YELLOW Submarine FOR

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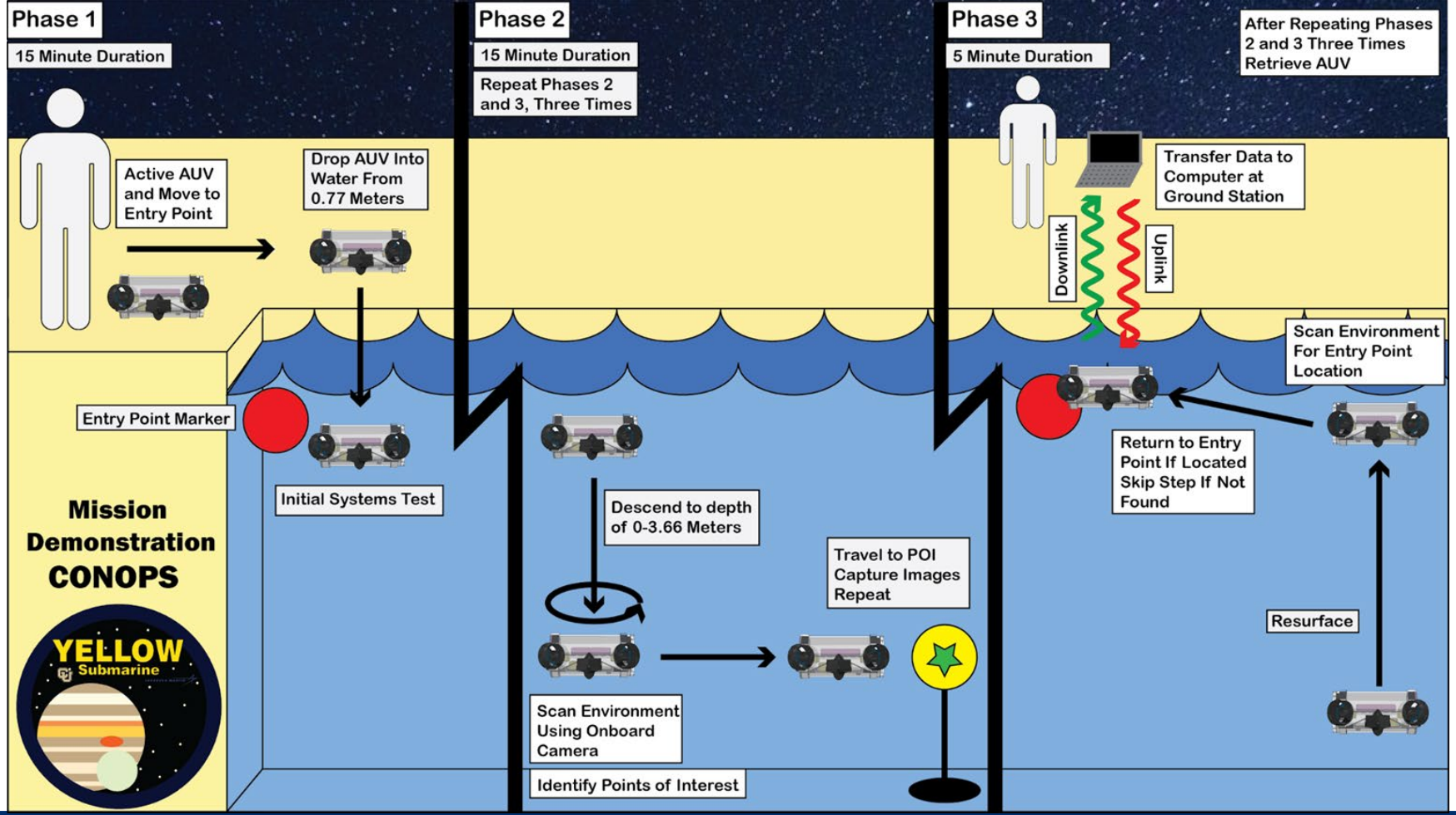
Project Purpose and Objectives

Motivation

- Exploration of Europa's subsurface ocean
- Autonomous Underwater Vehicle (AUV)
  - Navigate
  - Identify points of interest (POI)
  - Downlink data to orbiter

Project Description

- Proof-of-concept
- Technology demonstrator in a pool environment
  - Autonomously explore
  - Find POIs
  - Take images of POIs
  - Resurface to communicate data
  - Repeat for an hour


Phase 1
15 Minute Duration
Active AUV and Move to Entry Point
Drop AUV Into Water From 0.77 Meters
Entry Point Marker
Initial Systems Test
Phase 2
15 Minute Duration
Repeat Phases 2 and 3, Three Times
Descend to depth of 0-3.66 Meters
Travel to POI Capture Images Repeat
Scan Environment Using Onboard Camera
Identify Points of Interest
Phase 3
5 Minute Duration
After Repeating Phases 2 and 3 Three Times Retrieve AUV
Transfer Data to Computer at Ground Station
Downlink
Uplink
Scan Environment For Entry Point Location
Return to Entry Point If Located Skip Step If Not Found
Resurface
Mission Demonstration CONOPS
YELLOW Submarine

Mission Objectives/Levels of Success

- Detect stationary simple objects of different colors
- Rotate in place scanning environment and move toward POIs
- Avoid collision with objects within field of view
- Capture images of POIs and environmental data
- Surface and transfer data to ground station every 20 minutes 3 times

Main Metrics					
Level	1	2	3	4	5
Object Detection	-Single-class (1 color) -Stationary -Simple object (uniform dimensions)	-Multi-class (more than 1 color) -Stationary -Simple object (uniform dimensions)	-Multi-class (more than 1 color) -Stationary -Complex object (non-uniform dimensions)	-Moving objects (non-stationary) -Multi-class (more than 1 color) -Complex object (non-uniform dimensions)	-
Navigation	-Rotates in place (without explicitly commanded translation)	-Rotates in place then moves towards POI	-Rotates in place -Moves towards POI -Repeat for mulitple POIs	-Rotates in place -Moves towards POI -Repeats for multiple POIs -For each POI, orbit keeping the area of the bounding box of the POI wtihin 30-40% of the total image area	-
Collision avoidance (needs Navigation level 2)	-	-Comes to a complete stop before hitting an object (POI, wall, or junk) in view of front RGB camera -Holds position	-Navigates around "junk" object in view -Detects "junk" object in view of front RGB camera and moves to the left or right until junk is out of frame -Moves forward past obstacle	-Can navigate around multiple "junk" objects in view -Detects "junk" objects in view of front RGB camera -Moves left or right until all obstacles are out of frame or if there's sufficient space between them, then move sideways until the AUV is between the obstacles -Proceeds to move forward past obstacle	-Avoids walls even when not in view -In addition to level 4 capabilities, AUV can avoid walls that are not view of the front RGB camera
Imaging	-Capture at least 1 image of POI, where POI is at least partly in the frame	-Capture at least 1 image of POI, where POI is fully in frame	-Capture multiple images of POI, where POI is fully in frame	-Capture image of POI from multiple angles	-
Downlink	-AUV health packet reported to ground station during communication period	-Images, temperature data, and pressure data reported to ground station	-	-	-
Uplink	-Can recieve kill-switch command from ground station during communication period	-Can be commanded to return to a specific search depth	-Can be commanded to look for a specific class of object	-	-
Surfacing	-Moves straight up to surface and can remain on surface	-Rotates once to look for drop point marker -If found, returns to within 2 m of drop point before surfacing -Otherwise, resurfaces in place	-Returns to drop area using IMU data while looking for drop point marker -If marker found, returns to within 2 m of drop point before surfacing -If marker not found within 2 minutes, surface in place	-Returns to within 2 m of drop point without a marker, then surfaces	-

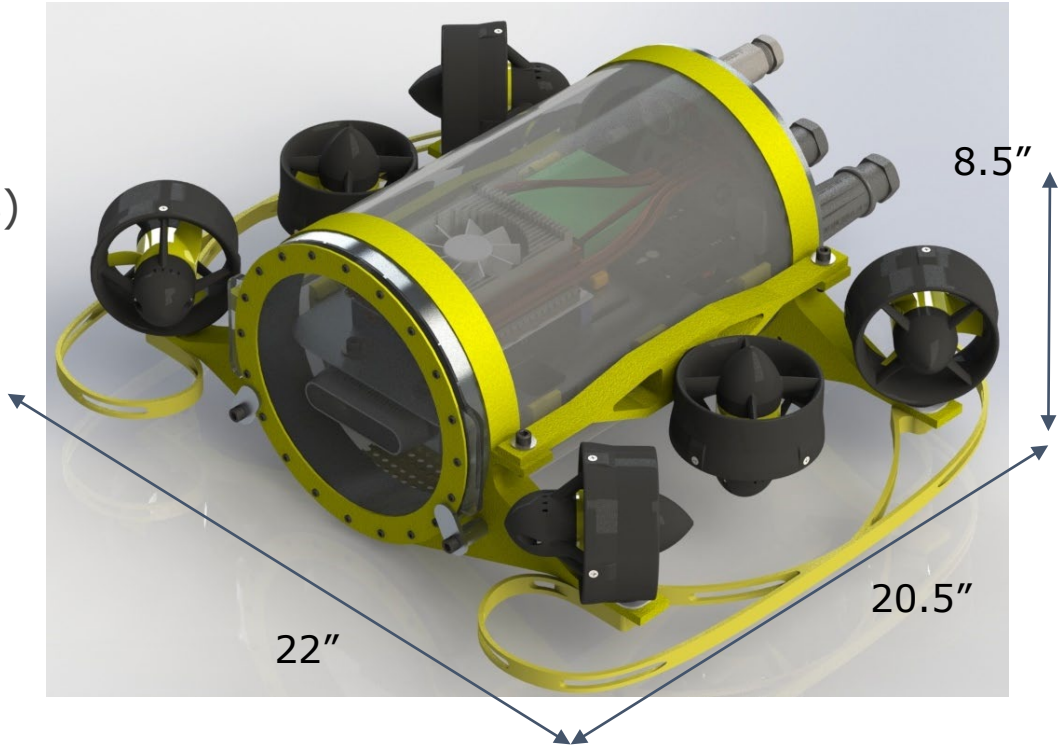
Design Description

Critical Project Elements

- Structural Integrity
  - Ensures system can survive the mission environment
- Power
  - Keeps system active for duration of mission
- C&DH
  - Necessary for navigation, relaying data to ground station
- Autonomous Navigation
  - Human input impossible in mission environment
- Image Processing
  - Used in Autonomous Navigation, reporting of Points of Interest to the ground station

Baseline Design

- Weight: 12.6kg (27.8lbs)
- Buoyant Force: 124.6N (28.0lbs)
- 6 Thrusters (5 DOF)
- Yaw rate: 0.1028-0.7rad/s
- Max Cruise velocity: 0.48 m/s
- Intel RealSense D435 Camera
- NVIDIA Jetson Xavier
- 12.8V 12Ah $LiFePO_4$ Battery

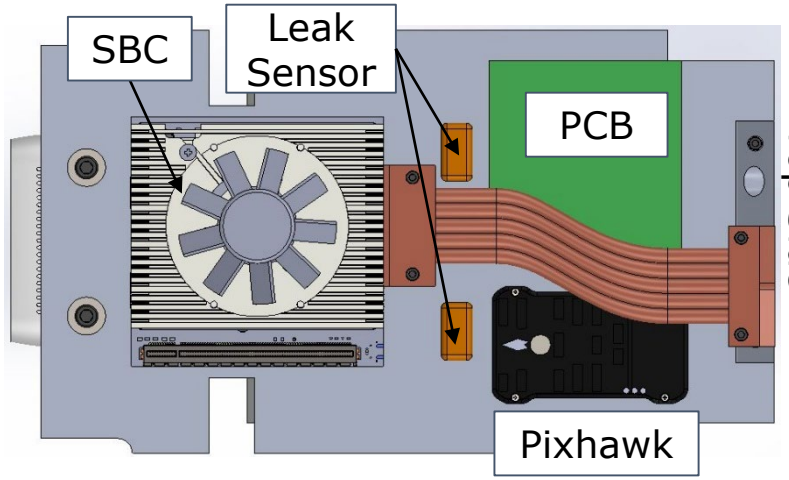


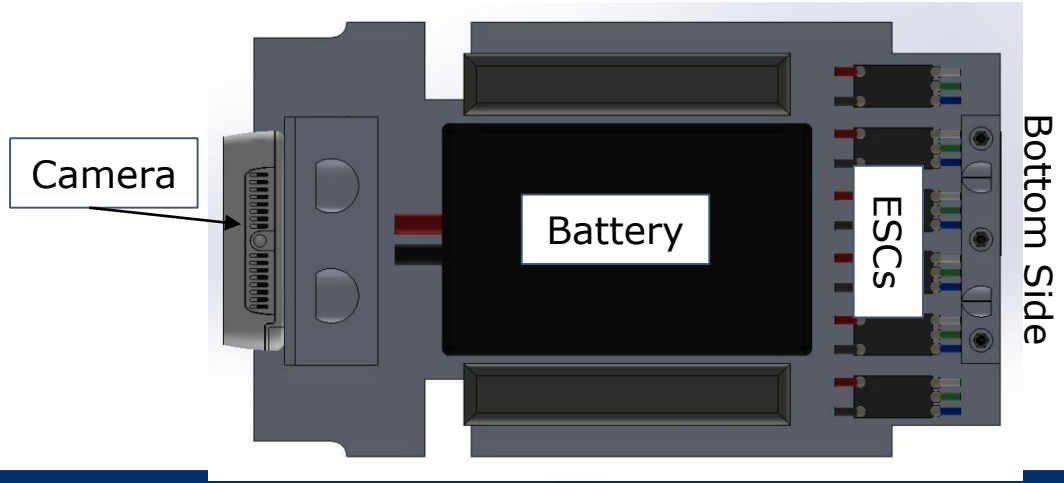
Physical Design

- 6 T200 Thrusters
  - 49 N thrust each
  - 5 degrees of freedom
- Acrylic tube dry space
  - 0.00868 m^3 internal volume
- Positively Buoyant
  - 124.6 N buoyant force
  - 1 N net buoyant force
- Rear Aluminum Endcap
  - Sealed by 2 static radial O-rings
  - Bulkhead wire passthroughs
- Front Endcap
  - Clear acrylic front plate
  - Sealed by 2 static radial O-rings and gasket
- 3D Printed Bumpers

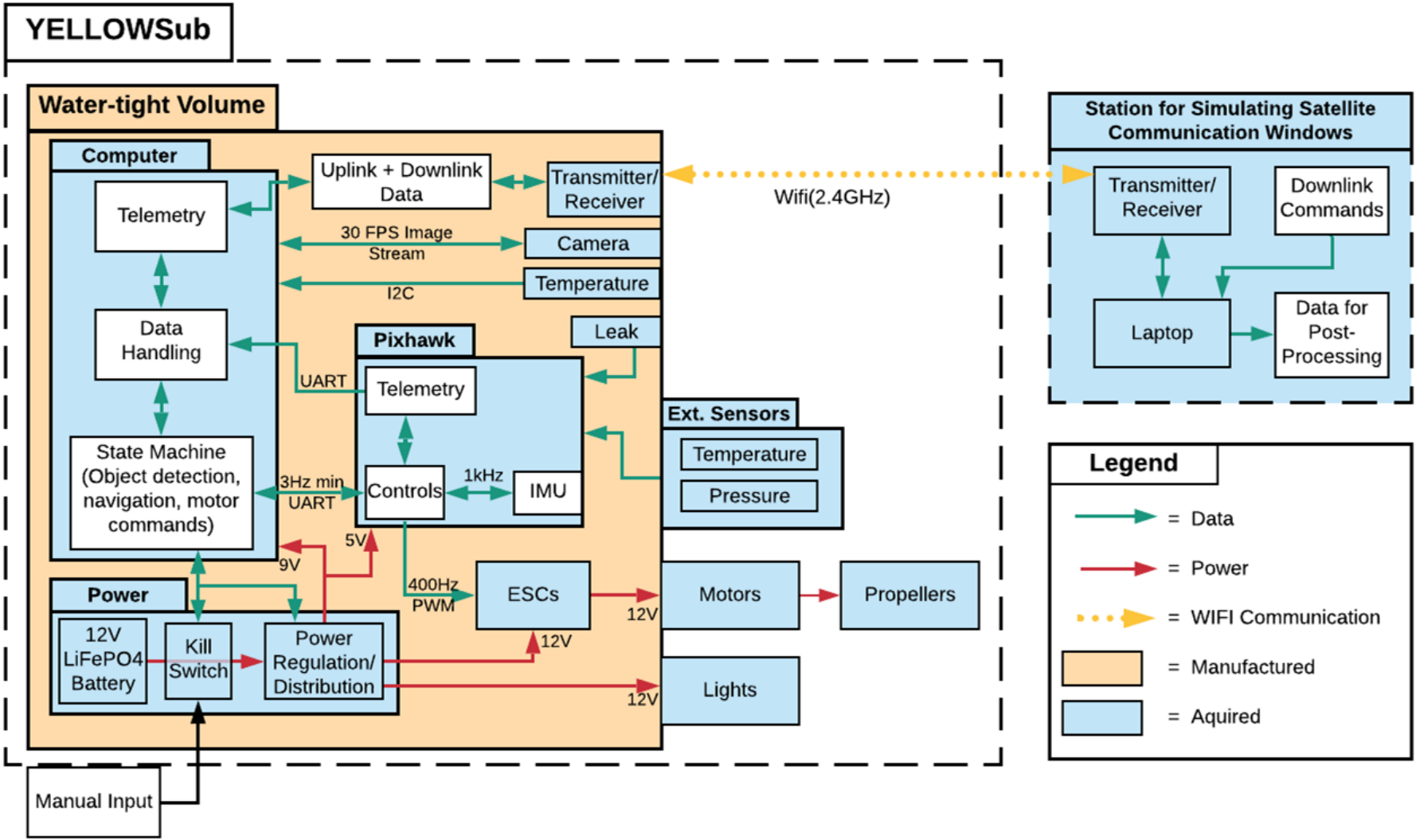
Electrical Design

- Power System
  - 12.8V 12Ah lithium iron phosphate battery
  - Custom PCB for distributing power and kill switch
  - Step-down buck converters
  - Motor ESCs
- Environmental Sensors
  - Leak Detection
  - Temperature and pressure (internal and external)



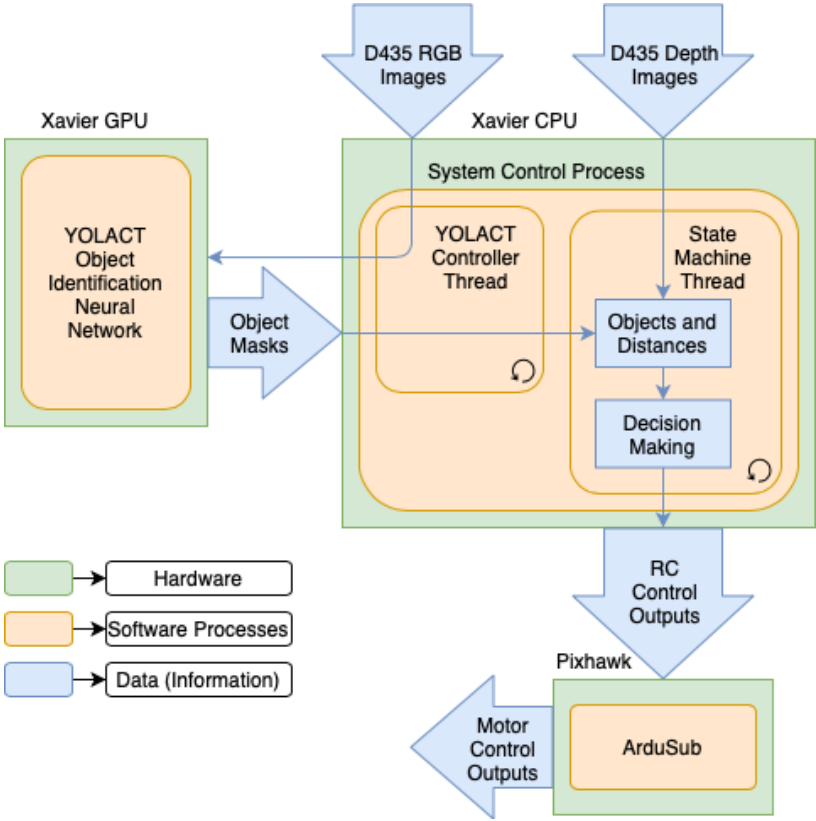


LOCKHEED MARTIN


YELLOWSub
Water-tight Volume
Computer
Telemetry
Data Handling
State Machine (Object detection, navigation, motor commands)
Uplink + Downlink Data
Transmitter/ Receiver
30 FPS Image Stream
Camera
I2C
Temperature
Leak
Pixhawk
UART
Telemetry
3Hz min UART
Controls
1kHz
IMU
Ext. Sensors
Temperature
Pressure
5V
9V
Power
12V LiFePO4 Battery
Kill Switch
Power Regulation/ Distribution
400Hz PWM
ESCs
12V
12V
Motors
Propellers
12V
Lights
Manual Input
Wifi(2.4GHz)
Station for Simulating Satellite Communication Windows
Transmitter/ Receiver
Downlink Commands
Laptop
Data for Post-Processing
Legend
= Data
= Power
= WIFI Communication
= Manufactured
= Aquired

Software Design

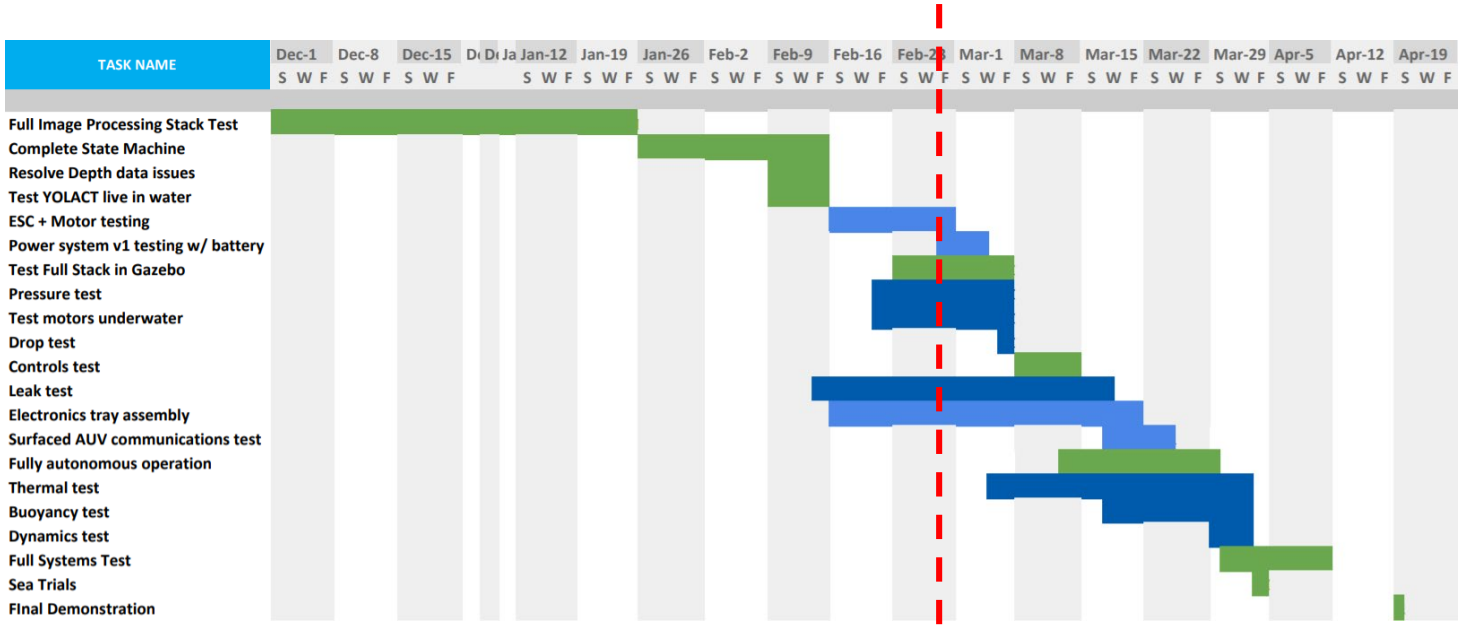
- Visual Distance Sensing Camera
  - Intel RealSense D435
- Powerful NVIDIA Single-Board Computer
  - NVIDIA Jetson XAVIER
  - Runs YOLACT Neural Network Image Processing Algorithm
- YOLACT image processing algorithm
  - Instance segmentation to identify POIs
  - 3.2 FPS
- Pixhawk Autopilot
  - Runs ArduSub motor control software



Updates from TRR

- The 6-motor systems test was successfully troubleshooted
  - ArduSub motor initialization/arming issue
- AUV structure and internals were assembled
- 1st systems integration test was conducted
  - Potential short in the motor wires → unsuccessful test
- Due to ongoing COVID-19 pandemic, all development on the project was ordered to be halted on Friday, March 13th

Updates from TRR



Project Halted

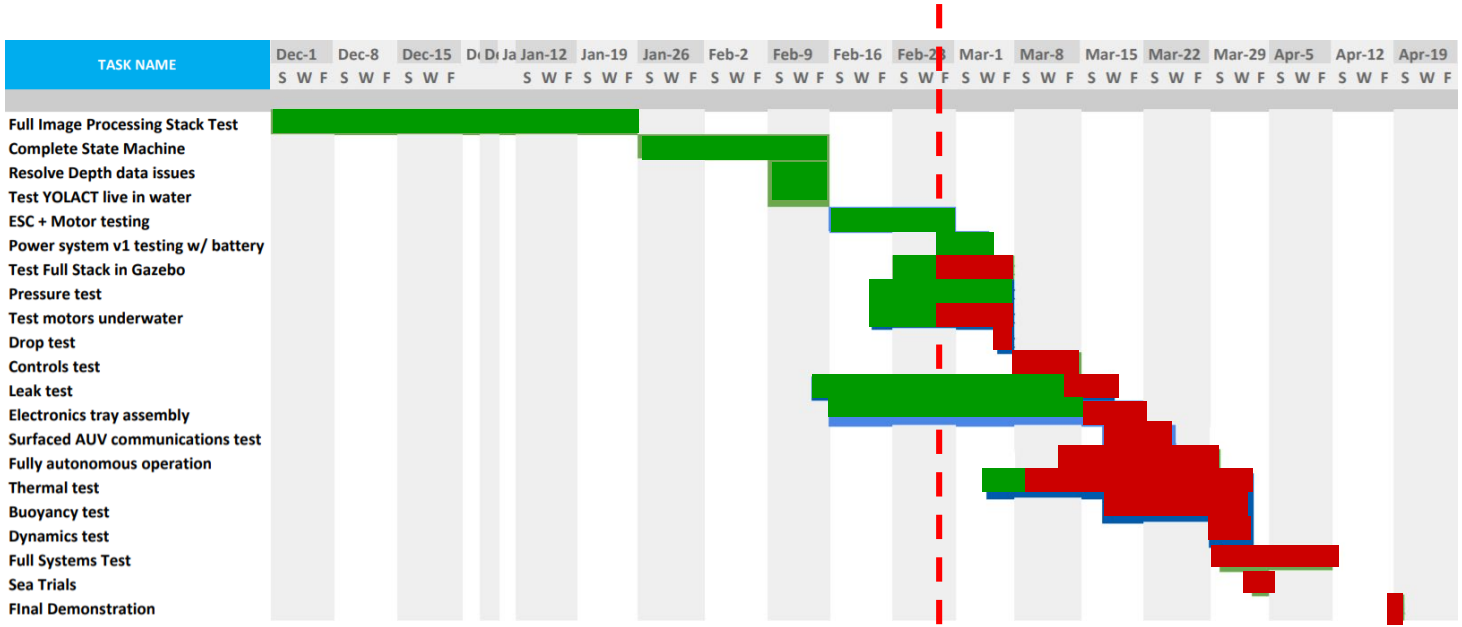
Key:

Mechanical

Software

Hardware

Updates from TRR



Project Halted

Key:

Complete

Incomplete

Test Overview & Results

Verification and Validation

Completed

- Leak Test
- Full Power System Test
- Six Motor Bench Test

In Progress

- Dynamics/Controls Test

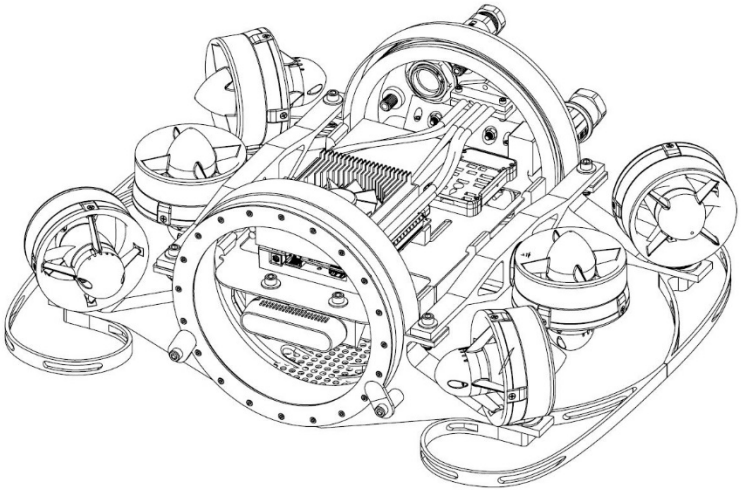
To be completed

- Drop Test and Leak Test 2
- Thermal Test
- Live YOLACT and Xavier Integration Test
- Full Software Simulation Test
- Sea Trials
- Demonstration

Mechanical Testing

Completed/In progress:

- Leak Test
- Pressure Test



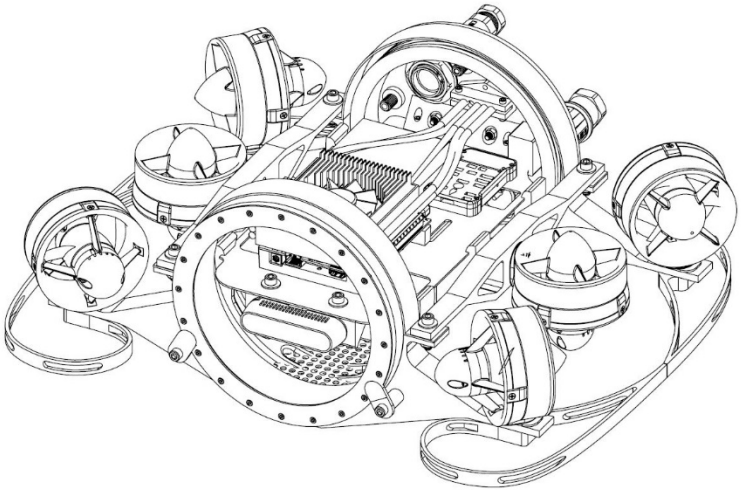
To be completed:

- Drop test
- Thermal test
- Buoyancy test

Mechanical Testing

Completed/In progress:

- Leak Test
- Pressure Test



To be completed:

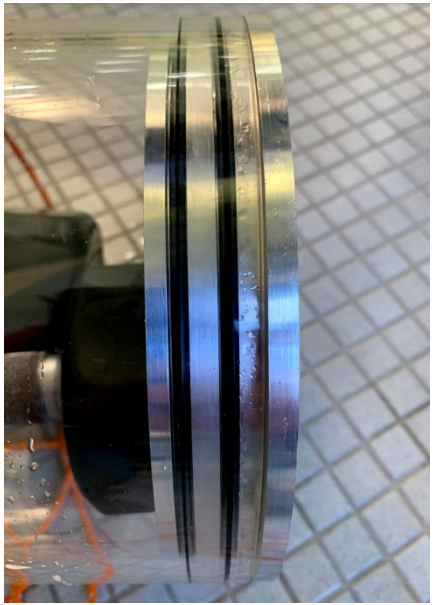
- Drop test
- Thermal test
- Buoyancy test

Leak Test

- Scheduled: 2/14 - 3/18 (Multiple leak tests will take place)
- Completion Status: **In progress**
- Test Readiness
  - Rationale: Testing whether end caps provide waterproof seal
  - Location: Rec center pool
- Risk Reduction
  - Water Intrusion, Corrosion Damage
- Requirement Verification
  - Requirement 1.5.3: Vehicle shall be waterproof

Water Sealing the Housing

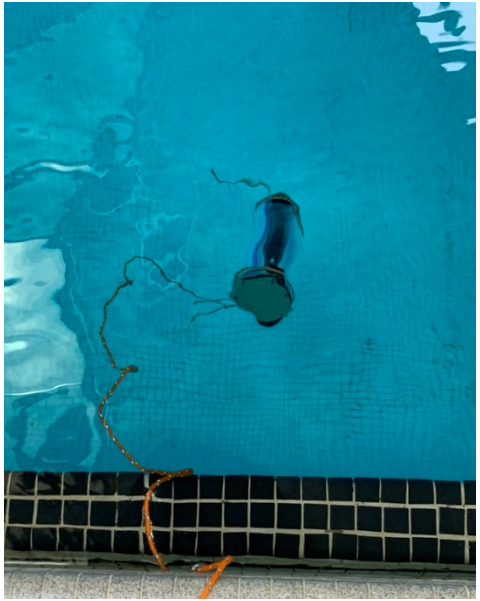
- O-rings
- Rubber gasket w/ aluminum ring mount



Leak Test - Procedure

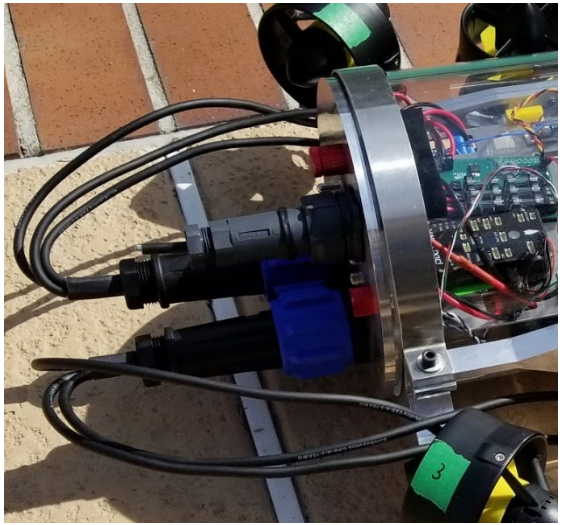
- Paper inside of the housing along the acrylic tube
- Let housing sit at operating depth for at least 15 minutes

- Success: If paper remains dry



Leak Test (Full System)

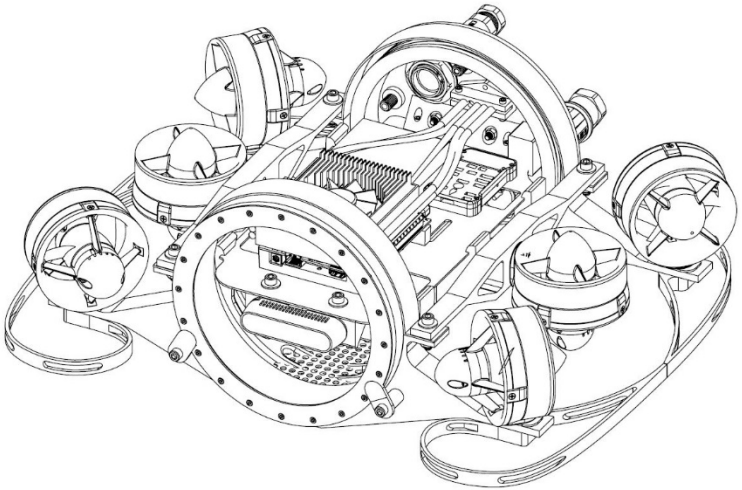
- Included bulkhead wire connections and endcap penetrations
- Small leak in bulkhead wire connectors



Mechanical Testing

Completed/In progress:

- Leak Test
- Pressure Test



To be completed:

- Drop test
- Thermal test
- Buoyancy test

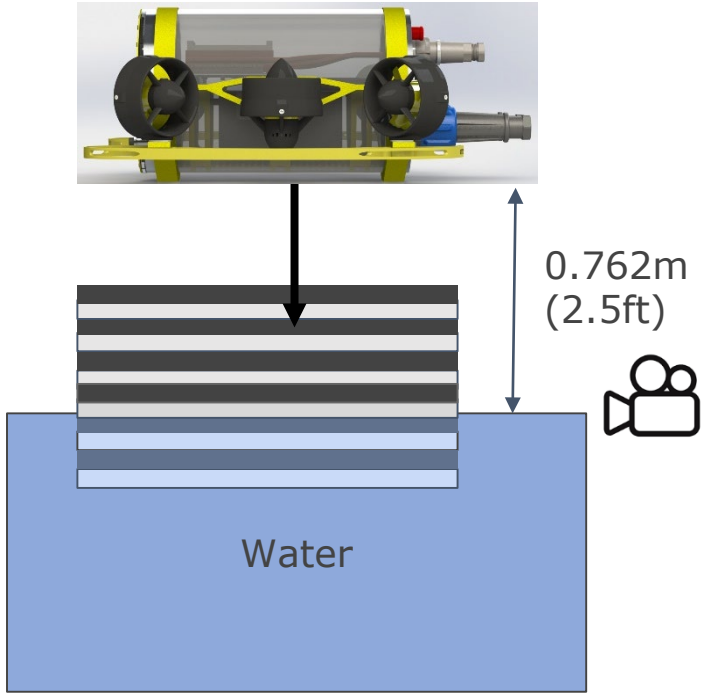
Drop Test

- Scheduled: 3/6 - 3/8
- Completion Status: **To be completed**
- Test Readiness
  - Rationale: Determine if the AUV can survive the 2.5 ft drop requirement
  - Location: Rec center pool
- Risk Reduction
  - Impact damage
- Requirement Validation
  - Requirement 5.3: The vehicle shall withstand impact to surface of body of water from 2.5 ft above the surface

Drop Test - Procedure

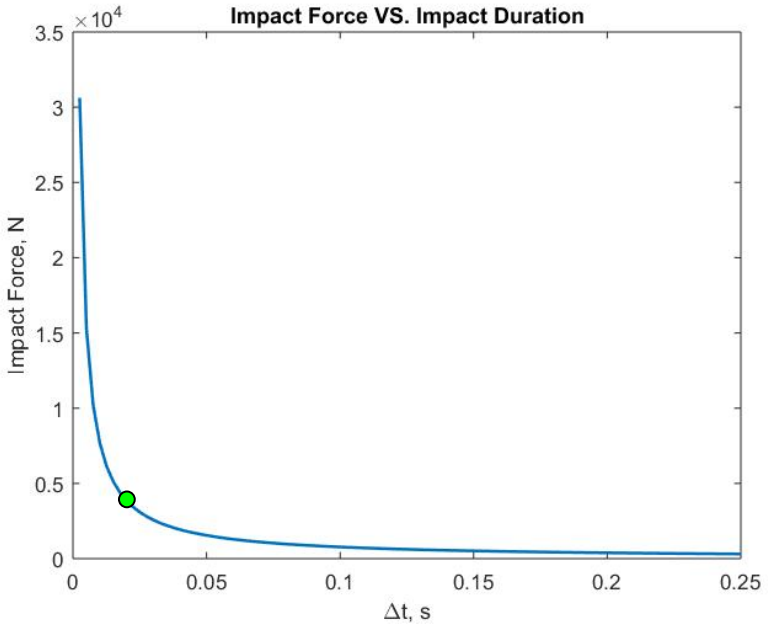
- Paper inside of acrylic tube
- Load electronics tray with weight
- Film impact site
- Drop AUV
- Inspect structure for damage and inspect paper for wetness

- **Success:** If structure is undamaged and paper has no wet spots



Drop Test - Expected Results

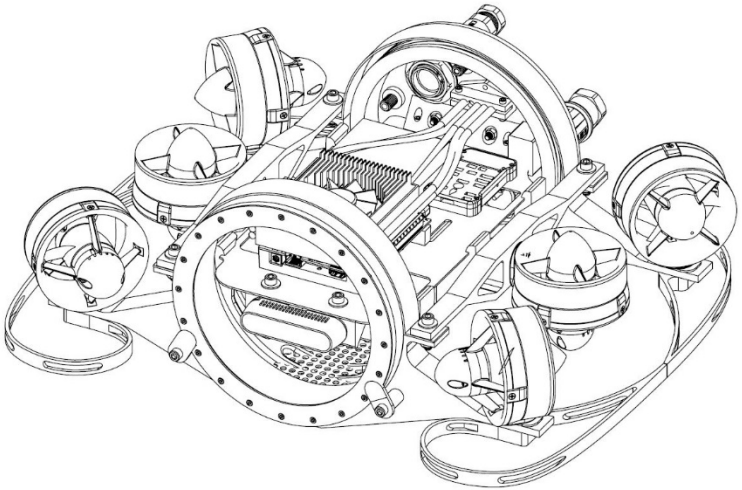
- Expected AUV structure to survive fall without damage
- Planned to use camera footage to validate impact model assumptions
  - Impact time
  - Impact velocity
- Expected model to be an overestimate of impact force



Mechanical Testing

Completed/In progress:

- Leak Test
- Pressure Test



To be completed:

- Drop test
- Thermal test
- Buoyancy test

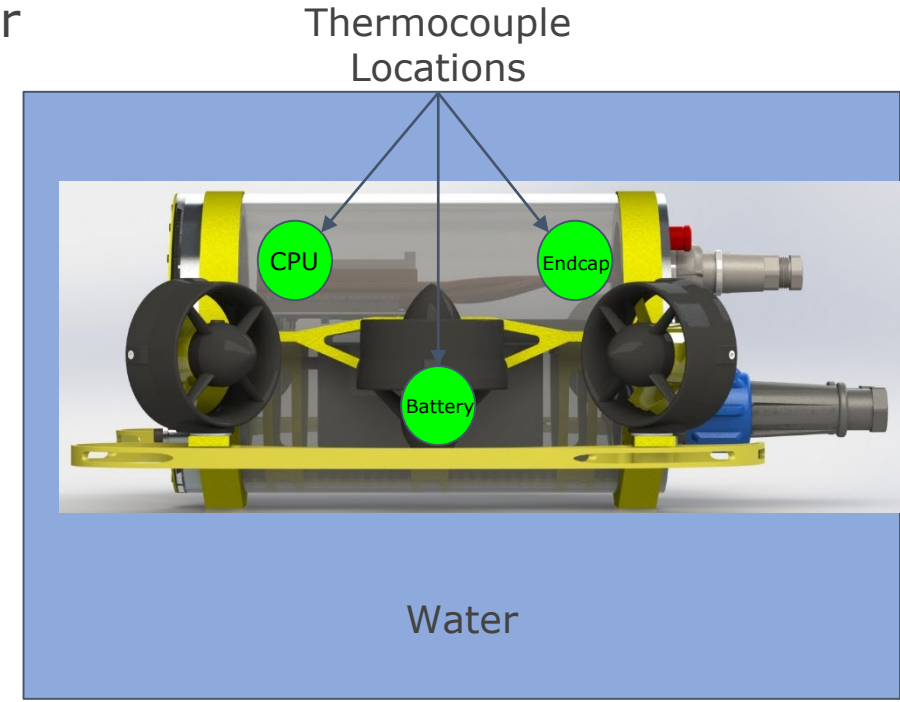
Thermal Test

- Scheduled: 3/5 - 4/2
- Completion Status: **To be completed**
- Test Readiness
  - Rationale: Determine whether steady state temperature is low enough such that all electronics stay operational
  - Location: Rec center pool
- Risk Reduction
  - Compartment Temperature
- Requirement Verification
  - Requirement 1.6.1: The vehicle shall be thermally tested in an aquatic environment

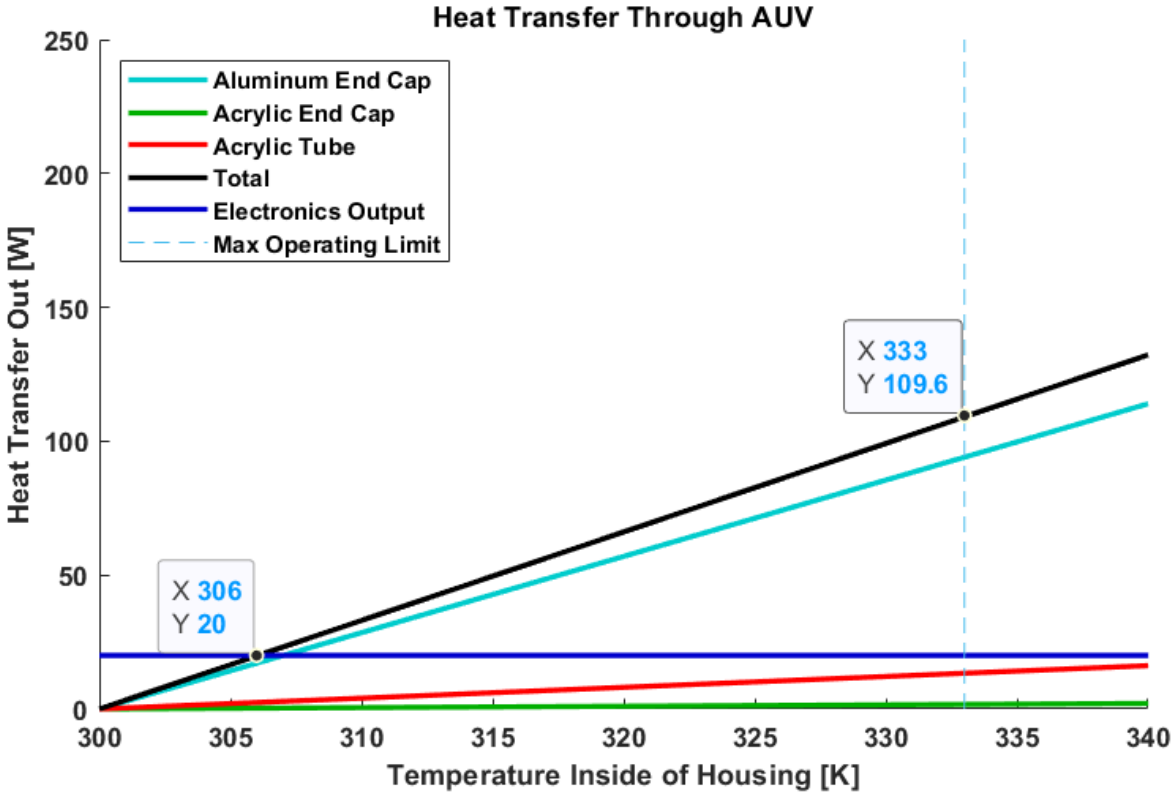
Thermal Test - Procedure

- Run AUV under steady operation for 10 minutes
- Record internal temperature of all thermocouples
- Repeat two additional times with longer durations

- **Success:** If internal temperature values stay under 333K (60°C)



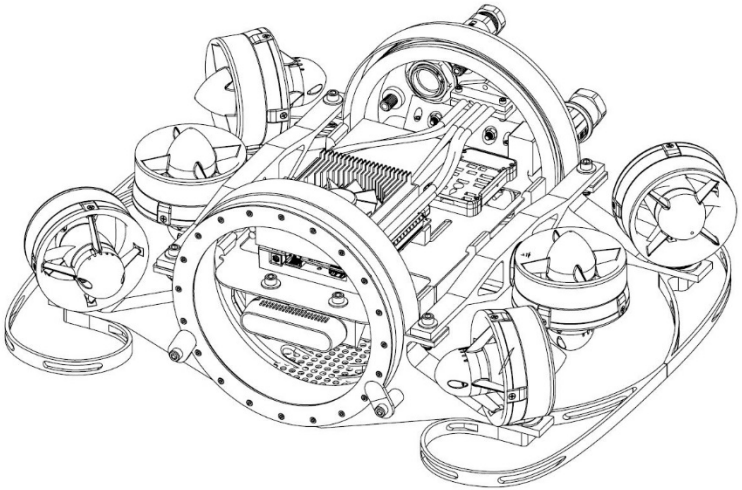
Thermal Test - Expected Results



Mechanical Testing

Completed/In progress:

- Leak Test
- Pressure Test



To be completed:

- Drop test
- Thermal test
- Buoyancy test

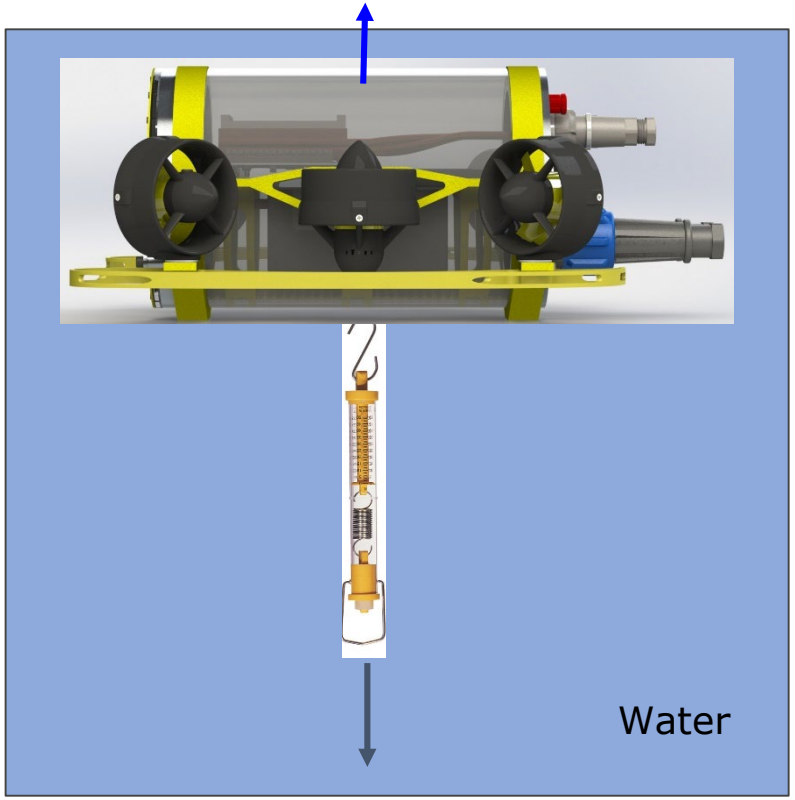
Buoyancy Test

- Scheduled: 3/18 - 4/2
- Completion Status: **To be completed**
- Test Readiness
  - Rationale: Testing whether positive buoyancy is 1N
  - Location: Rec center pool
- Risk Reduction
  - Battery Usage
- Requirement Verification
  - Requirement 6.5: The vehicle shall weigh no more than 20kg

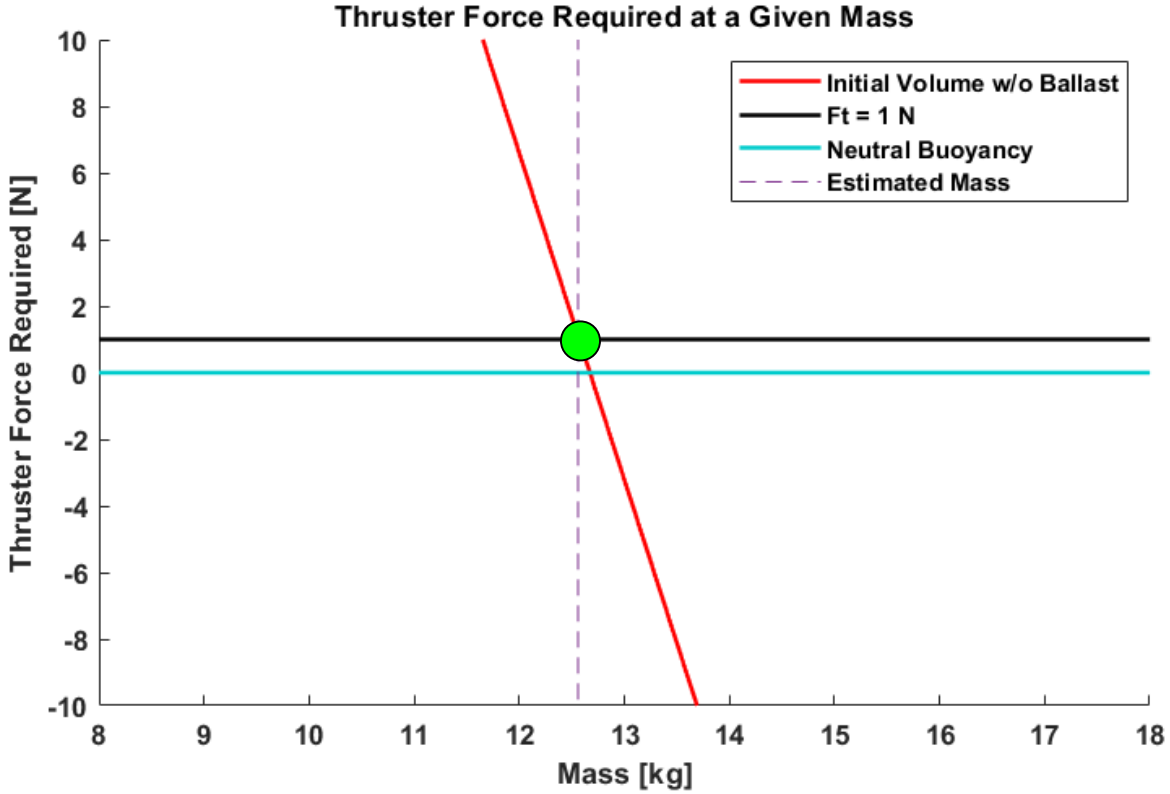
Buoyancy Test - Procedure

- Weigh fully assembled AUV before placing in water
- Attach a spring scale to the bottom of the AUV and submerge to at least 1m
- Record spring scale value

- **Success:** If spring scale reads 1N±0.5N



Buoyancy Test - Expected Results



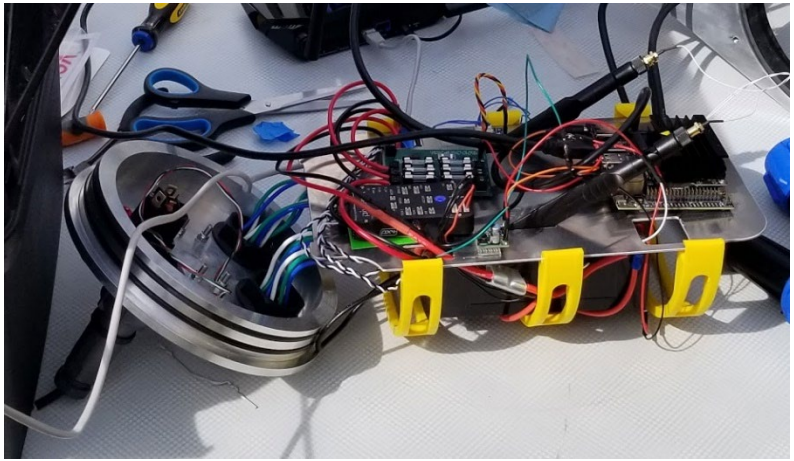
Electronics Testing

Completed/In progress:

- Motor + ESC initial test
- Basic communications
- Battery under load
- Regulators under load
- PCB v1 test
- Leak sensor test
- Full power system

To be completed:

- PCB v2 test
- Full vehicle integration
- More full power system tests



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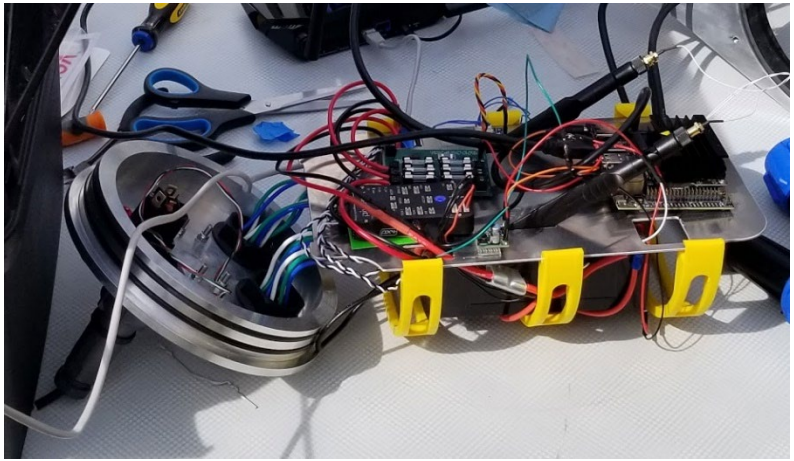
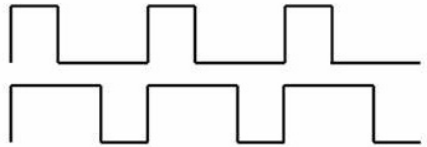


Motor + ESC Tests

- Scheduled: 2/17 - 2/28
- Completion Status: **Complete**
- Test Readiness
  - Rationale: Ensure all motors and ESCs function as expected
- Risk Reduction
  - Control failure
- Requirements Validation
  - 5.1.2: The vehicle shall navigate an underwater course



Motor + ESC initial test

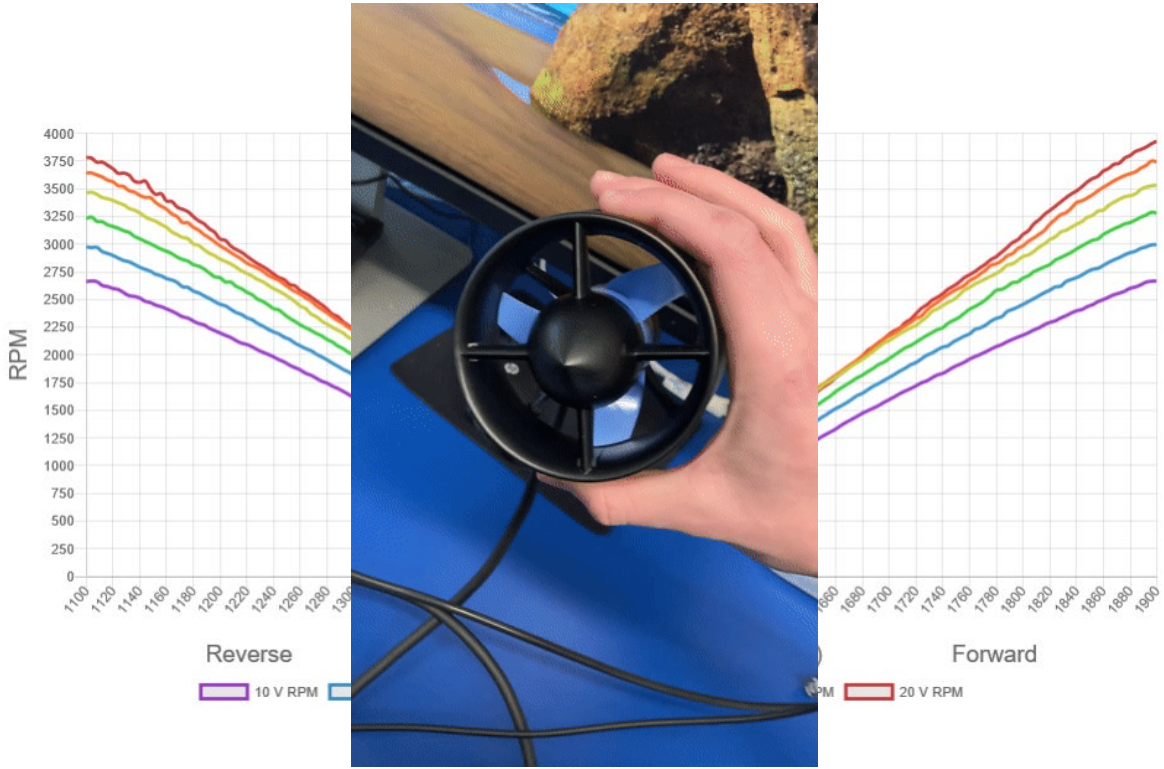
Procedure

- Connect ESCs to waveform generator and motors
- Send PWM signals and observe results

Expectations

- Roughly linear trend

Success: All motors followed trend



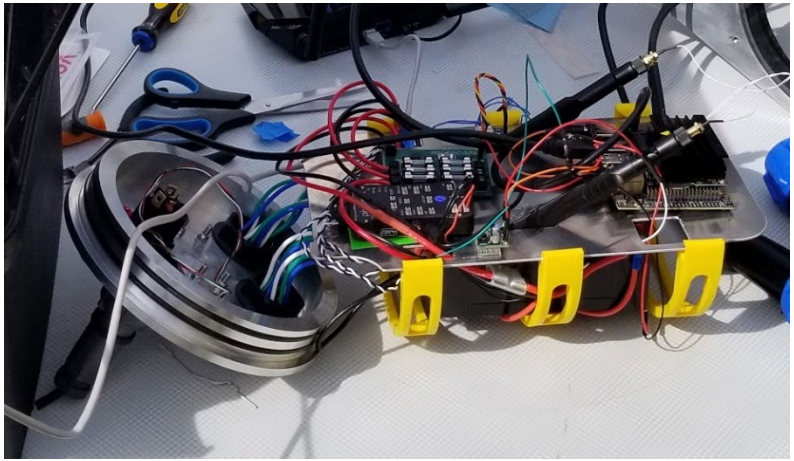
Electronics Testing

Completed/In progress:

- Motor + ESC initial test
- Basic communications
- Battery under load
- Regulators under load
- PCB v1 test
- Leak sensor test
- Full power system

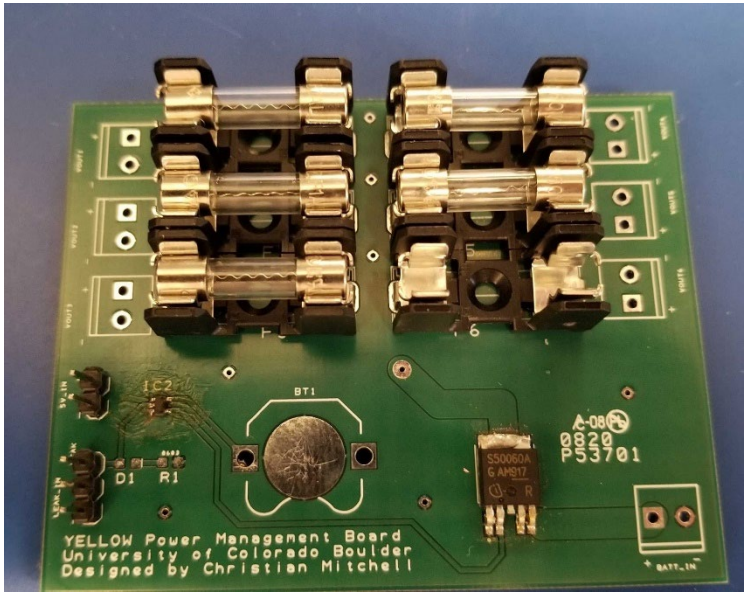
To be completed:

- PCB v2 test
- Full vehicle integration
- More full power system tests

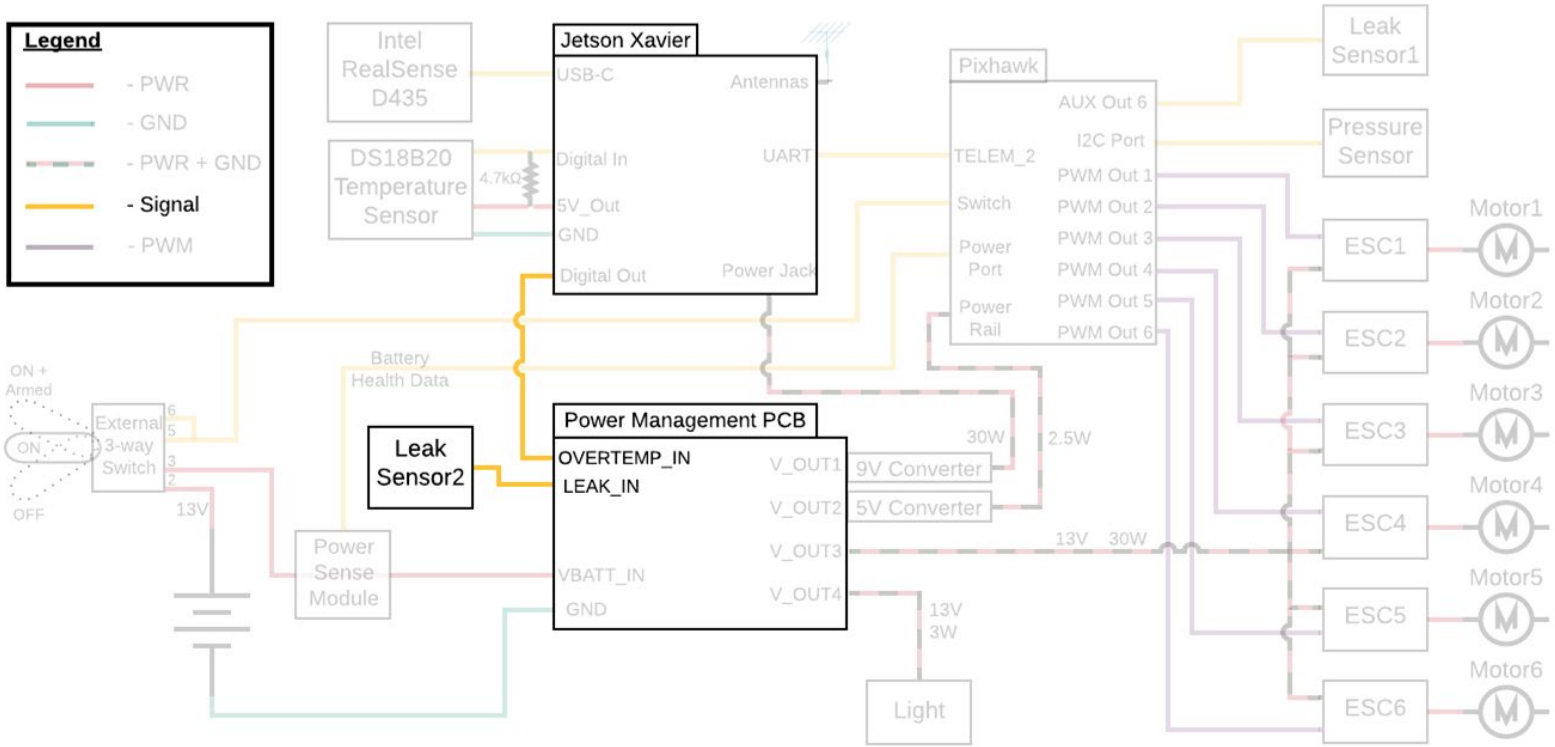


PCB v1 Test

- Scheduled: 2/26 - 2/28
- Completion Status: **Complete**
- Test Readiness
  - Rationale: Ensure PCB distributes power as expected
- Risk Reduction
  - Power overload
- Requirements Validation
  - 6.2: The vehicle shall prevent circuit overloads



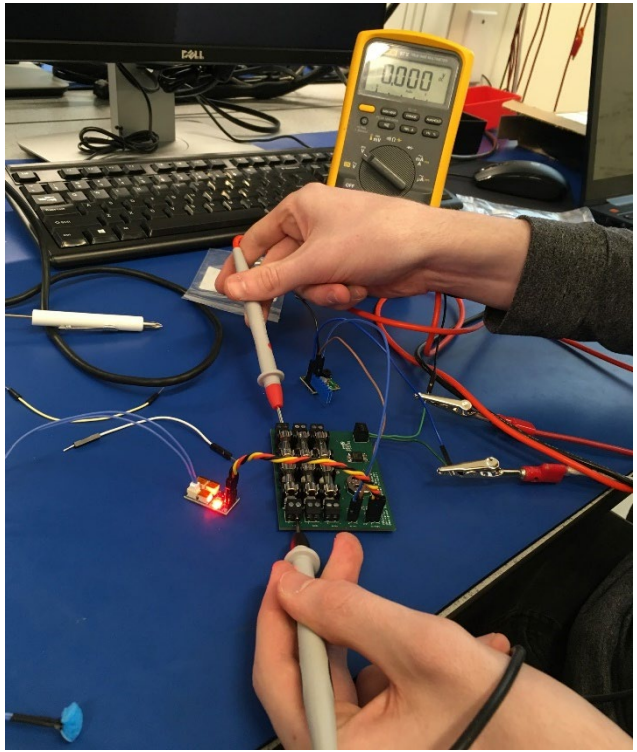
PCB v1 Test - Expected Results



PCB v1 Test - Results

- Operating voltage
  - Mostly successful
  - Fuses did not break when expected
- Leak signal
  - Power was cut to leak sensor as well
  - Reduced power (2.4 V) with leak

Partial Success: Updated design needed



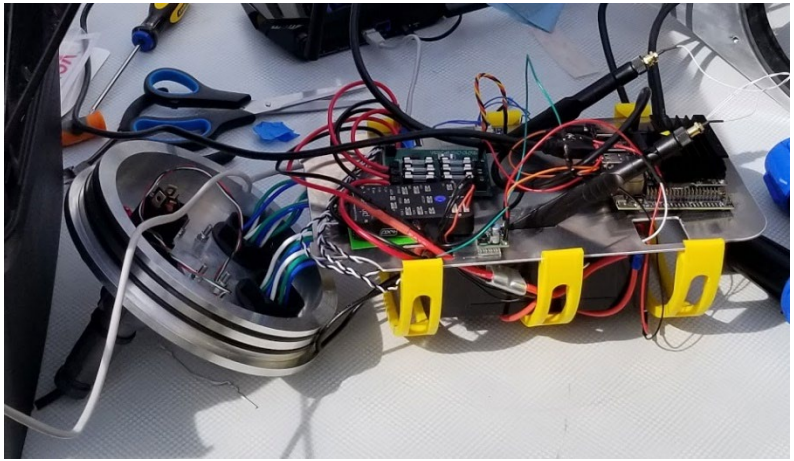
Electronics Testing

Completed/In progress:

- Motor + ESC initial test
- Basic communications
- Battery under load
- Regulators under load
- PCB v1 test
- Leak sensor test
- Full power system

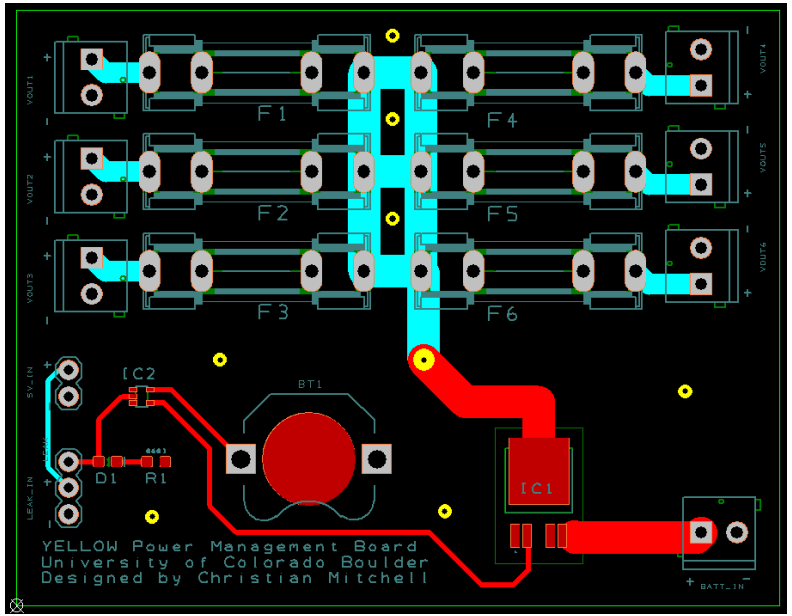
To be completed:

- PCB v2 test
- Full vehicle integration
- More full power system tests



PCB v2 Test

- Scheduled: 3/6 - 3/20
- Completion Status: **To be completed**
- Test Readiness
  - Rationale: Ensure PCB consistently distributes power as expected
- Risk Reduction
  - Power overload
- Requirements Validation
  - 6.2: The vehicle shall prevent circuit overloads



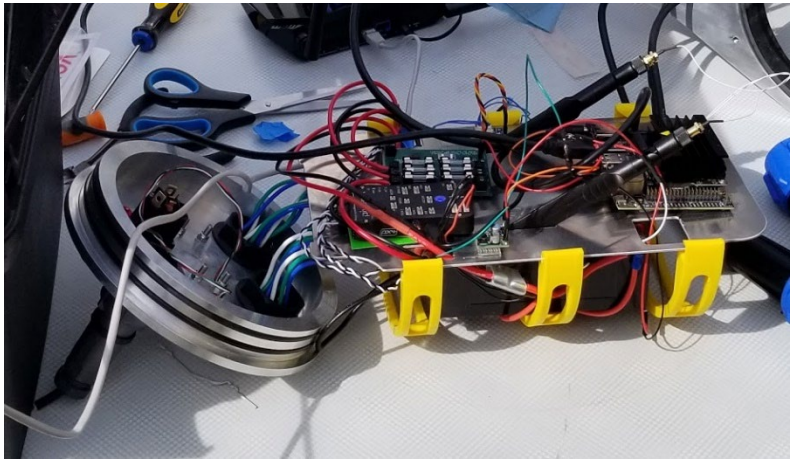
Electronics Testing

Completed/In progress:

- Motor + ESC initial test
- Basic communications
- Battery under load
- Regulators under load
- PCB v1 test
- Leak sensor test
- Full power system

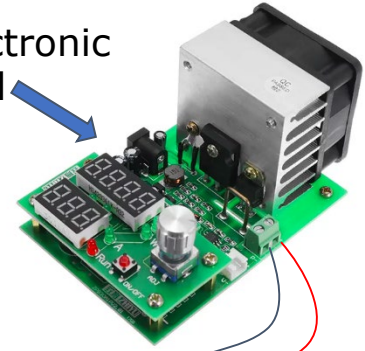
To be completed:

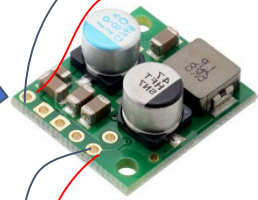
- PCB v2 test
- Full vehicle integration
- More full power system tests

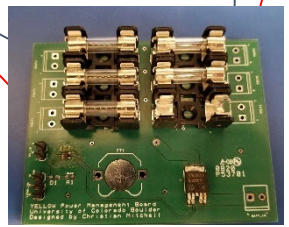


Power System Test

- Scheduled: 2/28 - 3/4
- Completion Status: **Complete**
- Test Readiness
  - Rationale: Ensure power system will function for entire mission duration
- Risk Reduction
  - Power budget (008-a)
  - Power regulation (009-a)
- Requirements Validation
  - 1.1: The vehicle shall be self-powered







Power System Test - Procedure

Procedure

- Connect battery though PCB to electronic load
- Monitor power until 85% nominal voltage

Vehicle State	Current (A)	Power (W)	Time Spent in State (hrs)	Weighted Average Total Current (A)	Weighted Average Total Power (W)
Total:			1.00	**6.85**	**66.5**

Battery Characteristics	
Voltage (V)	13
Depth of Discharge	0.75
Temperature Correction Factor	1
Design Margin	1.2

Peak Current (A)	Peak Power (W)
8.17	**83.7**

Total Consumption (Ah)	Battery capacity required (Ah)
7.44	**11.9**

Regulator Characteristics	
Efficiency	0.92

Power System Test - Results

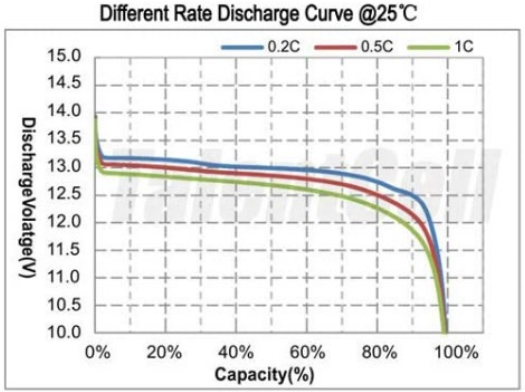
Expected Results

- Near 13V for first hour
- Cutoff at 1 hour, 20 minutes

Results

- Somewhat lower average voltage (12.8V)
- 7 Amps for 1.5 hours

Success: Power system lasts for mission duration



Software Testing

Completed/In progress:

- Simulated controls test
- Live in-water YOLACT/Xavier test
- Ground Station WiFi transfer test
- Full-stack simulation test

To be completed:

- Collision avoidance test

Software Testing

Completed/In progress:

- Live in-water YOLACT/Xavier test
- Simulated controls test
- Ground Station WiFi transfer test
- Full-stack simulation test

To be completed:

- Collision avoidance test

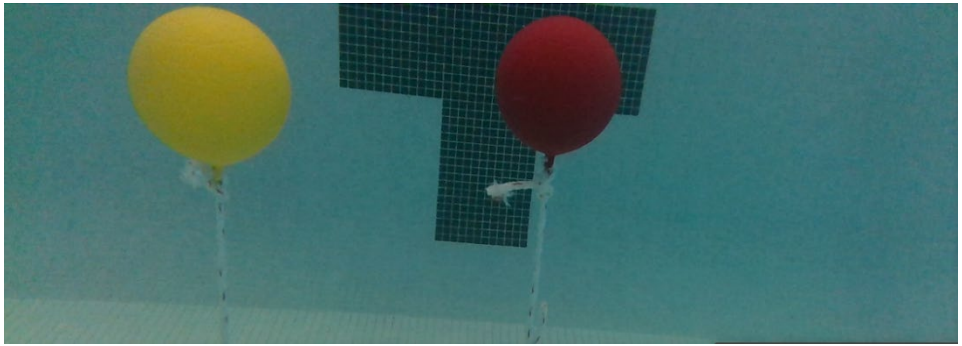
Live in-water YOLACT and Xavier Integration Test

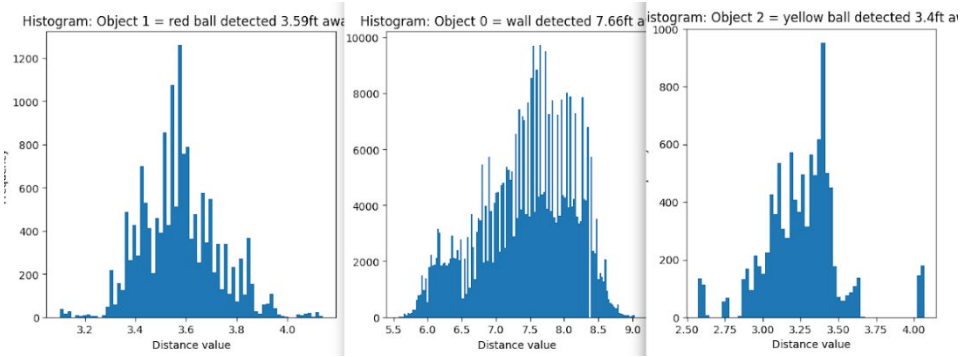
- Scheduled: 2/15
- Completion Status: **Complete**
- Test Readiness
  - Rationale: Prove and evaluate YOLACT in live testing environment
  - Location: Rec center pool
- Risk Reduction
  - Lack of capability to conduct mission, unproven test set-up, poor integration
- Requirement Verification
  - Requirement 5.2: The vehicle shall mark points of interest

Live in-water YOLACT and Xavier Integration Test - Procedure and Results

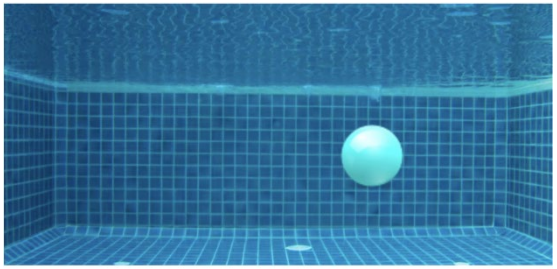
- Connect Xavier to camera and monitor
- Place POI 5 ft from wall
- Place camera in box
- Submerge underwater
- Power on Xavier
- Run live image processing script
- Confirm measured distance with actual distance

Success: Accurate distance estimates within 1 ft tolerance

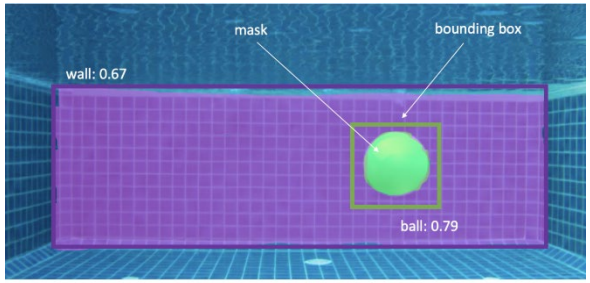




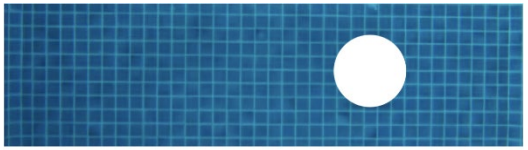
Expected Results - Image Processing



Original 2D image captured by RGB camera

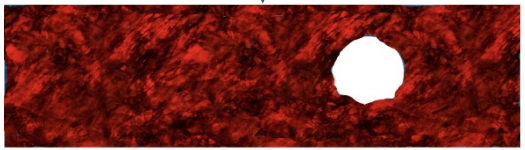


Output of instance segmenter



Extracted pixels corresponding to pool wall (sides)

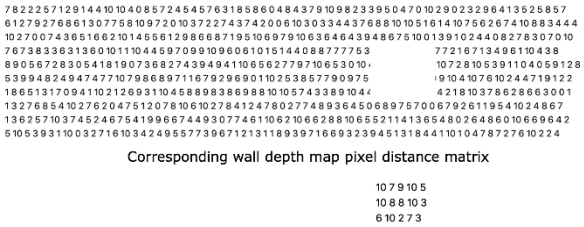
Extracted pixels corresponding to ball



Corresponding wall depth map pixels

= Far away
= Close

Corresponding ball depth map pixels



Corresponding wall depth map pixel distance matrix

Corresponding ball depth map pixel distance matrix

3 ft

Final wall distance estimate (average distance of all corresponding pixels)

1.5 ft

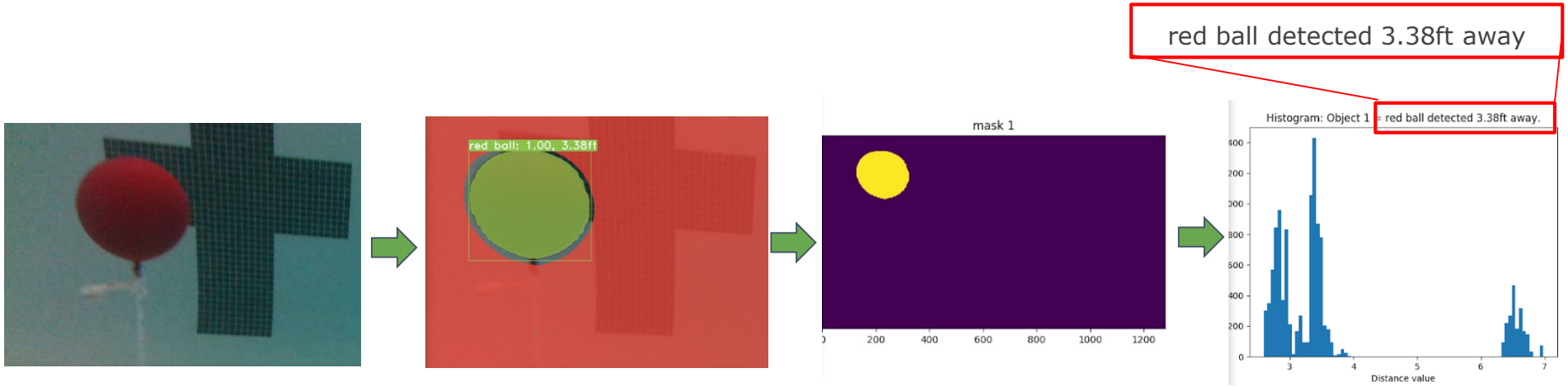
Final ball distance estimate (average distance of all corresponding pixels)

Actual Results - Image Processing

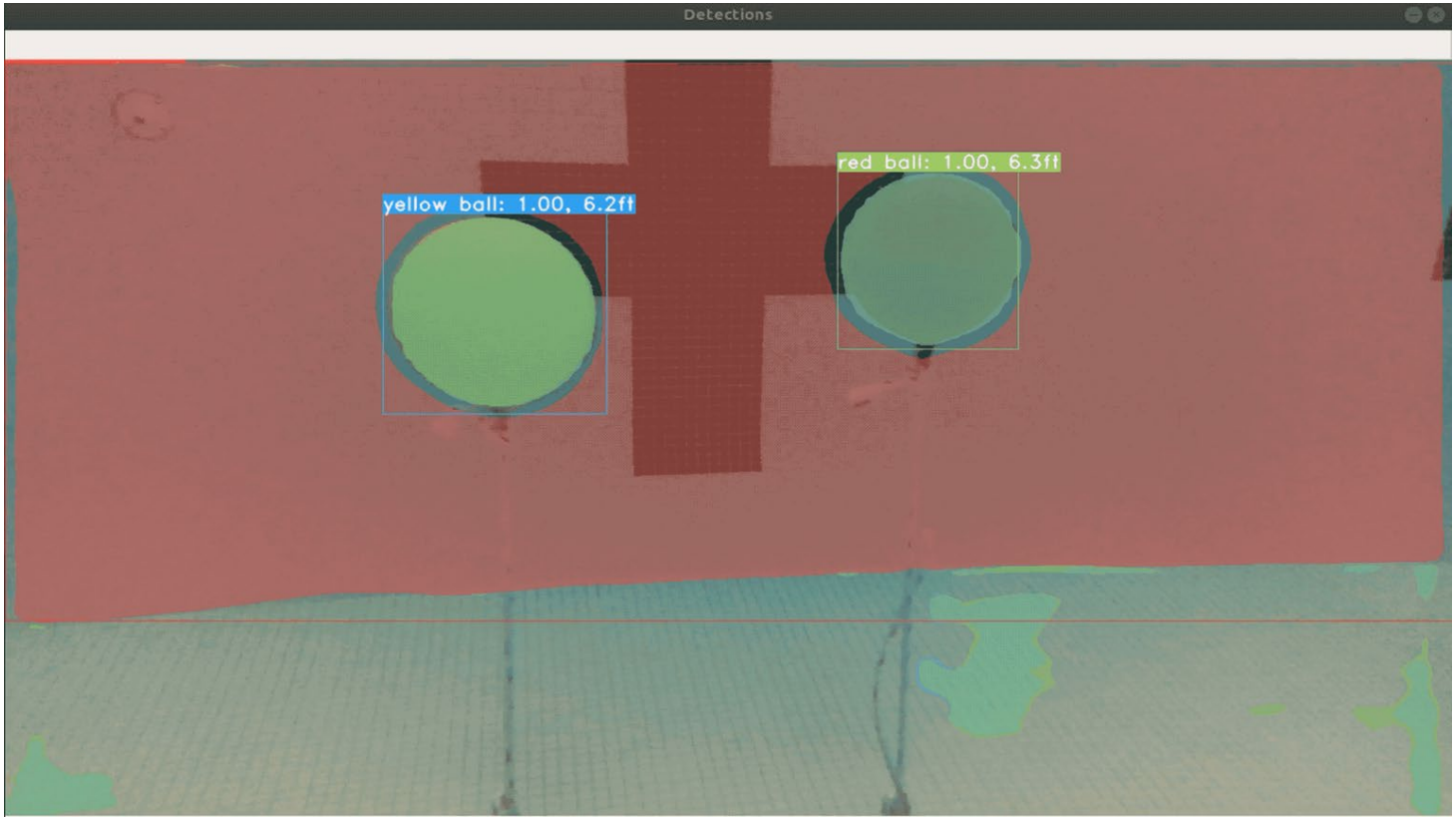
Successfully identifies objects in front of AUV and estimates their distances within 1 ft accuracy in pseudo-real time 3.2 FPS

Algorithm:

1. Identify objects and corresponding masks
2. Sample subset of points in each mask
3. Extract distance estimates of each point in subset
4. Use mode of distances as final distance estimate



Actual Results - Image Processing

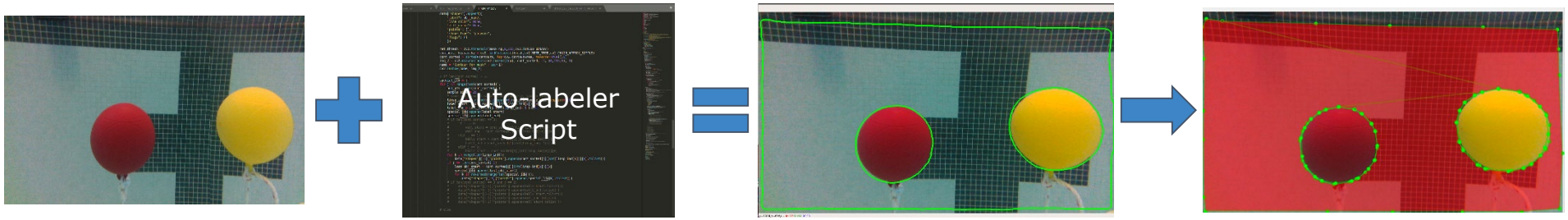


Additional Results - Image Processing

Successfully created auto-labeler that can label 125 images/minute

Algorithm:

1. Use OpenCV Contour on object masks
2. Uniformly sample points from each contour
3. Convert and output as JSON file



Software Testing

Completed/In progress:

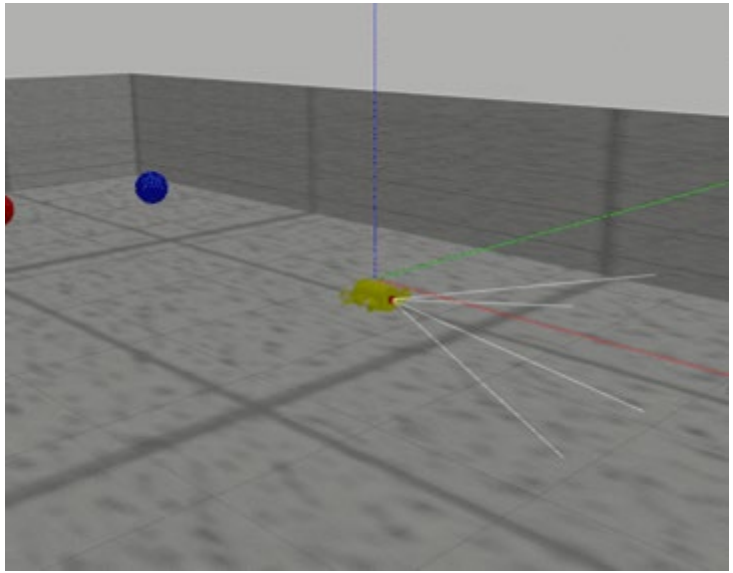
- Live in-water YOLACT/Xavier test
- Simulated controls test
- Ground Station WiFi transfer test
- Full-stack simulation test

To be completed:

- Collision avoidance test

Simulated Controls Test

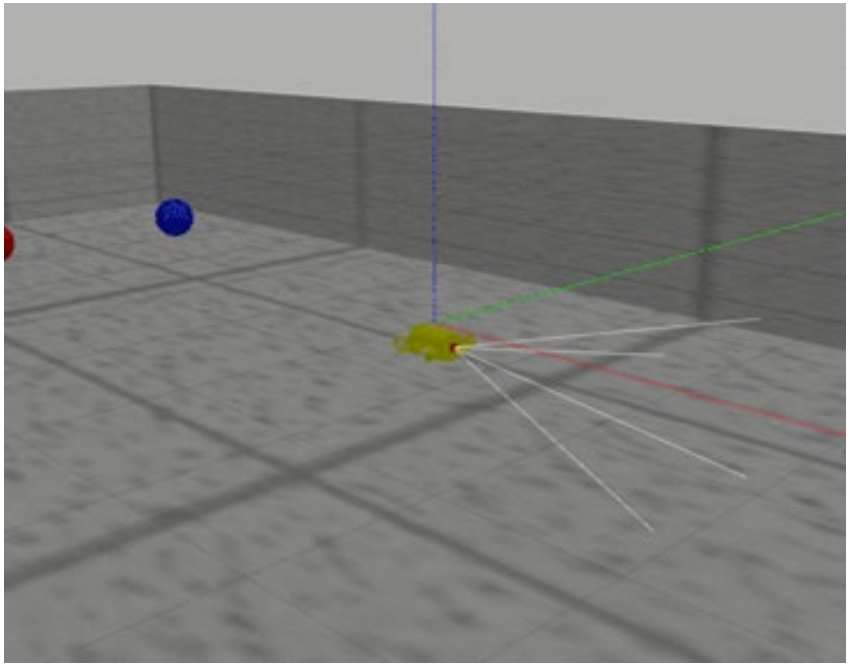
- Scheduled: 1/20 - 2/13
- Completion: **Complete**
- Test Readiness
  - Rationale: Ensure we can achieve control of AUV before attempting a pool test
- Risk Reduction
  - Controls Failure, Unexpected Behavior
- Requirement Verification
  - Requirement 2.1.1: Vehicle shall autonomously navigate underwater



Simulated Controls Test - Procedure and Results

- Open simulation environment
- Start ArduSub control software
- Start control test script
- Verify that control test script controls simulated AUV as expected

Success: Can control all 5 DOF in simulation



Software Testing

Completed/In progress:

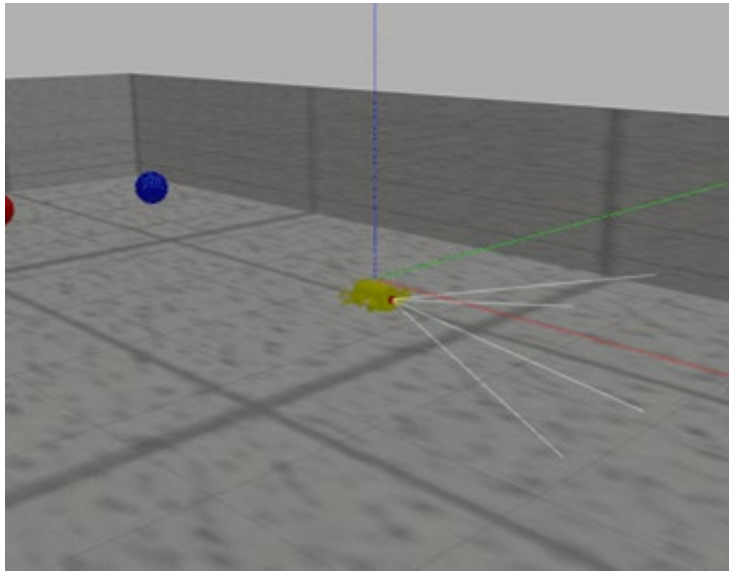
- Live in-water YOLACT/Xavier test
- Simulated controls test
- Ground Station WiFi transfer test
- Full-stack simulation test

To be completed:

- Collision avoidance test

Full Stack Simulation Tests

- Scheduled: 2/24 - 3/15
- Completion: **In Progress**
- Test Readiness
  - Rationale: Test the decision-making process and state machine in simulation before attempting a pool test
- Risk Reduction
  - Controls Failure, Unexpected Behavior
- Requirement Verification
  - Requirement 2.1.1: Vehicle shall autonomously navigate underwater



Full-Stack Simulation Test - Procedure and expected Results

Procedure:

- Start simulation, ArduSub code, state machine
- Verify AUV completes the mission with visual data from simulation

Expected Results:

- AUV successfully completes mission without human input

In progress: Encountered difficulties retrieving camera images from simulation

Systems Testing

Completed/In progress:

- 6-motor integration test
- Controls/dynamics test

To be completed:

- Full systems test

Systems Testing

Completed/In progress:

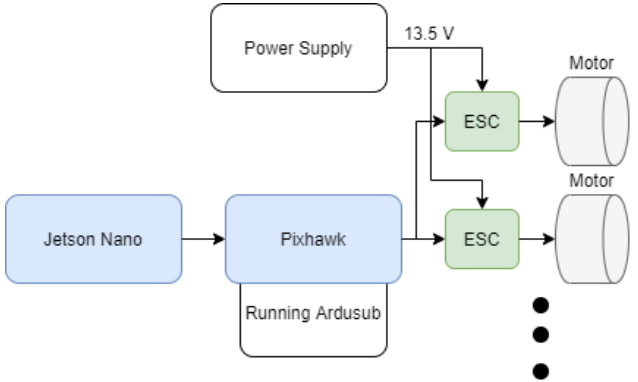
- 6-motor integration test
- Controls/dynamics test

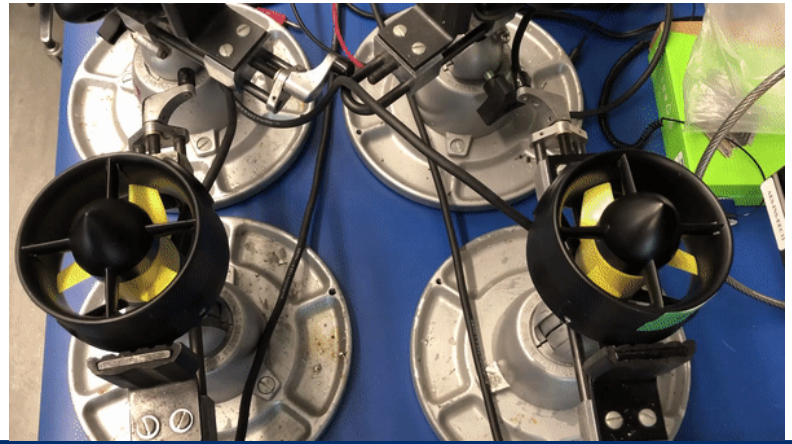
To be completed:

- Full systems test

6 Motor and Ardusub Test Procedure and Results

- Connect all electrical components
- Run controls script in MANUAL mode
  - Visually verify appropriate motor response for each channel
- Run controls script in STABILIZE mode
  - Tip Pixhawk about the front-back axis
  - Verify that side motors produce appropriate response to instability





SUCCESS: Verified the simulation model and the ArduSub control system

Systems Testing

Completed/In progress:

- 6-motor integration test
- Controls/dynamics test

To be completed:

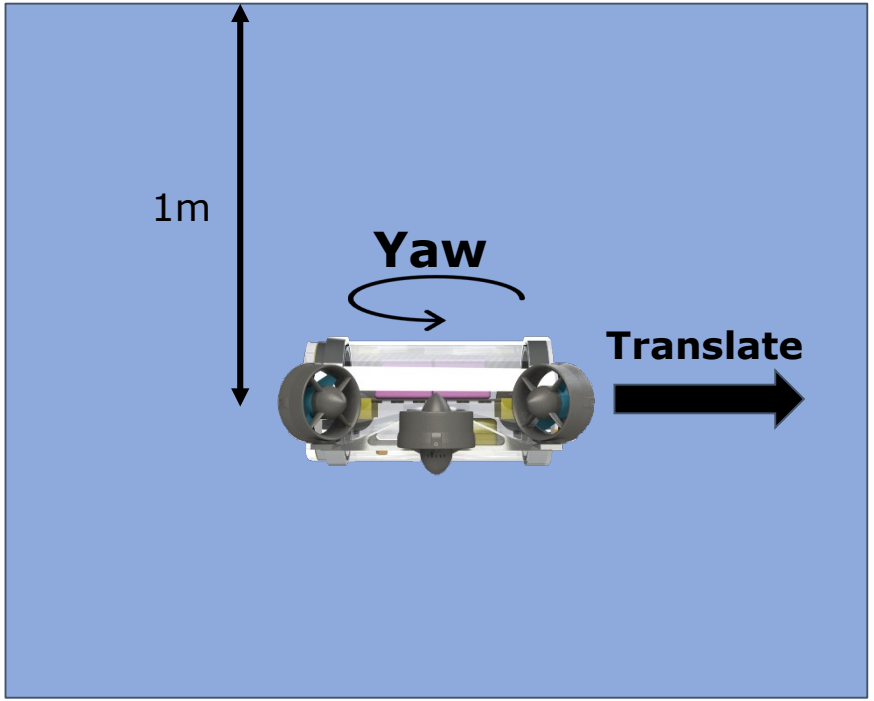
- Full systems test

Dynamics Test

- Scheduled: 3/7 - 3/15
- Completion: **To be completed**
- Test Readiness
  - Rationale: Testing whether AUV is statically and dynamically stable
  - Location: Rec center pool
- Risk Reduction
  - Instability of AUV
  - Instability of controls system
- Requirement Validation
  - Requirement 2.1.1: The vehicle shall autonomously navigate underwater

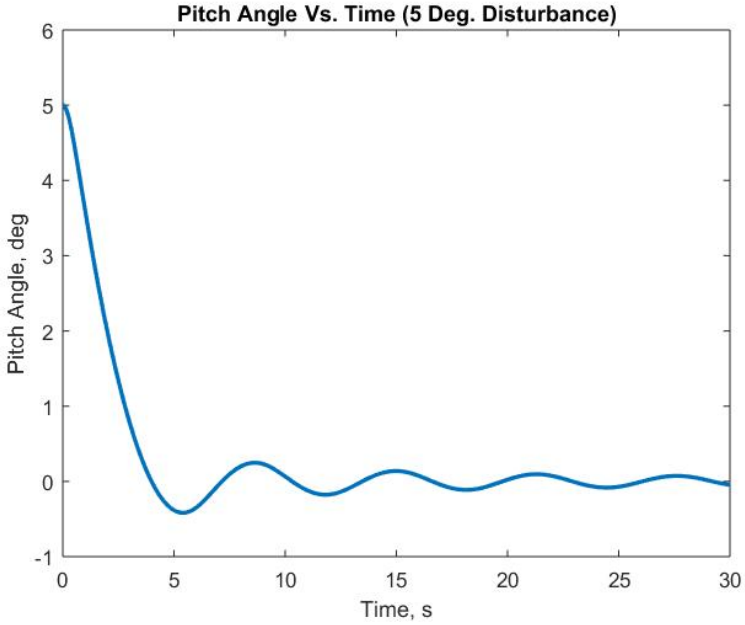
Dynamics Test - Procedure

- Start filming with GoPro
- Command AUV to descend to 1m depth and hold
- Disturb AUV to test static stability
- Command AUV to yaw in place for 1 minute
- Command AUV to translate forward for 15 seconds



Dynamics Test - Expected Results

- If signs of instability
  - Move weights inside AUV to adjust CG location
- Planned to use IMU measurements to validate dynamics model
  - Time constant
  - Damping
  - Amplitude
- Camera footage as backup



Systems Testing

Completed/In progress:

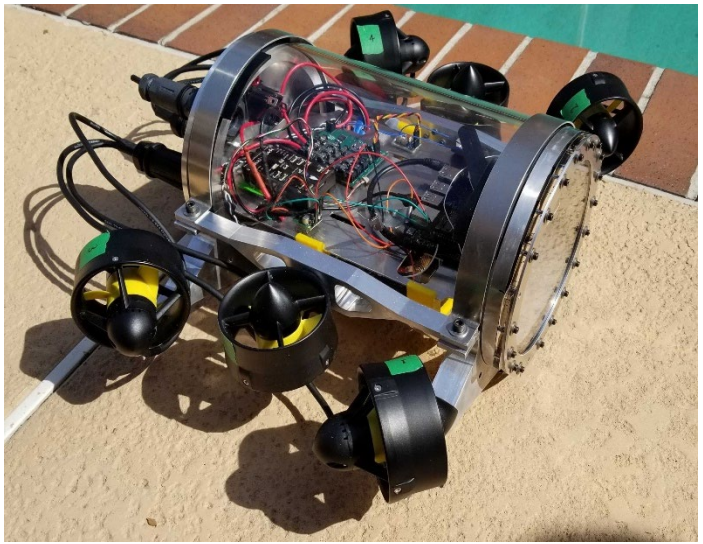
- 6-motor integration test
- Controls/dynamics test

To be completed:

- Full systems test

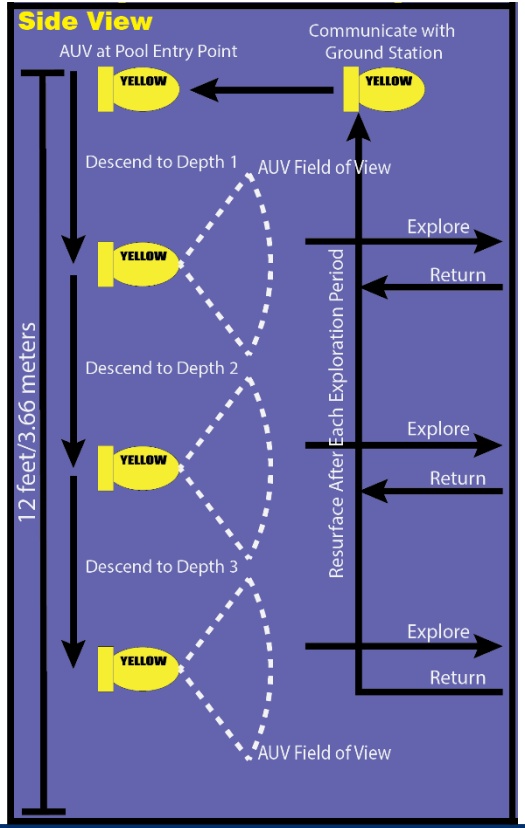
Full Systems Test

- "Sea Trials" planned for April 3-5
  - Entire system integrated, POIs laid out in obstacle course
  - Was to be used to debug the system and verify requirements
  - Only our team present
- Demonstration planned for April 18-19
  - AUV run through its paces for Lockheed Martin advisors, faculty members
  - Purpose is to validate requirements
  - Was in process of reserving the Dive Well at the Rec Center



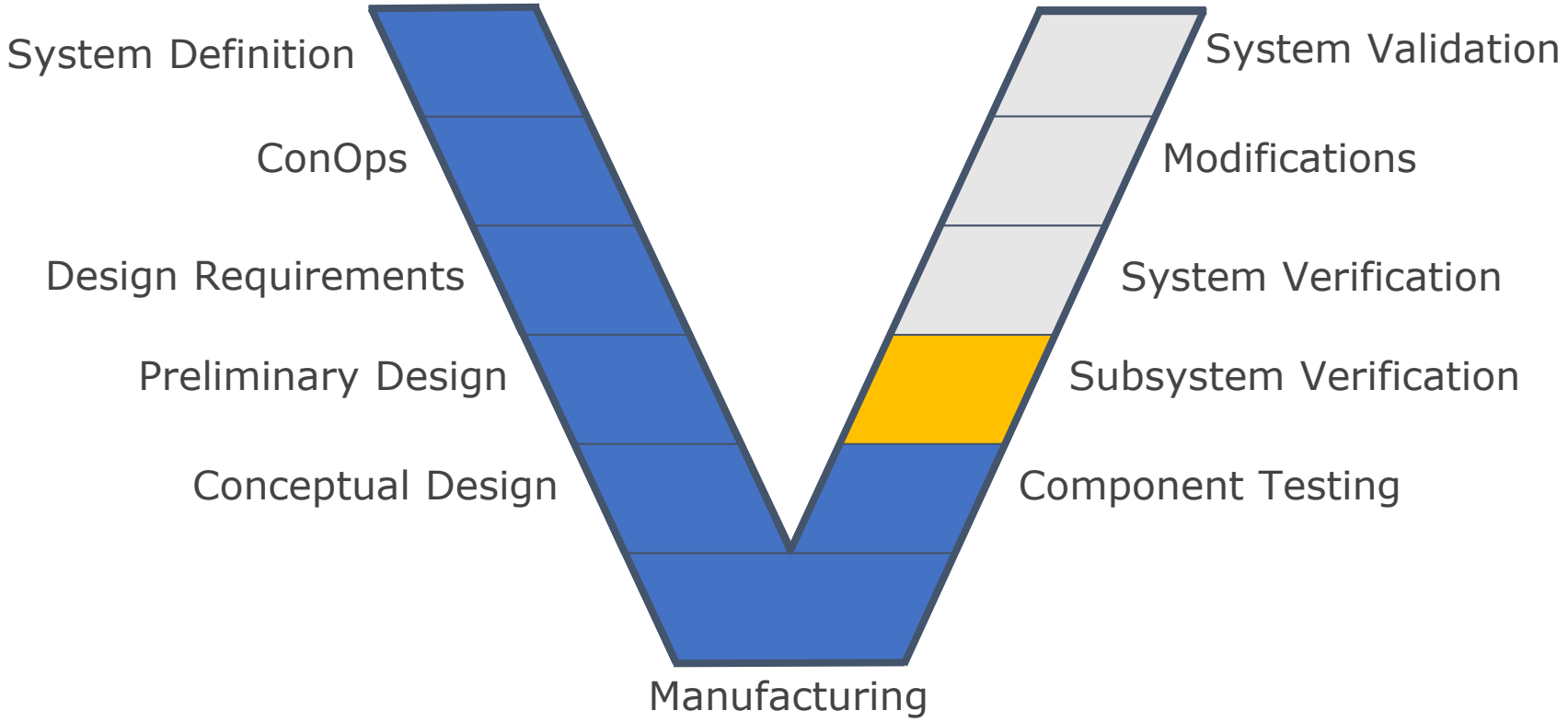
Full Systems Test - Procedure

- Lay out course
- Activate AUV
- Gently set it in pool - Lockheed suggestion after testing drop separately
- Monitor during operations
- Receive data during surface intervals
- Retrieve upon surfacing



Systems Engineering

Systems Engineering "V" Approach



Trade Studies

- Vehicle Shape
  - Informed the layout of our AUV, how it would move
- Localization
  - Learned that it would not have been feasible to make the AUV spatially aware
- Imaging
  - Informed development of the obstacle course, the use of depth perception

Traditional Torpedo with Control Fins	Torpedo (Motor Propulsion for Yaw & Pitch)	Non-Torpedo (4-5 DOF)	Non-Torpedo (6 DOF)	Gimbaling Motors (6 DOF)
1	3	4	5	5
1	3	3	5	3
1	2	3	5	4
5	3	2	2	3
5	4	3	1	1
5	3	3	2	2
5	4	2	1	1
2.8	3.1	3.1	3.4	3

IMU	360 Camera	Landmark Detection	Scanning Imaging Sonar	SONAR Triangulation	LIDAR Triangulation	DVL
5	3	3	5	2	1	5
3	2	4	3	3	2	5
1	3	5	5	4	2	3
5	1	1	3	1	1	5
5	4	2	4	4	1	5
0	5	0	4	3	4	0
2	3	4	5	3	2	2
5	5	4	2	4	0	0
3.5	3.4	3.15	3.6	3.05	1.4	2.75

360 Action Camera	Intel RealSense D435i & T265	Ping360 & Science Camera
2	3	4
1	3	3
2	4	4
1	2	4
1	3	4
5	4	1
2.4	3.35	2.85

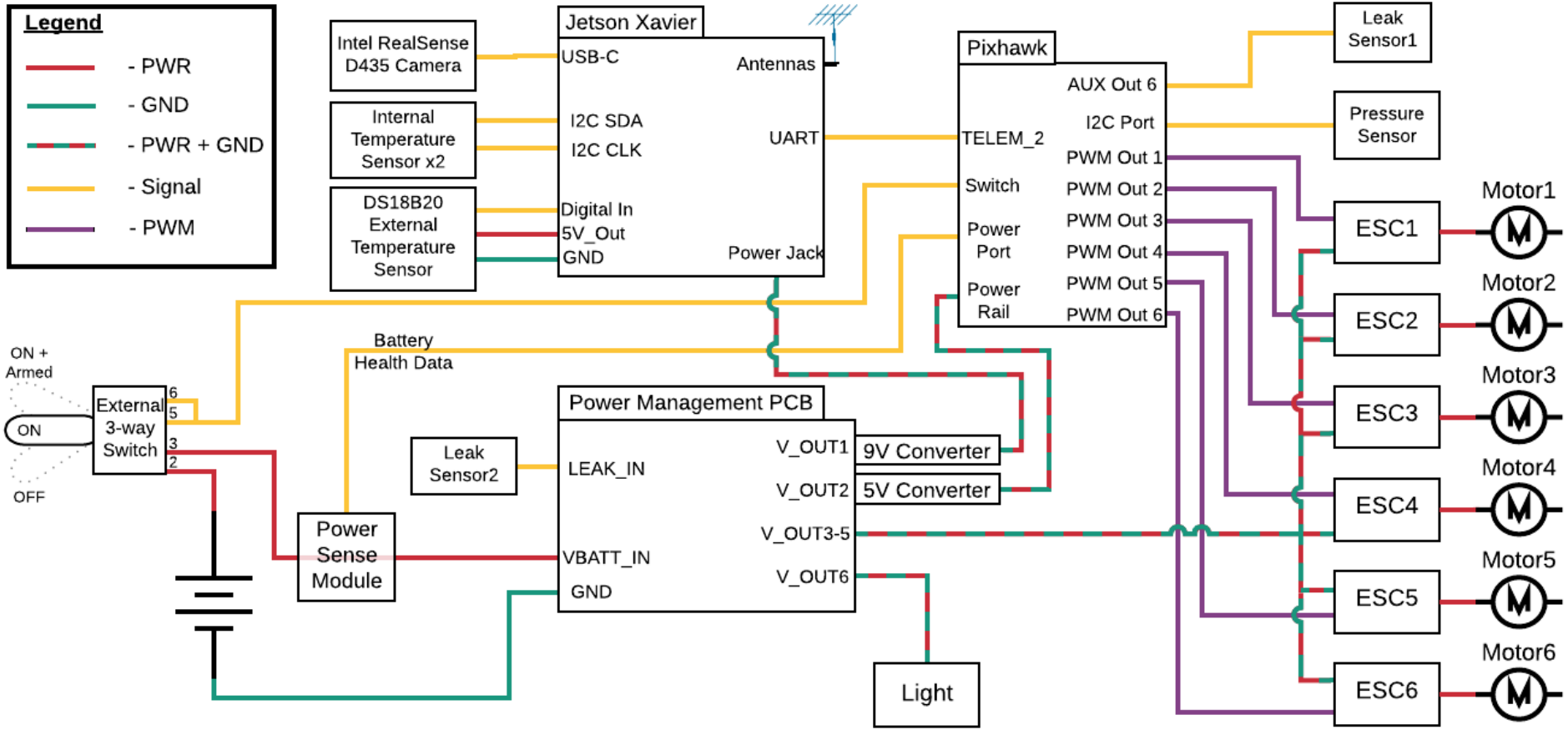
Design Requirements

- Functional Objective: Operate without human control
  - 2.1.1 The vehicle shall autonomously navigate underwater
  - 2.1.2 The vehicle shall perform computations onboard

- Functional Objective: Navigate through an unfamiliar environment
  - 5.1.1 The vehicle shall detect and avoid the walls of a closed body of water
  - 5.1.2 The vehicle shall navigate an underwater course of our design
  - 5.1.2.1 The underwater course shall contain points of interest for the vehicle to find

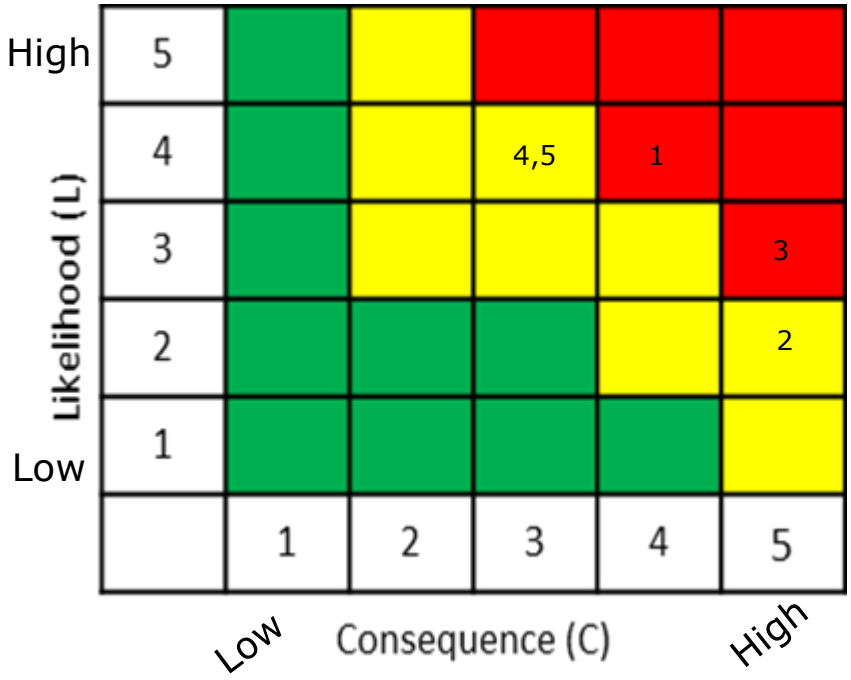
- Functional Objective: Utilize a “Kill Switch”
  - 6.6.1 The kill switch shall detect water
  - 6.6.2 The kill switch shall cut power to all subsystems and surface the vehicle

Interconnection Diagram



Risks

Risk	Color
1) Object Misidentification	
2) Sealing Main Compartment	
3) Stability of AUV	
4) Compartment Temperature	
5) Camera Integration	



- Wire pass-throughs presented a leaking point
- Testing vehicle stability

On track to mitigate red risks

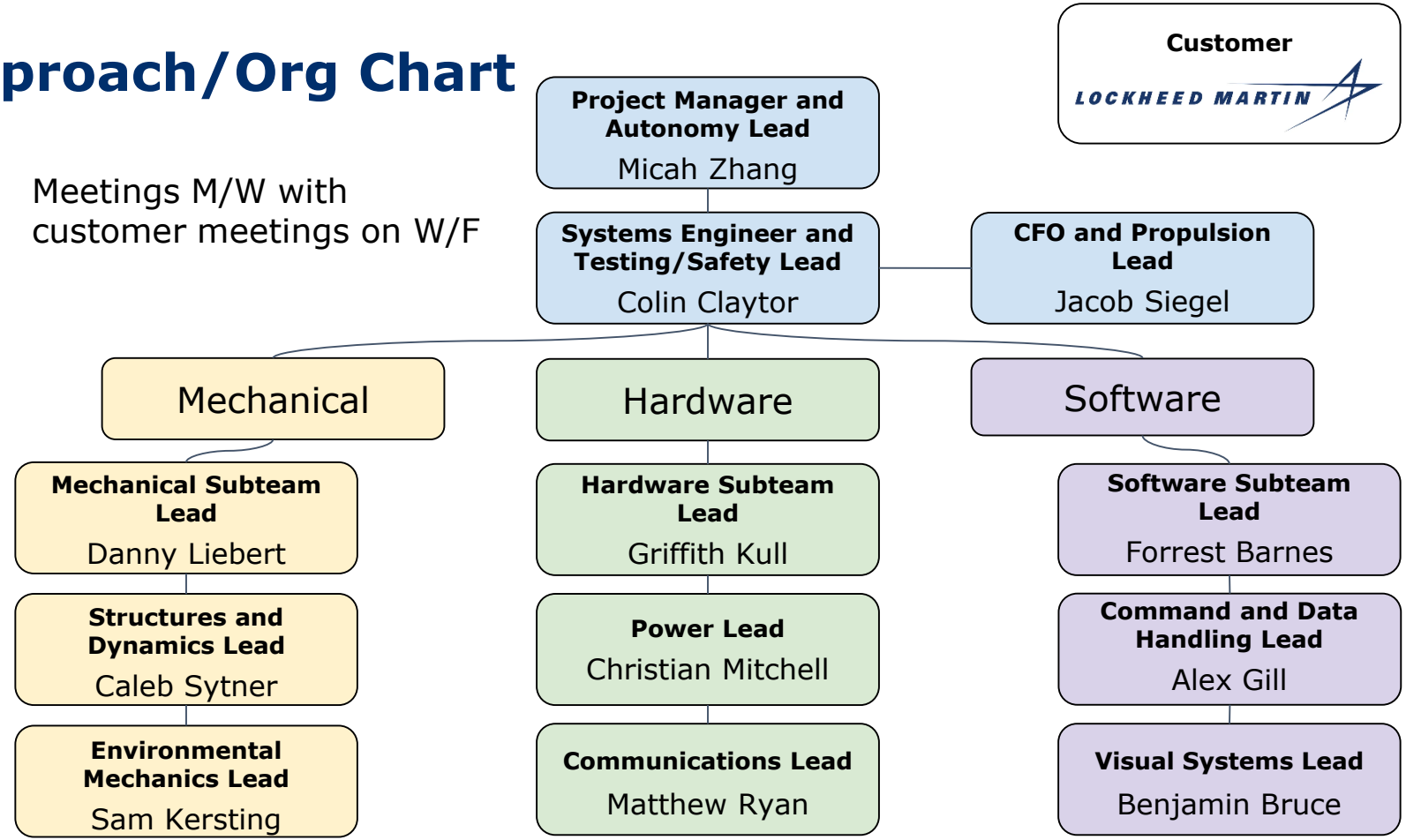
Lessons Learned - Engineering

- Integrate early
- Test often, test early
- Acrylic is prone to cracking
- Human factors in seal development - make access inside easier, more margin in internal space allocation
- Consider all electrical connections and wiring requirements early
- Wire pass throughs are difficult to successfully implement
- Simulations and version control are very valuable
- Be mindful of compute power requirements early

Project Management

Approach/Org Chart

Meetings M/W with customer meetings on W/F



Successes and Lessons Learned - Management

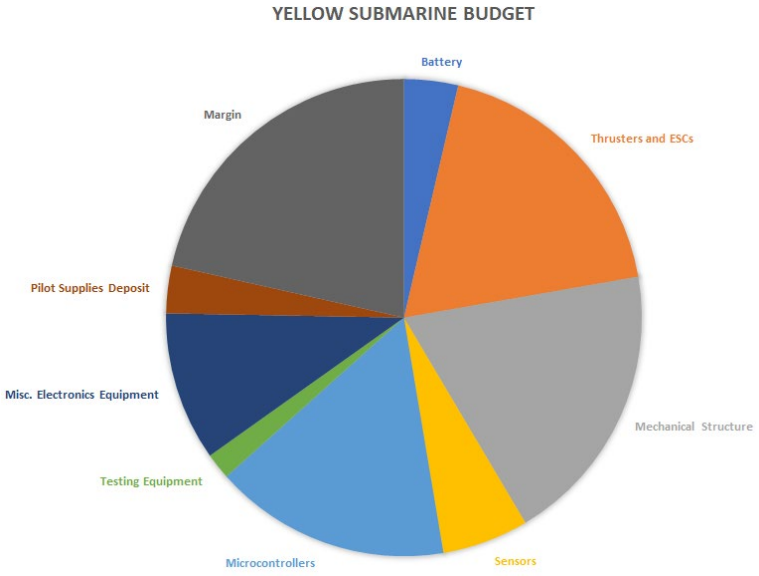
- Successes:
  - Semi-autonomous sub-team management allowed for simultaneous development on multiple critical areas of the project
  - Subteam leads being field-experts facilitated rapid development
  - Hierarchical org-chart allowed for efficient operation and management

- Lessons Learned:
  - Subteams may have conflicting priorities and/or timelines
  - Open, transparent, and frequent communication between subteams is critical

Planned vs. Actual Budget

Planned Cost at CDR	**$3700.33**
Total Expenditure at Cancellation	**$4917.98***
Total Budget	**$6202.36**

*Shipping cost: $380.06



Project upgrades after EEF:

- Higher performance computer (better FPS)
- New model vertical thrusters
- Ability to test and add features

ENGINEERING EXCELLENCE FUND

Calculation of Effort

- Combined 1st + 2nd Semester:
  - Total: 3767 hours
  - Average/week: 157 hours
  - Estimated cost: $358075
  - $31.25/hour

As of March 13:

- Approx Hours of Code: 150
  - Approx lines of Code: 2000
- Approx Hours of CAD: 80
- Approx Hours of Manufacturing: 60
  - Approx hours of Machine time: 40
- Approx Hours of Electronics Manufacturing/integration: 30
- Approx Hours of Image Processing work: 80

Thank You

Backup

Backup Table of Contents

Critical Project Elements

- **Structural Integrity --** 1.5.1: Water Pressure, 5.3.1: Drop Survival, 1.6.1: Thermal Testing
  - Ensures system can survive the mission environment
- **Power --** 1.1.1: Onboard Batteries, 1.4.1: Electrically Driven
  - Keeps system active for duration of mission
- **C&DH --** 3.2.1: Image and Data Packets, 3.3.1: Onboard Data Storage, 4.1.1: Complete Data Transmittal
  - Necessary for navigation, relaying data to ground station
- **Autonomous Navigation --** 1.5.2: Depth Control, 2.1.1: Underwater Movement
  - Human input impossible in mission environment
- **Image Processing --** 2.1.1.4: Collision Avoidance, 5.2.1: POI Data
  - Used in Autonomous Navigation, reporting of Points of Interest to the ground station

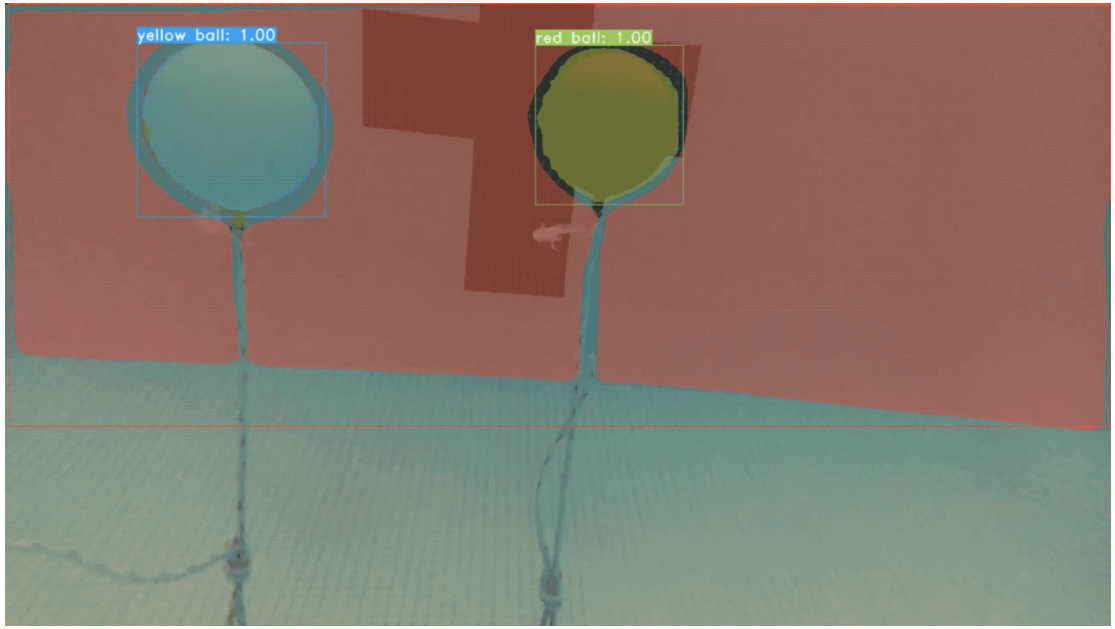
Approach

General Structure:

- 3 semi-autonomous subteams - software, mechanical, electrical
- Each subteam has a subteam lead
- Mon., Wed. meetings are group meetings
- Customer meetings held 1/week alternating b/t Wed. and Fri.
- Fri. meetings reserved for either customer meetings or individual team meetings on an as-needed basis
- 1 PM
- 1 Systems Engineer
- 1 CFO

General Results - Image Processing

Successfully recognizes POIs and pool wall in pseudo-real time 3.2FPS with high accuracy



Calculation of Effort

- 1st Semester:
  - Total: 2205 hours
  - Average/week: 157 hours
  - Estimated cost: $68906
- 2nd Semester:
  - Total: 1562 hours
  - Average/week: 156 hours
  - Estimated cost: $48813

Possible addition:

- Approx Hours of Code:
  - Approx lines of Code:
- Approx Hours of CAD: 80
- Approx Hours of Manufacturing: 60
  - Approx hours of Machine time: 40
- Approx Hours of Electronics Manufacturing/integration:
- Approx Hours of Image Processing work:

Mechanical

Pressure Test

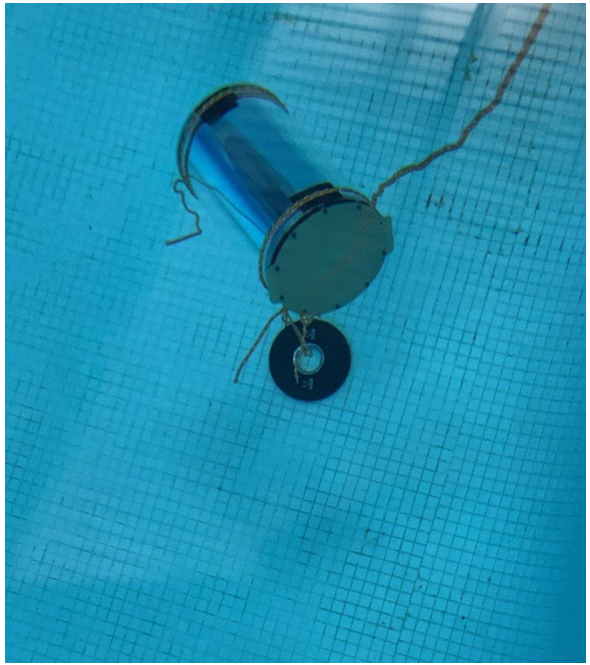
- Scheduled: 2/21 - 3/6
- Completion Status: Completed on 3/1
- Test Readiness
  - Rationale: Testing whether housing can withstand pressure at maximum operating depth
  - Location: Rec center pool
- Risk Reduction
  - Buckling
- Requirement Verification
  - Requirement 1.5.1: Vehicle shall withstand water pressure at its mission depth

Pressure Test - Results

- AUV housing submerged at 3.66m in rec center pool
- This will determine if the housing will buckle at deepest operational depth

- Result: Housing did not buckle and there were no signs of structural damage
- Time Elapsed: 15 minutes

Success



Leak Test 1 - Results

- First leak test consisted of main housing (tube and endcaps) floating in a sink
- This determined if there were any high level leaks while floating

- Completed: 2/29
- Result: Minimal leakage found along the gasket
- Time Elapsed: 1 hour
- Solution: Try a softer rubber gasket, add silicone grease

Leak Test 2 - Results

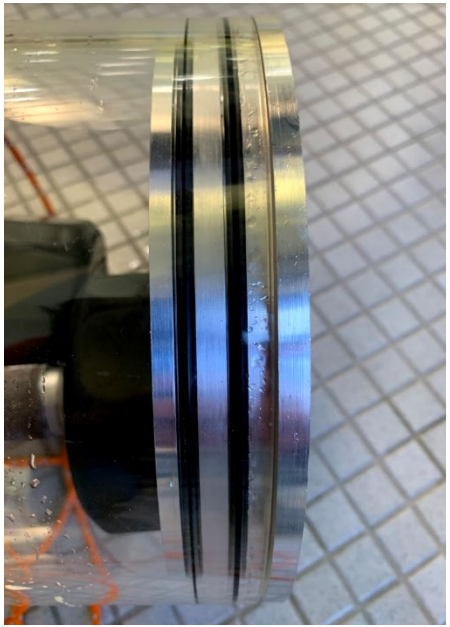
- Consisted of main housing (tube and endcaps) located at 3.66m depth in the rec center pool
- High level leak test

- Completed: 3/1
- Result: Small leakage found along the gasket and acrylic bowed between bolts
- Time Elapsed: 15 minutes
- Solution: Increase number of bolts along acrylic plate, try a harder rubber gasket, and add silicone grease

Leak Test (Preliminary) - Results

- Multiple preliminary leak tests
- Tests resulted in leaks

- Solution:
  - Increased number of bolts
  - Added aluminum ring
  - Increased o-ring size

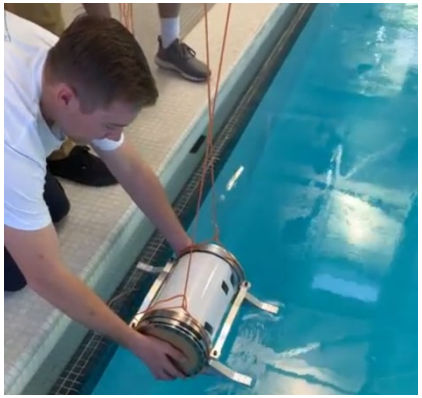


Preliminary Leak Validation

- With the mitigations, the tube and endcaps (with no passthroughs) successfully passed the preliminary leak test.

- This allowed for the penetrations and holes to be cut in the endcap to progress with leak testing

Success



Electrical

Electronics Testing

Completed:

- Motor + ESC initial test
  - 2/17 - 2/28
    - Basic communications
      - 2/17 - 2/28
        - Battery under load
          - 2/10 - 3/6
            - PCB v1 test
              - 2/26 - 2/28
                - Full power system
                  - 2/28 - 3/13

Electronics Testing

To be completed:

- PCB V2 test
  - 3/16 - 3/27
    - Environmental sensor test
      - 3/16 - 3/20
        - Full vehicle integration
          - 3/20 - 3/31
            - Surfaced communication test
              - 3/28 - 4/4

Power System Test - Expected Results

Procedure

- Connect battery though PCB to electronic load
- Monitor power until 85% nominal voltage

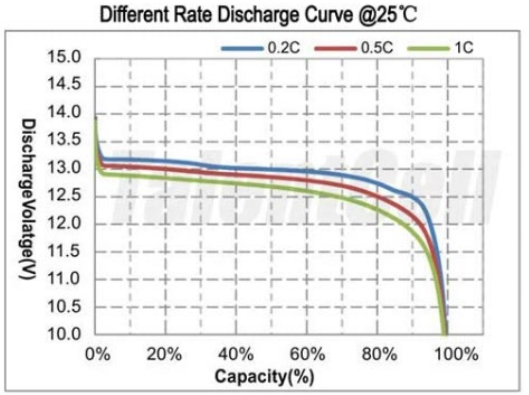
Expected Results

- Near 13V for first hour
- Cutoff at 1.3 hours

Vehicle State	Current (A)	Power (W)	Time Spent in State (hrs)	Weighted Average Total Current (A)	Weighted Average Total Power (W)
Total:			1.00	**6.85**	**66.5**

Battery Characteristics				Peak Current (A)	Peak Power (W)
Voltage (V)	13			**8.17**	**83.7**
Depth of Discharge	0.75				
Temperature Correction Factor	1			Total Consumption (Ah)	Battery capacity required (Ah)
Design Margin	1.2			7.44	**11.9**

Regulator Characteristics	
Efficiency	0.92



Software

WiFi Transfer Tests

- Mostly completed
- First test was to send 1-3 images over the school network
  - Successful
- Second test was to send around 300 images over the new router acquired
  - Transfer time was approximately 5-7 seconds
- Third test would have been sending images from the AUV to the ground station from the pool
  - Incomplete, but expected to succeed due to the addition of the antenna to the AUV

Collision Avoidance Test

- Scheduled: 3/13 - 3/20
- Completion Status: To be completed
- Test Readiness
  - Rationale: Verify that the vehicle will avoid collisions without interrupting its mission.
  - Location: Rec center pool
- Risk Reduction
  - Harm to vehicle, failure to complete mission
- Requirement Verification
  - 2.1.1.4: The vehicle shall avoid collisions within its field of view

Collision Avoidance Test - Procedure and Expected Results

Procedure:

- Place AUV in pool
- Begin running mission
- Place unexpected object in FOV of AUV during mission
- Observe AUV behavior

Expected Results:

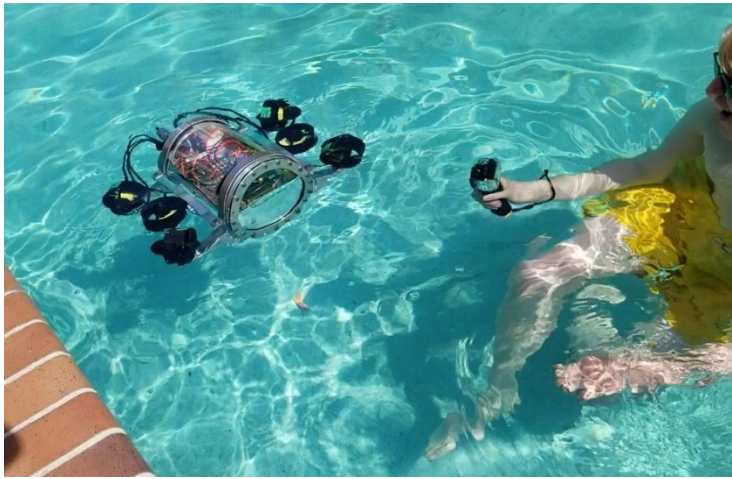
- AUV avoids objects with a clearance of 0.3m without interrupting mission
- Verify that the vehicle passes requirement 2.1.1.4 Collision Avoidance

Not completed: Awaiting full system integration test

Systems Tests

Controls/Dynamics Test

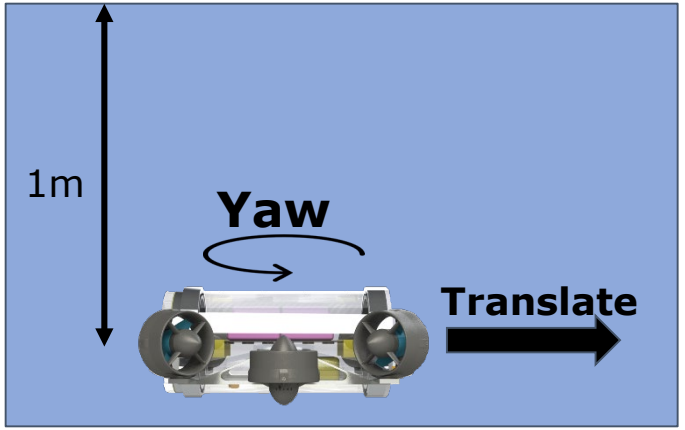
- Scheduled: 3/7 - 3/15
- Completion: **In Progress**
- Test Readiness
  - Rationale: Compare real controls behavior to simulation
  - Location: Rec center pool
- Risk Reduction
  - Motor Failure, Controls Failure, Unexpected Behavior
- Requirement Verification
  - Requirement 2.1.1: Vehicle shall autonomously navigate underwater



Controls/Dynamics Test - Procedure and Expected Results

Procedure:

- Integrate AUV with motors and basic control functionality
- Connect to Nano over WiFi/SSH
- Insert AUV into pool and activate
- Run preset script from laptop
- Observe AUV behavior
- Deactivate and remove AUV



Expected Results:

- Verify the simulation with visual and IMU data of the reactions of the vehicle to control inputs

Miscellaneous

Mechanical Schedule

	TASK NAME	START DATE	END DATE	DURATION (WORK DAYS)	TEAM MEMBER	PERCENT COMPLETE
Spring	Purchase Materials	-	-	-	Jake	90
	Laser cut acrylic front panel and gasket	1/24/2020	2/1/2020	6	Danny	100
	Machine Al end-cap	2/1/2020	2/14/2020	10	Danny	80
	Machine front ring seal	2/1/2020	2/14/2020	10	Danny	95
	3D Print elec tray mounts	2/14/2020	2/18/2020	3	Danny	90
	Leak test	**2/14/2020**	**3/18/2020**	**24**	**Sam**	**20**
	Machine AL bottom clamps	2/14/2020	3/3/2020	13	Danny	100
	Machine AL Vertical Motor Mounts	2/14/2020	3/3/2020	13	Danny	100
	Pressure test	**2/21/2020**	**3/6/2020**	**5**	**Sam**	**100**
	Test motors underwater	**2/21/2020**	**3/6/2020**	**11**	**Caleb**	**10**
	3D Print bumpers	2/21/2020	3/20/2020	21	Danny	45
	3D Print water baffle	2/22/2020	3/5/2020	9	Danny	100
	Role and Bend AL top clamps	3/1/2020	3/4/2020	3	Danny	0
	Water jet AL motor shims and clips	3/4/2020	3/11/2020	6	Danny	0
	Water jet AL electronics tray	3/4/2020	3/11/2020	6	Danny	0
	Mount motors and structure to tube	3/5/2020	3/8/2020	2	Danny	0
	Thermal test	**3/5/2020**	**4/2/2020**	**4**	**Sam**	**0**
	Drop test	**3/6/2020**	**3/8/2020**	**3**	**Caleb**	**0**
	Machine elec tray-endcap interface	3/9/2020	3/13/2020	5	Danny	0
	Manufacture thermal strap	3/13/2020	3/20/2020	6	Sam	0
	Buoyancy test	**3/18/2020**	**4/2/2020**	**7**	**Sam**	**0**
	Dynamics test	**3/30/2020**	**4/2/2020**	**4**	**Caleb**	**0**

Electrical Schedule

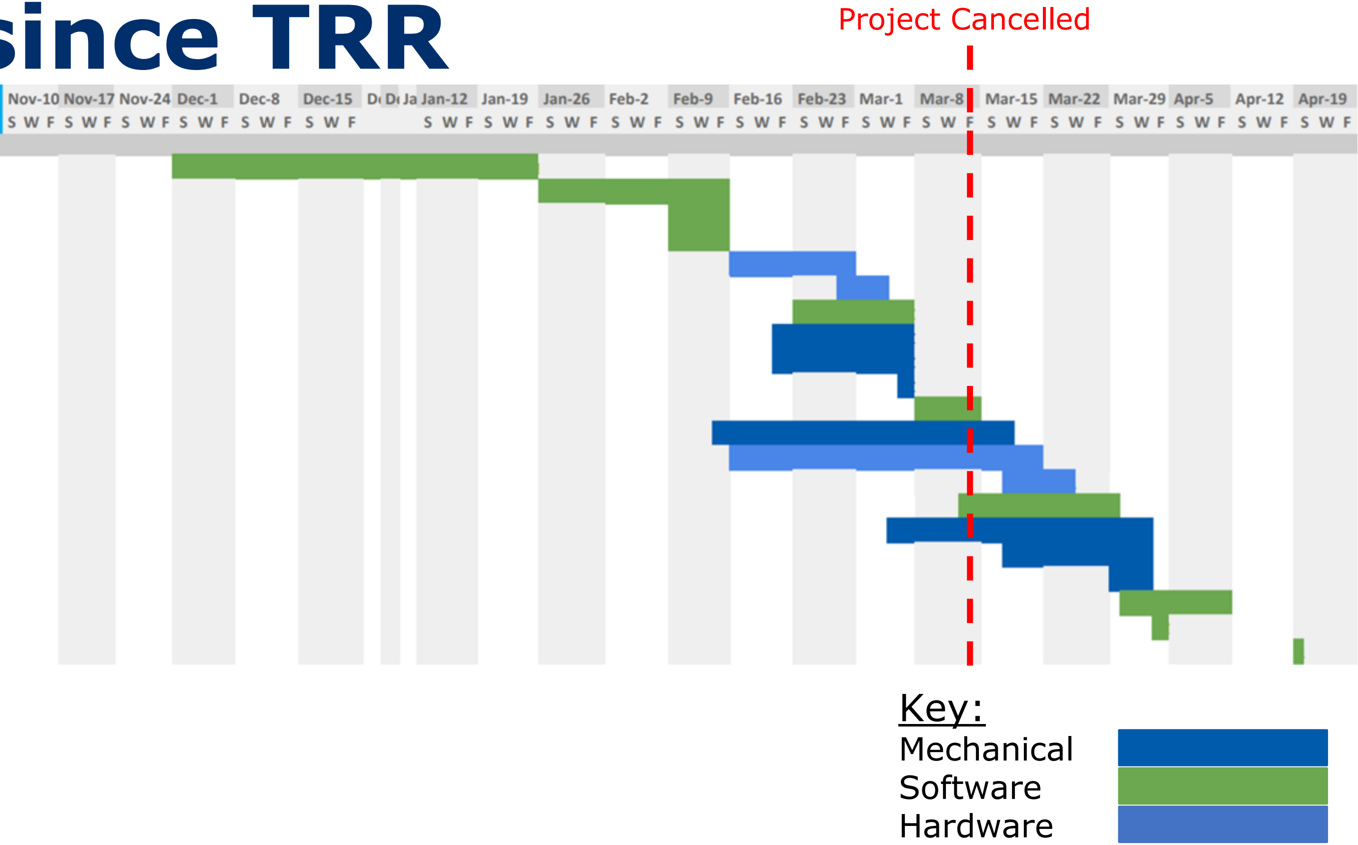
	TASK NAME	START DATE	END DATE	DURATION (WORK DAYS)	TEAM MEMBER	PERCENT COMPLETE
Spring	**Electronics tray assembly**	**2/17/2020**	**3/20/2020**	**25**	**Hardware**	**10**
	Battery testing	2/10/2020	3/6/2020	20	Matt	15
	ESC + Motor testing	**2/17/2020**	**2/28/2020**	**10**	**Christian**	**90**
	PCB v1 order + assembly	2/17/2020	2/26/2020	8	Matt	100
	Power system v1 testing w/ stable power supply	2/26/2020	2/28/2020	3	Christian	20
	Power system v1 testing w/ battery	**2/28/2020**	**3/4/2020**	**4**	**Christian**	**0**
	Calibrate and test temperature sensor	2/26/2020	3/4/2020	6	Griff	0
	Calibrate and test pressure sensor	2/26/2020	3/4/2020	6	Griff	0
	PCB v2 design buffer	3/4/2020	3/6/2020	3	Christian	0
	PCB v2 order + assembly buffer	3/6/2020	3/11/2020	4	Griff	0
	PCB v2 + converters testing buffer	3/11/2020	3/13/2020	3	Christian	0
	PCB v2 + converters + battery testing buffer	3/11/2020	3/13/2020	3	Griff	0
	Out of water communications testing	2/17/2020	2/28/2020	10	Matt	100
	Surfaced AUV communications test	**3/18/2020**	**3/25/2020**	**6**	**Matt**	**0**

Software Schedule

	TASK NAME	START DATE	END DATE	DURATION (WORK DAYS)	TEAM MEMBER	PERCENT COMPLETE
Spring	**Full Image Processing Stack Test**	**12/2/2019**	**1/24/2020**	**40**	**Software**	**100**
	Gazebo Controls Test	1/20/2020	2/13/2020	19	Software	100
	Integrate D435 w/ Jetson TX2	1/24/2020	2/1/2020	6	Software	100
	Benchmark TX2	1/26/2020	2/1/2020	5	Micah	100
	Complete State Machine	**1/26/2020**	**2/14/2020**	**15**	**Alex**	**100**
	Integrate Python with ArduSub	1/26/2020	2/1/2020	5	Forrest	100
	Import AUV model into Gazebo	1/29/2020	2/8/2020	8	Forrest/Ale	100
	Integrate camera into Gazebo	2/8/2020	2/22/2020	10	Alex	80
	Resolve Depth data issues	**2/9/2020**	**2/15/2020**	**5**	**Software**	**100**
	Test YOLACT live in water	**2/9/2020**	**2/15/2020**	**5**	**Software**	**100**
	Create ground station software	2/16/2020	3/4/2020	13	Benjamin	85
	Optimize YOLACT	2/16/2020	3/13/2020	20	Micah	20
	Single Motor Integration Test	2/17/2020	2/21/2020	5	Forrest	100
	WIFI Transfer Test	2/17/2020	2/24/2020	6	Benjamin	100
	Integrate YOLACT with State Machine	2/16/2020	3/6/2020	15	Software	50
	Test Full Stack in Gazebo	**2/23/2020**	**3/6/2020**	**10**	**Software**	**20**
	6 Motor Integration Test	2/24/2020	3/6/2020	10	Forrest	50
	Integrate other sensors	3/7/2020	3/15/2020	5	Software	0
	Controls Test	**3/7/2020**	**3/13/2020**	**5**	**Software**	**0**
	Collision avoidance test in water	3/13/2020	3/20/2020	6	Software	0
	Fully autonomous operation	**3/13/2020**	**3/30/2020**	**12**	**Software**	**0**
	Extra control operations	3/30/2020	4/14/2020	12	Software	0
	Full Systems Test	**3/31/2020**	**4/10/2020**	**9**	**Software**	**0**

Changes since TRR

TASK NAME	START DATE	END DATE	TEAM
Full Image Processing Stack Test	12/2/2019	1/24/2020	Software
Complete State Machine	1/26/2020	2/14/2020	Software
Resolve Depth data issues	2/9/2020	2/15/2020	Software
Test YOLACT live in water	2/9/2020	2/15/2020	Software
ESC + Motor testing	2/17/2020	2/28/2020	Hardware
Power system v1 testing w/ battery	2/28/2020	3/4/2020	Hardware
Test Full Stack in Gazebo	2/23/2020	3/6/2020	Software
Pressure test	2/21/2020	3/6/2020	Mechanical
Test motors underwater	2/21/2020	3/6/2020	Mechanical
Drop test	3/6/2020	3/8/2020	Mechanical
Controls test	3/7/2020	3/13/2020	Software
Leak test	2/14/2020	3/18/2020	Mechanical
Electronics tray assembly	2/17/2020	3/20/2020	Hardware
Surfaced AUV communications test	3/18/2020	3/25/2020	Hardware
Fully autonomous operation	3/13/2020	3/30/2020	Software
Thermal test	3/5/2020	4/2/2020	Mechanical
Buoyancy test	3/18/2020	4/2/2020	Mechanical
Dynamics test	3/30/2020	4/2/2020	Mechanical
Full Systems Test	3/31/2020	4/10/2020	Software
Sea Trials	4/3/2020	4/5/2020	All
FInal Demonstration	4/19/2020	4/20/2020	All



Systems Engineering

- Trades x3: Shape, Localization, Imaging
- Some design requirements
- Interface: interconnect diagram
- Risks
- Systems Challenge: meeting complexity, changing hardware to accommodate new insight