RiBBIT

River **B**athymetry **B**ased **I**ntegrated **T**echnology

Test Readiness Review

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Project Overview

Mission Motivation

Problem

Rivers are a critical resource to monitor due to contributions to agriculture, urban development, hazard monitoring, and environmental monitoring.

There is a lack of updated and accurate global data for river discharge, especially in hard to access rivers.

A hard to access river is one which presents a physical risk for humans to access on foot.

Existing Solutions

Earth Orbiting Satellites

Boat tagline system with acoustic instrument and velocity tracker

Helicopters towing radar systems

ASTRALite EDGE

Market Gaps

Data Resolution

Safety

Low-Cost

Ease of use
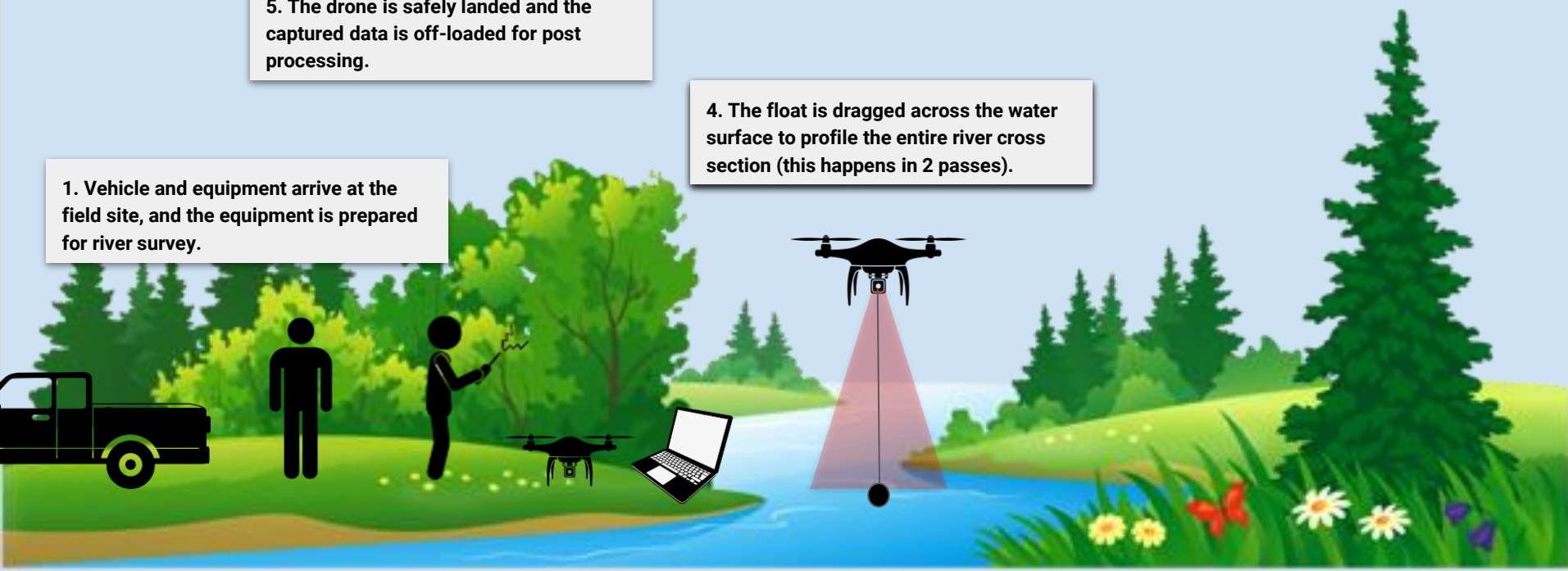
Quick set-up and data collection

Mission Statement

"The long term goal of this project is to design, manufacture, and test a drone-mounted sensor system to gather river depth profile and velocity data in hard-to-access areas for the purpose of monitoring river discharge."
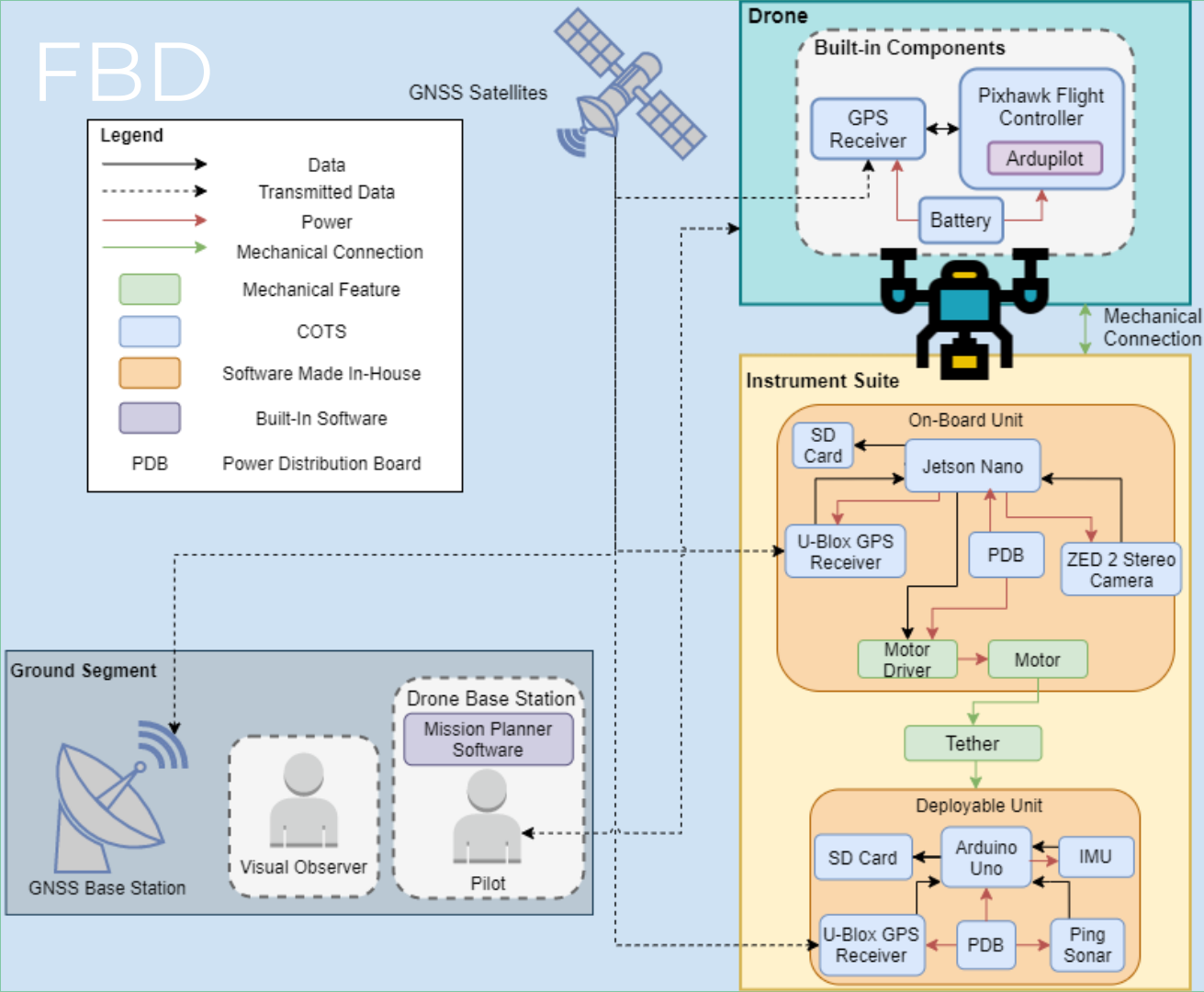
CONOPS

5. The drone is safely landed and the captured data is off-loaded for post processing.

4. The float is dragged across the water surface to profile the entire river cross section (this happens in 2 passes).
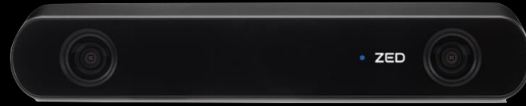
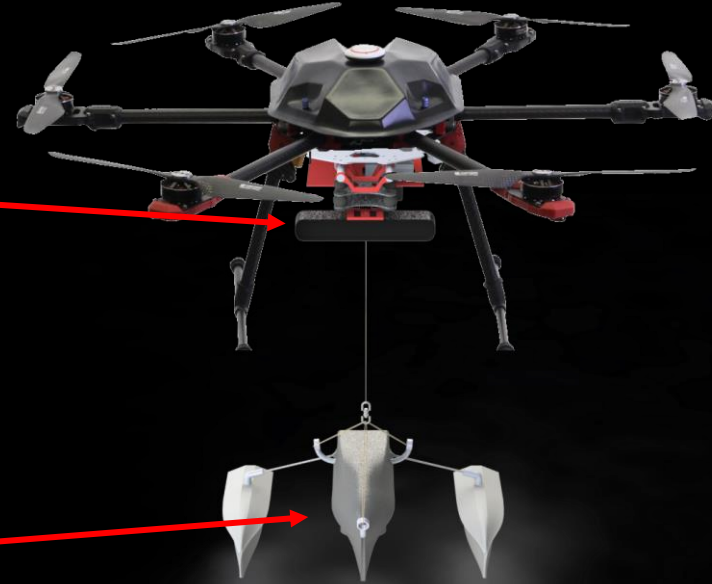1. Vehicle and equipment arrive at the field site, and the equipment is prepared for river survey.

FBD

Legend

→	Data
⇢	Transmitted Data
→	Power
→	Mechanical Connection
▢	Mechanical Feature
▢	COTS
▢	Software Made In-House
▢	Built-In Software
PDB	Power Distribution Board

GNSS Satellites

Drone

Built-in Components

GPS Receiver

Pixhawk Flight Controller

Ardupilot

Battery

Mechanical Connection

Instrument Suite

On-Board Unit

SD Card

Jetson Nano

U-Blox GPS Receiver

PDB

ZED 2 Stereo Camera

Motor Driver

Motor

Tether

Deployable Unit

SD Card

Arduino Uno

IMU

U-Blox GPS Receiver

PDB

Ping Sonar

Ground Segment

Drone Base Station

Mission Planner Software

Visual Observer

Pilot

GNSS Base Station

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Science Instruments

Zed 2 Stereo Camera

Ping Sonar Echosounder

Deployment Mechanism

Vibration dampener

Jetson

Battery

GNSS

Servo

Motor

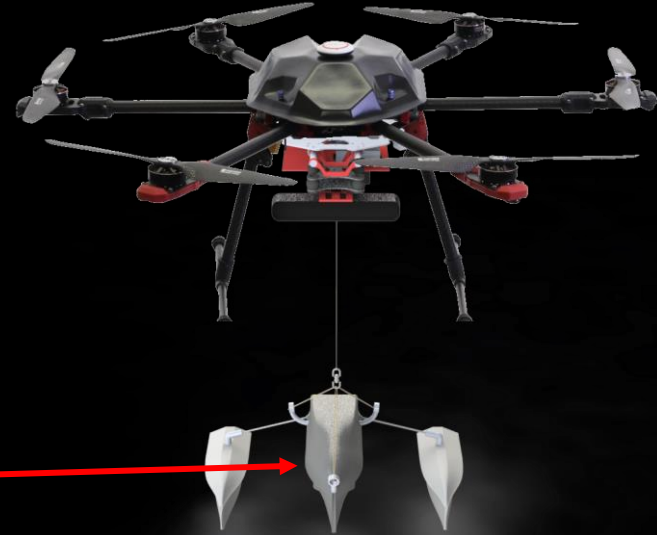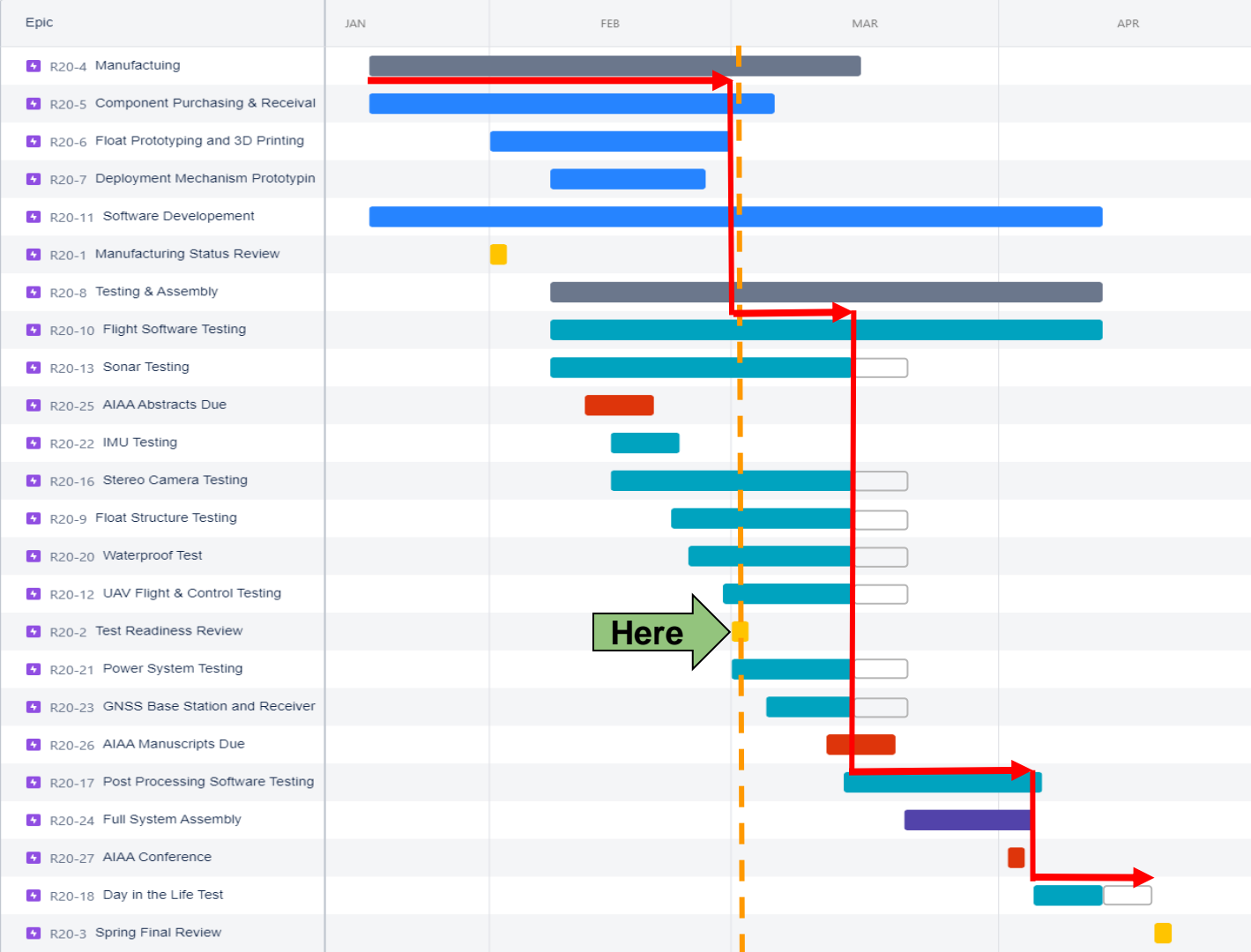Camera
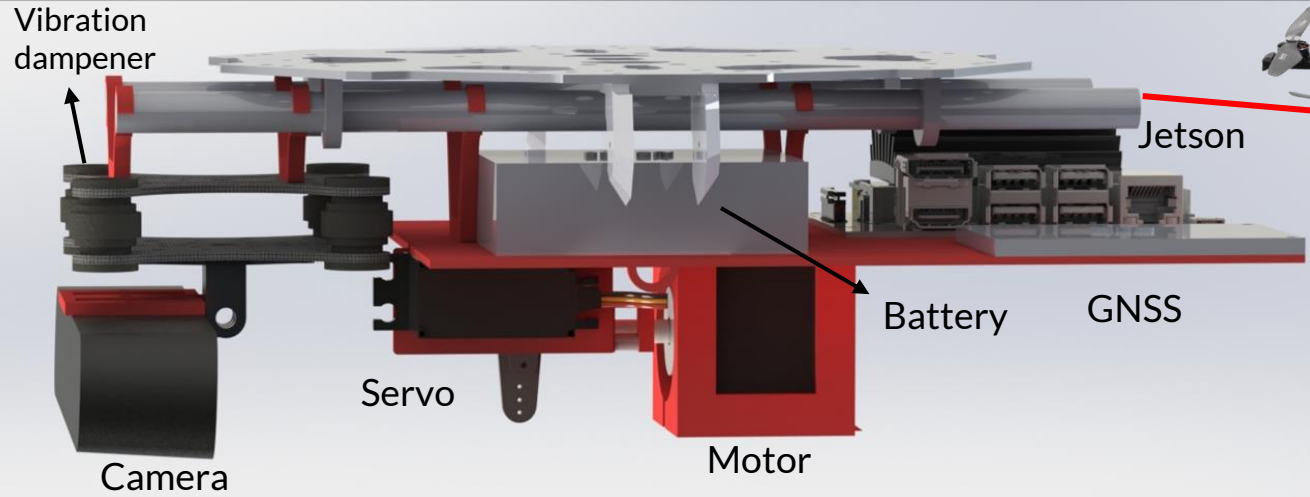
Sonar Float Design

Total est. weight: 894 grams

Note Banana for scale ONLY, not a part of design

Schedule

Gantt Chart

Epic	JAN	FEB	MAR	APR
R20-4 Manufactuing				
R20-5 Component Purchasing & Receival				
R20-6 Float Prototyping and 3D Printing				
R20-7 Deployment Mechanism Prototypin				
R20-11 Software Developement				
R20-1 Manufacturing Status Review				
R20-8 Testing & Assembly				
R20-10 Flight Software Testing				
R20-13 Sonar Testing				
R20-25 AIAA Abstracts Due				
R20-22 IMU Testing				
R20-16 Stereo Camera Testing				
R20-9 Float Structure Testing				
R20-20 Waterproof Test				
R20-12 UAV Flight & Control Testing				
R20-2 Test Readiness Review				
R20-21 Power System Testing				
R20-23 GNSS Base Station and Receiver				
R20-26 AIAA Manuscripts Due				
R20-17 Post Processing Software Testing				
R20-24 Full System Assembly				
R20-27 AIAA Conference				
R20-18 Day in the Life Test				
R20-3 Spring Final Review				

Here

Legend:
- Manufacturing
- Testing
- Margin
- Assembly
- AIAA Deadlines
- Milestones
- Critical Path

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Test Readiness

Test Overview

- **Structural**
  - [Float Structure Test](#)
  - [Waterproof Test](#)
- **Flight Software**
  - [Jetson Nano Flight Software Test](#)
  - [Arduino Uno Flight Software Test](#)
  - [Pixhawk-Jetson Communication Test](#)
- **Avionics**
  - [UAV Flight & Control Test](#)
  - [Deployment Mechanism Test](#)
  - [Power System Test](#)

- **Science Instruments**
  - Sonar Test
  - [IMU Test](#)
  - [Stereo Camera Test](#)
  - [GNSS Base Station & Receiver Test](#)
- **Data Post Processing Software**
  - [Depth Profile Correction Test](#)
  - [Stereo Camera Image Verification Test](#)
  - [SLAM Test](#)
  - Velocity Post-Processing Testing (RiVER Software)
  - [Uncertainty Quantification Program](#)

Day In the Life Test

Sonar Testing: Overview

Design Requirements:

DR4.1.2 - The SONAR instrument shall be capable to measure depths to an accuracy of <1% of the total depth.

DR4.6.2 - The IMU shall measure the angular displacement between the SONAR pointing ray within ± 1 degree accuracy.

DR6.2.1 - The micro-controller shall be responsible for storing the data locally to an SD card.

DR7.2.1 - The depth profile shall be post-processed to correct for the angular displacements of the float.

Test Purpose: Verify the corrected depth measurements from sonar and IMU are within accuracy requirements and that data is written to and stored on the onboard SD card.

Test Status: SONAR and IMU have been tested in air. Data collection trigger has been tested and is functional. Sensor data is written to SD card and has the correct format.

Test Validation: Compare corrected distance measurements with known distance

Test Criteria: Corrected depth measurements shall be accurate to <1% of the true depth

Sonar Testing: Equipment and Facilities
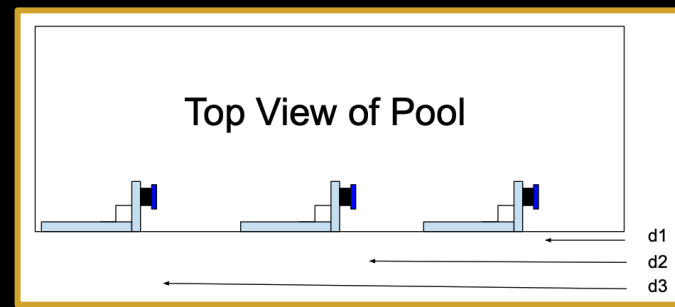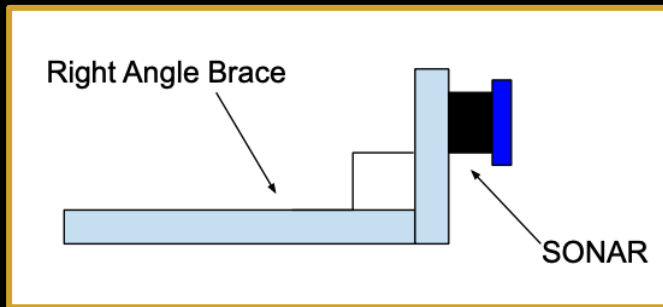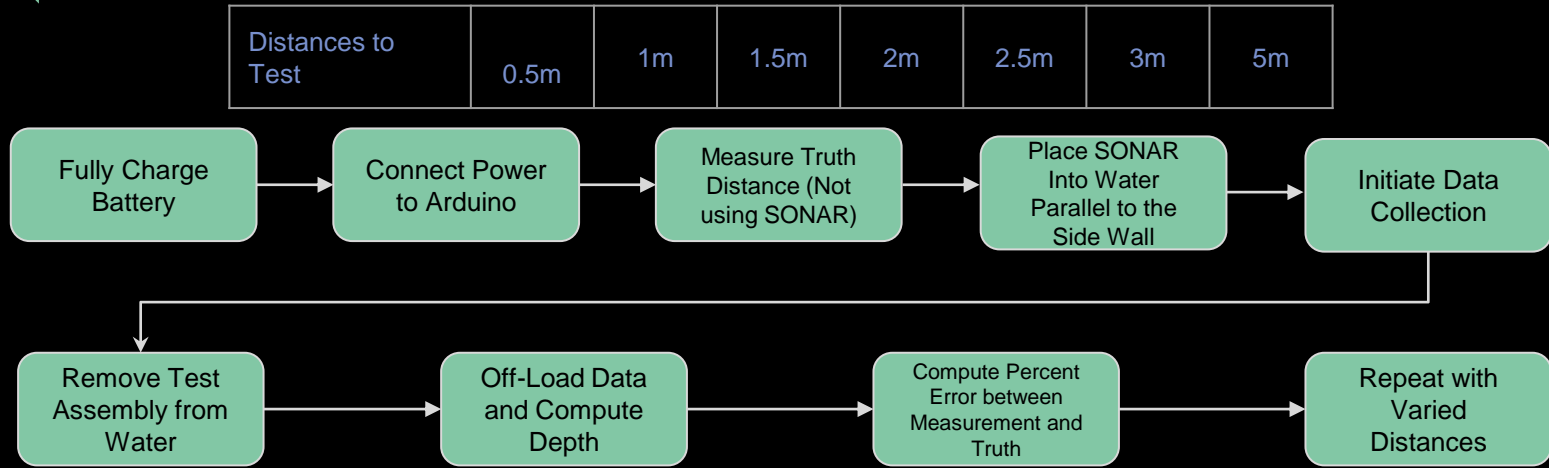
Test Facilities:

- CU Clare Pool
- Right Angle Brace

Equipment:

- Ping Sonar
- Right Angle Brace
- IMU
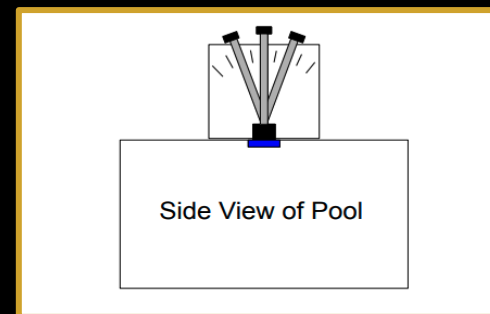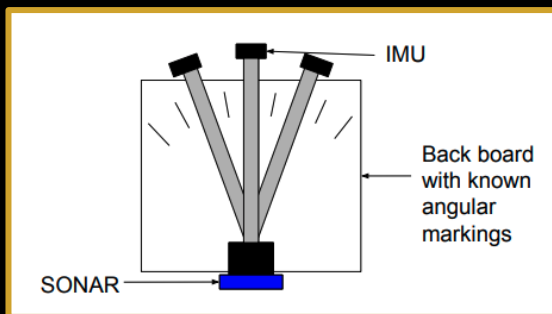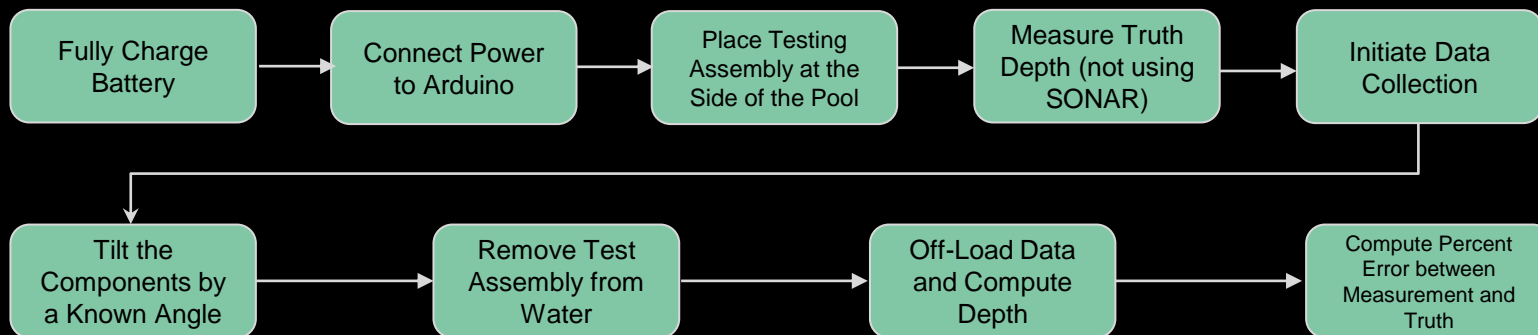- Water Sensor
- Arduino UNO
- SD Card Reader with SD Card

Sonar Depth Testing: Test Procedure Review

Distances to Test	0.5m	1m	1.5m	2m	2.5m	3m	5m

```
Fully Charge Battery → Connect Power to Arduino → Measure Truth Distance (Not using SONAR) → Place SONAR Into Water Parallel to the Side Wall → Initiate Data Collection
```

```
Remove Test Assembly from Water → Off-Load Data and Compute Depth → Compute Percent Error between Measurement and Truth → Repeat with Varied Distances
```

Right Angle Brace

SONAR

Top View of Pool

d1
d2
d3

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Sonar Angular Displacement Testing: Test Procedure Review

Angles to Test	±2⁰	±5⁰	±10⁰	±15⁰	±20⁰

Fully Charge Battery → Connect Power to Arduino → Place Testing Assembly at the Side of the Pool → Measure Truth Depth (not using SONAR) → Initiate Data Collection

Tilt the Components by a Known Angle → Remove Test Assembly from Water → Off-Load Data and Compute Depth → Compute Percent Error between Measurement and Truth

IMU

Back board with known angular markings

SONAR

Side View of Pool

Velocity Post-Processing Testing and Validation

Design Requirements:

DR5.1.2 - The stereo camera shall be able to capture surface velocities between 0-4m/s.

DR6.1.1 - The main computer shall store the data collected by the stereo camera locally to an SD card.

DR7.1   - The stereo camera shall be post-processed to calculate to river surface velocity.

DR7.1.1- The computed surface velocity shall be within 20% of the true surface velocity.

Test Purpose: Ensure meaningful surface velocity calculations can be computed via collected stereo camera river video and 3D depth data

Test Status: Test of data run-through in RIVeR software application complete. Must still collect stereo camera data and truth data to run through software. Plan to be completed mid-March.

Test Validation: Computed surface velocity will be compared to collected truth data.

Test Criteria: Computed surface velocity will have less than 20% error.

Velocity Post-Processing Testing and Validation

Test Facilities:
- East Boulder Rec Center Lazy River

Equipment:
- Stereo Camera
- Jetson Nano
- Power Source
- Measuring Tape
- Ping-Pong Balls
- iPhone Camera
- Logger Pro Software
- Ladder

Velocity Post-Processing Testing Procedure

Truth Data Collection

Line up row of ping-pong balls in lazy river → Set up iPhone camera directly overhead pointing down → Raise ping pong ball holding gate → Compute truth particle velocity with Logger Pro

Credit: Boulder Creek rubber duck race

Stereo Camera Data Collection

Fully Charge Battery → Connect Stereo Camera, Jetson Nano, and Power Source → Initiate Camera Data Collection → Hold Components 3m from water's surface facing directly down → Offload data & run through post-processing software → Compare system collected data to truth data

Day in the Life Test Overview

Design Requirements: **FR1-FR8**

Test Purpose: Demonstrate "day in the life" functionality, supplying final river discharge and supplementary data from instrument suite.

Test Status: Scheduled April 5 - April 12

Test Validation: Test validates drone communication, deployment mechanism functionality, power supply, microcontroller functionality, data collection and post-processing

Test Criteria: Full system functionality and requirements are verified. Data is successfully off-loaded and post processed and compared to truth data.

Day in the Life: Equipment and Facilities

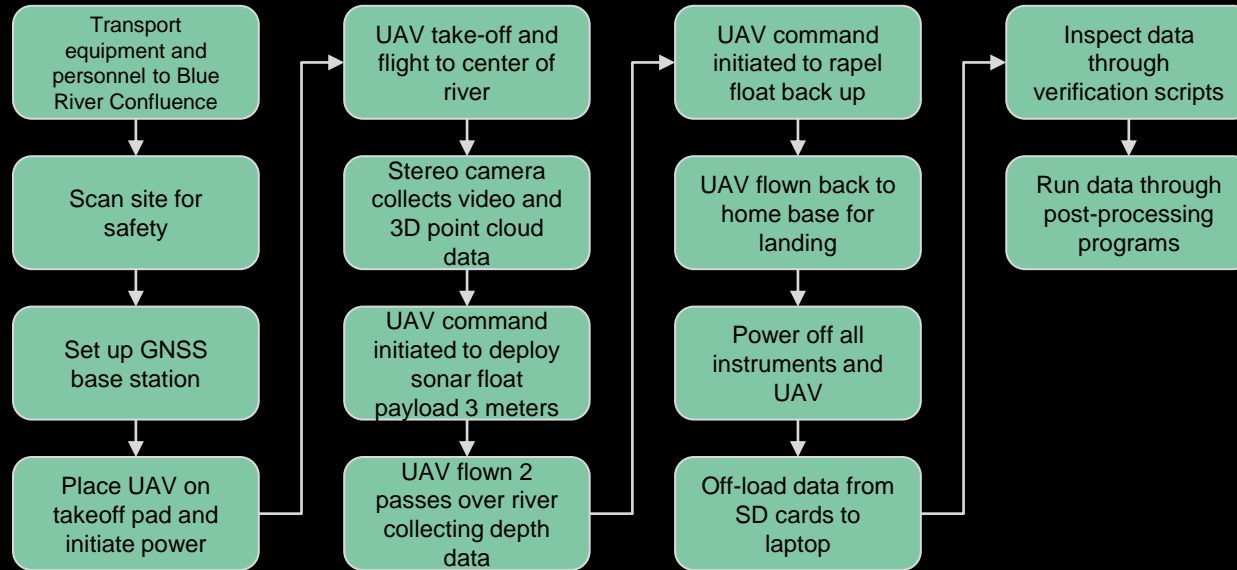**Test Facilities:**

- Colorado Blue River Confluence

Equipment:

- UAV
- On-Board and Deployable Instrument Suite
- GNSS Base Station
- Extra charged battery
- Laptop for off-loading and inspecting data
- Measuring tape & meter stick
- Ping pong balls
- Net
- Waders (for wading into the water)

Day in the Life Test Procedure

Test Procedure:

```
Transport                UAV take-off and        UAV command            Inspect data
equipment and            flight to center of      initiated to rapel      through
personnel to Blue        river                    float back up           verification scripts
River Confluence
        ↓                        ↓                        ↓                        ↓
Scan site for            Stereo camera           UAV flown back to       Run data through
safety                   collects video and      home base for           post-processing
                         3D point cloud          landing                 programs
                         data
        ↓                        ↓                        ↓
Set up GNSS              UAV command             Power off all
base station            initiated to deploy      instruments and
                        sonar float              UAV
                        payload 3 meters
        ↓                        ↓                        ↓
Place UAV on            UAV flown 2              Off-load data from
takeoff pad and         passes over river        SD cards to
initiate power          collecting depth         laptop
                        data
```

Data Collected: Stereo camera river surface video, river 3D point cloud, sonar depth measurements, on-board and deployed unit GNSS coordinates

Day in the Life Truth Data Collection Procedure

True Velocity Data Collection

| Set up net in river to catch ping-pong balls down river | → | Line up row of ping-pong balls behind holding gate in river | → | Set up iPhone camera directly overhead pointing down | → | Raise ping pong ball holding gate | → | Capture video of ping pong balls | → | Compute truth particle velocity with Logger Pro |

True Depth Data Collection

| Wade into river at desired cross-section | → | Lay measuring tape across river cross-section | → | With meter stick, measure depth at 10-15 stations, recording distance from bank |

Day in the Life Data Validation

Depth Data Validation:

Primary Post-processing Software: Depth Correction Program (in-house)

- Compare with truth data. Verify collected sonar depth measurements are within 1% relative error of the measured truth depth at each station

Velocity Data Validation:

Primary Post-processing Software: RiVER (open source, credit: USGS)

- Compare with truth data. Verify collected surface velocity measurements are within 20% relative error of the truth surface velocity at each station

SLAM:

Primary Post-processing Software: SLAM (open source, credit: Georgia Tech)

- Compare with truth data. Verify collected surface velocity measurements are within 20% relative error of the truth surface velocity at each station

Final River Discharge Uncertainty Quantification:

Primary Post-processing Software: Uncertainty Quantification Program (in-house)

- Output the total uncertainty bounds of the computed discharge at field site

Budget

January: 3112.61$
- UAV, Storage, Ping Echosounder, Stereo Camera, Arduino, Pilot License, Jetson Nano

February: 705.45$
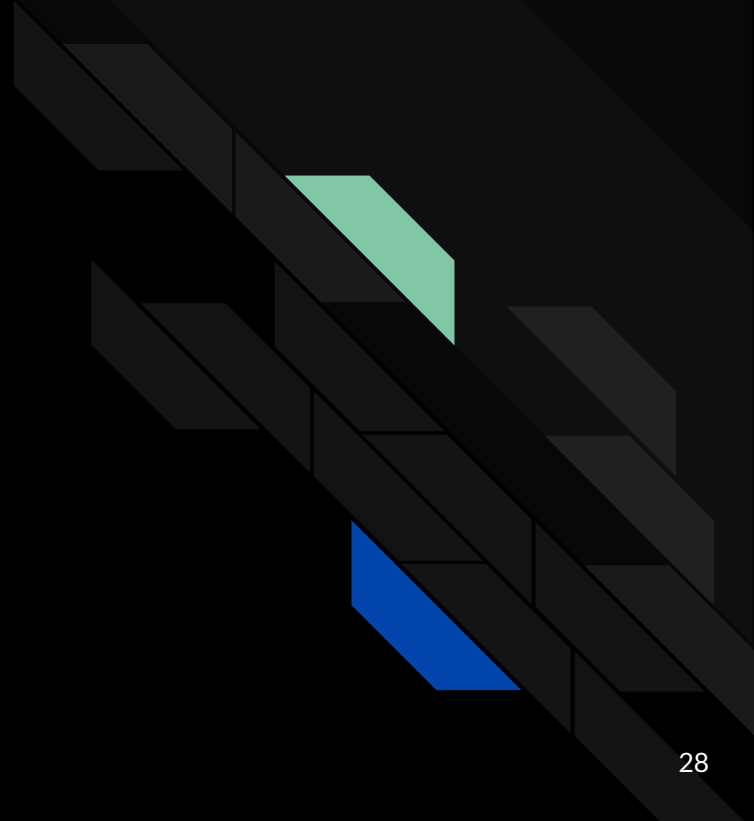- Batteries, Avionics, 3D printing, FAA registration

Remaining: 1181.94$
- Servo Motor
- Replacement parts
- Manufacturing & printing costs

Questions?

Backup Slides

Backup Slides Table of Contents

Budget

UAV	$1,492.11
PLA & Arduino	$152.14
UAV License	$75
Ping Sonar	$310.50
Jetson Nano & SD Card	$102.24
Lipo Batteries	$462.54
U-Blox	$409.99
Stereo Camera	$489
Battery Charger	$81.63
fuse cartridge	$24.84
Breadboard & Screws	$40.35
3D Printing	$12.50
Vector Board	$29.92
Voltage Regulator	$13.04
SD Shield	$5.43
Adapter	$11.93
Water Sensor & Rods	$39.60
FAA Registration	$5
Jetson Developer Kit	$54.41
IMU Fusion Breakout	$25.89

Testing Schedule

Round 1 - Complete by Early March

Component Testing

- Zed 2 Camera
- Ping Sonar
- UAV + Pixhawk Controller
- Deployment Mechanism/Motor
- Float & Electronics Box

On-Board Unit Interface Testing

- Zed Camera + Jetson
- U-blox receiver + Jetson
- Remote Controller + Pixhawk + Jetson
- Data Initiation & Collection Programs

Deployable Unit Interface Testing

- Ping + Arduino
- IMU + Arduino
- U-blox receiver + Arduino
- Data Initiation & Collection Programs

Round 2 - Complete by Mid-April

On-Board Unit Integration

- On-Board Electronics Integration
- On-Board Electronics Fastening to payload housing
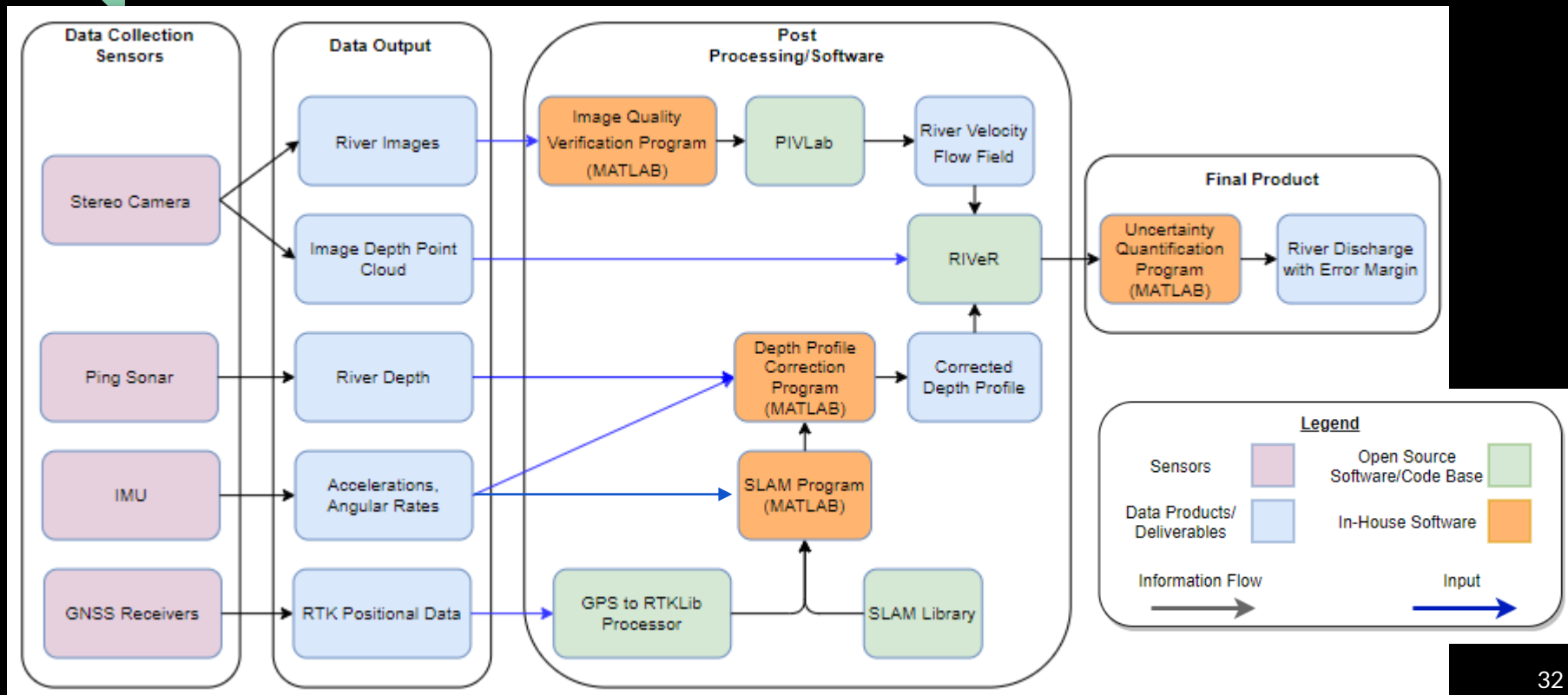- Complete Data Initiation & Collection Programs

Deployable Unit Integration

- Pre-stacked electronics integration
- Stacked electronics integration
- Float + Electronics Box Integration
- Complete Data Initiation & Collection Programs

UAV Integration

Post-Processing Software

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Post-Processing Software Overview

Float Structure Test

Design Requirements: The Float shall be designed such that the…

DR 4.2.1 … bottom 2.5 cm of the SONAR instrument is submerged under water.

DR 4.2.3 … amount of time the float is angularly displaced by +/- 20 degrees is minimized.

Test Purpose: Gain insight into float stability and buoyancy characteristics with simulated weights in float.

Test Status: Waterline and center of buoyancy: March 1st-3rd. Stability: March 4th

Test Validation: A ruler will be placed in background to enable a relative sense of displacement and pivot location.
The expected center of buoyancy and waterline will be calculated using the Solidworks model.

Test Criteria: The float does not *per se* excessively wobble after disturbance and is not easily submerged. When in a current it exhibits weathervane stability.

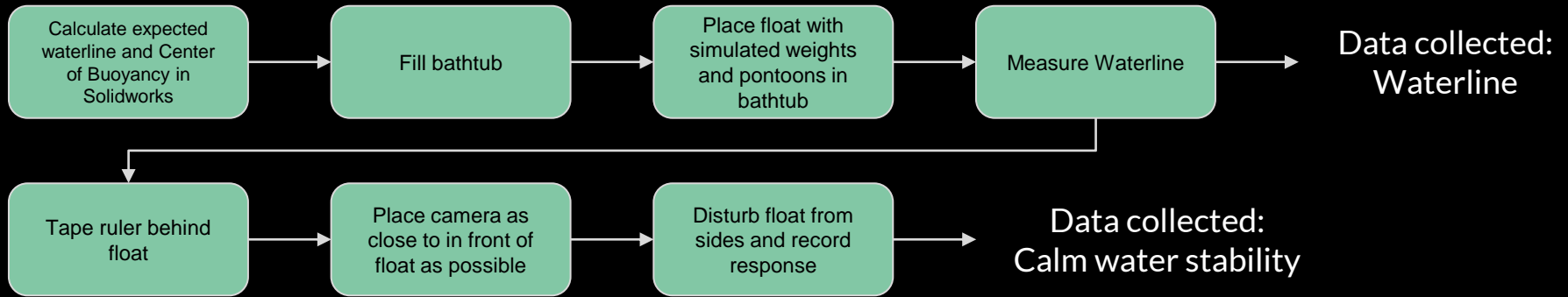# Float Structure Test

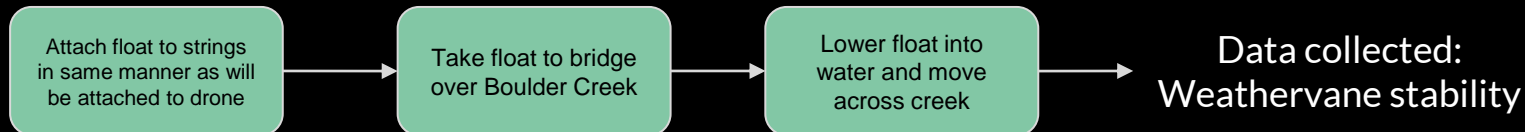**Test Facilities:**
- Bathtub
- Boulder Creek

Equipment:
- Ruler
- Phone Camera
- String
- Weights

Float Structure Test Procedure

Test Procedure for waterline and calm water stability

| Calculate expected waterline and Center of Buoyancy in Solidworks | → | Fill bathtub | → | Place float with simulated weights and pontoons in bathtub | → | Measure Waterline | → | Data collected: Waterline |

| Tape ruler behind float | → | Place camera as close to in front of float as possible | → | Disturb float from sides and record response | → | Data collected: Calm water stability |

Test Procedure for weathervane stability

| Attach float to strings in same manner as will be attached to drone | → | Take float to bridge over Boulder Creek | → | Lower float into water and move across creek | → | Data collected: Weathervane stability |

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Waterproof Test

Design Requirements:
DR 4.2.2 The float shall be designed such that the electronic components are located inside of a waterproof housing.

Test Purpose: Ensure that polyurethane coating is waterproof and electronics lid make a waterproof seal. Both when fully submerged and when experiencing disturbances. Ensure remains waterproof through conditions far worse than anticipated.

Test Status: In progress - polyurethane has been applied and passed a 30 min partial submersion test. Full submersion lid seal testing planned for Match 4th-8th.

Test Validation: A paper towel will be placed inside of hull while undergoing testing.

Test Criteria: Submersion testing will be done at least 5 times and then twice a day until the electronics need to be placed inside the box. If the paper towel is completely dry each and every time the test will be considered successful.
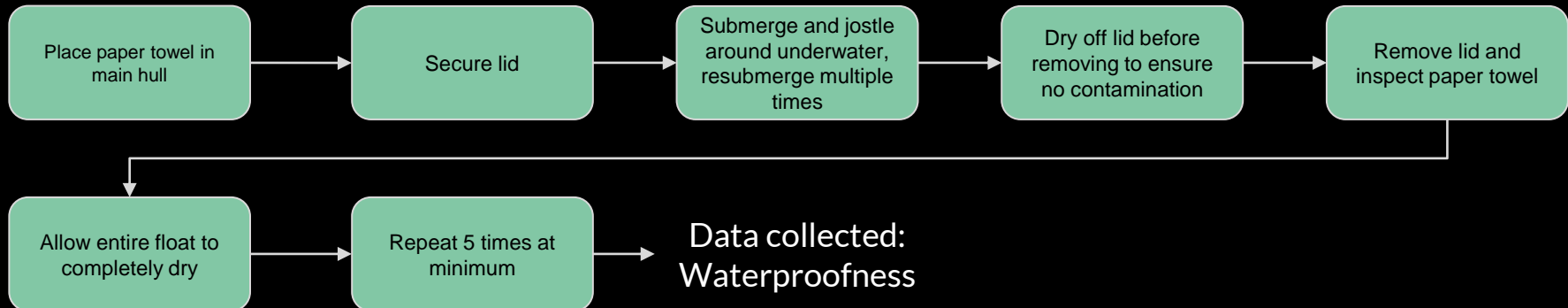
Waterproof Test and procedure

Test Facilities:

- Team members house

Equipment:

- Bucket big enough to fully submerge hull
- Paper towel

Test Procedure for waterproof test

Place paper towel in main hull → Secure lid → Submerge and jostle around underwater, resubmerge multiple times → Dry off lid before removing to ensure no contamination → Remove lid and inspect paper towel

Allow entire float to completely dry → Repeat 5 times at minimum → Data collected: Waterproofness

Jetson Nano Flight Software Test

Design Requirements:

DR6.1.1 The main computer shall be responsible for storing the data collected by the on-board instruments locally to an SD card.

DR6.1.2 The SD card shall be capable of storing the necessary data volume.

Test Purpose: Verify that the Jetson Nano can initiate on-board data collection and save the data correctly to the micro-SD card.

Test Status: In Progress

Test Validation: The Jetson Nano will initiate data collection on the ZED stereo camera and U-Blox receiver. The instruments will collect data for an amount of time. The collected data will be saved to a micro-SD card on the Jetson Nano. After collecting data for a specified amount of time, the Jetson will stop data collection.

Test Criteria: Data collection must be initiated by the Jetson Nano computer on board the drone. All of the collected data must be saved in the correct format.
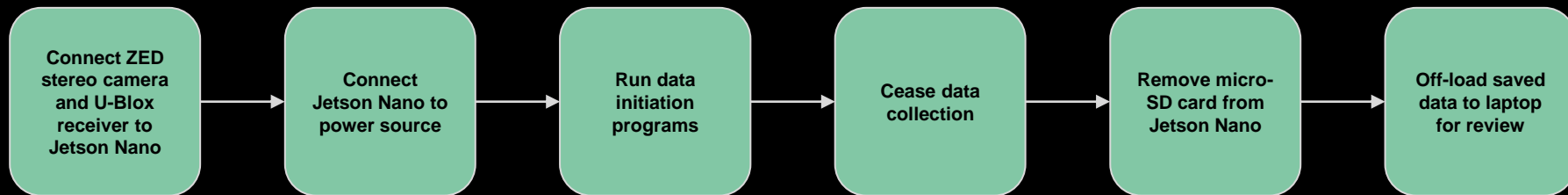
Jetson Nano Flight Software Test

Test Facilities:

- N/A

Equipment:

- Jetson Nano
- ZED stereo camera
- U-Blox GNSS receiver
- micro-SD card

Jetson Nano Flight Software Test Procedure

Connect ZED stereo camera and U-Blox receiver to Jetson Nano → Connect Jetson Nano to power source → Run data initiation programs → Cease data collection → Remove micro-SD card from Jetson Nano → Off-load saved data to laptop for review

On-Board Initiation Programs

Research   **Write**   **Test**   **Integrate**   **Complete**
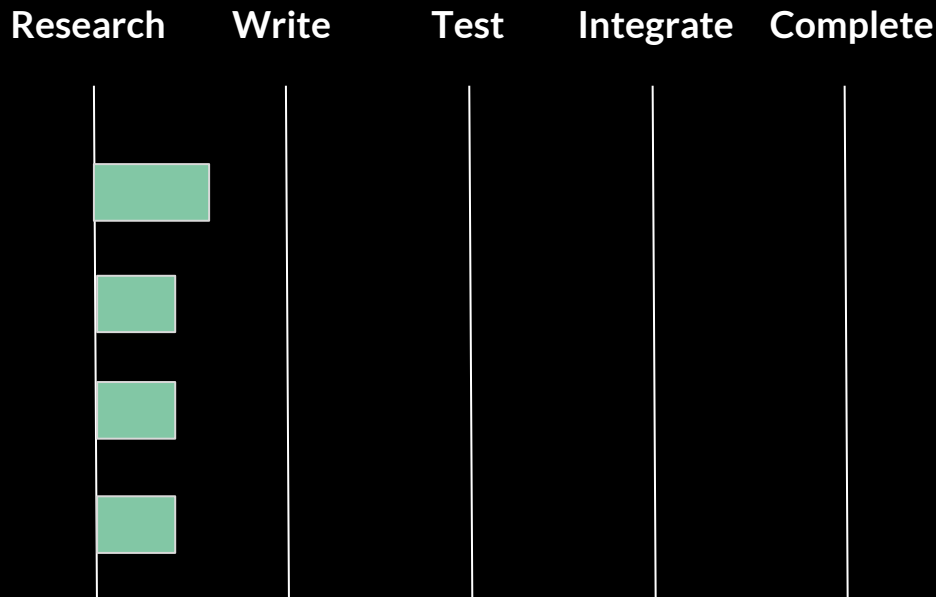
Language: Bash or Python

Critical Tasks:

1. Respond to commands from Pixhawk controller

2. Initiate ZED camera data collection program

3. Initiate GNSS Receiver data collection program

4. Initiate deployment system functions

Largest Uncertainty: What communication between the Pixhawk and Jetson Nano will look like
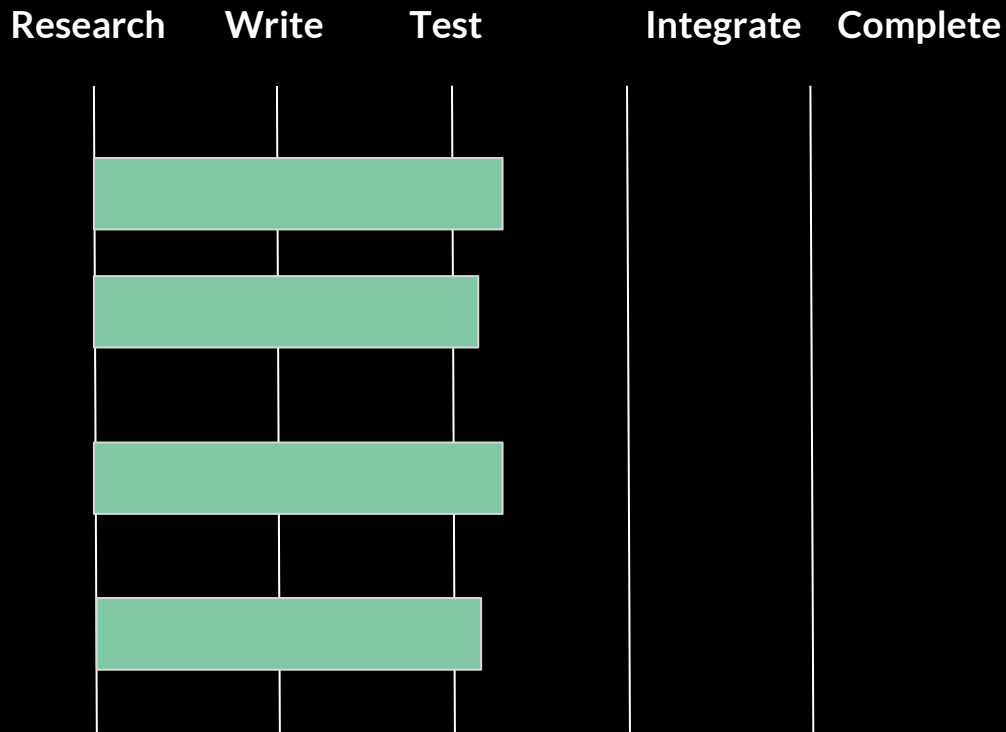
Estimated Date of Completion: 03/08/2021

Stereo Camera Data Collection Program

Language: Python

Critical Tasks:

1. Adjust camera controls

2. Record video data

3. Save recorded video to output file on

    micro SD card in SVO format

4. Collect 3D depth point cloud data

Estimated Date of Completion: 03/08/2021

Research	Write	Test	Integrate	Complete

Arduino Uno Flight Software Test

Design Requirements:

DR6.1.1 The main computer shall be responsible for storing the data collected by the on-board instruments locally to an SD card.

DR6.2.1 The micro-controller shall be responsible for storing the data collect by the deployed instruments locally to an SD card.

Test Purpose: Validate that Data Collection from IMU and SONAR is initiated and Data is Stored Successfully and in the Correct Format to the Onboard SD Card

Test Status: Complete with the exception of U-Blox integration

Test Validation: The water sensor will be placed in contact with water triggering data collection. Following this the IMU and SONAR will be moved around while data is being collected. Finally, the water sensor will be taken out of the water, stopping data collection, and the SD card will be connected to a computer to inspect the data.

Test Criteria: Data collection must be triggered and stopped by the Water sensor and the collected data must be stored in the correct format on the SD Card.

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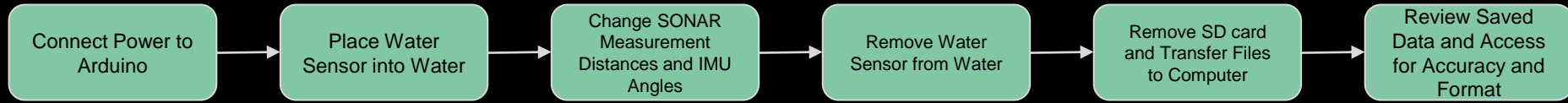# Arduino Uno Flight Software Test

Test Facilities:

- N/A

Equipment:

- Computer running Arduino IDE
- Arduino
- SONAR
- IMU
- SD Card Reader with SD Card
- Water Sensor
- Bowl of Water

Arduino Uno Flight Software Test Procedure

Connect Power to Arduino → Place Water Sensor into Water → Change SONAR Measurement Distances and IMU Angles → Remove Water Sensor from Water → Remove SD card and Transfer Files to Computer → Review Saved Data and Access for Accuracy and Format

Deployable Float Initiation Programs

Language: c/c++ (Arduino)

Critical Tasks:

1. SONAR sensor initiation/ data collection

2. IMU sensor initiation/ data collection

3. SD card data logging (from sensors above)

4. Data collection trigger

5. U-Blox initiation

Largest Uncertainty: Arduino SRAM availability once ublox code is implemented.

Estimated Date of Completion: 02/28/2021

	Research	Write	Test	Integrate	Complete
SONAR sensor initiation/ data collection	████	████	████	████	
IMU sensor initiation/ data collection	████	████	████	████	
SD card data logging (from sensors above)	████	████	████	████	
Data collection trigger	████	████	████	████	
U-Blox initiation	██				

Pixhawk-Jetson Communication Test

Design Requirements:
DR6.1 There shall be a main computer with the drone-fixed instrument suite to command and direct power to all drone-fixed instruments and mechanisms.

Test Purpose: To make sure the Jetson can act on commands received by the Pixhawk

Test Status: Not Complete

Test Validation: HITL simulation with Pixhawk

Test Criteria: Jetson must be able to execute code once a command is sent through a HITL simulation

Pixhawk-Jetson Communication Test

Test Facilities:

- None

Equipment:

- Laptop, Pixhawk, Jetson Nano, cables/wires

Pixhawk-Jetson Communication Test Procedure

1) Pixhawk is connected to Laptop using USB, Jetson is connected to Pixhawk using UART

1) HITL simulation is run using jMAVsim and Qgroundcontrol, MAVproxy is run on the Jetson to connect to the Pixhawk

1) Flight plan with Start camera command and do Winch command uploaded to Pixhawk using Qgroundcontrol

1) Jetson prints out message received

Pixhawk-Jetson Communication Program

Language: Bash or Python

Critical Tasks:

1. Send a signal from the ground controller

2. Pixhawk receives and processes signal from controller

3. Jetson Nano listens for appropriate signal

4. Jetson Nano calls requested initiation program

Largest Uncertainty: What commands can be sent through Ground Control software

Research	Write	Test	Integrate	Complete

Estimated Date of Completion: 03/14/2021

UAV Flight & Control Test

Design Requirements:

DR1.1 - The system shall have a minimum operational flight time of 12 minutes.

DR1.2 - The flight vehicle shall have a minimum carrying capacity of 2 kg.

Test Purpose: To confirm the capabilities of the drone without the payload

Test Status: Incomplete

Test Criteria: Drone will be capable of performing an autonomous flight

UAV Flight & Control Test

Test Facilities:
- Boulder Model airport

Equipment:
- Drone, controller

UAV Flight & Control Test Procedure

1) Preflight checks

2) Take off

3) In stabilize mode perform flight maneuvers and use landing button to land

4) Take off in stabilize mode and land using RTL mode

5) Switch to autonomous mode and fly a short mission with a landing sequence

6) Using autonomous mode fly the same mission but interrupt it with RTL mode

Deployment Mechanism Test

Design Requirements:

DR4.3 There shall be a mechanism which lowers the float to the water surface

DR4.3.4 The mass lowered by the mechanism shall not exceed 1kg

Test Purpose: Demonstrate ability to carry a simulated payload as well as test the behavior of the stepper motor at various voltages

Test Status: Complete

Test Results: Stepper motor gets hot at 12V. 8V was sufficient to lift a 1kg payload

Test Validation: The voltage and current were verified using a multimeter

Test Criteria: Stepper motor must be able to lift a 1kg payload

Deployment Mechanism Test

Test Facilities:

- At home

Equipment:

- Stepper motor, motor driver, Jetson nano, power supply

Deployment Mechanism Test Procedure

1) Jetson nano is connected to a monitor and powered using a USB-C cable
2) Stepper motor is connected to a motor driver which connects to the GPIO pins of the Jetson nano
3) Portable power supply generates the voltage needed to the stepper motor
4) Short python script controls runs the stepper motor at a controlled speed
5) The current and voltage supplied to the stepper motor is validated using a multimeter
6) A 1kg payload is attached to the stepper motor to simulate lifting the float
7) Test is run at various voltages (8V-12V)

Deployment Mechanism Test

- 8V supplied to stepper motor

- 1kg payload

Power System Test

Design Requirements:

DR6.1 There shall be a main computer with the drone-fixed instrument suite to command and direct power to all drone-fixed instruments and mechanisms.

DR6.3 Both the on-board and deployed sensor units shall include batteries to provide enough power for 30 minutes of operation at maximum power consumption.

Test Purpose: To verify that power distribution units (PDU) supply proper voltage and current to proper components and the batteries operate at max voltage/current operation for 30 minutes.

Test Status: Power distribution unit in prototyping stage

Test Validation: The test will use a digital multimeter to ensure the PDU produces enough power

Test Criteria: The power distribution boards provide 5V output at 5A of current

Power System Test

Test Facilities:

- The testing will take place in the PILOT lab

Equipment:

- The test will utilize a digital multimeter and a DC power supply

Power System Test Procedure

1) Check the output voltage of the PDU using a digital multimeter to ensure there is consistent 5V output
2) Check the current coming out of the PDU to ensure the board has the capacity to output 5A of current
3) Construct a simple circuit that draws maximum voltage and current from each battery
   a) For on-board avionics unit:
      i) 8-12V @ 100mA
      ii) 5V @ 4A
      iii) Minimum 30 minute battery life
   b) For float avionics unit:
      i) 7-12V @ 80mA
      ii) 5V @ 180mA
      iii) Minimum 30 minute battery life

Deployed Float Data Collection Testing

Test Purpose: Demonstrate initiation with water contact and proper data collection and storage

Test Equipment: SONAR, IMU, Water Sensor SD card reader, arduino UNO

Test Facilities: N/A

Test Status: Complete (SONAR in air) (2/24/2020)

Test Criteria: Data collection from SONAR and IMU must start and stop based on water detection with data being saved to the onboard SD card

Results: All sensors and systems functioned as expected and produced valid data

IMU Test

Design Requirements:

DR4.6.2 - The IMU shall measure the angular displacement between the SONAR pointing ray within ± 1 degree accuracy.

Test Purpose: Test Functionality and Accuracy of IMU

Test Status: Hardware and Software are Complete and Functional. Constructing Test Stand

Test Validation: Compare IMU Readings to Known Measurements

Test Criteria: IMU angular displacement measurements shall be accurate to within ±1°
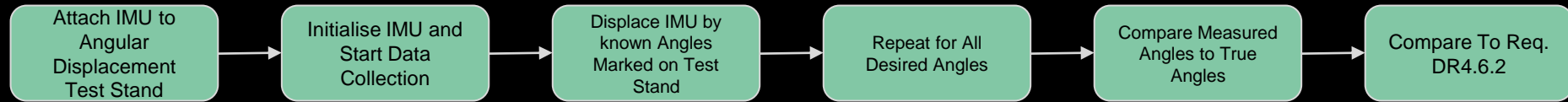
IMU Test

Test Facilities:
- No specific Facilities needed

Equipment:
- IMU
- Arduino
- SD card reader with SD card
- Computer to review Data
- Angular Displacement Test Stand (see slide 19)

IMU Test Procedure

Attach IMU to Angular Displacement Test Stand → Initialise IMU and Start Data Collection → Displace IMU by known Angles Marked on Test Stand → Repeat for All Desired Angles → Compare Measured Angles to True Angles → Compare To Req. DR4.6.2

Stereo Camera Test

Design Requirements:
DR5.1 The drone-fixed instrument suite shall use a stereo camera to measure river surface velocities.
DR5.1.2 The camera shall be able to sufficiently capture river velocity data between 0-4m/s.

Test Purpose: Test functionality and image quality of ZED stereo camera.

Test Status: In progress

Test Validation: Use image processing scripts to verify quality of stereo camera images.

Test Criteria: Images meet particle size and density requirements set for use of PIVlab. User can change camera settings, capture video, and capture a 3D depth point cloud. Images are sufficient for measuring velocities within 0-4 m/s.

Stereo Camera Test

Test Facilities:
- N/A

Equipment:
- ZED stereo camera
- Jetson Nano or other computer with Nvidia GPU
- ZED SDK software

Stereo Camera Test Procedure
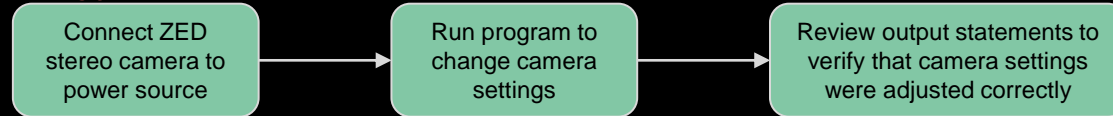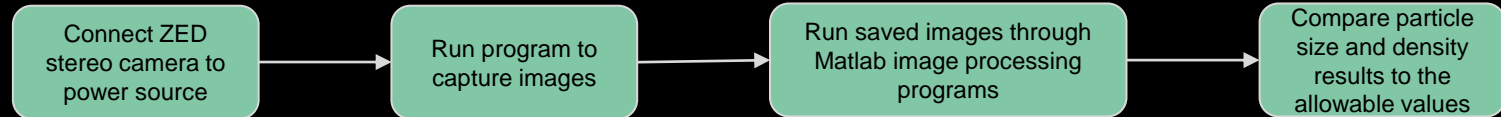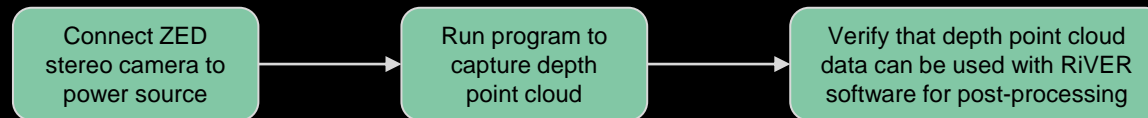
Camera Controls Test:

```
┌─────────────────┐     ┌─────────────────┐     ┌──────────────────────┐
│ Connect ZED     │ →   │ Run program to  │ →   │ Review output        │
│ stereo camera to│     │ change camera   │     │ statements to verify │
│ power source    │     │ settings        │     │ that camera settings │
│                 │     │                 │     │ were adjusted        │
│                 │     │                 │     │ correctly            │
└─────────────────┘     └─────────────────┘     └──────────────────────┘
```

Image Capture Test:

```
┌─────────────────┐   ┌─────────────────┐   ┌──────────────────────┐   ┌──────────────────┐
│ Connect ZED     │ → │ Run program to  │ → │ Run saved images     │ → │ Compare particle │
│ stereo camera to│   │ capture images  │   │ through Matlab image │   │ size and density │
│ power source    │   │                 │   │ processing programs  │   │ results to the   │
│                 │   │                 │   │                      │   │ allowable values │
└─────────────────┘   └─────────────────┘   └──────────────────────┘   └──────────────────┘
```

Depth Point Cloud Capture Test:

```
┌─────────────────┐   ┌─────────────────┐   ┌──────────────────────┐
│ Connect ZED     │ → │ Run program to  │ → │ Verify that depth    │
│ stereo camera to│   │ capture depth   │   │ point cloud data can │
│ power source    │   │ point cloud     │   │ be used with RiVER   │
│                 │   │                 │   │ software for         │
│                 │   │                 │   │ post-processing      │
└─────────────────┘   └─────────────────┘   └──────────────────────┘
```

GNSS Base Station & Receiver Test

Design Requirements:

DR4.7 - The deployable float shall include a GNSS receiver

DR5.2 - The drone-fixed instrument suite shall include a GNSS receiver

DR7.4 - The GNSS data shall enable post-processed positioning with horizontal accuracy of +/- 4 cm and vertical accuracy of +/- 5 cm in ideal conditions.

Test Purpose: **Validate GNSS functionality and accuracy**

Test Status: **Complete for u-blox receivers, waiting on base station**

Test Validation: **Run data collection outdoors with base station and both u-blox receivers**

Test Criteria: **Successful data collection and accurate results within horizontal position accuracy within 4 cm and vertical position accuracy within 5 cm.**

GNSS Base Station & Receiver Test

Test Facilities:

- Outdoor space with ground truth markings, such as a track

Equipment:

- Two u-blox receivers
- Jetson Nano
- Arduino Uno
- Portable usb-c power supply
- Emlid base station

GNSS Base Station & Receiver Test Procedure

- Set up and power on u-blox receivers, Jetson Nano, Arduino Uno, and Emlid base station at suitable location.
- Connect to base station from mobile device via ReachView3 app to initialize data collection.
- With one person holding each u-blox receiver, walk between quantitatively marked ground locations and record trajectory.
- Verify u-blox results onsite with a laptop.

Depth Profile Correction Program Test

Design Requirement:

DR4.6.2 - The IMU shall measure the angular displacement between the SONAR pointing ray within ± 1 degree accuracy.

DR7.2.1- The depth profile shall be post-processed to correct for the angular displacements of the float.

Test Purpose: Show that our corrected depth accuracy complies with DR4.1.2

Test Status: All required electronics are functional, waiting for approval from Rec Center

Test Validation: Comparing corrected measurement to physical Truth values

Test Criteria: The measured depth should be accurate to <1% of Truth value (within ±20°)

Depth Profile Correction Program Test

Test Facilities:

- Pool with Minimum Depth of 0.5 Meters

Equipment:

- SONAR
- IMU
- Arduino
- SD card reader with SD card
- Computer running Matlab
- Angular Displacement Test Stand (see slide 19)

Depth Profile Correction Program Test Procedure

Retrieve Test Data from SD card → Import Test Data Into Matlab → Calculate Net Angular Displacement from Gravity Vector → Calculate Corrected Depth (Adjacent side of Right Angle Triangle) → Compute Percentage Error between Truth and Corrected Distance → Compare To Req. DR4.6.2
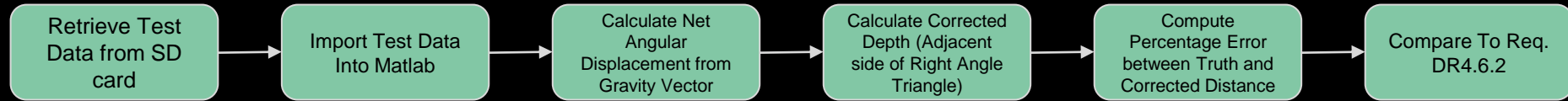
Stereo Camera Image Verification Program Test

Design Requirements:

DR7.1 The stereo camera data shall be post-processed to calculate river surface velocity.

DR7.1.1 The computed surface velocity shall be within 20% of the true surface velocity.

Test Purpose: Verify that image processing programs provide reliable particle size and particle density values for various images.

Test Status: In progress

Test Validation: Look at a variety of test results to get an expected particle size and density for different river conditions

Test Criteria: Image processing programs should give consistent particle size and density values for various river conditions

Stereo Camera Image Verification Program Test

Test Facilities:
- Outdoor river

Equipment:
- Matlab
- IPhone camera

Stereo Camera Image Verification Program Test Procedure

```
┌─────────────────┐      ┌─────────────────┐      ┌─────────────────────┐
│ Collect various │      │ Run all images for │    │ Analyze results and determine │
│ images of different │──▶│ different conditions │──▶│ an expected particle size and │
│ river conditions │      │ through Matlab image │    │ particle diameter for various │
│                 │      │ processing scripts │    │ river conditions │
└─────────────────┘      └─────────────────┘      └─────────────────────┘
```
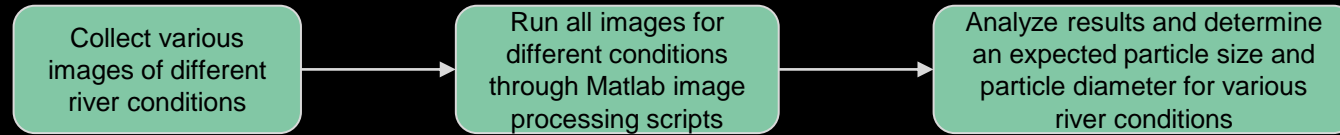
SLAM Test

Design Requirements:

DR7.5 - Positional data post-processing requirement.

DR7.4 - The GNSS data shall enable post-processed positioning with horizontal accuracy of +/- 4 cm and vertical accuracy of +/- 5 cm in ideal conditions.

Test Purpose: Validate our capacity to obtain an accurate mission trajectory.

Test Status: Preliminary code structure has been implemented.

Test Validation: Processing GNSS and IMU data from a path of known relative distances.

Test Criteria: Horizontal position accuracy within 4 cm and vertical position accuracy within 5 cm.

SLAM Test

Test Facilities:
- N/A

Equipment:
- Emlid base station
- Jetson Nano
- U-blox receivers
- Arduino Uno
- IMU
- Power supply
- Computer

SLAM Test Procedure


```
From the same           Collect GNSS
test mission with  -->  data from u-blox
verified distances      receivers
                                          -->  Perform PPK
                        Collect GNSS           processing of GNSS  -->  Convert
                   -->  data from Emlid        data                     measurements to  -->  Review variation of
                        base station                                    factor graph within     uncertainty across
                                                                        GTSAM                    trajectory, compare
                        Collect IMU                                                              to DR7.4
                   -->  data                -->
```
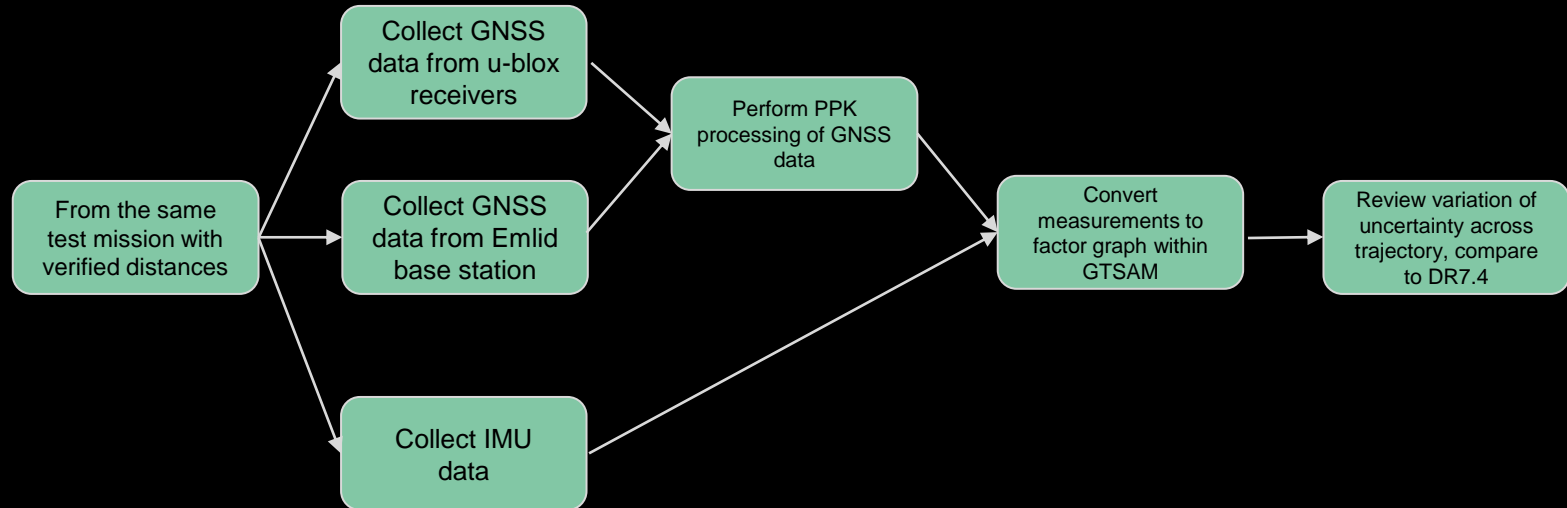
Uncertainty Quantification Program Test

Design Requirements:
DR7.5 - The computed discharge data shall be delivered with the associated error uncertainty bounds.

Test Purpose: Ensure system calculated river discharge with error bounds encompass the collected truth river discharge measurement.

Test Status: In-progress, final testing will be with full day in the life test

Test Validation: Truth river discharge calculation will lie in error bounds of system-calculated river discharge

Uncertainty Quantification Program Test

Test Facilities:

- Blue River Confluence

Equipment:
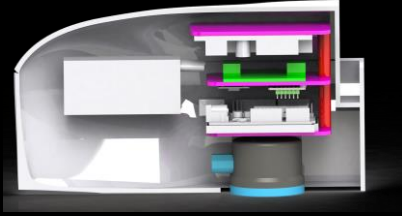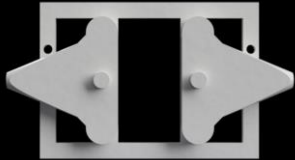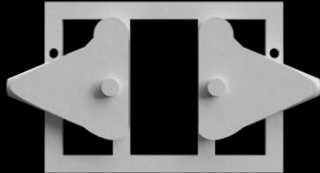
- Computer
- Full UAV + instrument suite
- GNSS base station & receivers

Uncertainty Quantification Program Test Procedure

```
┌─────────────────────┐      ┌─────────────────────┐      ┌─────────────────────┐
│  Compute river      │      │  Collect truth      │      │  Validate that      │
│  discharge (with    │─────▶│  velocity and       │─────▶│  error margin       │
│  error margin) from │      │  depth data for     │      │  encompass truth    │
│  DITL test data     │      │  truth river        │      │  river discharge    │
│                     │      │  discharge          │      │                     │
│                     │      │  measurement        │      │                     │
└─────────────────────┘      └─────────────────────┘      └─────────────────────┘
```
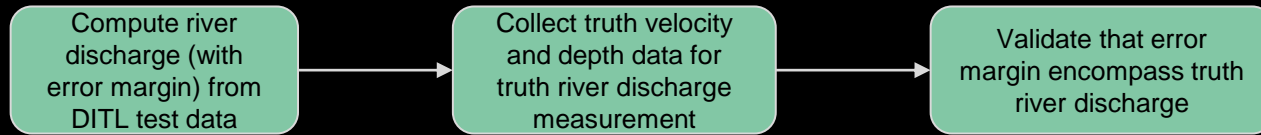
Design Changes Since CDR

| Part	Old Design	New Design	Rational
SONAR float	Electronix box sat atop the float	Box is entire hull body	- Fewer parts - Lower CG - Better cable management - Less wasted space - Original box was undersized
Stability Mech	Wider plate and longer pivot shoulders	Shorter plate and shorter pivot shoulders	- Account to float dimension change - Eliminate shoulder collisions while rotating

Updated Dimensions

All units are [cm]

All units are [cm]

84
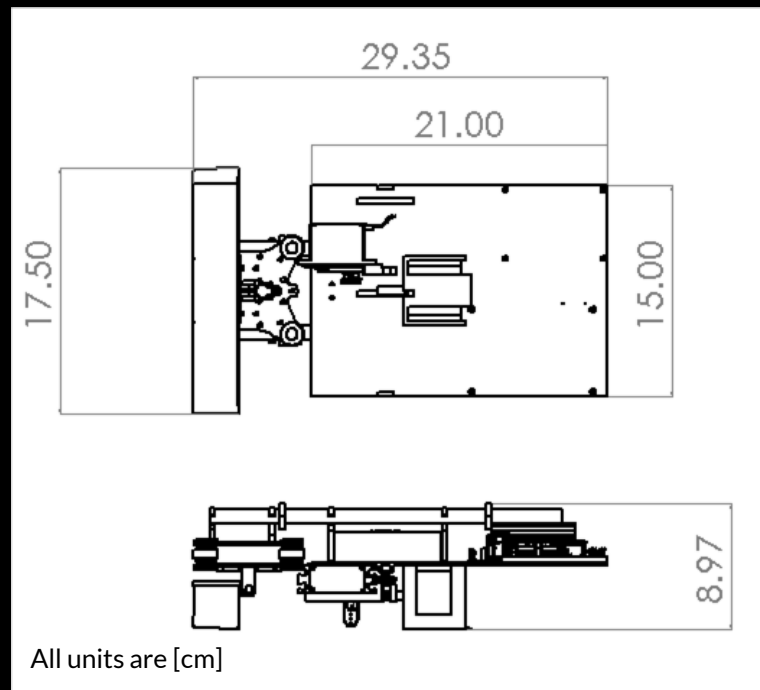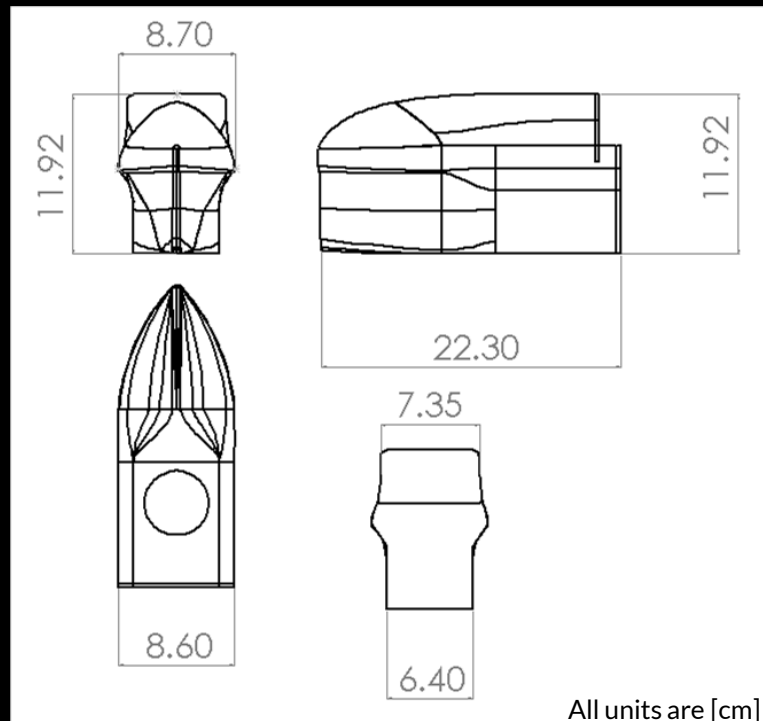
Comparison of new hull to old hull
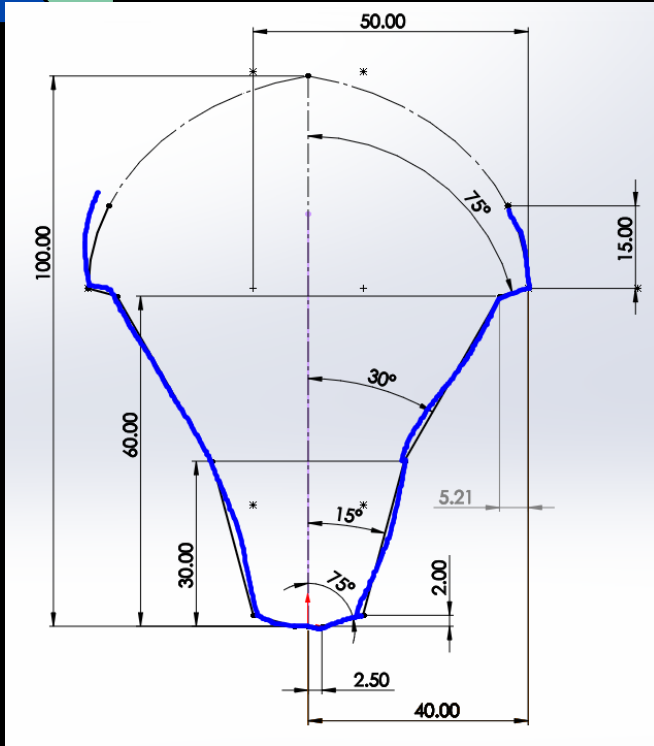
New design
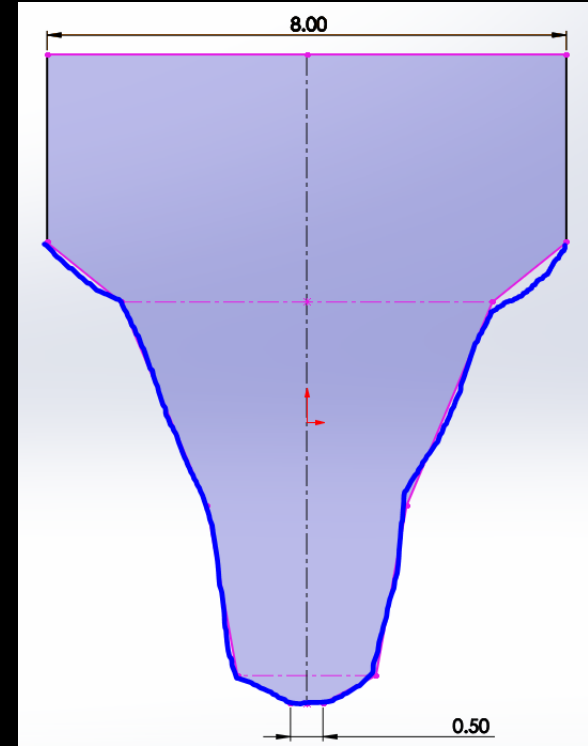
Old design

Main drawing defining float shape has not changed very much

Hand-held LSPIV Guidelines – On Site Checklist

Video and Site Requirements

Video

- ☐ Video resolution is at least 640 x 480 pixels (most smart phone cameras)
- ☐ Minimum of 15 frames per second
- ☐ No wide angle lens or other distortion
- ☐ Video duration at least 60 to 90 seconds
- ☐ Camera platform is as stable as possible by mounting on a tripod or bracing against a fixed object

Site

- ☐ Surface flow disturbance patters are uniform with time
- ☐ No effects of pier wake or other flow disturbances. If near a structure, shoot video looking upstream.
- ☐ Ideally, river has a stable bottom not subject to erosion

Field of View Requirements

Visible items

- ☐ Entire width of channel at measurement cross-section
- ☐ Fixed locations on both sides of the channel (e.g. banks, trees, structures)
- ☐ Minimum of 4 control points

Camera angle

- ☐ High angle is best (closest to 90°), therefore try to look down on the water as opposed to looking across it
- ☐ If standing on the bank, ensure angle is higher than 15°
- ☐ If standing on a bridge, ensure all visible items are in the field of view

Lighting

- ☐ Avoid shadows and reflections
- ☐ Avoid sparkling patterns on water surface

Control Points and Measurements

Control Points

- ☐ Minimum of 4 fixed control points, positioned as to maximize size of velocity field in camera field of view
- ☐ At least 2 on each bank, but can add more to enlarge visible velocity field
- ☐ Located at or as close as possible to the water surface
- ☐ Distance between points is known or can be measured

Note: do not need to form a perfect square

Examples: rocks, trees, stakes, pylons

Additional Measurements

- ☐ Distances between control points, including diagonals
- ☐ One cross-section bathymetry
- ☐ Fill in LSPIV Data Submission Form

Contact

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Video from bank: Field of view includes all visible items, very well defined control points

Video from bridge: Field of view includes both banks, control points not well defined

Float Weight Budget

Part	Weight [g]
Arduino Uno	25
1000mAh Battery	98
SD Shield	5
Wiring	15
Ping Sonar	135
IMU	3
U-Blox	35
Hull	219
Pontoons	364
TOTAL	**894**

FR1			**RiBBIT shall be an unmanned aerial vehicle (UAV) system.**
	DR1.1		The system shall have a minimum operational flight time of 12 minutes.
	DR1.2		The flight vehicle shall have a minimum carrying capacity of 2 kg.
	DR1.3		The surveyor shall choose river cross sections with open sky and minimal tree obstruction.
FR2			**RiBBIT shall be capable of operating in *customer specified* river conditions.**
FR3			**RiBBIT shall include an instrument suite payload that is compatible with the Tarot 680.**
	DR3.1		The payload shall be have a maximum total weight of 2 kg.
	DR3.2		The instruments shall be composed of commercial off the shelf components.
	DR3.3		The payload shall be designed such that it minimizes the external applied moments on the drone.
	DR3.4		The payload shall be mounted such that it minimizes the external applied moments on the drone.
	DR3.5		The drone-fixed payload shall be capable of operating in ambient temperatures between -10 and 50 degrees Celsius.
FR4			**The instrument suite shall be capable of measuring the bathymetric profile of a river cross section from one bank to the other, perpendicular to the current.**
	DR4.1		The instrument suite shall use SONAR to capture depth measurements.
		DR4.1.1	The SONAR instrument shall be capable of sensing depths from 0.5 meters to 3 meters in ideal conditions.
		DR4.1.2	The SONAR instrument shall be capable to measure depths to an accuracy of <1% of the total depth in ideal conditions.
		DR4.1.3	The SONAR instrument shall be capable of measuring depths in water temperatures between 0 and 20 degrees Celsius.
	DR4.2		The SONAR instrument shall be located on a deployable float.
		DR4.2.1	The float shall be designed such that the bottom 2.5 cm of the SONAR instrument is submerged under water.
		DR4.2.2	The float shall be designed such that the electronic components are located inside of a waterproof housing.
		DR4.2.3	The float shall be designed such that the amount of time the float is angularly displaced by +/- 20 degrees is minimized.
	DR4.3		There shall be a mechanism which lowers the float to the water surface.
		DR4.3.1	The mechanism shall be triggered to lower and raise the float via the drone pilot controller.
		DR4.3.2	The mechanism shall lower the float to the water surface in a controlled manner such that the drone is minimally perturbed.
		DR4.3.3	The mechanism shall include a failsafe option to release the payload if the translated forces and moments to the drone exceed its flying ability.
		DR4.3.4	The mass lowered by the mechanism shall not exceed 1 kg.
	DR4.4		The float shall be attached to the drone through a non-rigid material.
	DR4.5		The UAV shall fly at a minimum of 3 meters above the river surface while collecting depth measurements.
	DR4.6		The deployable float shall include an IMU.
		DR4.6.2	The IMU shall be capable of measuring the angular displacement between the gravity vector and the SONAR pointing ray with +/- 1 degree accuracy.
	DR4.7		The deployable float shall include a GNSS receiver.
	DR4.8		The total deployed weight shall not exceed the 1.6 kg torque capacity of the motor.
FR5			**The instrument suite shall be capable of measuring the surface velocity of a river cross section**
	DR5.1		The drone-fixed instrument suite shall use a stereo camera to measure river surface velocities.
		DR5.1.1	The camera shall be fixed to the instrument suite that is mounted to the drone.
		DR5.1.2	The camera shall be able to sufficiently capture river velocity data between 0-4m/s.
	DR5.2		The drone-fixed instrument suite shall include a GNSS receiver.
FR6			**RiBBIT shall be able to power and command all instruments and sensors.**
	DR6.1		There shall be a main computer with the drone-fixed instrument suite to command and direct power to all drone-fixed instruments and mechanisms.
		DR6.1.1	The main computer shall be responsible for storing the data collected by the on-board instruments locally to an SD card.
	DR6.2		There shall be a microcontroller on the deployed sensor unit which commands and directs power to all deployed instruments.
		DR6.2.1	The micro-controller shall be responsible for storing the data collect by the deployed instruments locally to an SD card.
	DR6.3		Both the on-board and deployed sensor units shall include batteries to provide enough power for 30 minutes of operation at maximum power consumption.
FR7			**The collected data shall be post-processed to calculate river discharge.**
	DR7.1		The stereo camera data shall be post-processed to calculate river surface velocity.
		DR7.1.1	The computed surface velocity shall be within 20% of the true surface velocity.
	DR7.2		The SONAR data shall be post-processed to model the river cross section.
		DR7.2.1	The depth profile shall be post-processes to correct for the angular displacements of the float.
	DR7.3		The river discharge shall be calculated by the product of the surface velocity multiplied by the area of the river cross section.
	DR7.4		The GNSS data shall enable post-processed positioning with horizontal accuracy of +/- 4 cm and vertical accuracy of +/- 5 cm in ideal conditions.
	DR7.5		The computed discharge data shall be delivered with the associated error uncertainty bounds.

Requirements cont.

FR8			The UAV shall comply with all FAA and safety requirements
	DR8.1		The flight vehicle shall be operated under all FAA safety regulations
		DR8.1.1	The UAV shall be registered if it weighs more than 0.55 lbs (250 grams).
		DR8.1.2	Unmanned aircraft must weigh less than 55 lbs (25 kg).
		DR8.1.3	UAV shall be flown below 400 feet above ground level at all times.
		DR8.1.4	UAV shall be flown in line of sight.
		DR8.1.5	UAV shall not be flown within 5 mile radius from any active airport/airfield.
		DR8.1.6	UAV shall be flown in daylight-only operations, or civil-twilight with appropriate anti-collision lighting.
		DR8.1.7	The smartphone app B4UFLY shall be referenced before flight to determine airspace restrictions.
	DR8.2		The UAV shall be operated by a person with proper FAA and/or municipal permissions
		DR8.2.1	A person operating a small UAS must either hold a remote pilot airman certificate with a small UAS rating or be under the direct supervision of a person who does hold a remote pilot certificate (remote pilot in command)
	DR8.3		The UAV shall not be operated in any way that may cause harm to any person or property
		DR8.3.1	UAV shall have a safety control in case of emergency to return to pilot.
		DR8.3.2	UAV shall not be flown near or over sensitive infrastructure or property.
		DR8.3.3	All personnel shall remain clear of the UAV and not interfere with it's flight.
	DR8.4		There shall be visual observer to monitor the environment that the drone is flying in.

Levels Of Success

Drone

	Level 1	Level 2	Level 3
Drone Command & Control	- Drone is capable of being flown manually the entire course of the flight.	- Drone is capable of being flown manually the entire flight with commands to correct for wind or other disturbances.	- Drone is capable of using autopilot along a pre-programmed flight path.
Drone Performance	- Drone is capable of carrying payload - Drone is capable of flight time of at least 12 minutes carrying payload	- Drone can fly 12 minutes with 5 minutes of additional flight time for travel	- Drone can fly for 25 minutes.

Structural and Instrument

	Level 1	Level 2	Level 3
Depth Sensing	- Instrument system can measure river depths of 0.5m-3m in ideal conditions to an accuracy of <1% of the total depth	- Instrument system can measure river depths of 0.5m-3m in ideal conditions to an accuracy of <0.75% of the total depth. - Instrument can measure river depths to 3-5m in ideal conditions with an accuracy of <1% of the total depth.	- Instrument system can measure river depths to 0.5m-3m in ideal conditions to an accuracy of <0.5% of the total depth. - Instrument can measure river depths to >5m in ideal conditions with an accuracy of <1% of the total depth.
Velocity Measurements	- Instrument system can sufficiently capture surface velocity of 0m/s-4m/s.		
Instrument Positional Measurements	- The instrument system can know its relative horizontal position to an accuracy of +/-3 cm and its vertical position to an accuracy of +/-4 cm using RTK or PPK. - The instrument system will know its angular position to an accuracy of +\- 1 degree.	- Inclusion of GNSS receivers on both the drone and sensor suite.	- Inclusion of ground control points or use of advanced base station localization techniques such as truthing to survey landmarks. - Perform SLAM algorithm to integration receivers and IMU.
Drone Mount	- Instrument suite can be mounted to the selected drone.		

Software and Electronics

	Level 1	**Level 2**	**Level 3**
Data Handling	- All data is stored in on-board memory		
Power	- All onboard sensors shall be powered at minimum for the flight duration of 720 seconds	- All onboard sensors shall be powered for 720 seconds with reserve charge	- Drone shall be able to draw upon reserve sensor suite power under necessary conditions
Velocity Data Post Processing	- The river is modeled as a flat plane. - The velocity of the flow is the horizontal component of true velocity.	- The river is modeled as a 3D surface. - The velocity of the flow is the horizontal component of true velocity.	- The river is modeled as a 3D surface. - The velocity of the flow is the true velocity. [See appendix section 7.1 for schematic of flow velocity components].
Data Verification and Validation	- River velocity and depth profile data shall be compared to in-situ measurements to observe system accuracy.	- Depth profile data shall be compared to that collected by AstraLite.	- Ground control points shall be collected and integrated into the depth profile model to ensure the model is accurately georeferenced.