriate hole diameters, the descent rate can be tuned to ensure a predictable and stable transition to the seafloor. This approach enables passive ballast control using simple mechanical means and enhances safety and maneuverability during deployment



Hole Diameter (mm)	Time (s)	Ingress Rate(mL/s)
1.00	34.32	8.36
2.00	13.99	20.51
3.00	13.27	21.63
3.97	14.16	20.27
4.76	10.31	27.84
5.56	8.36	34.33

Building on the insights from ingress testing, comprehensive pool trials were conducted to assess full-system integration in a controlled underwater environment. These trials were essential for evaluating overall waterproofing, buoyancy behavior, and mechanical performance. The system demonstrated reliable submersion and maintained structural integrity throughout the test. Custom pipe plugs facilitated a controlled descent, while strategically placed ballast rings provided the mass required to resist disturbance from potential currents. The adjustable tripod legs performed well on simulated uneven terrain, allowing for precise positioning and leveling underwater. Additionally, the ease of in-water manipulation confirmed that the system design supports intuitive deployment and fine-tuning in real-time. These results significantly reinforced confidence in the system's underwater readiness and operational reliability ahead of ocean deployment.

A key aspect of the system's primary function—image acquisition—was thoroughly tested through extended timelapse trials. The Raspberry Pi Zero was configured to capture photos at five-minute intervals, enabling verification of the full power management sequence: waking from low-power mode, checking ambient light via photoresistor, activating infrared lighting when necessary, capturing an image, and returning to sleep mode. Collected data confirmed that the system can sustain four-week deployments on a single charge using the onboard 18650 lithium-ion batteries.

Further assessments included verification of the internal display functionality used during initial deployment. Although the screen remains off for most of the mission to conserve power, its activation during setup provides essential visual feedback for framing and positioning. Tests confirmed that the waterproof toggle switch could reliably activate and deactivate the display without compromising enclosure integrity. The performance of the camera module itself—along with its adjustable mounting height and lens interchangeability—was evaluated to ensure optimal field of view and image quality for monitoring marine life. These combined results demonstrate the system's readiness for extended underwater observation in real-world marine environments.

Broader Impacts

The development of this cost-effective, reproducible camera system for observing marine animal populations has significant broader impacts that extend beyond the immediate research community, touching upon global scientific understanding, cultural engagement, and societal well-being.

Advancing Marine Research and Conservation:

At its core, this project directly addresses a critical barrier in marine research: the prohibitive cost of specialized underwater observation equipment. By providing an open-source, easily replicable design using off-the-shelf and 3D-printed components, this camera system democratizes access to advanced data collection tools. This will enable a wider range of research groups, particularly those with limited funding, to conduct essential studies on seafloor ecosystems. The ability to deploy affordable, long-duration (four-week) monitoring systems will lead to a more comprehensive understanding of marine animal populations, such as clams and lobsters in the Santa Barbara area. This enhanced data collection is vital for informing conservation strategies, assessing the health of marine habitats, and monitoring the impacts of environmental changes. For example, consistent, long-term monitoring of indicator species can provide early warnings of ecosystem distress or recovery, allowing for more proactive and effective conservation interventions.

Fostering Global Collaboration and Innovation:

The emphasis on reproducibility and readily available components inherently promotes global collaboration. Researchers worldwide can adapt and deploy this system to study diverse marine environments, leading to a broader, more interconnected understanding of global marine biodiversity. This shared technological foundation can facilitate data sharing, comparative studies across different regions, and the development of standardized monitoring protocols. The iterative nature of scientific discovery suggests that the groundwork laid by this project could inspire further innovation in low-cost, high-impact environmental sensing technologies, potentially extending to other ecological monitoring challenges.

Educational and Cultural Empowerment:

Beyond professional researchers, this project has the potential for significant educational impacts. The use of accessible technologies like the Raspberry Pi Zero and 3D printing makes this system an excellent educational tool for students at various levels, from university engineering and marine biology programs to community science initiatives. It offers a tangible example of applied engineering solving real-world ecological problems, fostering interest in STEM fields and environmental stewardship. Culturally, increasing our understanding of marine ecosystems, especially local ones, can deepen public appreciation for ocean health and promote a sense of responsibility towards marine conservation. Engaging local communities in data collection or educational outreach using such accessible technology can create a stronger connection between people and their marine environment.

Economic and Societal Benefits:

From an economic perspective, reducing the cost of marine observation equipment can free up valuable research funds that can then be allocated to other critical aspects of scientific inquiry, such as data analysis, policy development, or community engagement. This project aligns with the broader societal need for sustainable resource management and environmental protection. Accurate and consistent data on marine populations can inform fisheries management, support sustainable aquaculture practices, and contribute to the economic well-being of coastal communities that rely on healthy marine resources. The system's robustness against challenges like uneven seafloor deployment, waterproofing at depth, corrosion, and efficient power management demonstrates a practical and resilient solution applicable in challenging real-world conditions, contributing to the development of reliable and deployable environmental monitoring tools.

Appendix

SOPs

Underwater Frame Testing

Standard Operating Procedure:

[Underwater Frame Testing]

Author:	Matthew Santos
Course:	ME 189 Capstone
Building/Room:	Recreation Center
Date:	5 February 2025

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1. Description

This SOP describes the procedure and possible hazards associated with testing the waterproofing of the frame assembly.

2. Hazards Overview

- Water Danger
  - Testing will take place in a pool/body of water deep enough to fully submerge the entire assembly.
    - For recreation center testing - lifeguard will be on duty
  - Testers must be mindful of retrieval system to make sure they are not pulled into water
- Slip Hazard
  - Area around pool may be wet, which can cause slips

3. Required Personal Protective Equipment (PPE)

- Proper attire is required during construction: pants, closed toe/heel shoes, no skin showing between pants and shoes.
- Safety glasses or safety goggles while assembling the frame
- Protective mask required for cutting frame elements
- Proper swim attire for entering water (shallow water testing)

4. Waste Disposal

Ensure all scraps from frame assembly are properly disposed of. Before testing, make sure there are no loose components that could fall into the pool.

5. Accident and Spill Procedure

In the event of a slip or fall

- Ask for assistance before standing
- Seek medical assistance if the following symptoms are experienced:
  - Headache
  - Feeling mentally foggy
  - Dizziness
  - Feeling slowed down
  - Balance problems

    - Difficulty concentrating
    - Nausea/Vomiting
    - Difficulty remembering
    - loss of consciousness
- Call 9-1-1 if injury or unconsciousness occurs

In the event of fall into pool

- Remain calm, do not immediately jump in and put more people in danger
- Use floatation device to help pull person to wall/shallow water
- Call for assistance of lifeguard if person is unable to exit the water themselves

In the event of a cut

- Seek medical assistance for severe cuts
- Use first aid kit (if available)

6. Approvals Required

Approval of facilities manager(Rick Van Hoorn or Nancy Clayton) before conducting test. Need to make sure the testing area is clear before conducting the test. Approval of procedure from advisor before conducting any tests. Scheduling required for testing conducted in diving tank (deep testing).

7. Procedure

Set Up:

This test includes the assembled frame, with members joined together. The test aims to verify that the seals of the frame can maintain waterproofing, which will ensure that the frame can withstand

Pre-test:

I. Construction of Frame

1. **Setup:**
    - Cut all pipe lengths to size in the machine shop
    - Ensure all necessary endcaps and rubber cement mixing areas are present
2. **Steps:**
    - For each leg
        - Deburr cut edges before fitting to end caps
        - File end of pipe sections to prepare for rubber cement application
        - Apply rubber cement to each pipe before placing endcaps on
    - Ensure each end cap is given enough time to cure/solidify

II. Set Up at Pool

1. Before Testing:
    - Fill out release waivers for pool use
    - Coordinate with Rick or Nancy to confirm testing day of

2. At Recreation Center:
    - Speak with front desk about bringing frame through side door
    - Set up frame and equipment/belongings on side of pool area
        i. Near entrance gate/underneath tarp area

Test:

III. Investigation of Seal Integrity

1. Setup:
    - Each tester should come with suitable pool attire(suit/towel/etc)
2. Steps:
    - Primary tester will bring frame to pool to ensure assembly can be moved by single user
        i. Secondary tester provides support in lowering frame if necessary
    - Attach ballast(if necessary) and allow frame to be fully submerged in the pool
3. Analysis:
    - Once fully submerged, primary and secondary tester will observe all endcap connections
        i. Looking for any signs of leaks(bubbles)
    - Allow water to fully settle around frame to reduce interference when checking connections

Spec Sheets

Blue RoboticsWatertight Enclosures and Accessories

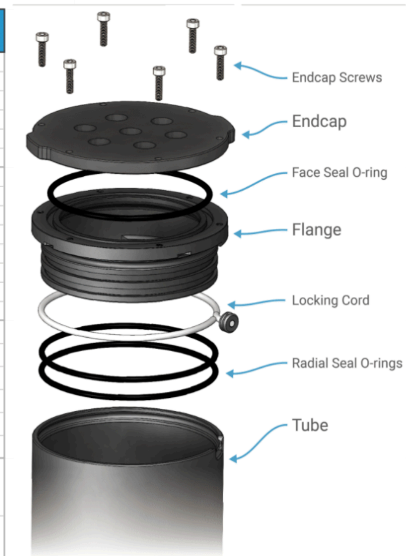
BlueRobotics

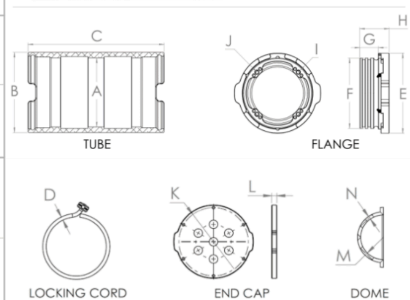
Watertight Enclosures (WTE) Technical Specifications

Datasheet Rev C.2 (Feb-2025)

Tubes

Series Diameter [mm]	Tube Material / Finish	(A) Tube ID [mm]	(B) Tube OD [mm]	(C) Overall Length [1] [mm]	Weight [g]	Depth Rating [2] [msw]	Item Number
50 (2")	6061-T6 Aluminum, Type III Anodized	Ø50.0 ± 0.5	Ø58.0 ± 0.2	100	169	1000	BR-100534-100
				150	261		BR-100534-150
				300	536		BR-100534-300
	Cast Acrylic	Ø49.5 ± 1.5	Ø58.0 ±1.0	100	75	225	BR-100230-101
				150	115	130	BR-100230-151
				300	238	100	BR-100230-301
75 (3")	6061-T6 Aluminum, Type III Anodized	Ø80.14 ± 0.20	Ø86.5 ± 0.3	150	328	1000	BR-100611-150
				240	530	1000	BR-100611-240
				300	665	900	BR-100611-300
				400	890	750	BR-100611-400
	Cast Acrylic	Ø76.2 ± 2.0	Ø88.9 ± 0.7	150	264	275	BR-101066
				240	442	150	BR-100352
				300	560	135	BR-100895
				400	758	120	BR-100293
100 (4")	6061-T6 Aluminum, Type III Anodized	Ø104.16 ± 0.20	Ø112.0 ± 0.3	200	707	1000	BR-100195-200
				300	1066	1000	BR-100195-300
				400	1426	800	BR-100195-400
	Cast Acrylic	Ø101.6 ± 2.1	Ø114.3 ± 0.8	200	488	140	BR-101052-200
				300	746	100	BR-101052-300
				400	1004	60	BR-101052-400
130 (5")	6061-T6 Aluminum, Type III Anodized	Ø130 ± 0.5	Ø138.7 ± 0.3	300	1450	1000	BR-101409-300
				500	2441	500	BR-101409-500
150 (6")	6061-T6 Aluminum, Type III Anodized	Ø150 ± 0.5	Ø163.9 ± 0.3	300	2510	1000	BR-101411-300
				500	4360	1000	BR-101411-500
200 (8")	6061-T6 Aluminum, Type III Anodized	Ø200 ± 0.5	Ø214.2 ± 0.3	300	3420	1000	BR-101412-300
				500	5915	1000	BR-101412-500





Flanges

Series Diameter [mm]	Face Seal O-ring	Radial Seal O-ring	Material / Finish	(D) Locking Cord Diameter [mm]	(E) Flange OD [mm]	(F) Piston Diameter [mm]	(G) Piston Length [mm]	(H) Overall Length [mm]	(I) Inner Mounting Holes	(J) Inner Mounting Hole Circle	Weight [g]	Item Number
50 (2")	-030 Buna-N 70A	-031 Buna-N 70A	6061-T6 Aluminum, Type III Anodized	2.8 ± 0.2	Ø58.0 ± 0.1	Ø50.93 ± 0.05	15.5 ± 0.1	21.5 ± 0.1	4x M3x0.5	Ø43.0 ± 0.1	41	BR-100276-998
75 (3")	-148 Buna-N 70A	-150 Buna-N 70A			Ø88.9 ± 0.1	Ø79.93 ± 0.05	19.1 ± 0.1	27.0 ± 0.1		Ø68.6 ± 0.1	81	BR-100647
100 (4")	-154 Buna-N 70A	-154 Buna-N 70A			Ø114.3 ± 0.1	Ø103.91 ± 0.05				Ø94.0 ± 0.1	107	BR-100665
130 (5")	-157 Buna-N 70A	-248 Buna-N 70A			Ø137.7 ± 0.1	Ø130.89 ± 0.05	28.0 ± 0.1	34.0 ± 0.1	8x M3x0.5	Ø115.0 ± 0.1	238	BR-102200
150 (6")	-162 Buna-N 70A	-255 Buna-N 70A			Ø165.4 ± 0.1	Ø156.40 ± 0.06	30.0 ± 0.1	36.0 ± 0.1		Ø142.0 ± 0.1	308	BR-102201
200 (8")	-170 Buna-N 70A	-265 Buna-N 70A			Ø215.7 ± 0.1	Ø205.91 ± 0.07	36.0 ± 0.1	42.0 ± 0.1		Ø186.0 ± 0.1	540	BR-102202

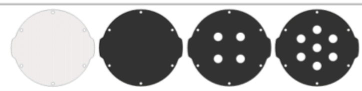
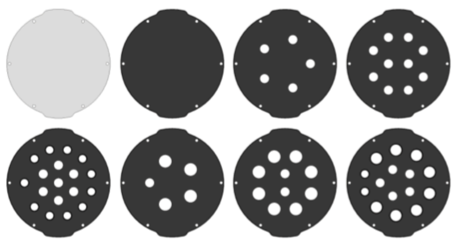
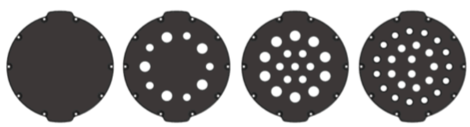
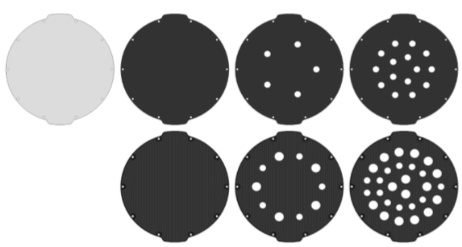
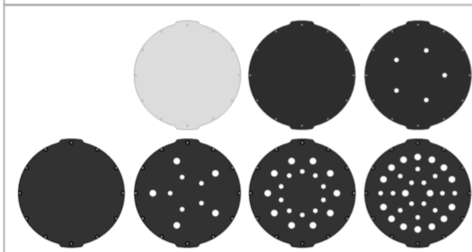
BlueRobotics

Watertight Enclosures (WTE) Technical Specifications

Datasheet Rev C.2 (Feb-2025)

End Caps

Warning: Images not to scale

Series Diameter [mm]		Material	Hole Configuration	Endcap Screws (SS316 Socket Head Cap Screws)	(K) Endcap Screw Hole Circle	(L) Thickness [mm]	Weight [g]	Depth Rating² [msw]	Item Number
	50 (2")	Cast Acrylic	Blank (No holes)	6x M2x0.4-10	Ø50.8 ± 0.1	6 (4.85 min, 6.63 max)	17	500	**BR-100094**
		6061-T6 Aluminum, Type III Anodized	Blank (No holes)	Note: Flange integral to endcap, does not require separate flange			63	1000	**BR-100276-999**
			2x M10 Hole				59		**BR-100276-002**
			4x M10x1.5 Threaded				58		**BR-100276-004**
			1x M10 Hole 8x M6x1 Threaded				60		**BR-100276-009**
	75 (3")	Cast Acrylic	Blank (No holes)	6x M3x0.5-12	Ø82.6 ± 0.1	9 (7.47 min, 9.75 max)	58	400	**BR-100949-998**
		6061-T6 Aluminum, Type III Anodized	Blank (No holes)			6 ± 0.1	102	1000	**BR-100949-999**
			4x M10 Hole				97		**BR-100949-004**
			7x M10 Hole				93		**BR-100949-007**
	100 (4")	Cast Acrylic	Blank (No holes)	6x M3x0.5-16	Ø108.0 ± 0.1	12.7 (10.20 min, 12.75 max)	135	300	**BR-102993-998**
		6061-T6 Aluminum, Type III Anodized	Blank (No holes)	6x M3x0.5-12		10 ± 0.1	234	1000	**BR-102993-999**
			5x M10 Hole				223		**BR-102993-005**
			10x M10 Hole				212		**BR-102993-002**
			7x M10 Hole 11x M10x1.5 Threaded				196		**BR-102993-003**
			4x M14 Hole 1x M10 Hole				215		**BR-102993-004**
			8x M14 Hole 2x M10 Hole				195		**BR-102993-006**
			8x M14x1.5 Threaded 5x M10 Hole 2x M10x1.5 Threaded				186		**BR-102993-007**
	130 (5")	7075-T6 Aluminum, Type III Anodized	Blank (No holes)	10x M3x0.5-12	Ø133.0 ± 0.1	10 ± 0.1	427	1000	**BR-102203-001**
			5x M14 Hole 5x M10 Hole				393		**BR-102203-002**
			10x M14 Hole 7x M10 Hole				367		**BR-102203-003**
			11x M10 Hole 15x M10x1.5 Threaded				369		**BR-102203-004**
	150 (6")	Cast Acrylic	Blank (No holes)	10x M3x0.5-16	Ø158.7 ± 0.1	12.7 (10.20 min, 12.75 max)	331	150	**BR-100273-004**
		6061-T6 Aluminum, Type III Anodized	Blank (No holes)	10x M3x0.5-12		6 ± 0.1	359	150	**BR-100273-003**
			5x M10 Hole				353		**BR-100273-002**
			15x M10 Hole				339		**BR-100273-001**
		7075-T6 Aluminum, Type III Anodized	Blank (No holes)			12 ± 0.1	687	1000	**BR-102205-001**
			5x M10 Hole 5x M14 Hole				647	1000	**BR-102205-002**
			16x M14 Hole 13x M10 Hole				566	1000	**BR-102205-003**
	200 (8")	Cast Acrylic	Blank (No holes)	12x M3x0.5-16	Ø209.1 ± 0.1	12.7 (10.20 min, 12.75 max)	564	75	**BR-101065-003**
		6061-T6 Aluminum, Type III Anodized	Blank (No holes)	12x M3x0.5-12		6 ± 0.1	599	75	**BR-101065-002**
			5x M10 Hole				592		**BR-101065-001**
		7075-T6 Aluminum, Type III Anodized	Blank (No holes)			16 ± 0.1	1458	1000	**BR-102206-001**
			5x M10 Hole 5x M14 Hole				1370		**BR-102206-002**
			10x M10 Hole 10x M14 Hole				1283		**BR-102206-003**
			16x M14 Hole 14x M10 Hole				1191		**BR-102206-004**

Domes

Series Diameter [mm]		Material	(M) Dome Internal Radius [mm]	(N) Dome Wall Thickness [mm]	Weight [g]	Depth Rating [msw]	Item Number
	50 (2")	Acrylic Dome, Polycarbonate Retaining Ring	18.0 ± 0.1	2.50 ± 0.10	15	950	**BR-100859**
	75 (3")		31.25 ± 0.10	3.1 ± 0.1	39	750	**BR-101059**
	100 (4")		43.5 ± 0.1	3.75 ± 0.10	81	500	**BR-100495**
	130 (5")	Hardened Polycarbonate Dome, Polycarbonate Retaining Ring	53.5 ± 0.05	7.00 ± 0.05	195	600	**BR-102597**

¹ Overall tube length tolerance ± 0.5 mm

² The depth ratings for cast acrylic components are applicable only for short-term submersions of less than two weeks. For longer submersion, use aluminum components only.

Blue Robotics Waterproof Switch

Parameter	Value	
Performance		
Maximum Rated Depth (seawater)	1000 m	3280 ft
Design Lifetime[1]	3 years or 500 cycles to rated depth	
Temperature Rating	-40 to 60°C	-40 to 140°F
Electrical		
Maximum Operating Voltage	120 VAC	26 VDC
Maximum Operating Current	5A	
Wire Gauge	22 AWG	
Turn ON	Clockwise	Red
Turn OFF	Counter-Clockwise	Grey
Switch Connector	TE Connectivity 61818-1	
Output Connector	0.1" Male Header Pin	
Tools		
Compatible Bulkhead Wrench	BR-100977-010	
Recommended Installation Torque	3.5 N·m	
Physical		
Recommended Through Hole Diameter	10.2 mm	
Bulkhead Thread	M10 x 1.5	
Bulkhead Thread Length	20 mm	
Bulkhead/Nut Wrench Flats	16 mm	
Overall Assembled Height From Endcap	25 mm	
Overall Outer Diameter	18 mm	
Bulkhead O-ring Size	AS568-013 Buna-N 70A	
Plug O-ring Size	1.5 x 11.5 mm Buna-N 70A	
Bulkhead/ Plug Material	7075-T6 Anodized Aluminum	
Wetted Materials	Buna-N Rubber Molykote 111 Compound 7075-T6 Anodized Aluminum	
In Air Weight (No Nut)	20.5 g	
In Water Weight (No Nut)	14.7 g	

Blue Robotics Cable Penetrator

Version 1.2 (Last updated 14-Oct-2022)

WETLINK

WetLink Penetrator (WLP) Technical Specifications

Performance Characteristics[1]

Maximum Tested Depth (seawater)	950 m / 3116 ft
Design Lifetime[2]	3 years or 500 cycles to rated depth

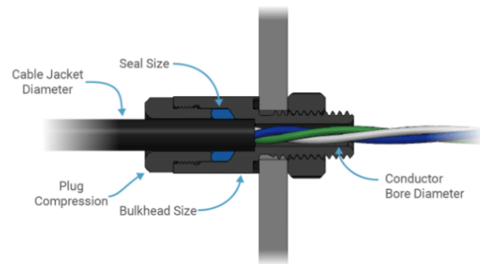
[1] *For reference only, performance may vary depending on application and cable construction, it is the responsibility of the customer to determine suitability for their application*

[2] *Design life was used to inform testing in an accelerated environment, does not reflect warranty period*

Size Index

Seal Size	Bulkhead Sizes	Conductor Bore Diameter [mm]	Plug Compression	Jacket Diameter Range[1] [mm]	Part Number
4.5	M06, M10	3.3 mm	High (HC)	4.0 ± 0.3	WLP-M06-4.5MM-HC WLP-M10-4.5MM-HC
			Low (LC)	4.5 ± 0.3	WLP-M06-4.5MM-LC WLP-M10-4.5MM-LC
5.5	M10	4.0 mm	High (HC)	5.0 ± 0.3	WLP-M10-5.5MM-HC
			Low (LC)	5.5 ± 0.3	WLP-M10-5.5MM-LC
6.5	M10	4.8 mm	High (HC)	6.0 ± 0.3	WLP-M10-6.5MM-HC
			Low (LC)	6.5 ± 0.3	WLP-M10-6.5MM-LC
7.5	M10	5.7 mm	High (HC)	7.0 ± 0.3	WLP-M10-7.5MM-HC
			Low (LC)	7.5 ± 0.3	WLP-M10-7.5MM-LC
8.5	M10	6.0 mm	High (HC)	8.0 ± 0.3	WLP-M10-8.5MM-HC
			Low (LC)	8.5 ± 0.3	WLP-M10-8.5MM-LC
9.5	M14	7.5 mm	High (HC)	9.0 ± 0.3	WLP-M14-9.5MM-HC
			Low (LC)	9.5 ± 0.3	WLP-M14-9.5MM-LC

[1] *Jacket diameter range varies for foam jacketed cables, see guides for more details*



Tools

Seal Size	Bulkhead Size	Bulkhead Wrench	Bulkhead/Nut Flat Size	Bulkhead Torque	Plug Wrench	Plug Hex Size	Plug Torque
4.5	M06	WL-M06-BULKHEAD-WRENCH	12 mm	1 N·m	WLP-11MM-PLUG-WRENCH	11 mm	14 N·m
4.5	M10	WL-M10-BULKHEAD-WRENCH	16 mm	3.5 N·m	WLP-11MM-PLUG-WRENCH	11 mm	14 N·m
5.5, 6.5, 7.5, 8.5	M10	WL-M10-BULKHEAD-WRENCH	16 mm	3.5 N·m	WLP-14MM-PLUG-WRENCH	14 mm	14 N·m
9.5	M14	WL-M14-BULKHEAD-WRENCH	20 mm	3.5 N·m	WLP-18MM-PLUG-WRENCH	18 mm	20 N·m

Tested Cables

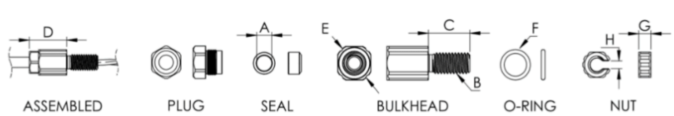
Part Number	Cable Part Name / Number	Manufacturer	Application	Jacket Diameter [mm]	Jacket Material	Conductors	Tested Current[1]	Nominal Voltage	Max Temp Recommended[2]
WLP-M06-4.5MM-HC WLP-M10-4.5MM-HC	Fathom Slim Tether (CAB-NBPUF-1UTP-26AWG-R3)	Blue Robotics	Tether	4.0	PUR Foam	1x UTP 26AWG	-	-	50°C
WLP-M06-4.5MM-LC WLP-M10-4.5MM-LC	Lumen/Gripper Cable (CAB-A-3-22AWG-R1)	Blue Robotics	Power / PWM	4.5	PUR	3x 22AWG	-	-	60°C
	Ping Cable (CAB-PUR-4-24AWG-R1)	Blue Robotics	Power / Serial	4.5	PUR	4x 24AWG	-	-	60°C
	Ping 360 Cable (CAB-PUR-3UTP-28AWG-R2)	Blue Robotics	Power / Ethernet	4.7	PUR	3x UTP 28AWG	-	-	50°C
WLP-M10-5.5MM-HC	chainflex® control cable CF9 (CF9-02-06)	IGUS	Power / Signal	5.0	TPE	6x 24AWG	-	300V	60°C
WLP-M10-5.5MM-LC	Etherline® (2170283)	LAPP	Cat5e	5.6	PUR	2x SFTP 26AWG	-	125V	60°C
WLP-M10-6.5MM-HC	Unitronic® (302206)	LAPP	Power / Signal	5.8	PVC	6x 22AWG	-	300V	60°C
WLP-M10-6.5MM-LC	T200 Thruster Cable (CAB-PUR-3-16AWG-R2)	Blue Robotics	Power	6.4	PUR	3x 16AWG	48A	-	60°C
	Etherline® (2170300)	LAPP	Cat5e	6.3	PUR	4x SFTP 26AWG	-	1000V	60°C
WLP-M10-7.5MM-HC	Fathom ROV Tether (CAB-NBPUF-4UTP-26AWG-R3)	Blue Robotics	Cat5 / Tether	7.6	PUR Foam	4x UTP 26AWG	-	-	50°C
WLP-M10-7.5MM-LC	Ethernet and Power Cable (CAB-PUR-2-22AWG-4UTP-26AWG-R1)	Blue Robotics	Cat5 + Power	7.5	PUR	4x UTP 26AWG + 2x 22AWG	-	-	60°C
WLP-M10-8.5MM-HC	chainflex® control cable CF9 (CF9-02-12)	IGUS	Power / Signal	7.7	TPE	12x 24AWG	-	300V	60°C
WLP-M10-8.5MM-LC	Power Cable, 2-conductor (CAB-A-2-12AWG)	Blue Robotics	Power	8.3	PUR	2x 12AWG	60A	-	60°C
WLP-M14-9.5MM-HC	T500 Thruster Cable (CAB-PUR-3-12AWG-R1)	Blue Robotics	Power	9.0	PUR	3x 12AWG	100A	-	60°C

[1] *Current ratings evaluated at ambient temperatures in water*

[2] *Sustained high temperatures can lead to performance loss over long periods of time*

Physical Properties

Bulkhead Size	M06	M10	M14
Seal Sizes (A)	4.5	4.5 , 5.5, 6.5, 7.5, 8.5	9.5
Bulkhead Thread (B)	M6 x 1	M10 x 1.5	M14 x 1.5
Bulkhead Thread Length (C)	10 mm	20 mm	25 mm
Recommended Bulkhead Through Hole Size	6.2	10.2	14.2
Assembled Height from Endcap (D)	23.5 mm	18 - 26 mm	23 mm
Overall Outer Diameter (E)	13 mm	18 mm	22 mm
O-ring Size (F)	1.5x7 Buna-N 70A	-013 Buna-N 70A	1.5x15 Buna-N 70A
Nut Height (G)	4 mm	8 mm	8 mm
Nut Slot Width (H)	3.5 mm	5 mm	9 mm
Assembled air weight (no cable)	7.6 g	13.9 - 15.6 g	24.9 g
Assembled water weight (no cable)	5.1 g	10.2 - 10.7 g	16.4 g
Seal Material	FKM		
Seal Material Temperature Range	-25°C to 200°C		
Bulkhead & Plug Material	7075-T6 Aluminum, Anodized		



Test Procedure[1]

Minimum Number of Test Samples	36
Test Pressure	950 msw
Number of Cycles	500 cycles
Water Temperatures at Pressure	2°C to 40°C
Tested Current at Pressure *(if applicable)*	✓
Temperature Shock Cycling in Air	-30°C to 70°C
Cable Axial Strain *(10 cycles)*	3.5 to 7.5 kg
Cable Radial & Torsional Straining	✓
1000V Hipot Test & Continuity Test	✓
Accelerated Age Test	✓

[1] *Test values shown for reference only, it is the responsibility of the customer to determine suitability for their application*

Blue Robotics Fathom Slim Cable

Parameter	Value	
Physical		
Tether Diameter	7.6 mm	0.30 in
Weight	0.043 kg/m	0.0287 lb/ft
Outer Jacket	Polyurethane Foam	
Buoyancy in Freshwater	Neutral	
Buoyancy in Saltwater	Slightly Positive	
Wire Gauge	0.14 mm^2	26 AWG
Working Strength	35 kg_f	80 lb
Breaking Strength	155 kg_f	350 lb
Minimum Working Bend Diameter	75 mm	3 in
Compatible WetLink Penetrator	M10-7.5mm-HC	
Electrical		
DC Resistance @ 20°C	0.0386 Ω/ft	0.127 Ω/m
Insulation Resistance @ 500 VDC	> 500 MΩ/kft	> 1640 MΩ/km
Voltage Rating	300 VDC	

ıom Slim ROV Tether

Parameter	Value	
Physical		
Tether Diameter	4.0 mm	0.16 in
Weight in Air	0.012 kg/m	0.00805 lb/ft
Jacket Material	Polyurethane Foam	
Buoyancy in Freshwater	Neutral	
Buoyancy in Saltwater	Slightly Positive	
Wire Gauge	0.14 mm^2	26 AWG
Working Strength	35 kg_f	80 lb
Breaking Strength	155 kg_f	350 lb
Minimum Working Bend Diameter	25 mm	1 in
Compatible WetLink Penetrator	M06-4.5mm-HC M10-4.5mm-HC	
Electrical		
DC Resistance @ 20°C	0.0445 Ω / ft	0.146 Ω / m
Voltage Rating	300 VDC	

Blue Robotics WetLink Penetrator Blank

Parameter	M06 Thread	M10 Thread	M14 Thread
Part Number	BR-100434-006	BR-100434-010	BR-100434-014
Performance Characteristics			
Maximum Rated Depth (seawater)	1000 m / 3280 ft		
Design Lifetime[1]	3 years or 500 cycles to rated depth		
Temperature Rating	-40 to 60°C / -40 to 140°F		
Tools			
Compatible Bulkhead Wrench	BR-100977-006	BR-100977-010	BR-100977-014
Physical			
Bulkhead Thread Size	M6	M10	M14
Bulkhead Thread Pitch	1 mm	1.5 mm	1.5 mm
Bulkhead/Nut Wrench Flats	12 mm	16 mm	20 mm
Hex Key	3 mm	6 mm	6 mm
O-ring Size	1.5 x 7 mm Buna-N 70A	AS568-013 Buna-N 70A	1.5 x 15 mm Buna-N 70A
Overall Assembled Height from Endcap	6 mm	8 mm	8 mm
Overall Thread Length	10 mm	20 mm	25 mm
Overall Outer Diameter	13 mm	18 mm	22 mm
Recommended Through Hole Size	6.2 mm	10.2 mm	14.2 mm
Bulkhead Material	Aluminum 7075-T6, type II anodized	Aluminum 7075-T6, type III anodized	
In Air Weight (no nut)	2.3 g	6.6 g	11.8 g
In Water Weight (no nut)	1.5 g	4.2 g	9.3 g
Recommended Installation Torque (bulkhead or nut)	1 N·m	3.5 N·m	3.5 N·m

Camera Module

Image & Video

Video Resolution	1080p
Video Capture Format	H.264
Effective Still Resolution	5 MP
Shooting Modes	Various shooting modes (portrait, landscape, sports, night mode, etc.)
Image Aspect Ration	16:9
Supported Image Format	JPEG
White Balance Settings	Auto
File Format	JPEG
Exposure Control Type	Automatic

Lens

Maximum Focal Length	3.6 Millimeters
Maximum Aperture	1.8 f
Minimum Focal Length	3.6 Millimeters
Lens Type	Wide Angle
Minimum Aperture	2 Millimeters
Focus Type	Fixed Focus

Monitor

Display Type	TFT - Color
Display Mode	Transmissive
Touchscreen	Non-Touch
Diagonal Screen Size	2" (50.80mm)
Viewing Area	31.20mm W x 41.40mm H
Backlight	LED - White
Dot Pixels	160 x 80
Interface	UART
Controller Type	NP9158, ST7789T3, STM32G030, W25Q32
Graphics Color	Red, Green, Blue (RGB)

Raspberry Pi Zero WH

Core Processor	Broadcom BCM2835 ARM1176JZF-S
Speed	1GHz
Number of Cores	1
Cooling Type	-
Size / Dimension	2.559" x 1.811" (65.00mm x 30.00mm)
Form Factor	Ultra Compact
Expansion Site/Bus	Wi-Fi
RAM Capacity/Installed	512MB
Storage Interface	microSD
Video Outputs	Composite, CSI, Mini HDMI
Ethernet	-
USB	micro USB (OTG)
Digital I/O Lines	40

Battery

Specifications

Electrical Characteristics	Nominal Voltage	3.2V
	Nominal Capacity	1500mAh 0.2C discharge, room temperature
	Internal Resistance	≤ 40mΩ (1kHz AC / fully charged)
	Cycle Life	≥ 2000 cycles@ 0.2C discharge, room temperature
Charge	Charge Voltage	3.65 ± 0.03V
	Charge Current	300mA
	Max. Charge Current	750mA
Discharge	Max. Discharge Current	4500mA
	Discharge Cut-off Voltage	2.0V
Environmental	Charge Temperature	0°C to 45°C (32°F to 113°F)
	Discharge Temperature	-10°C to 60°C -
	Storage Temperature	1 year: 20±5°C 3 months: 0 ~ 30°C 1 month: -20 ~ 45°C (Recommended 25 ± 5°C@ 50% SOC)
Mechanical	Diameter	18.2 +0.25/-0.15mm
	Height	64.5 ± 0.3mm
	Weight	Approx. 41g

Witty Pi L3V7 Hat

Dimension	65mm x 30mm x 7mm
Weight	10g (net weight without accessories)
Microcontroller	ATtiny841 (datasheet)
Realtime Clock	PCF85063A (datasheet), calibrated in factory.
Temperature Sensor	LM75B (datasheet)
DC/DC Converter	MP3423 (datasheet)
Charging Manager	TP4056 (datasheet)
Power In	DC 5V (via USB-C connector) or 3.7V Lithium ion/polymer battery
Output Current	Up to 3A for Raspberry Pi and its peripherals
Standby Current	~0.3mA on 3.7V battery, ~1mA on USB-C 5V
Operating Environment	Temperature -30°C~80°C (-22°F~176°F) Humidity 0~80%RH, no condensing, no corrosive gas

WittyPi4L3V7_UserManual.pdf

VSMY2850RG, VSMY2850G

www.vishay.com

Vishay Semiconductors

High Speed Infrared Emitting Diodes, 850 nm, Surface Emitter Technology

VSMY2850RG

VSMY2850G

LINKS TO ADDITIONAL RESOURCES

Infographics

DESCRIPTION

As part of the SurfLight™ portfolio, the VSMY2850 series are infrared, 850 nm emitting diodes based on GaAlAs surface emitter chip technology with extreme high radiant intensities, high optical power and high speed, m

olded in clear, untinted plastic packages (with lens) for surface mounting (SMD).

FEATURES

- Package type: surface-mount
- Package form: GW, RGW
- Dimensions (L x W x H in mm): 2.3 x 2.3 x 2.8
- Peak wavelength: λ_p = 850 nm
- High reliability
- High radiant power
- Very high radiant intensity
- Angle of half intensity: $\varphi = \pm 10°$
- Suitable for high pulse current operation
- Terminal configurations: gullwing or reverse gullwing
- Package matches with detector VEMD2500X01 series
- Floor life: 4 weeks, MSL 2a, according to J-STD-020
- Material categorization: for definitions of compliance please see www.vishay.com/doc?99912

Pb-free

e3

RoHS COMPLIANT

HALOGEN FREE

GREEN (5-2008)

APPLICATIONS

- Miniature light barrier
- Photointerrupters
- Optical switch
- Emitter source for proximity sensors
- IR illumination
- Smart metering

PRODUCT SUMMARY				
COMPONENT	I_e (mW/sr)	φ (°)	λ_P (nm)	t_r (ns)
VSMY2850RG	125	± 10	850	10
VSMY2850G	125	± 10	850	10

Note

- Test conditions see table “Basic Characteristics“

ORDERING INFORMATION			
ORDERING CODE	PACKAGING	REMARKS	PACKAGE FORM
VSMY2850RG	Tape and reel	MOQ: 6000 pcs, 6000 pcs/reel	Reverse gullwing
VSMY2850G	Tape and reel	MOQ: 6000 pcs, 6000 pcs/reel	Gullwing

Note

- MOQ: minimum order quantity

Schedule 40 1 ¼" PVC Pipe

For Use With	Drinking Water, Water
Shape	Straight
Type	Pipe
Schedule	80
Threading	Unthreaded
Connection Type	Pipe
Connection Style	Socket Connect
Socket Connect Type	Cement
Gender	Male
Pipe Size	1 1/4
Length	10 ft.
OD	1 21/32"
ID	1.278"
Wall Thickness	0.191"
Material	PVC Plastic
Color	Dark Gray
Clarity	Opaque
Maximum Pressure	520 psi @ 72° F
Maximum Vacuum	29 in. of Hg @ 72° F
Vacuum Rating	Standard
Temperature Range	Not Rated to 140° F
For Fitting Schedule	80
For Fitting Material	PVC Plastic
For Flange Class	150
For Flange Material	PVC Plastic
Environment	Food Industry
Specifications Met	ASTM D1784, ASTM D1785, NSF/ANSI 61
RoHS	Not Compliant
REACH	REACH (EC 1907/2006) (11/07/2024, 242 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	United States
USMCA Qualifying	No
Schedule B	391723.0000
ECCN	EAR99
Related Product	Pipe Cement for Max. Pipe Size 6

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