RiBBIT CDR

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

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Project Purpose and Objectives

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

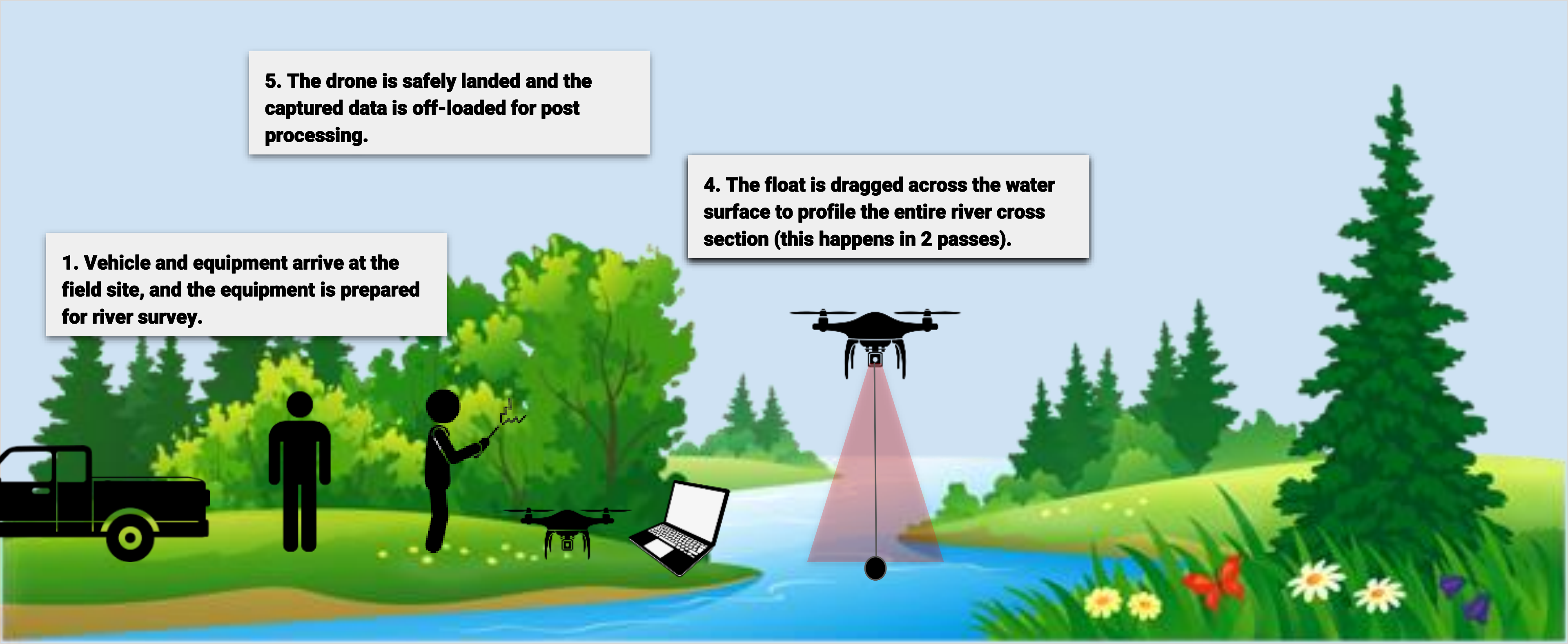
Ease of use

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."

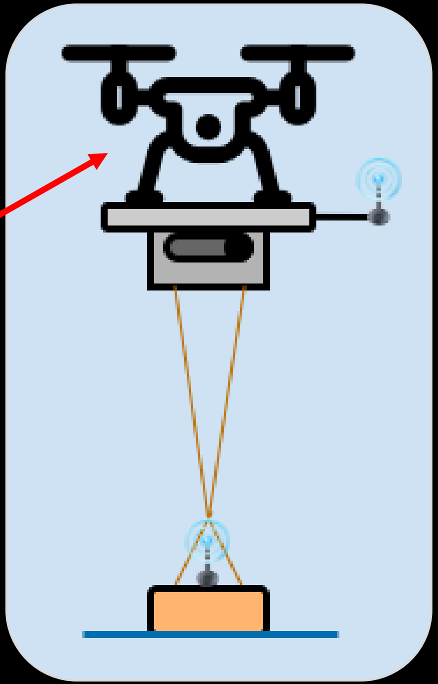
CONOPS


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.

Design Solution

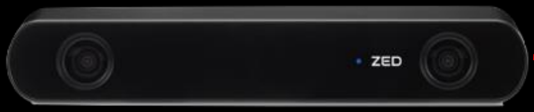
UAV

Tarot 680 Pro

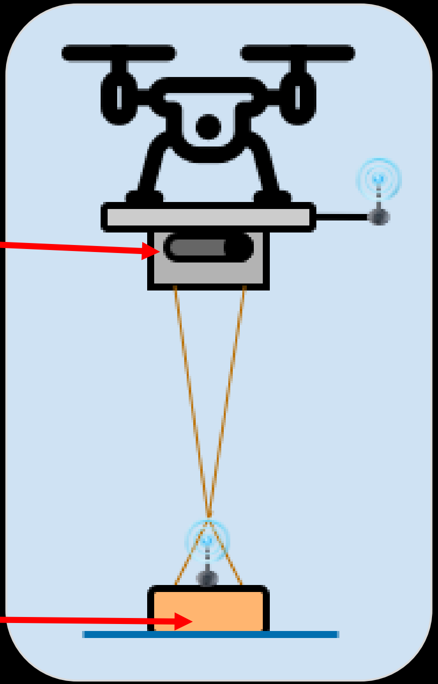


Science Instruments

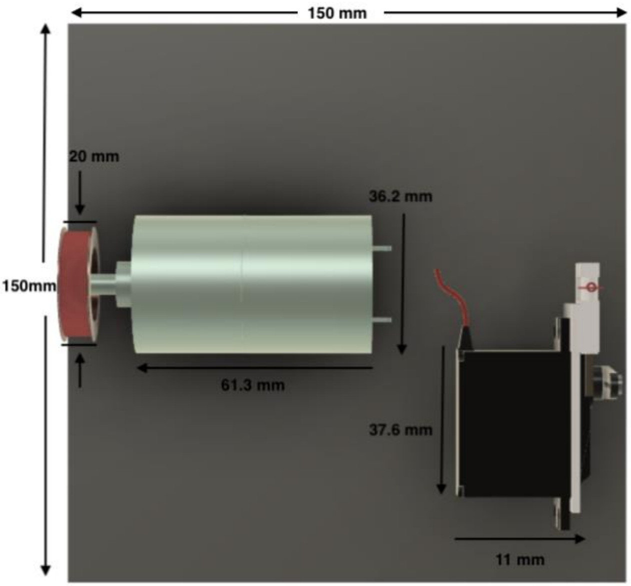
Zed 2 Stereo Camera



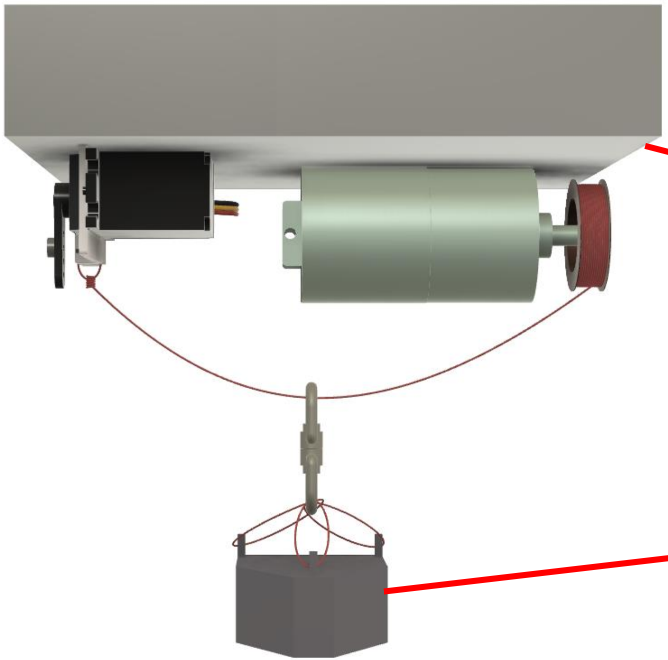
Ping Sonar Echosounder



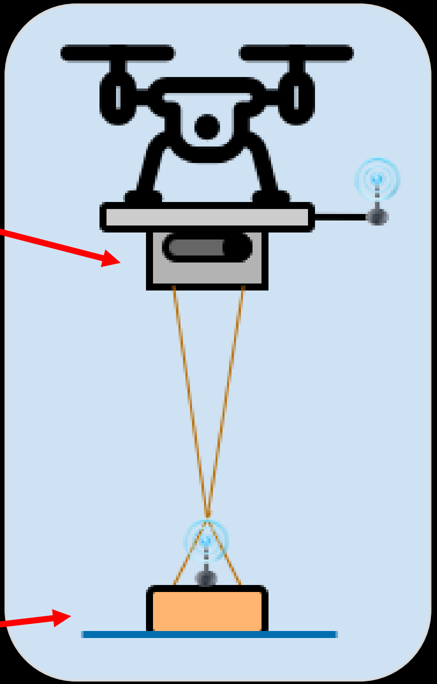
Deployment Mechanism



*Bottom view - no load attached

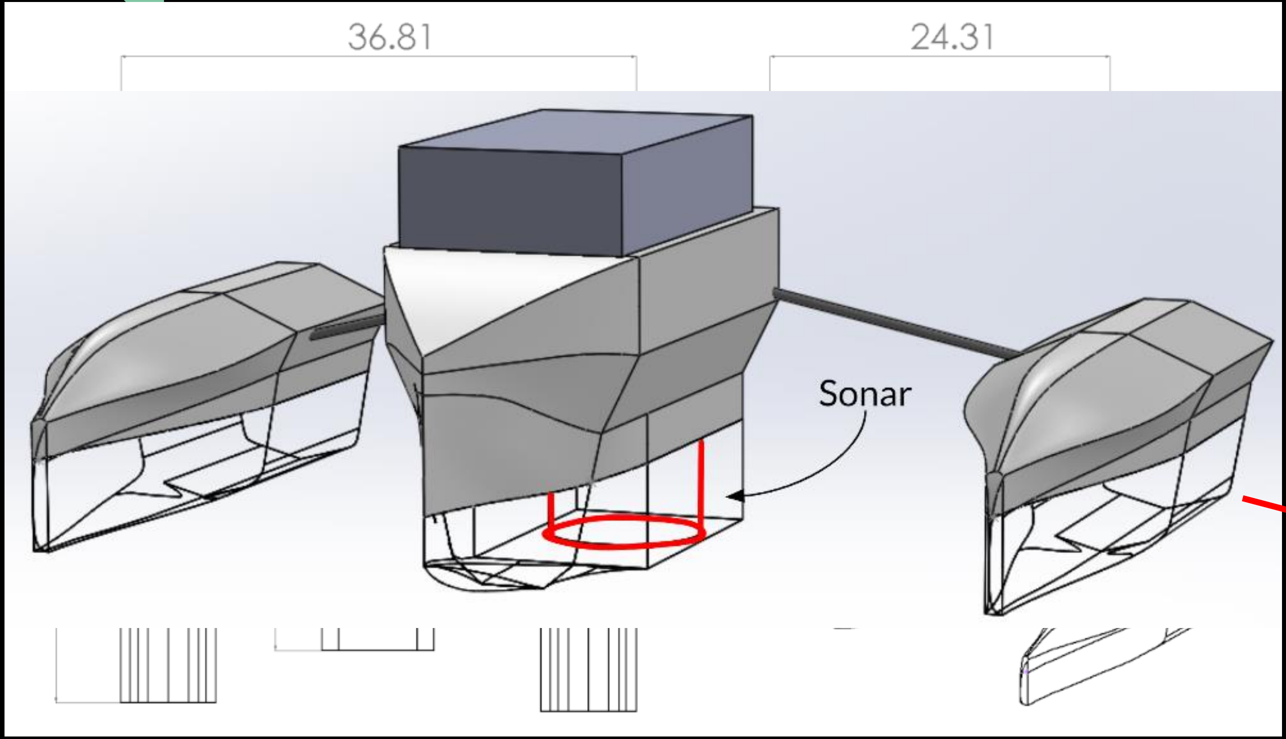


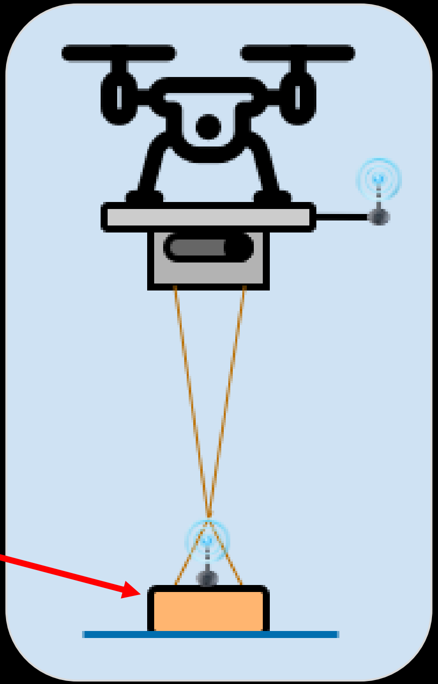
*Front view - load is attached



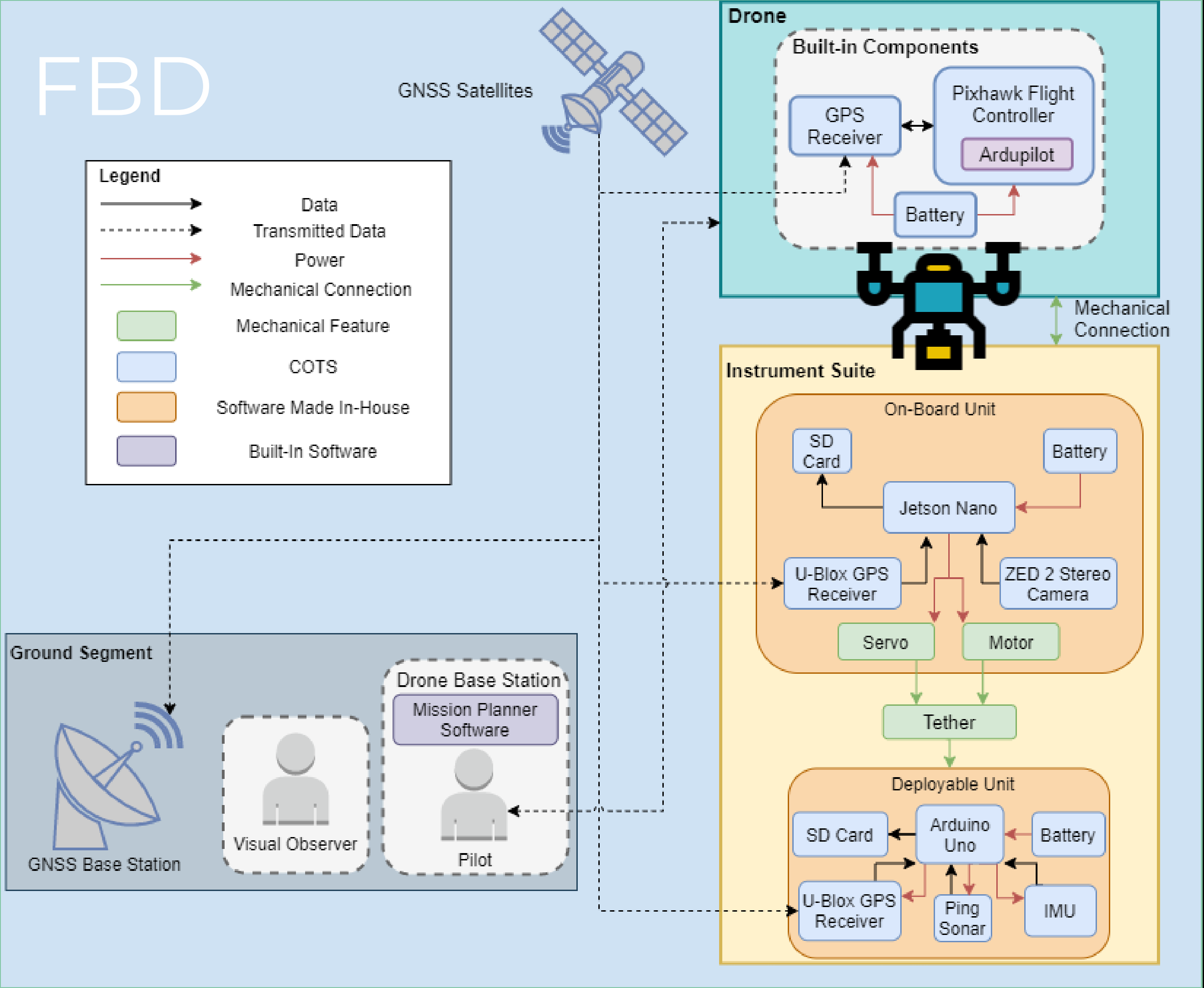
Sonar Float Design

Total est. weight: 961 grams

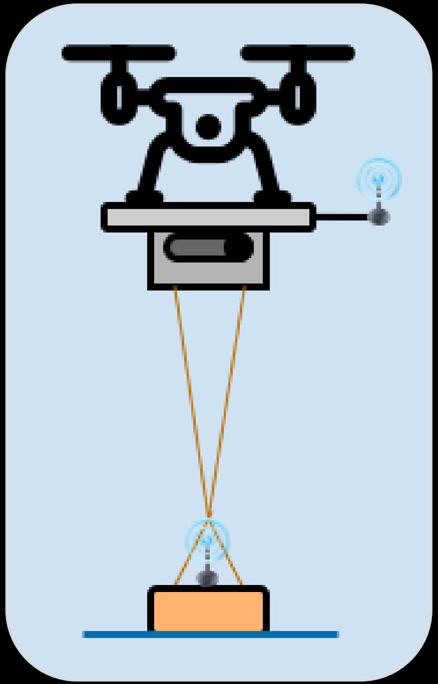




FBD

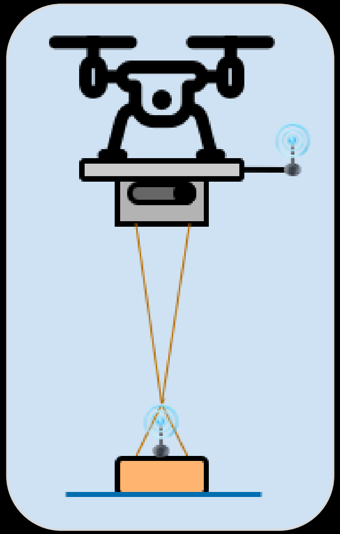


GNSS Satellites
Drone
Built-in Components
GPS Receiver
Pixhawk Flight Controller
Ardupilot
Battery
Mechanical Connection
Legend
Data
Transmitted Data
Power
Mechanical Connection
Mechanical Feature
COTS
Software Made In-House
Built-In Software
Instrument Suite
On-Board Unit
SD Card
Battery
Jetson Nano
U-Blox GPS Receiver
ZED 2 Stereo Camera
Servo
Motor
Tether
Deployable Unit
SD Card
Arduino Uno
Battery
U-Blox GPS Receiver
Ping Sonar
IMU
Ground Segment
Drone Base Station
Mission Planner Software
Visual Observer
Pilot
GNSS Base Station



Critical Project Elements

Critical Project Elements



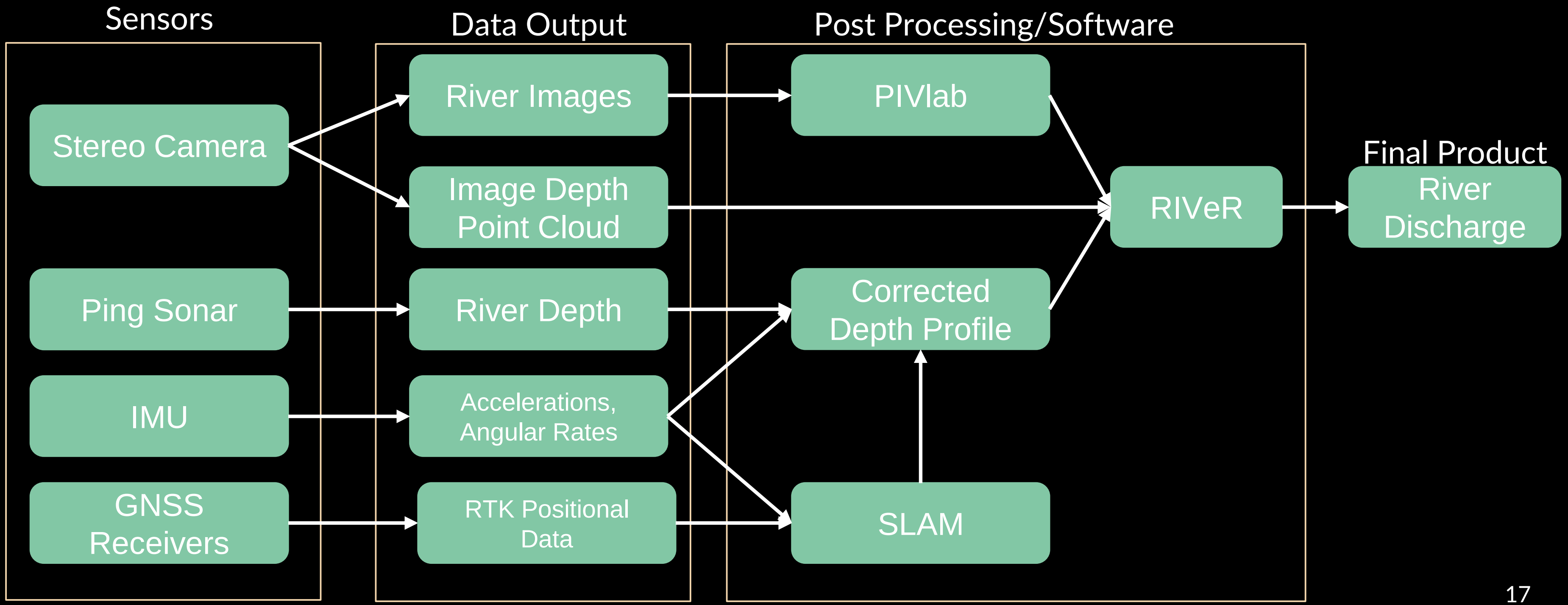
- UAV
- Science Instruments
  - Depth Sensing Instrument
  - Velocity Instrument
- Sonar Deployment Mechanism
- Deployed Sonar Float Angular Displacement Technique
- Payload Housing and Drone Mount
- Command and Data Handling
- Data Post-Processing

Design Requirements and Their Satisfaction

Design Analyses Conducted

- Error Uncertainty Quantification
- Stereo Camera Image Capturing and Velocity Post-Processing
- Float Stability and Contribution to Sonar Uncertainty
- Deployment Mechanism Analysis
- UAV Stability Analysis
- Software Data Flow Analysis
- Positional Tracking Analysis
- Power Analysis
- Weight Budget

Data Flow Overview



Velocimetry Error Uncertainty Quantification

DESIGN REQUIREMENT 7.1:

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

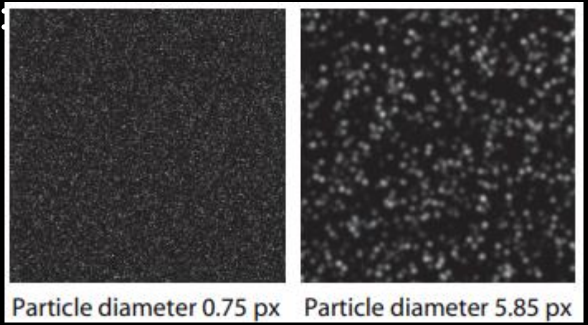
The surface velocity of the river is calculated using a Particle Image Velocimetry (PIV) tool developed in MATLAB.

Using this software we can achieve a bias error of less than 0.005 pixels and and random error of less than 0.02 pixels.[1,2]

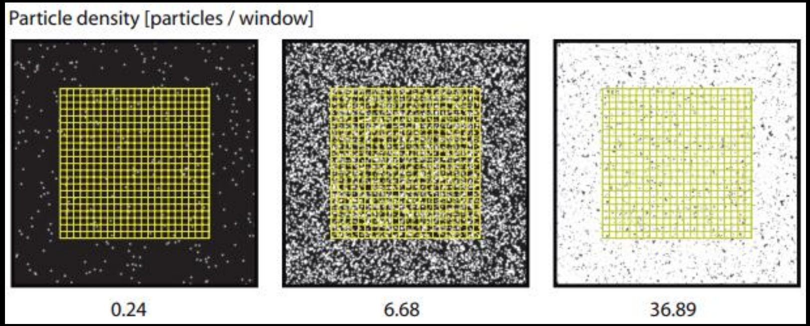
Stereo Camera → River Images → PIVlab

Velocimetry Error Uncertainty Quantification

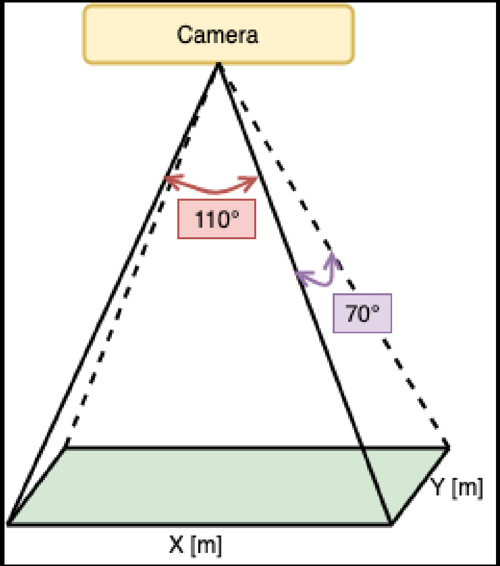
To get these results, we must prove that our images fall under the optimal conditions as defined by the PIVlab analysis[1,2]:

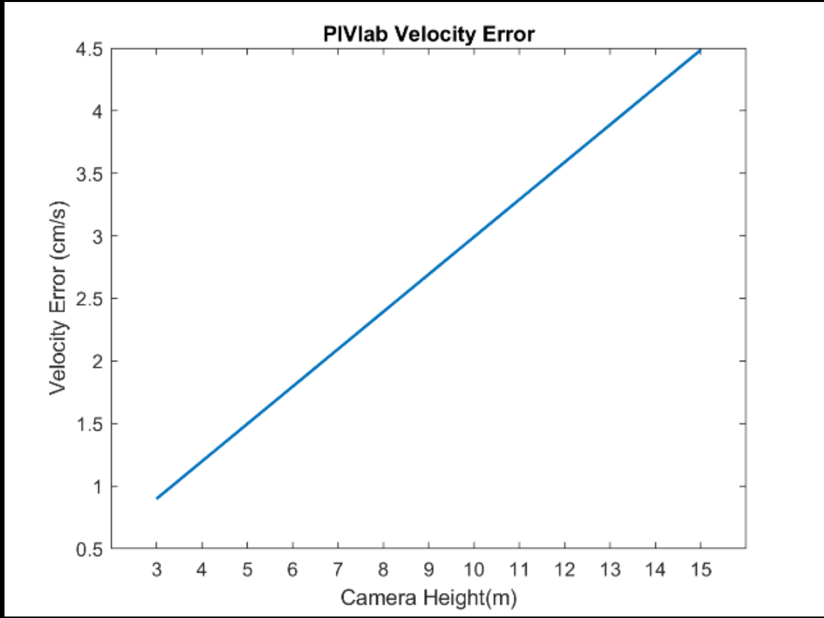


- Particle Image Diameter (1-4 pixels)
- Particle Density (1-8%)
- Sensor Noise
- Particle Pair Loss
- Motion Blur



Velocimetry Error from PIVlab





Camera Resolution: 1920 x 1080p

Bias Error <
0.005 pixels*

30 Frames per Second

Random Error < 0.02 pixels*

** assuming optimal conditions, additional information in backup slides*

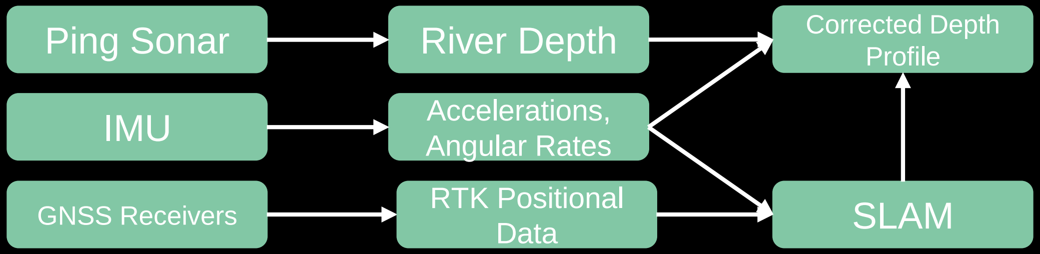
Depth Profile Error Uncertainty Quantification

The Ping Sonar outputs depth (m) and percent confidence in measurement.

The IMU data will be correlated to the Sonar data in time series to correct the measured depth with angular displacement.

The percent confidence will be used calculate a weighted average for the depth at each measurement station along the river bed.

The final depth data will be georeferenced/localized via a SLAM (simultaneous localization and mapping) algorithm using IMU and GNSS data.



Depth Error Due to Angular Displacement

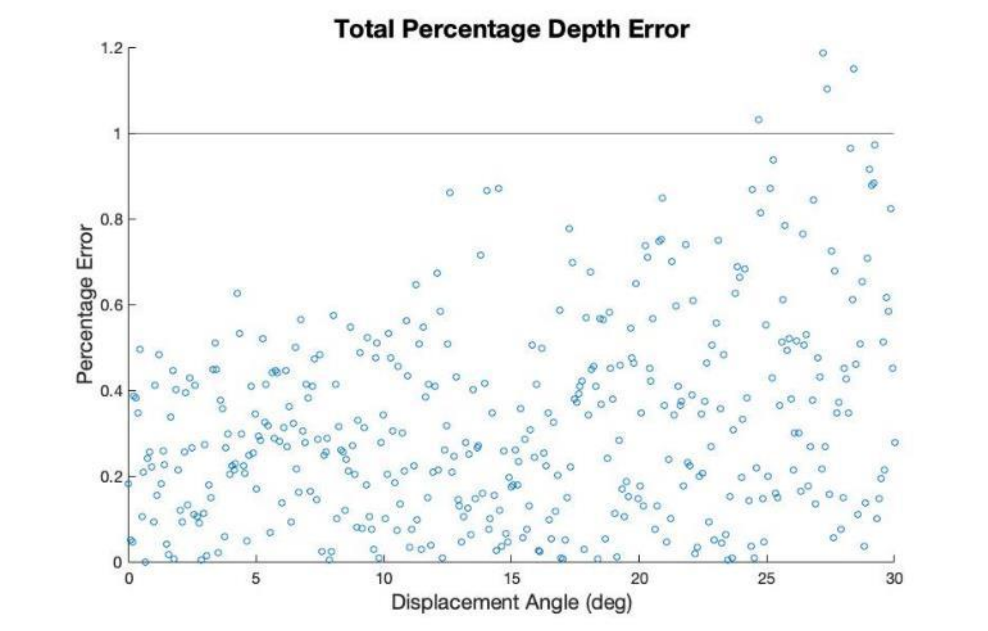
DESIGN REQUIREMENT 4.1.3-.4:

- SONAR shall measure depths to an accuracy of <1% total depth.
- The angle between the SONAR and the gravity shall be measured.

Given error in depth and angle, what level of disturbance can the float experience and remain <1% accurate?

- Monte Carlo Analysis
- Created by using a uniform distribution of errors that are added to test data whose results are then compared to a baseline value

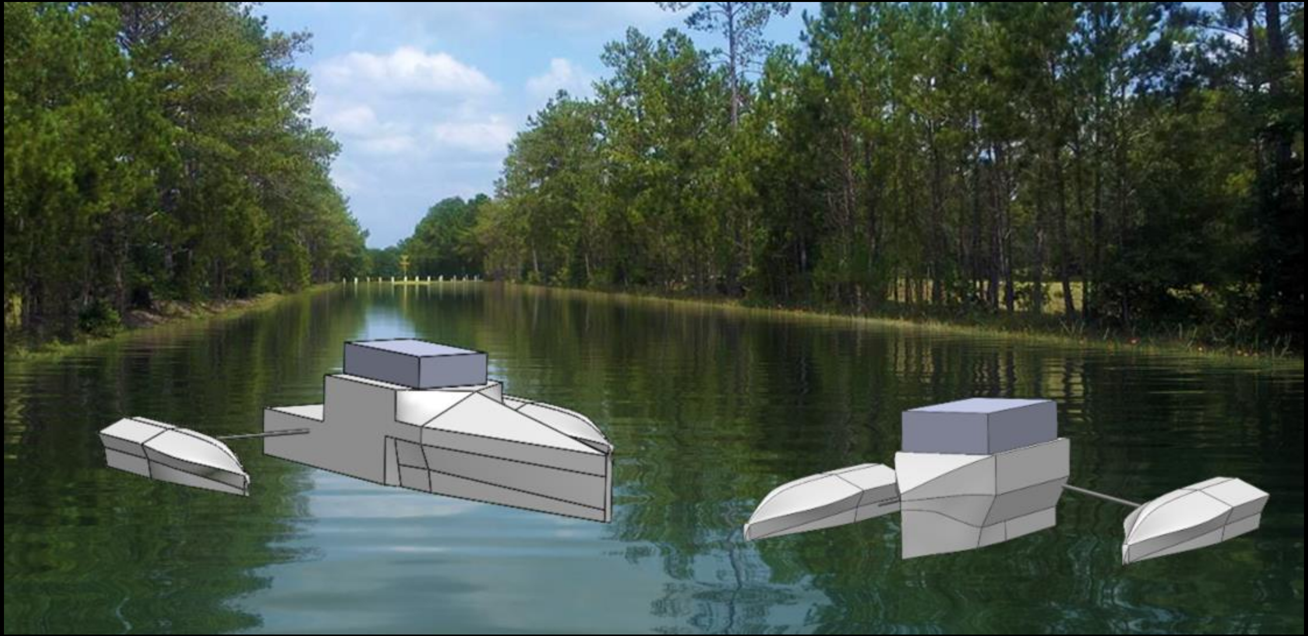
- Shows that we can have a displacement of up to 24.6˚ but do to the random nature we will be setting our threshold to 20˚



Float Requirements

<u>DESIGN REQUIREMENT 4.2:</u>

Minimize the angular displacement of sonar to <20°.
Bottom 2.5 cm of sonar is beneath waterline.



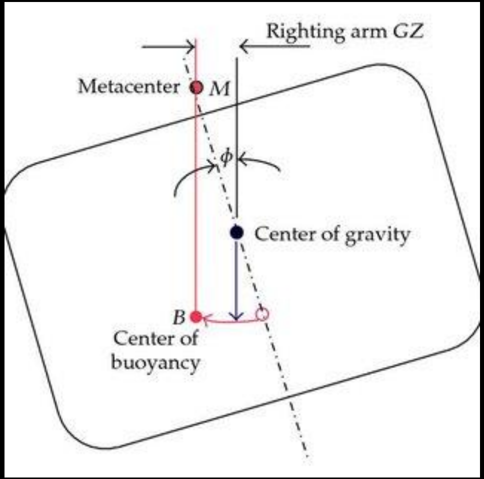
Two prototype float designs

Boat Stability Overview

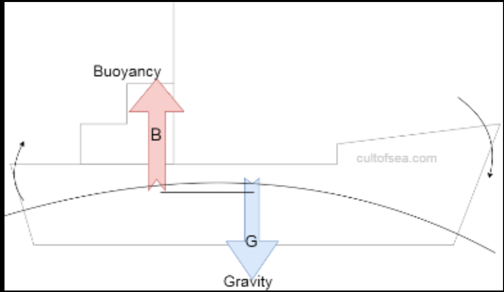
Governed by Archimedes Principle, our analysis assumes:

- Roll and pitch dominated by interaction of <u>Center of Gravity</u> (CG) and <u>Center of Buoyancy</u> (CB
- Heading dominated by interaction of <u>CG</u> and <u>Center of Pressure</u> (weather vane)

Righting moment caused by roll

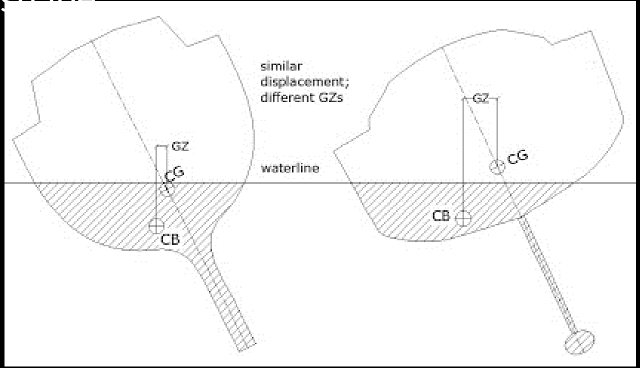


Sway moment caused by pitch



Longitudinal view

CB is a function of submerged shape



<u>Takeaway:</u>

- Always want a corrective moment

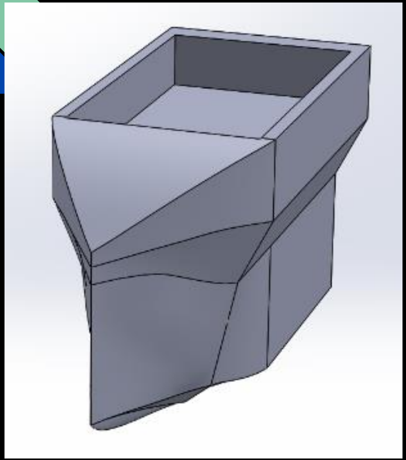
- Need CB below CG for roll stability
- Want CB behind CG longitudinally so there is a moment keeping tension on drone rope

Float Design Inspiration

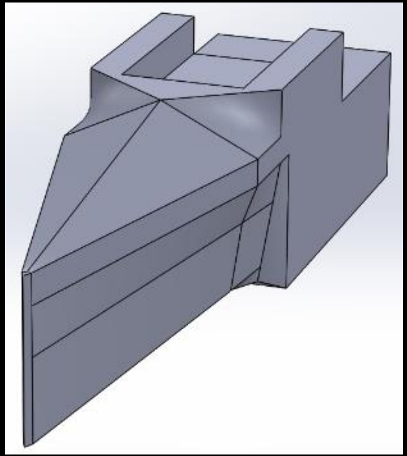
Looked at designs for passenger ships as they prioritize smooth, level travel

- Most of displacement of trimaran is found in main hull
- Stabilizers do not provide much buoyancy and are nearly entirely for roll stabilization
- Bow influences drag and how quickly boat reacts to vertical motion

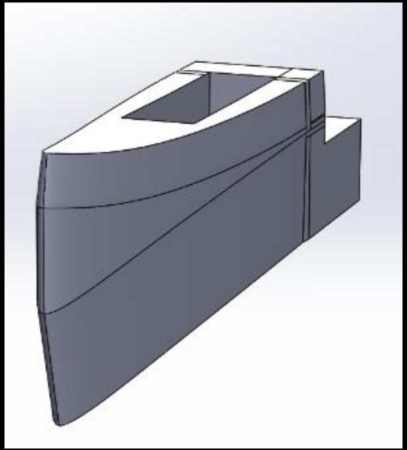
Float Hull Comparison



Weight	269 g
Waterline height	3.2 cm
CG location from leading edge	12.6 cm
CB location from leading edge	12.4 cm

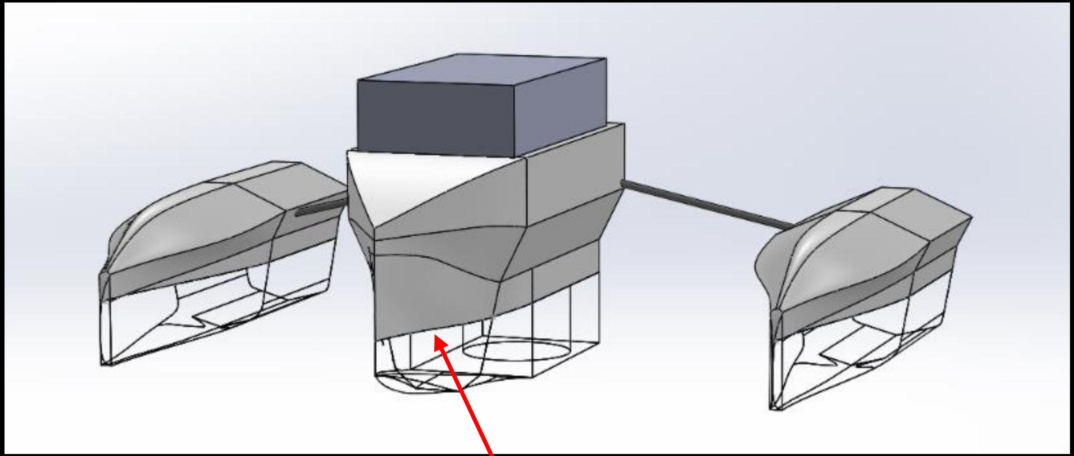


Weight	668 g
Waterline height	2.2 cm
CG Location from leading edge	26.6 cm
CB location from leading edge	29.2 cm



Weight	446 g
Waterline height	2.4 cm
CG Location from leading edge	17.3 cm
CB location from leading edge	17.4 cm

Float Stability Analysis



Calculated waterline where
weight of displaced water = weight of float

Technical performance measurements
for float prototyping

Structure Weight	640 g
Waterline height	3.2 cm
CG location from leading edge	-14.2 cm
CB location from leading edge	-14.5 cm
CG distance from bottom of hull	4.4 cm
CB distance from bottom of hull	1.81 cm

Deployment Requirements Satisfaction

DESIGN REQUIREMENT 4.6:

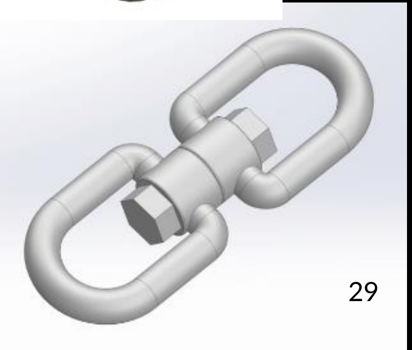
There shall be a mechanism which lowers the float to the water surface.

Technical Performance Measure (TPM)	Our design:	Feasible?
Weight	0.64 kg	yes
Time to Deploy	10 s	yes
Deployment Power Consumption	2.34 W	yes

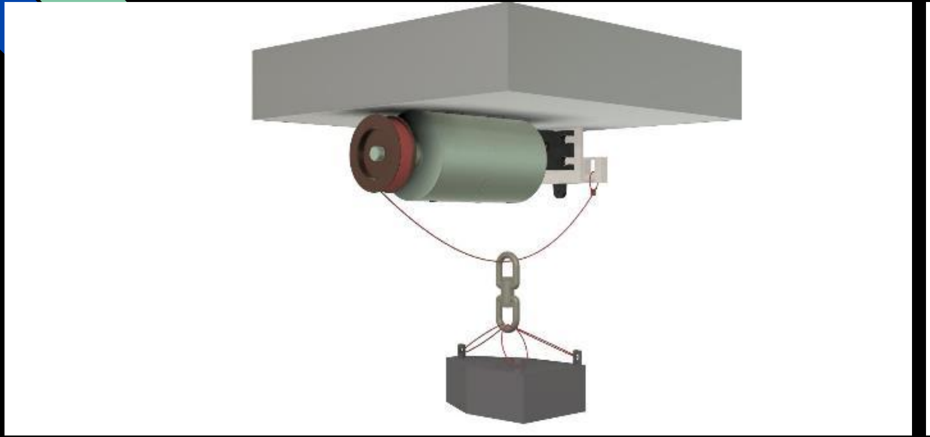
Deployment Mechanism Analysis

- Main components:
    - Motor - 300 RPM
    - Pulley - 1 cm radius
    - Fishing line - 4.5kg holding strength
    - Servo - 10kg throwing capability
    - Swivel - Prevent tangling
- Total weight = 290 g

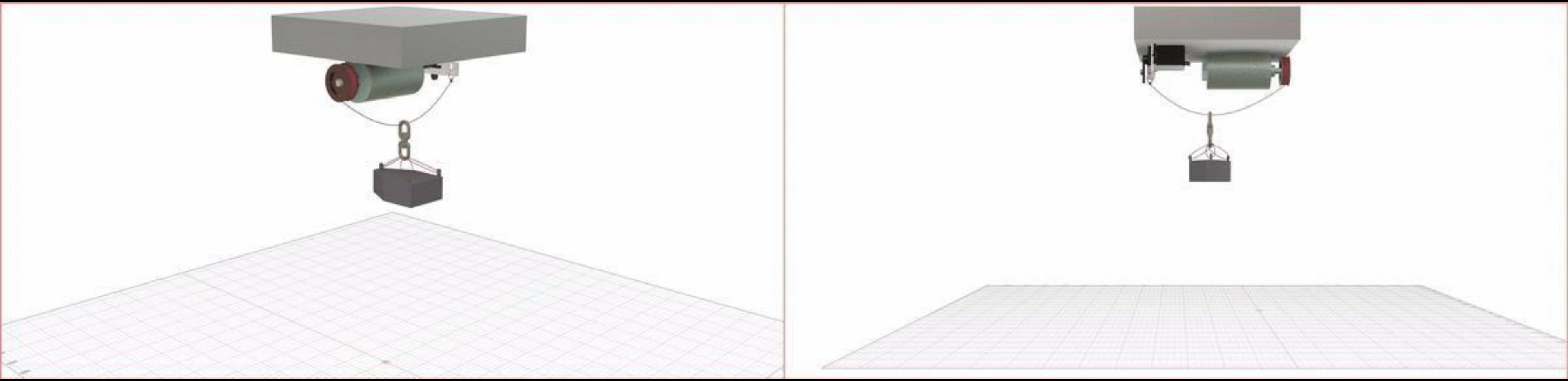


Deployment Mechanism Analysis



Deployment Mechanism Analysis



- Deploy the float to 3 m
- Deployment duration 10 s

Project Purpos e
Design Solution
Critical Project Elements
Design Requirements Satisfied
Project Risks
V&V
Project Planning

Project Risks

Pre-Mitigation Risk Matrix

		Severity				
		Negligible	Minor	Moderate	Major	Severe
Likelihood	Ext. High					
	High			5	1,2	
	Medium					3,4
	Low					
	Extra Low					

<u>Risks:</u>

1. Stereo Camera Data inadequate for measuring velocity

2. Sonar Collection Errors

3. Environmental Hazards

4. Float Deployment Mechanism Failure

5. Test Schedule Slips

Stereo Camera Data Inadequate for Velocity Calculations

		Severity				
		Negligible	Minor	Moderate	Major	Severe
Likelihood	Ext. High					
	High				1	
	Medium					
	Low				1	
	Extra Low					

<u>Consequences:</u>

- River discharge calculations won't be computed

<u>Mitigation:</u>

- Test post-processing capabilities

- Seed the river for easier tracking

- Single object tracking

Sonar Data Collection Errors

		Severity				
		Negligible	Minor	Moderate	Major	Severe
Likelihood	Ext. High					
	High				2	
	Medium					
	Low			2		
	Extra Low					

Consequences:
- River depth profile will be erroneous, contributing to discharge error

Mitigation:
- Stable boat design

- Data post-processing angular corrections and outlier filtering capabilities

Environmental Hazards

		Severity				
		Negligible	Minor	Moderate	Major	Severe
Likelihood	Ext. High					
	High					
	Medium					3
	Low		3			
	Extra Low					

<u>Consequences:</u>

- Equipment damaged or lost
- Inaccurate data

<u>Mitigation:</u>

- Safe testing site chosen
- Release mechanism to drop caught payload
- Professional drone pilot
- Drone flown in line of sight

Float Deployment Mechanism Failure

		Severity				
		Negligible	Minor	Moderate	Major	Severe
Likelihood	Ext. High					
	High					
	Medium					4
	Low			4		
	Extra Low					

<u>Consequences:</u>

- No sonar depth data collected

<u>Mitigation:</u>

- Testing motors and servos in varied environmental conditions
- Ensuring power needs of mechanism are met
- Testing RC commanding
- Manual deployment prior to flight as back up

Test Schedule Slips

		Severity				
		Negligible	Minor	Moderate	Major	Severe
Likelihood	Ext. High					
	High			5		
	Medium					
	Low		**5**			
	Extra Low					

<u>Consequences:</u>
Full system integration not properly tested before official river survey and data collection

<u>Mitigation:</u>
- Develop robust test plans
- Develop set of indoor test procedures
- Build in margin to test plan
- Plan backup days in case of poor conditions/ COVID delays

Post-Mitigation Risk Matrix

		Severity				
		Negligible	Minor	Moderate	Major	Severe
Likelihood	Ext. High					
	High					
	Medium					
	Low		5,3	4	1	
	Extra Low					

Risks:

1. Stereo Camera Data inadequate for measuring velocity

2. Sonar Collection Errors

3. Environmental Hazards

4. Float Deployment Mechanism Failure

5. Test Schedule Slips

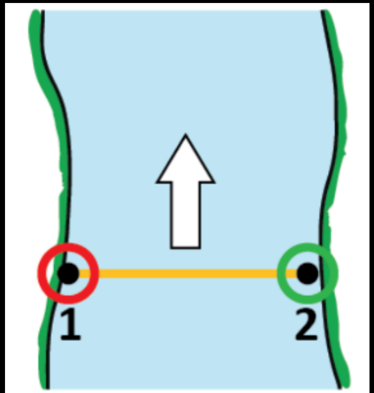
Verification and Validation

Tests Developed

- Stereo Camera Velocity Testing
- Sonar Float Prototype Test
- Deployment Mechanism Prototype Test
- Mock Sonar Data Post-Processing Test
- Mock Stereo Camera Data Post-Processing Test
- Full System Stability Test
- System Integration Testing
- Battery Life Testing
- Avionics Data Collection Testing

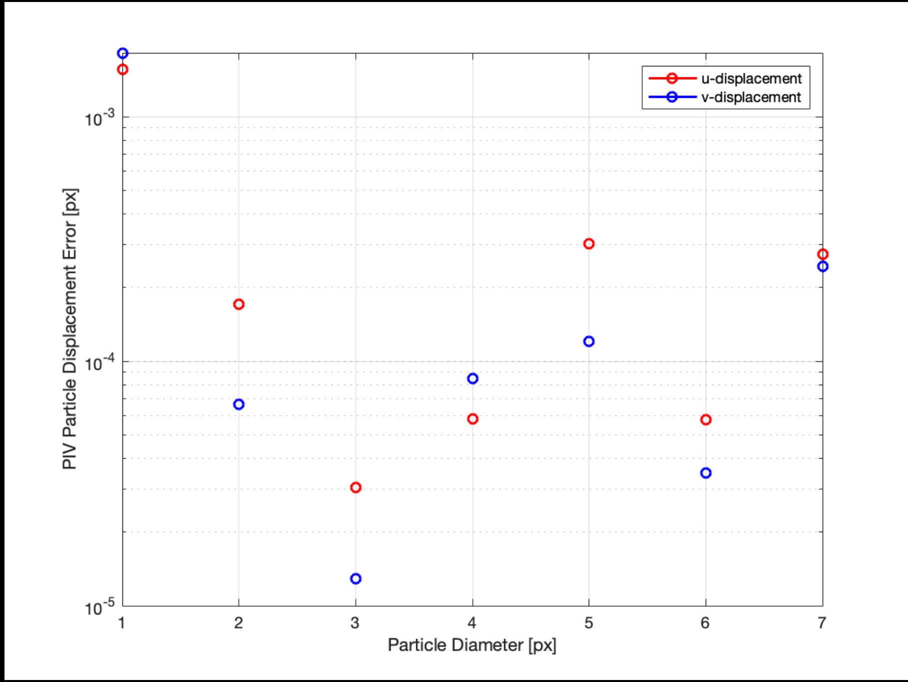
V&V: Stereo Camera Velocity Testing

- Data Collected for Post-Process Testing
  - Steady top-view video of flowing river
  - Control points (2 or 4) and distance measurements between them
  - In-situ river “truth” velocity measurement for data validation
- Measurements Collected from Post-Processing
  - PIVLab
    - Median velocity flow field
    - Plots of u and v components of velocity
  - RIVeR
    - Uses control points to convert pixels/frame to real world distances
    - Velocity vectors perpendicular to desired cross section
    - Mean velocity [m/s]
    - Total discharge [m^3/s]

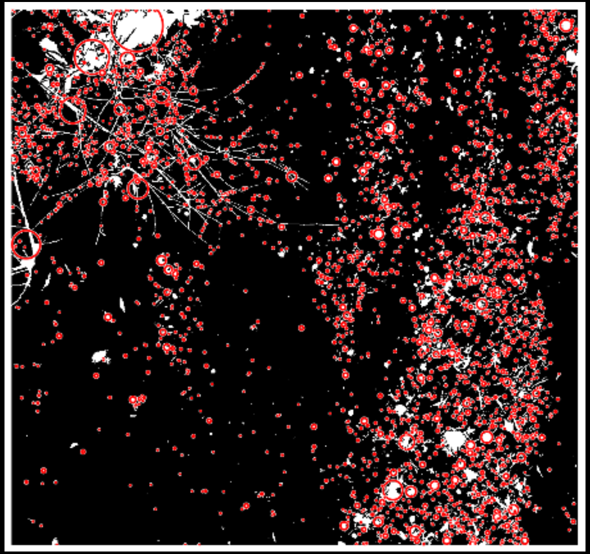


Pre-Processing Image Validation - Particle Diameter

- Matlab program derived from ‘Accuracy.m’ in PIVlab source code
- Generates artificial images to be run through PIV analysis using direct Fourier transform correlation with multiple passes
- Calculates the error between actual velocity of particles and velocity computed using PIV
- Errors were computed for images of different particle size (in pixels) and plotted (shown at right)

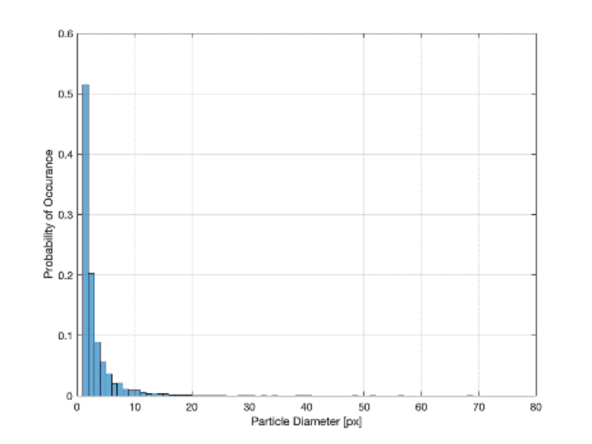


Pre-Processing Image Validation - Particle Diameter

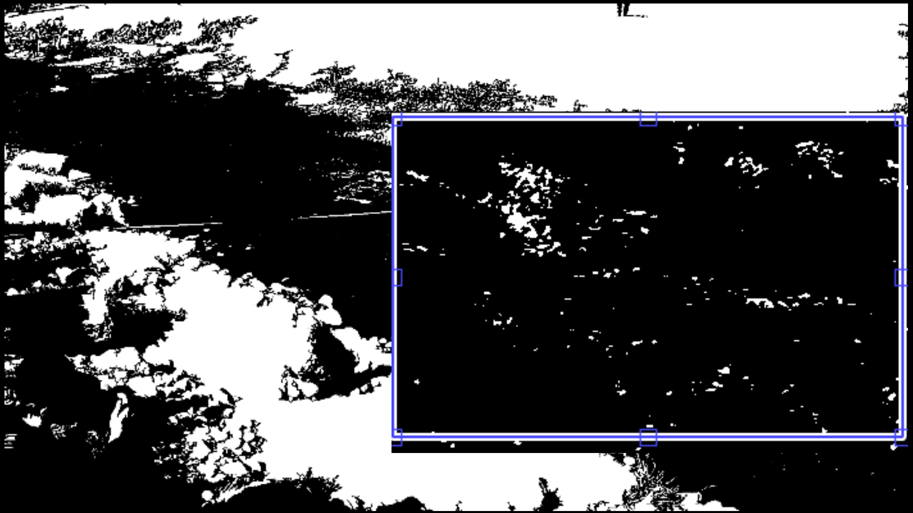


Mean Particle Diameter = 1.53 pixels

- Connected components - groups of pixels with similar intensity
- Get diameter of the connected components or particles
- Take the mean diameter of connected components
- If the particle diameter is between 1-4 pixels the RMS error will be less than 0.1 pixels



Pre-Processing Image Validation - Particle Density



function [density] = findDensity(image)

- Input: RGB image from river video
- Output: Density of particles in selected interrogation window

$$density = \frac{\%\text{white pixels}}{\%\text{total pixels}}$$

If the density of particles is between 1%-8%, the RMS error will be less than 0.1 pixels

Future Work: Create pre-processing tool to get particle diameter and density of selected region and output contribution to error in pixels.

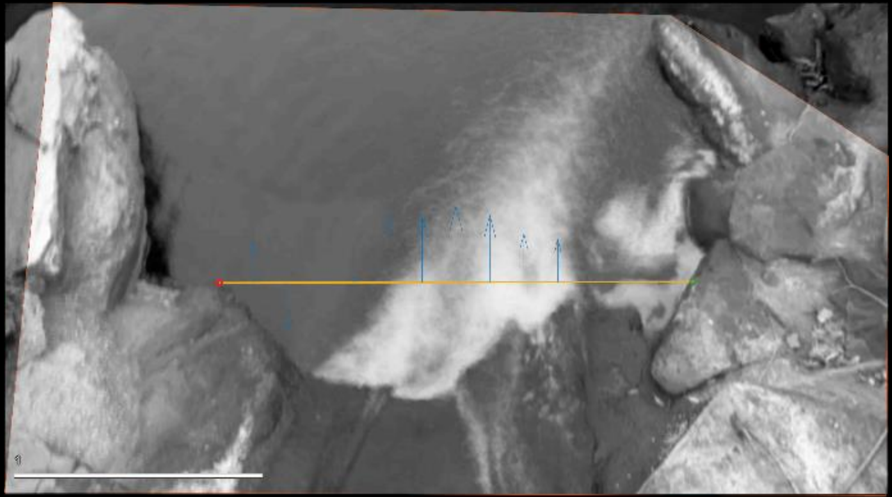
Velocity Post-Processing

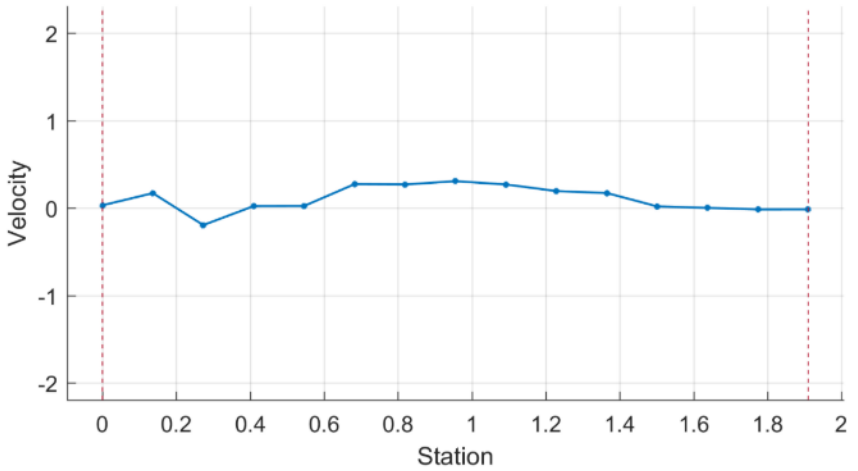
Bridge data was taken from

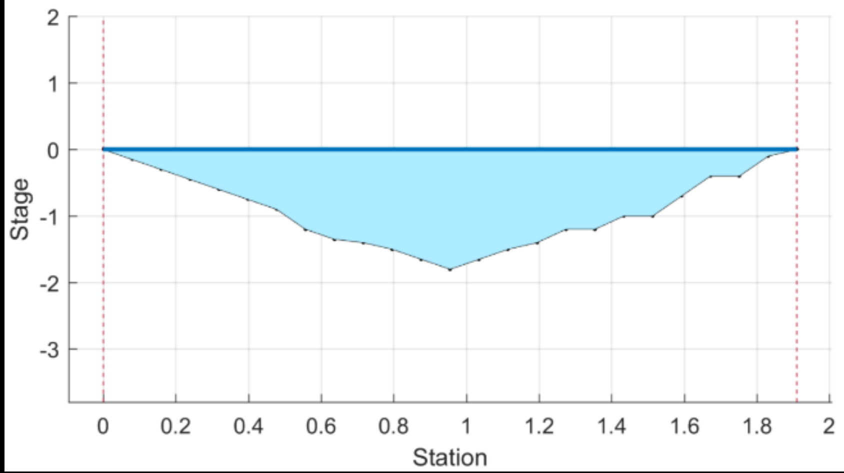
Testing Procedure

1. Collect video footage of a flowing river from bird's-eye view
2. Record distance between 4 ground control points
3. Measure "truth" velocity:
    a. Measure a particular distance along the river bed
    b. Place the tracker object into the river, upstream of the flow
    c. When the object enters the measured section, start the stopwatch. When the object reaches the end of the selected section, stop the stopwatch
    d. Calculate the truth velocity by computing distance travelled by the tracker object over the time recorded
4. Load video data from smartphone to Windows machine
5. Use RIVeR and PIVlab software tools to extract a median velocity field for the water's surface

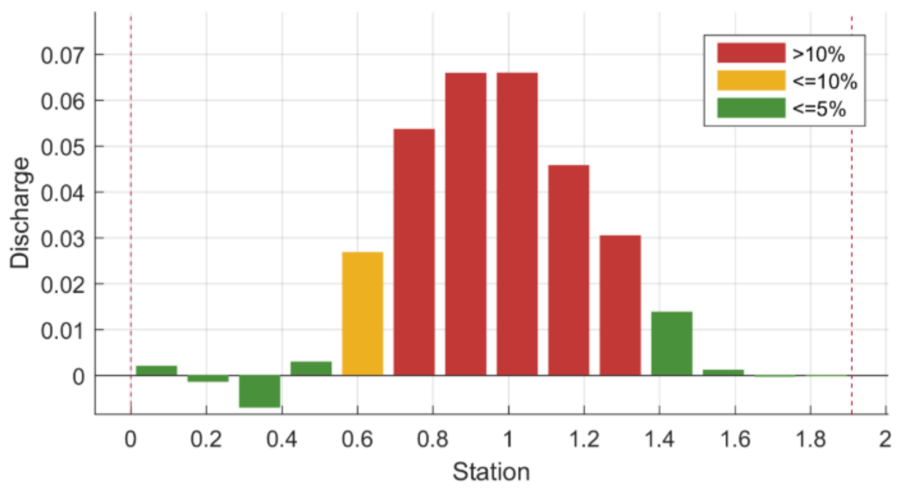
Boulder Creek







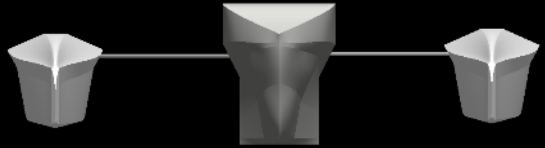
Average Velocity	0.17 m/s
Total Discharge	0.3 m^3/s



Velocity Post Processing Summary

Test Site	RiVER Velocity (average)	RiVER Velocity (fastest vector)	“Truth” Velocity	USGS Discharge	Calculated Discharge	Error
Boulder Creek	0.17 m/s	0.29 m/s	0.36 m/s	0.11 m^3/s	0.3 m^3/s	19.4%

V&V: Sonar Float Models



Model 1: Roll Moments

<u>Considered:</u>
Center of Mass
Center of Buoyancy
Front view

<u>Goal:</u>
Show force required to roll float out of 20 degree requirement

Model 2: Weather Vain Stability

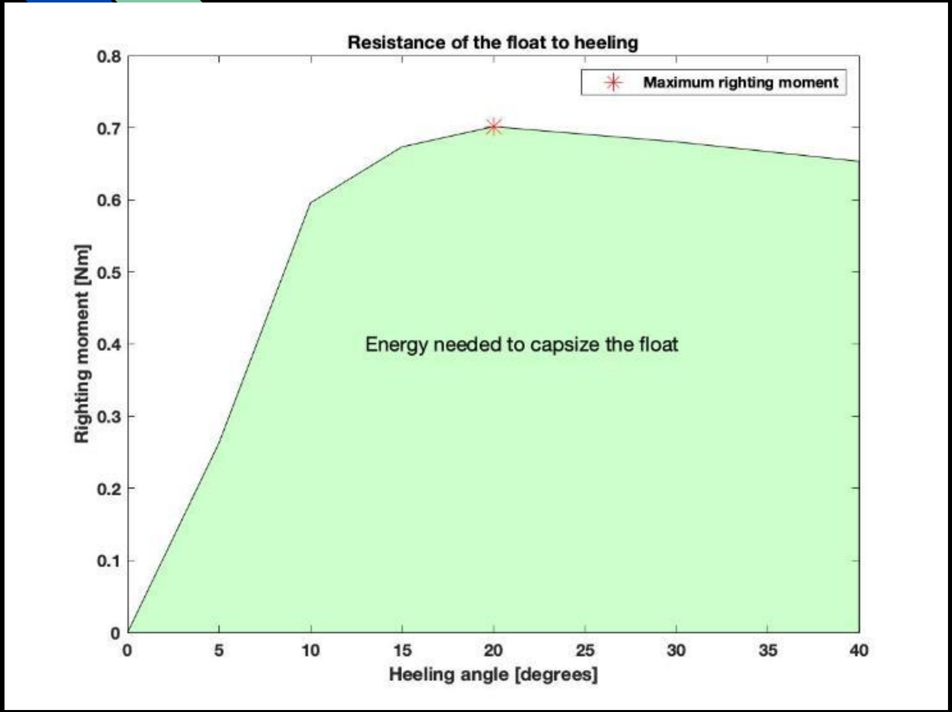
<u>Considered:</u>
Effective Area
Center of Pressure
Top down view

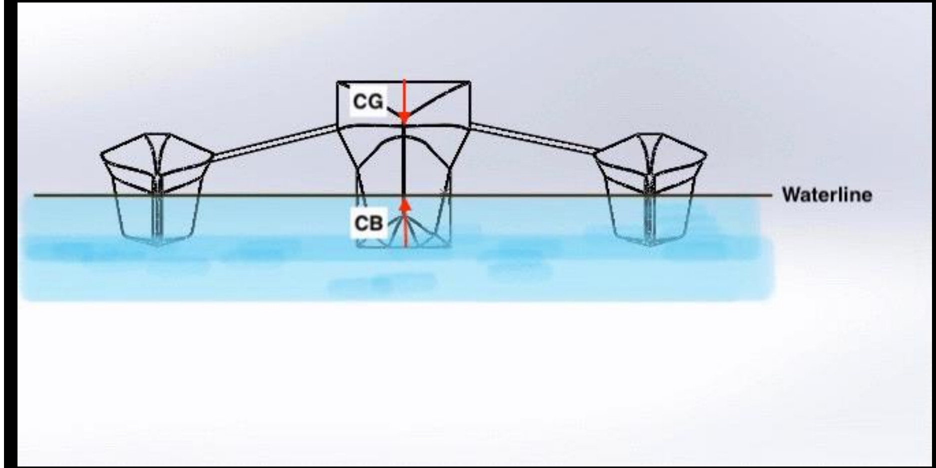
<u>Goal:</u>
Demonstrate the float exemplifies weathervane stability

Assumed:

- Steady, uniform 1D flow
- No vertical displacements
- No wind resistance

Roll/Heel Stability Analysis

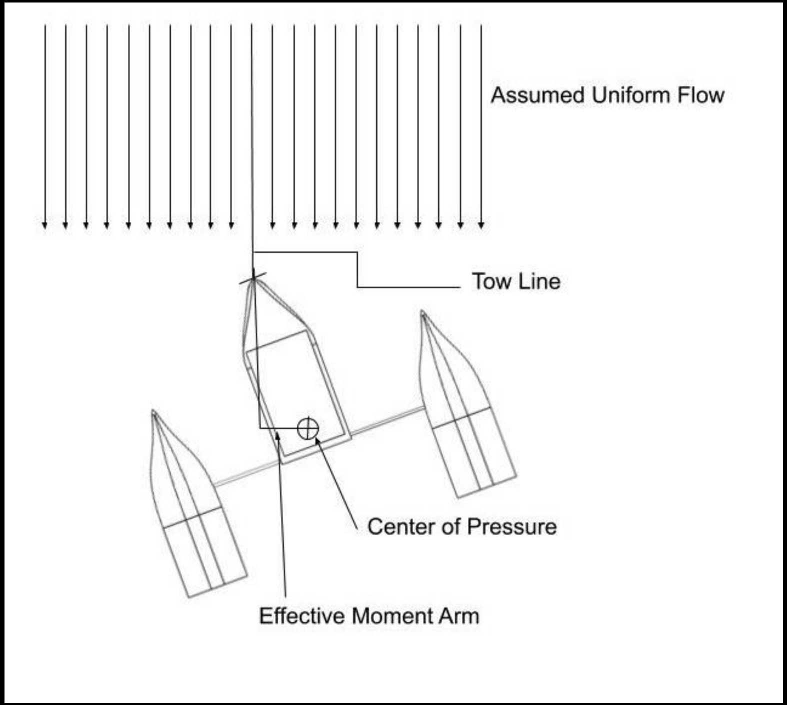




- Maximum righting moment = 0.70142 Nm at 20°
- Energy needed to capsize the float = 23 Nm

Yaw Stability Analysis

- Center of pressure found from weighted average of central float CP and side pontoon CP
- Effective area found based on float geometry, water line and displacement angle
- Corrective moment found from hydrodynamic force and effective moment arm

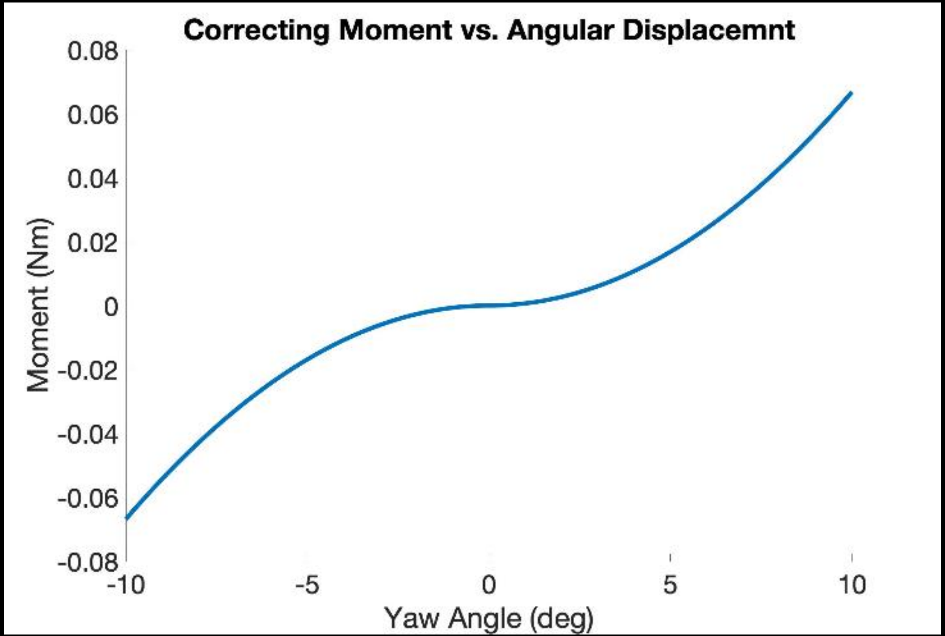


Yaw Stability Analysis

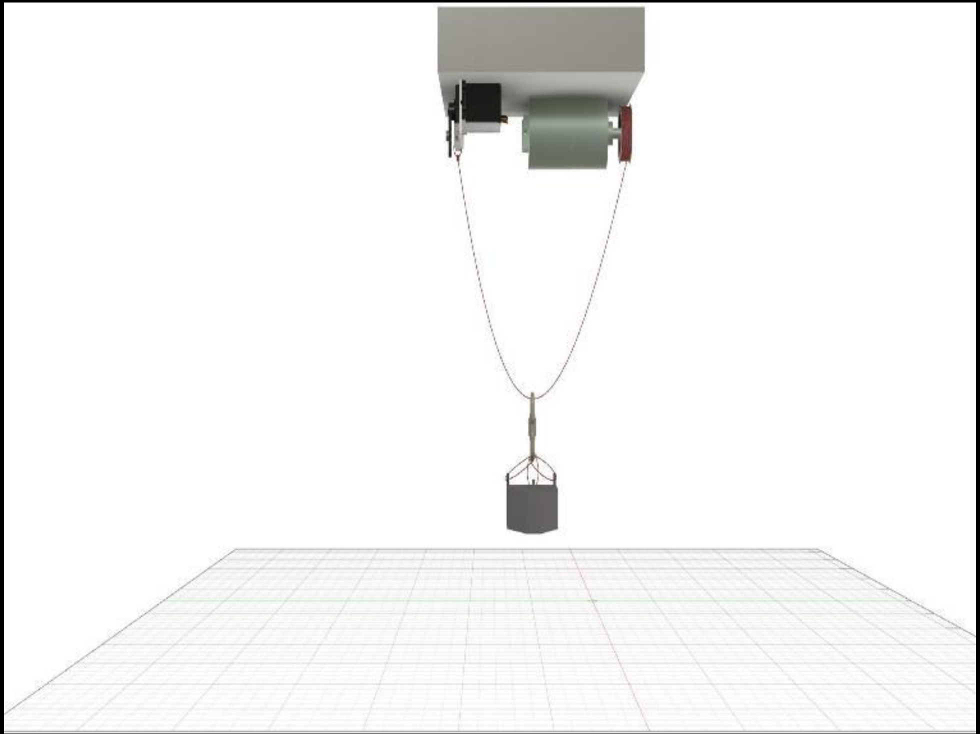
- We want the moment to counter the angular displacement of the float

- A negative displacement causes a negative moment
  - Implying the system has weathervane stability

- Ultimately we can move forward with this design



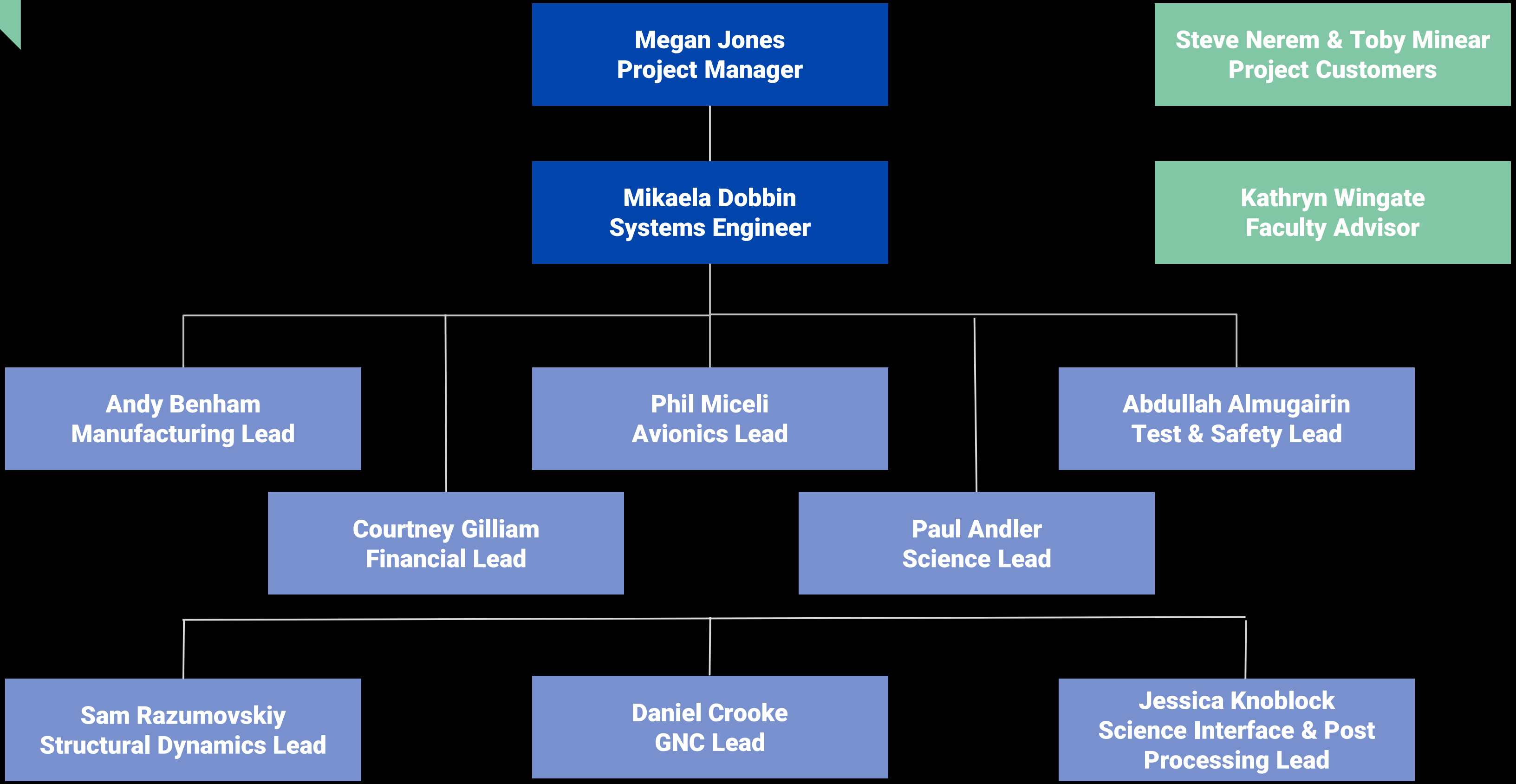
V&V: Deployment Mechanism Prototype Test



- Test components individually
  - Make sure that the motor and servo operate on the voltage identified by the manufacturer
- Use the CAD model to 3D print the pulley
- Assemble components and connect to the battery
- Integrated Test
  - Test with and without load (700g)
  - Ensure successful repeatability
- Measure total power consumption of the battery and time of deployment/retraction cycle

Project Planning

Organizational Chart



Organizational Chart

Subsystem	Members
Avionics	**Lead:** Phil Miceli Jessica Knoblock Samuel Razumovskiy Daniel Crook
Science	**Lead:** Paul Andler Courtney Gilliam Andrew Benham Abdullah Almugairin
Structural Dynamics	**Lead:** Samuel Razumovskiy Andrew Benham Abdullah Almugairin
Mechanisms	**Lead:** Abdullah Almugairin Courtney Gilliam Andrew Benham
GNC	**Lead:** Daniel Crook Phil Miceli Megan Jones

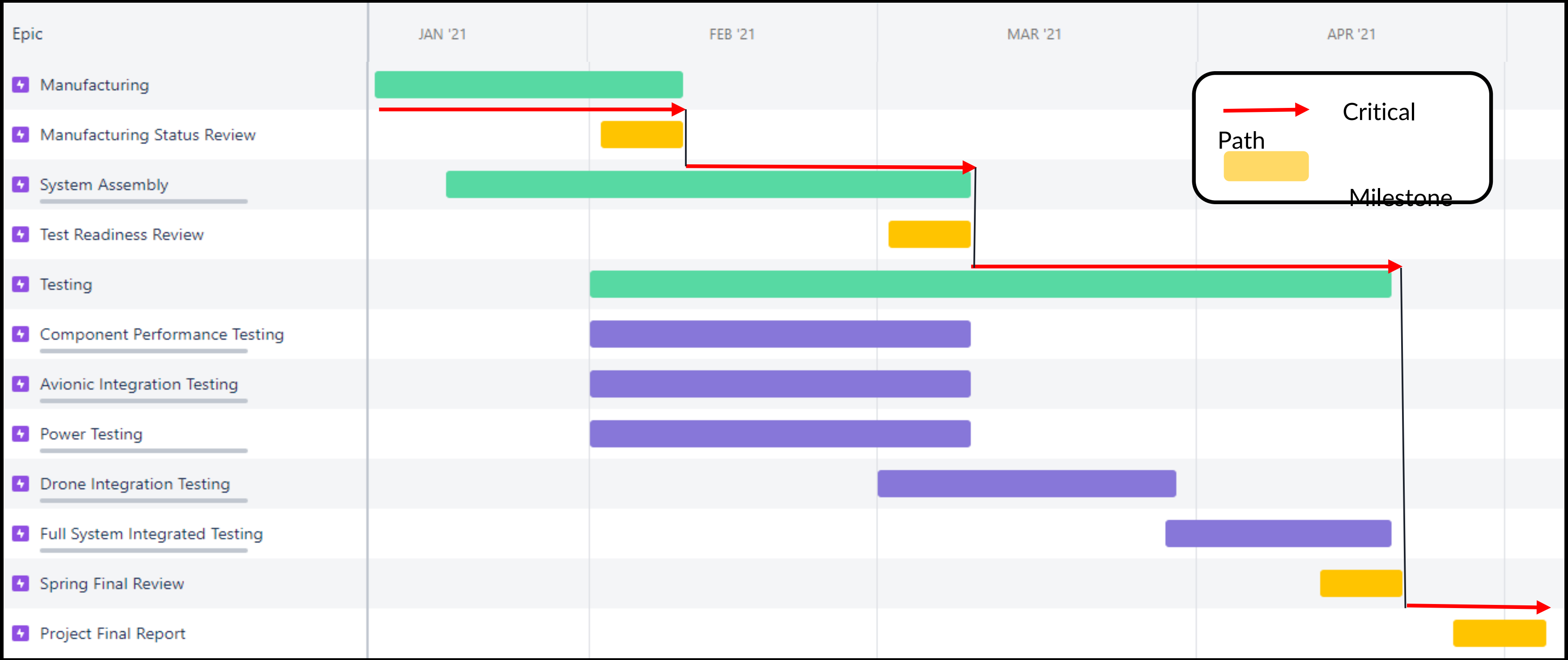
Work Breakdown Structure

Deliverables	Management	UAV & Structural Dynamics	Mechanisms	Avionics & Power	Data Processing	Safety/Test
PDD	Gantt Chart	Research	Research	Research	Research	FAA Guidelines Research
CDD	Org Chart	Drone Stability Algorithm Development	Deployment Mechanism Power Analysis	On-Board Computer Selection	Software Application Selection	Testing Site Research & Planning
PDR	WBS	Drone Stability Analysis	Deployment Cycle Time Analysis	Battery Selection	Velocity Software Application Test	Test Site Selection
CDR	Cost Plan	Data Collection Activation Flow Chart	Prototyping	Power Analysis	Sonar Software Application Test	Facilities Permission
FFR	Test Plan	CAD Float Design	Manufacturing	Data Flow Analysis	Discharge Software Application Test	Scheduling
MSR	Risk Matrix	Float Simulated Stability Analysis	Deployment & Retraction Weight Test	Product Integration	GNSS Software Application Test	Procedure Development
TRR	Part Purchasing	Float Prototyping & Manufacturing	Integration	Sonar Float Command & Data Collection Test	Hand-Held Stereo Camera Test	Test Equipment Acquisition
SFR		Float Stability Test (Pre-Integration)	UAV-Integrated Deployment & Retraction Test	Stereo Camera Command & Data Collection Test	Drone Integrated Stereo Camera Test	
PFR		Drone External Moment Stability Test		Deployment Mechanism Command & Power Test	Sonar Depth Profile Test (Unmounted)	
SDS		Drone Weight Capacity Test		Full System Day-in-the-Life Test	Sonar Depth Profile Test (On Float)	
AIAA		Drone Control, RC Command Test			Full Post-Processed Data Deliverable	

Legend

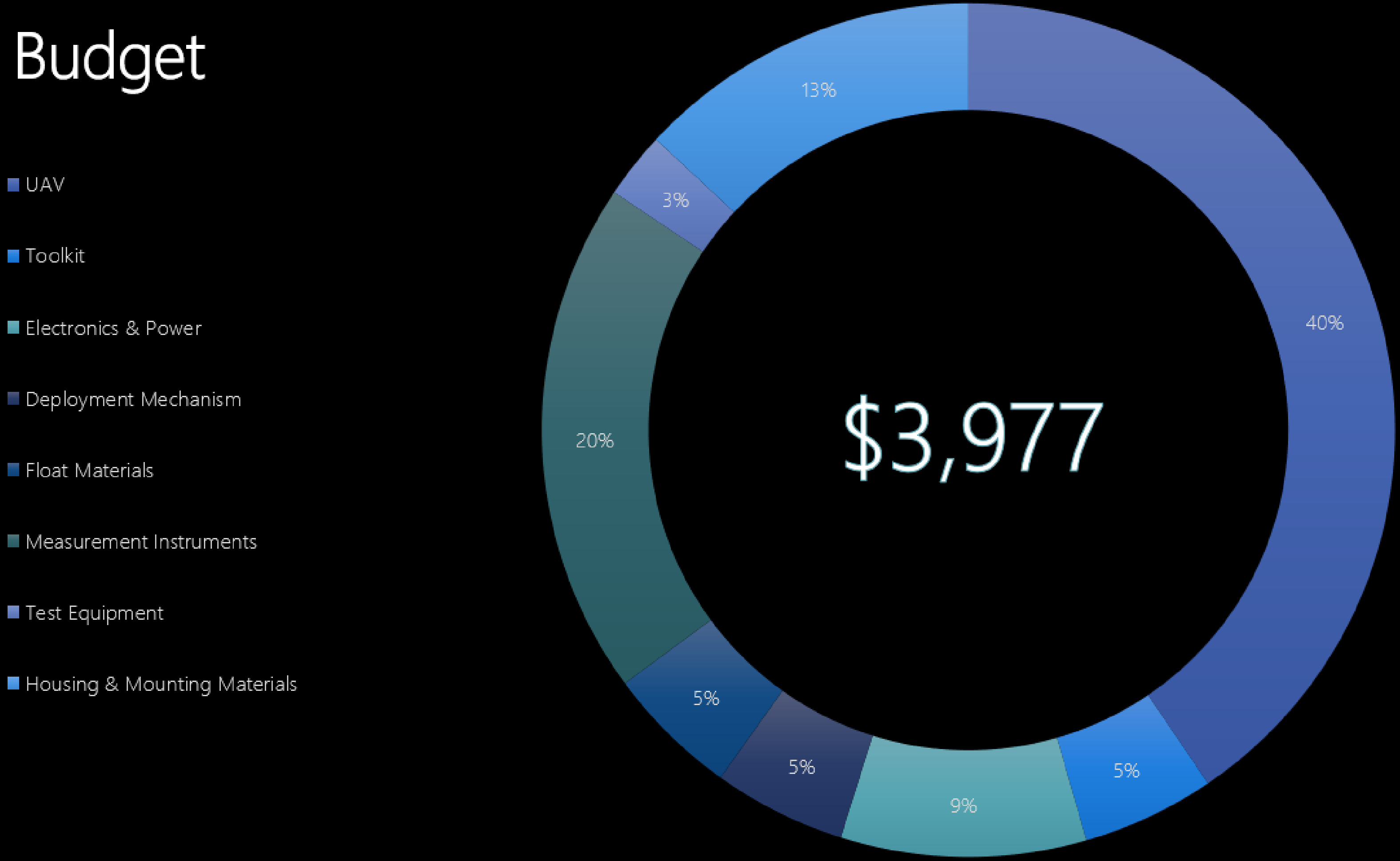
- Completed
- Future Work

Work Plan

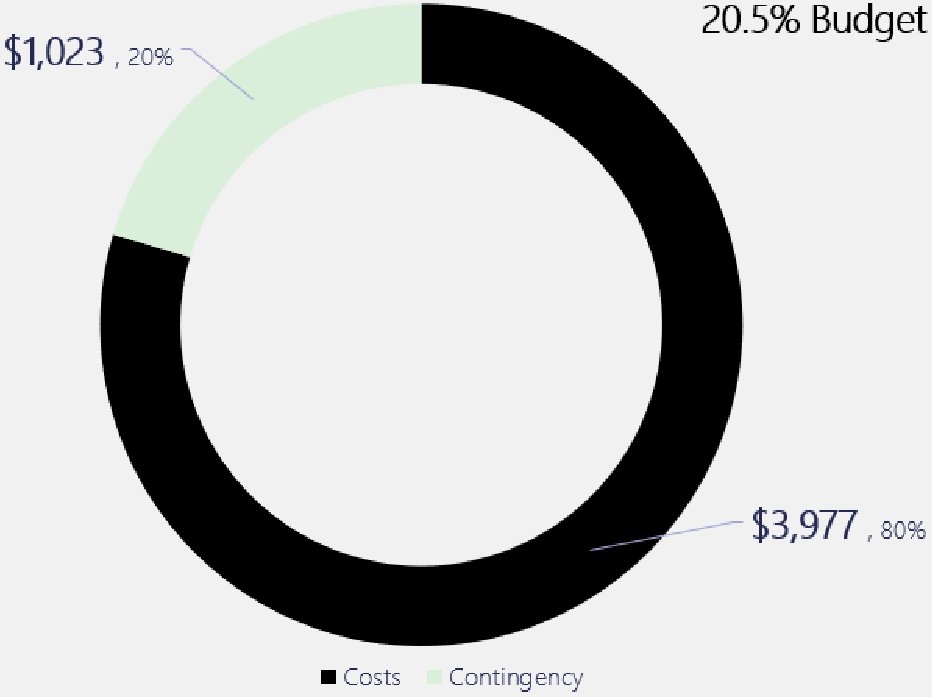


Epic
JAN '21
FEB '21
MAR '21
APR '21
Manufacturing
Manufacturing Status Review
System Assembly
Test Readiness Review
Testing
Component Performance Testing
Avionic Integration Testing
Power Testing
Drone Integration Testing
Full System Integrated Testing
Spring Final Review
Project Final Report
Critical
Path
Milestone

Budget


UAV
Toolkit
Electronics & Power
Deployment Mechanism
Float Materials
Measurement Instruments
Test Equipment
Housing & Mounting Materials
$3,977
40%
5%
9%
5%
5%
20%
3%
13%

20.5% Budget Remaining



Budget Uncertainty

Set costs: exact item and source has been determined

Budgeted costs: exact material or product and source undetermined

Set costs		**Budgeted Costs**	
Tarot	$1611	Deployment Materials	$200
Electronics	$318	Housing	$320
Power	$53	Mounting Parts	$200
Toolkit	$200	Test Equipment	$100
Instruments	$776	Float Materials	$200

Test Plan

Test	Date	Location
Stereo Camera Data Collection	2/1/2020 - 3/1/2020	Boulder Creek
Sonar Data Collection	2/1/2020 - 3/1/2020	Boulder Creek
Sonar Float Stability Test	2/1/2020 - 3/1/2020	Boulder Creek
UAV Control & Weight Capacity Test	3/1/2020 - 4/1/2020	CU East Campus
Deployment Mechanism & Emergency Release Test	3/1/2020 - 4/1/2020	Boulder Creek
System Integration Testing	3/1/2020 - 4/1/2020	CU South Campus
Final Demonstration	4/1/2020 - 4/19/2020	Colorado Blue River Confluence

Questions?

Backup Slides

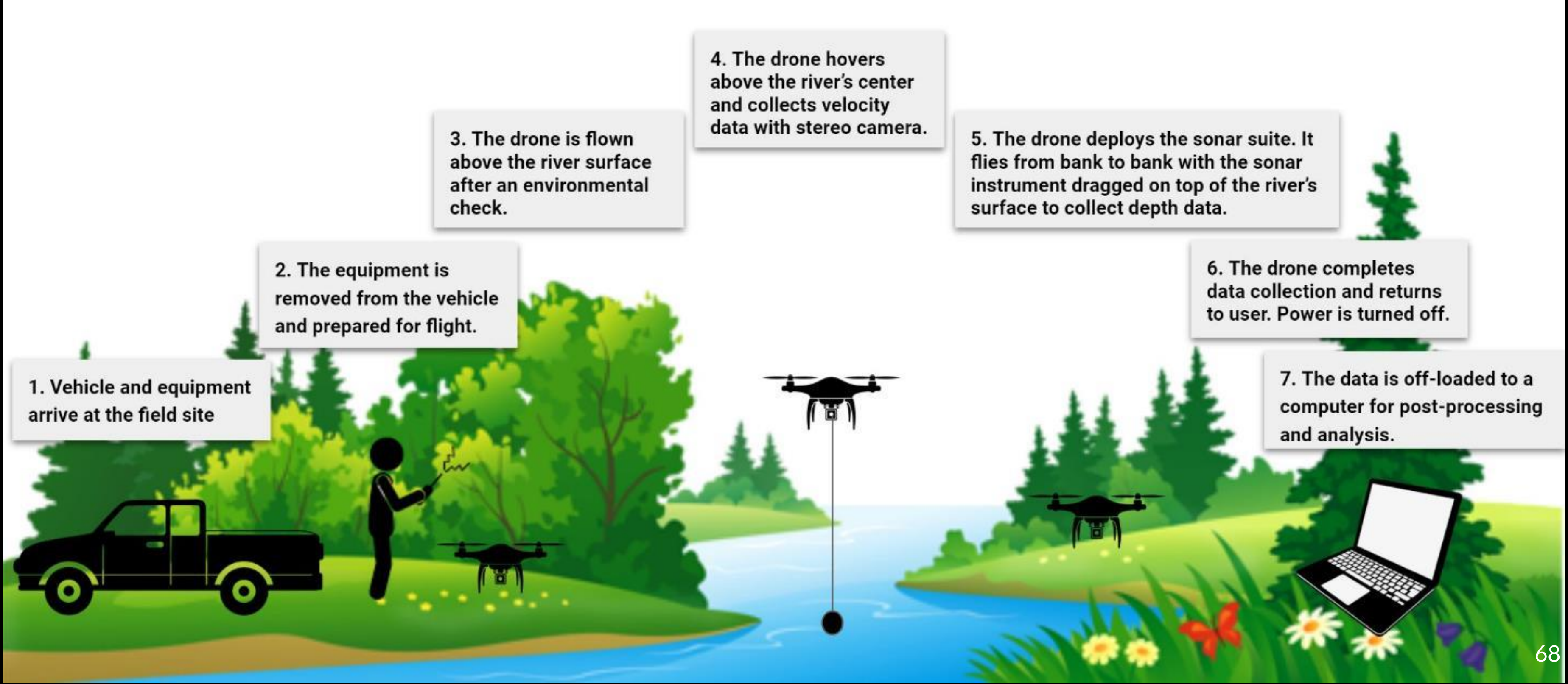
Backup Slides Table of Contents

References

[1] Thielicke, W. and Stamhuis, E.J. (2014): PIVlab – Towards User-friendly, Affordable and Accurate Digital Particle Image Velocimetry in MATLAB. *Journal of Open Research Software* 2(1):e30, DOI: http://dx.doi.org/10.5334/jors.bl

[2] Thielicke, W. (2014): The Flapping Flight of Birds - Analysis and Application. Phd thesis, Rijksuniversiteit Groningen. http://irs.ub.rug.nl/ppn/382783069

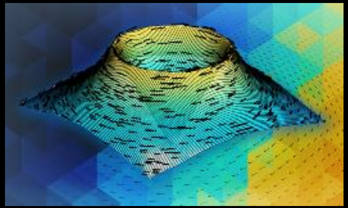
CONOPS


1. Vehicle and equipment arrive at the field site
2. The equipment is removed from the vehicle and prepared for flight.
3. The drone is flown above the river surface after an environmental check.
4. The drone hovers above the river's center and collects velocity data with stereo camera.
5. The drone deploys the sonar suite. It flies from bank to bank with the sonar instrument dragged on top of the river's surface to collect depth data.
6. The drone completes data collection and returns to user. Power is turned off.
7. The data is off-loaded to a computer for post-processing and analysis.

Mission Timeline

Action	Time	Total Elapsed Time
System Power Up	1:00	1:00
Drone flown to river center	1:00	2:00
Stereo Camera Data Collection	0:30	2:30
Drone Flown to Opposing Bank	0:10	2:40
Sonar Float Deployment	0:10	2:50
Bank to Bank Sonar Data Collection (2x)	1:20	4:10
Float Retraction	0:10	4:20
Drone Returns and Powers Off	1:00	5:20

Velocity Post-Processing



PIVlab - time-resolved particle image velocimetry software in Matlab

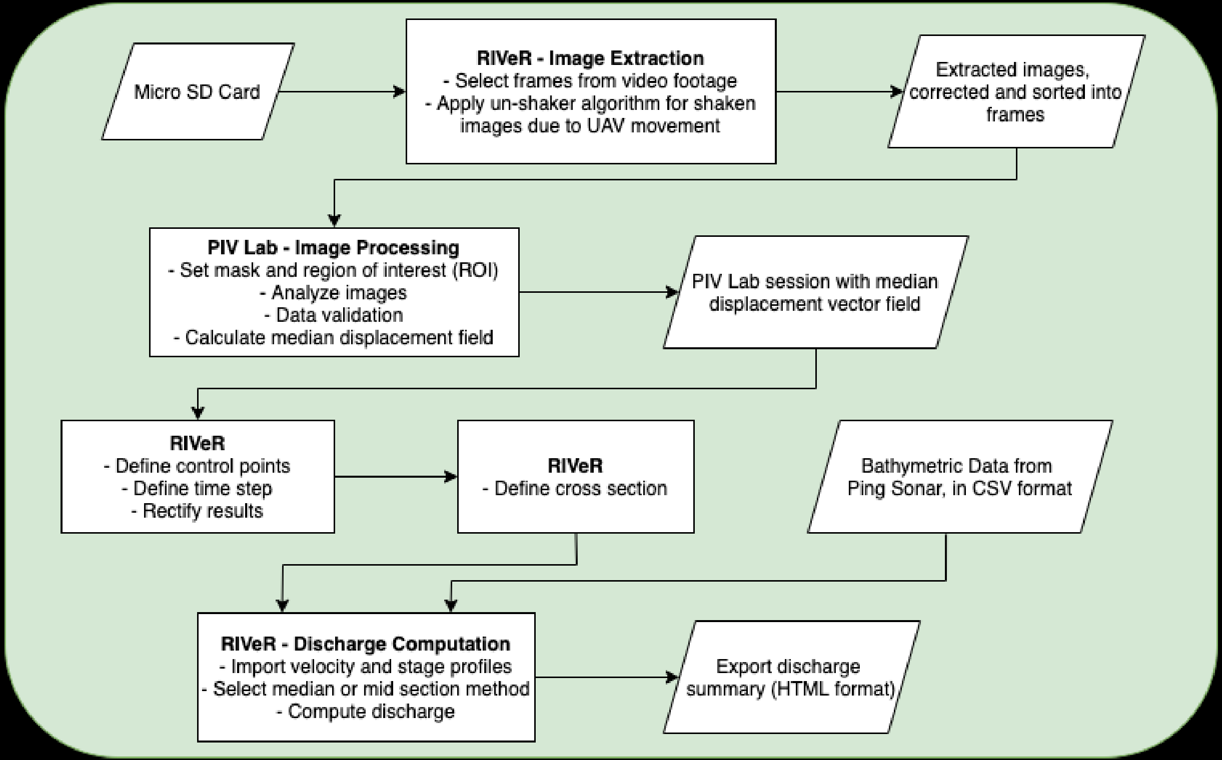
- Capable of calculating the velocity distribution between particle image pairs
- Uses corrected images from RIVeR to calculate the median velocity field on the water's surface

RIVeR - a tool developed in Matlab used for processing large scale water surface characterization

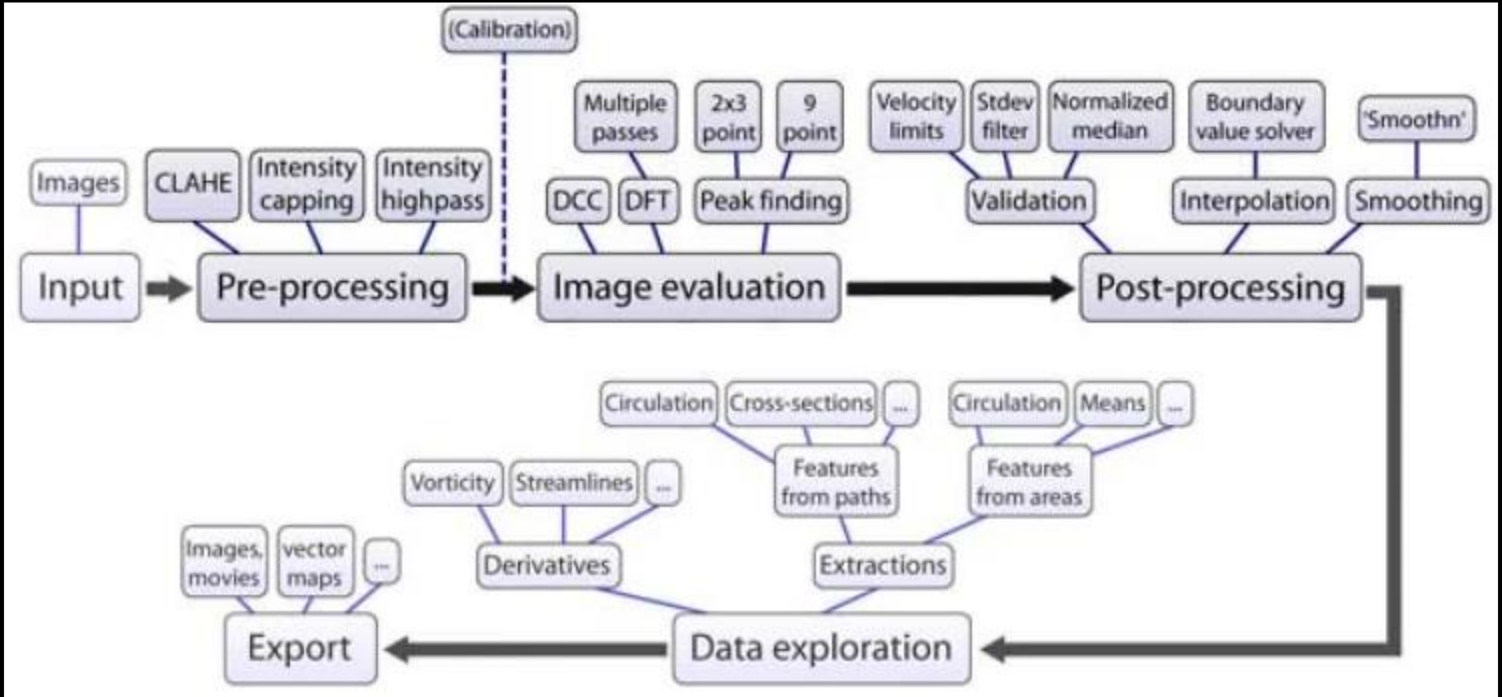
- Uses the median velocity field output of PIVlab to perform the river discharge calculation

RIVeR and PIVlab will be used together to compute river discharge

Velocity Post-Processing



Velocimetry PIVLab Data Flow



Velocimetry Error from PIVLab Explanation

Velocity is calculated by comparing the same particle from one frame to the next.

The distance that the particle traveled between frames can be calculated using the pixel difference and then relating it to distance.

If we consider the worst case scenario (bias error = 0.005, random error = 0.02 pixels) in both frames, we would have a total particle displacement error, ε_{total}=2*[bias+random errors] = 0.05).

The maximum distance that the particle can travel (per pixel) is the distance represented by the diagonal length of the pixel, *d*.

The Δt between frames is 1/30 sec. We can then calculate the velocity error using the maximum particle displacement error by:

$$\varepsilon_{velocity}\,[\text{m/s}] = (\varepsilon_{total}\,[\text{pixel}] \times d\,[\text{m/pixel}]) \,/\, \Delta t[\text{s}]$$

Velocity Error Data

Height Above River [m]	X [m]	Y [m]	X Resolution [m/pixel]	Y Resolution [m/pixel]	Diagonal Distance [m/pixel]	Worst Case Error* [m/s]	Worst Case Error* [cm/s]
3	6.54	5.31	0.0034	0.0049	0.0060	0.0090	0.8973
5	10.91	8.85	0.0057	0.0082	0.0100	0.0150	1.4954
10	21.81	17.70	0.0114	0.0164	0.0199	0.0299	2.9909
15	32.72	26.54	0.0170	0.0246	0.0299	0.0449	4.4863

PIVLab Particle Diameter & Density Errors[2]

Particle Diameter RMS Error

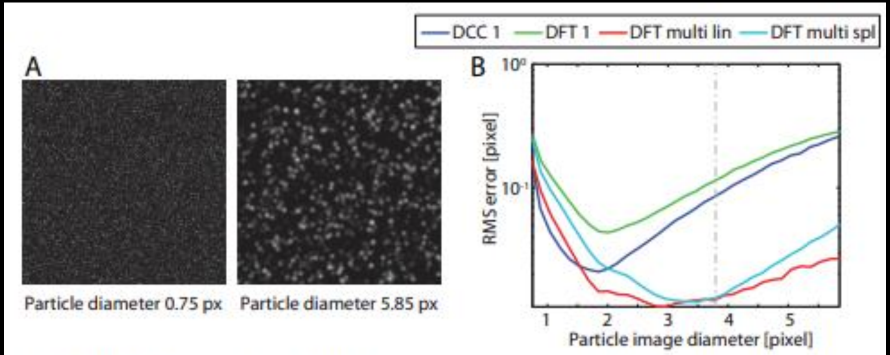


Fig. 2.12: A: Example of the particle image diameters tested. **B:** The effect of particle image diameter on the random error (particle displacement = 3.5 pixels).

Particle Density RMS Error

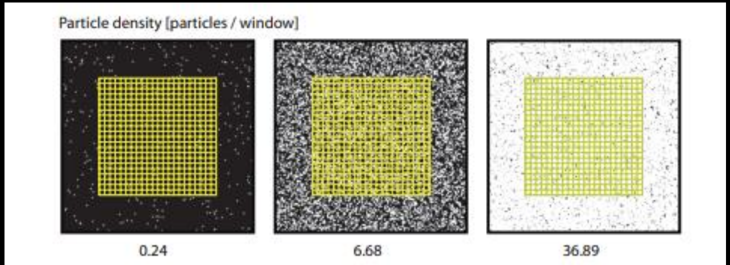


Fig. 2.13: Example of the particle densities tested. The yellow grid represents the interrogation areas of 16·16 pixels.

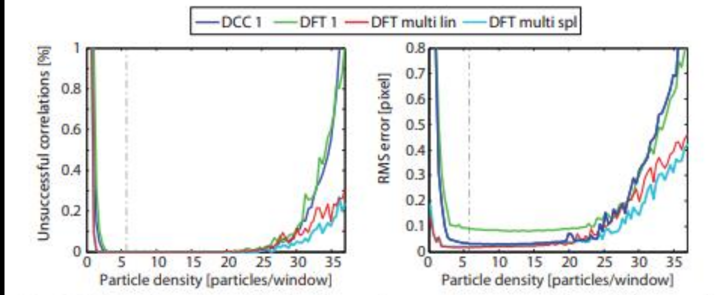
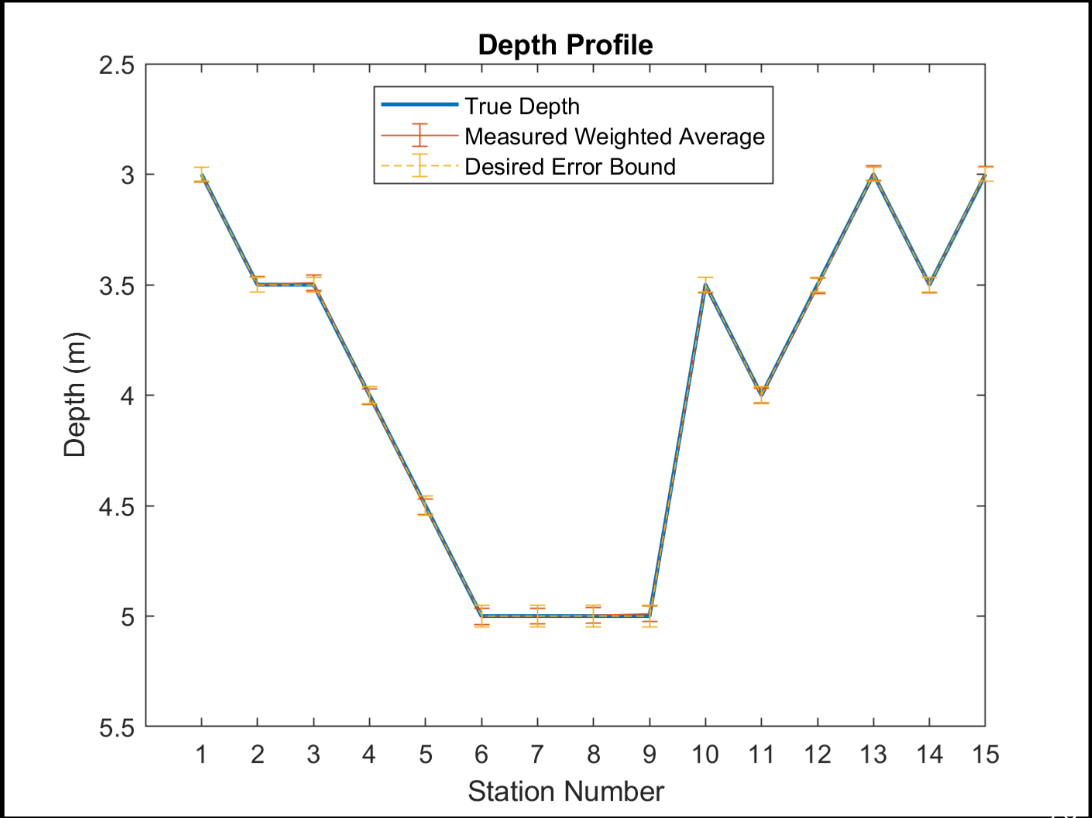


Fig. 2.14: The effect of particle density on the rate of unsuccessful correlations and on the random error (particle image diameter = 3 pixels, displacement = 3.5 pixels).

Depth Error Propagation

- Simulated depth and IMU data with associated percent confidence and error bounds

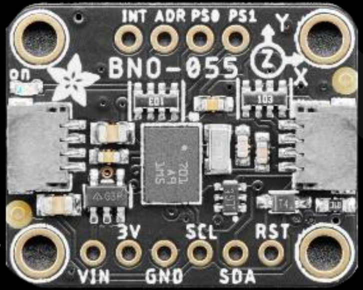


Inertial Measurement Unit

BNO055 IMU

- Full sensor Fusion
  - Absolute Orientation in both Euler Vector and Quaternion form (100 Hz)
  - Compass Heading (20hz)
  - Gravity vector (100hz)
  - Temperature (1Hz)

  Typical orientation accuracy of ±1



Command and Data Handling

Jetson Nano:

- The “on-board” computer
- Receives signal from PixHawk4 to initiate camera data collection
- Linux based operating system
- Mounted microSD slot for data storage

Arduino Uno:

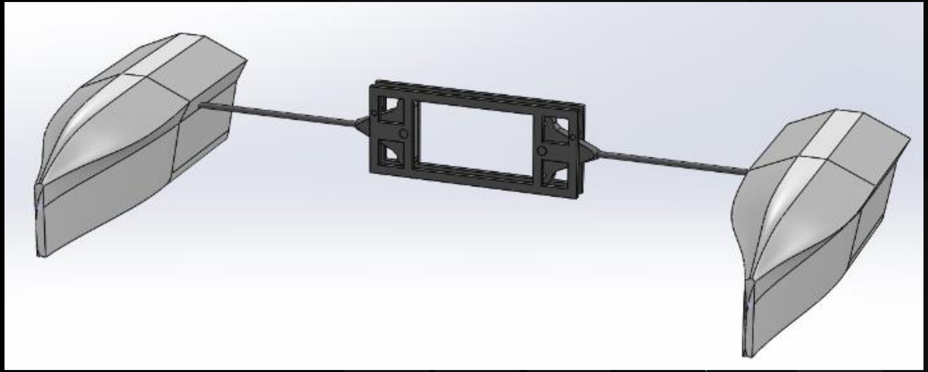
- The “deployable unit” computer
- Will connect to SD module for data storage
- Serial pins: 0(Rx), 1(Tx)
- USB connection

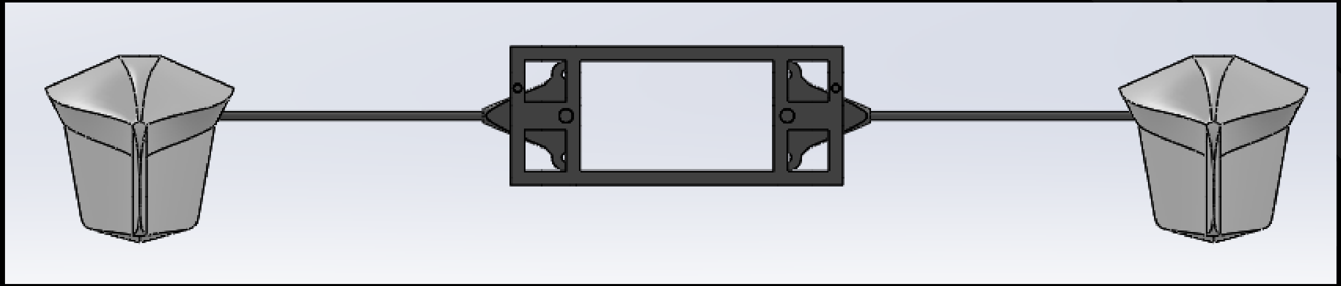
Folding Stability Floats

- Creates wide base for center float to improve roll stability

- Folding design enables the float to still fit onto drone mounting plate

- Spring loaded arms also act as dampers while deployed





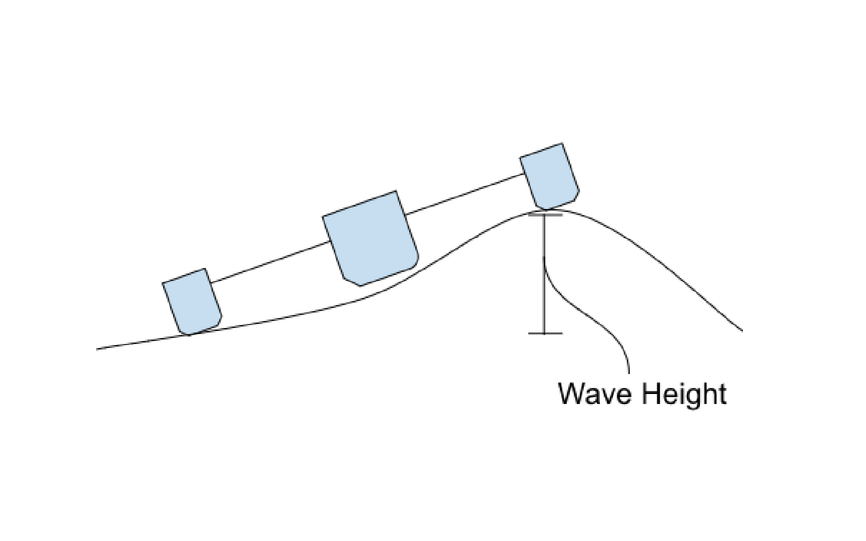
Why Waves are a Non-Issue

- Maximum angular displacement = 20˚

- Overall width = 36.8 cm

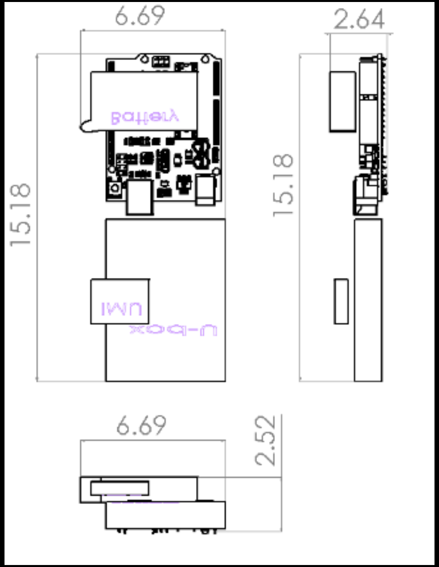
- Required wave height = 12.6 cm

- This wave height is greater than anything we reasonably expect to continuously occur especially since we recommend this system to be used in calm conditions.

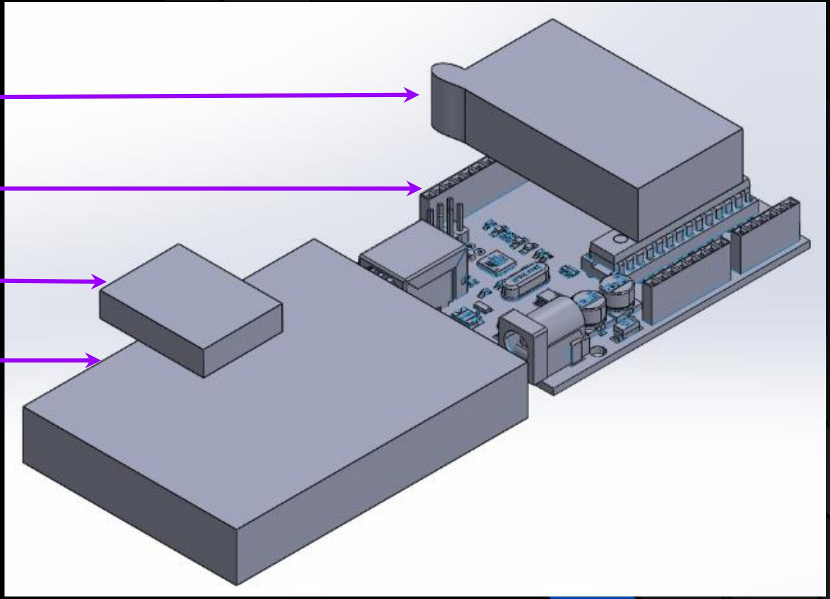


Electronics Box Sizing

Used ‘back of the envelope’ arrangement to get a approximate size for float design

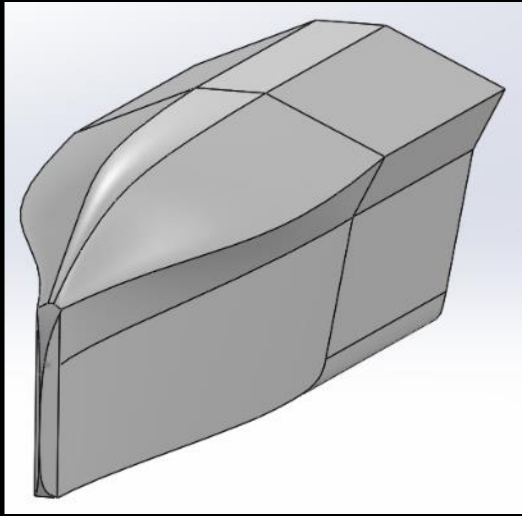


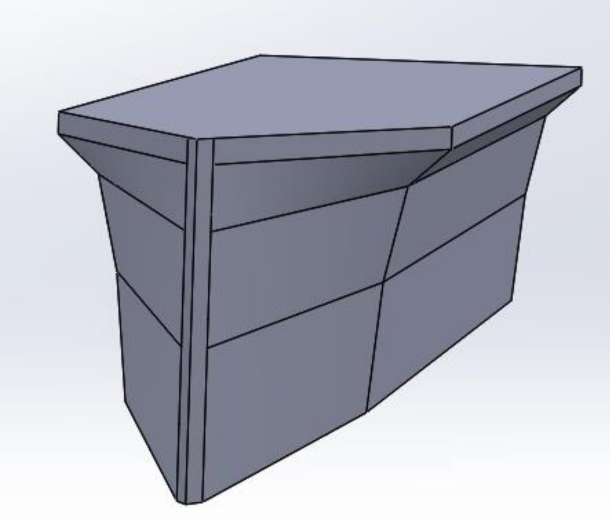
All measurements in cm

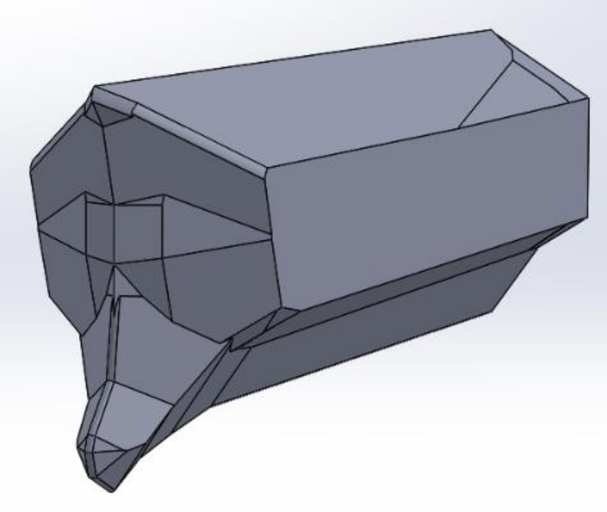


Stabilizer designs

Designs weight ~100-150g

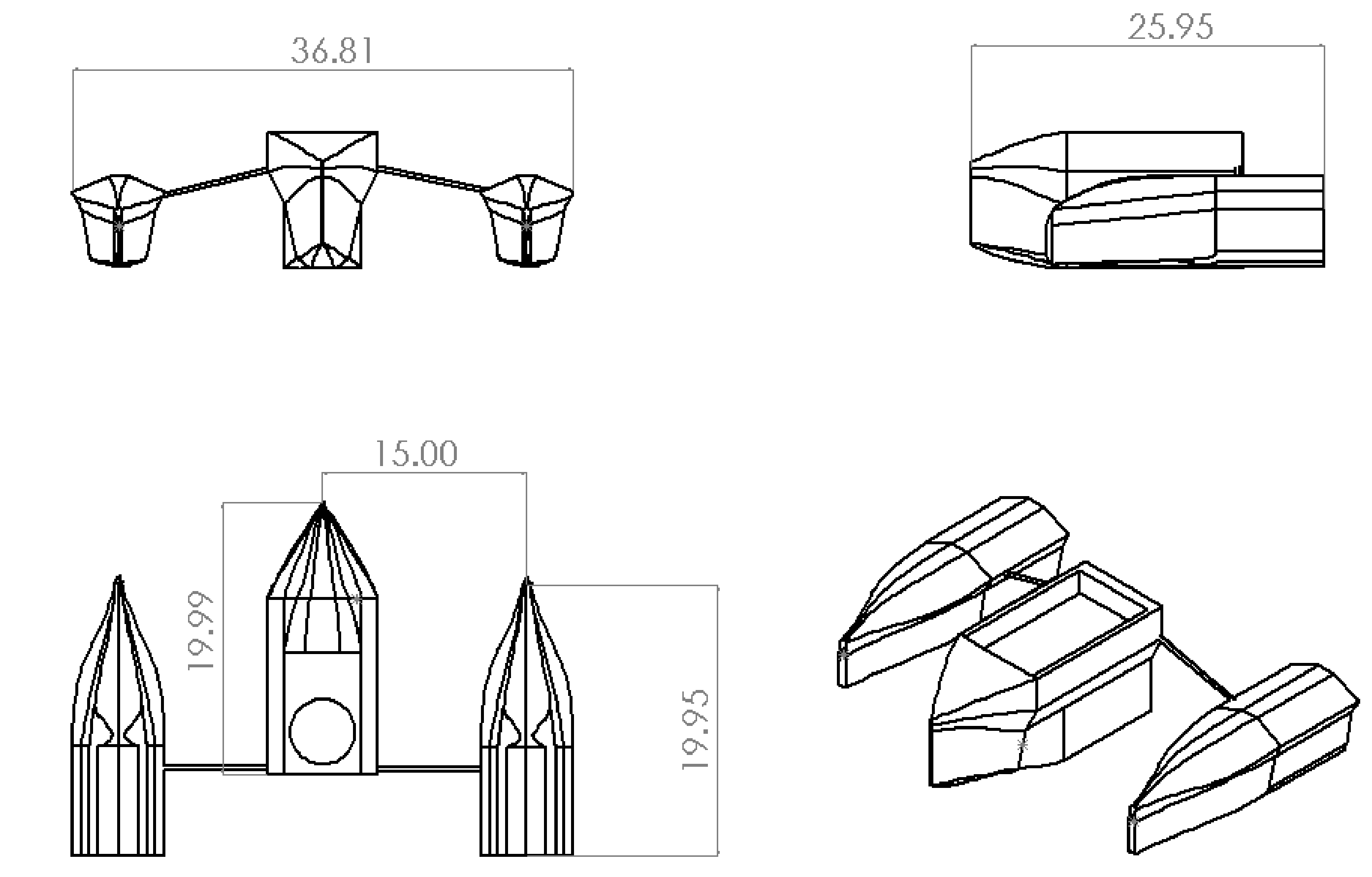






Want stabilizers to provide roll stability with low drag
Stabilizers can also be used to control waterline and longitudinal location of center of buoyancy of float on main hull.
- Stabilizers lower relative to hull results in hull sitting higher in water

Float major Dimensions



All measurements are in cm

CG and CB data from CAD model

Angel	CB [m]	Water mass displaced [kgf]	CG
0	[0,0,-0.15]	.64	[0,0.03,-0.14]
20	[0.1,0.01,-0.15]	.73	[0,0.03,-0.14]
40	[.09,.01,-.15]	.78	[0,0.03,-0.14]
60	[0.09, 0.02, -0.14]	.88	[0,0.03,-0.14]
80	[0.09,0.02,-0.14]	.86	[0,0.03,-0.14]
110	[0.08,0.03,-0.14]	1	[0,0.03,-0.14]
140	[0.07,0.03,-0.14]	1.07	[0,0.03,-0.14]
160	[0.07,0.03,-0.14]	1.07	[0,0.03,-0.14]
180	[0,0.04,-0.14]	1.17	[0,0.03,-0.14]

5 deg	[0.04,0.002,-0.14]	.64
10	[0.088,0.008,-0.14]	.68
15	[0.096,0.011,-0.15]	.73
30	[0.097,0.012,-0.15]	.73

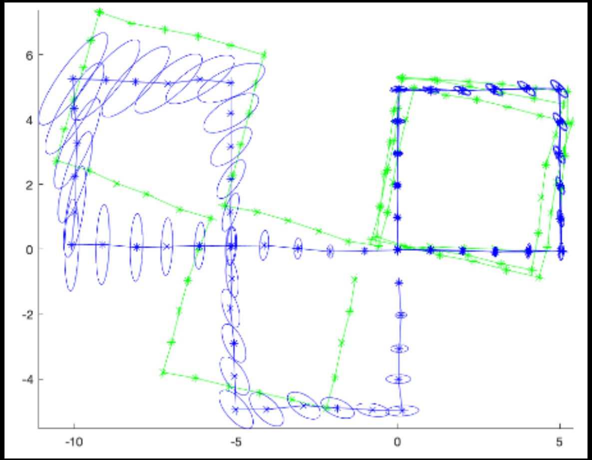
Mass of entire float (including pontoons) = 614 grams

Volume of entire float (including pontoons) = 1809.4 cm^3

SLAM based Localization

Georgia Tech Smoothing and Mapping (GTSAM) will be used offline to recover the drone/float's trajectory.

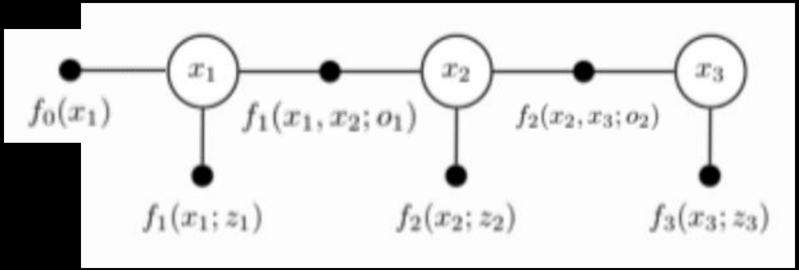
- Modeling motion as a continuous Markov chain specifies the posterior density P(X|Z) over the entire trajectory, smoothing our results.
- Applying loop closure constraints (and potentially landmark observations) tightens the resulting map.

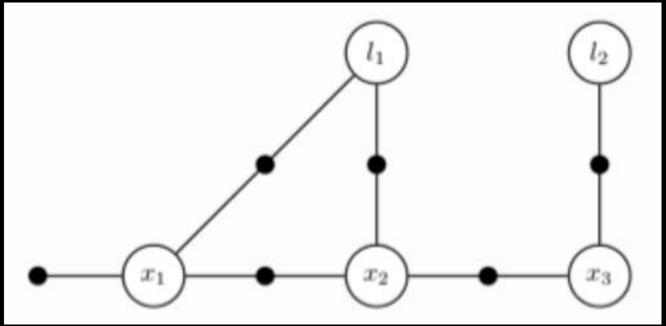


SLAM cont.

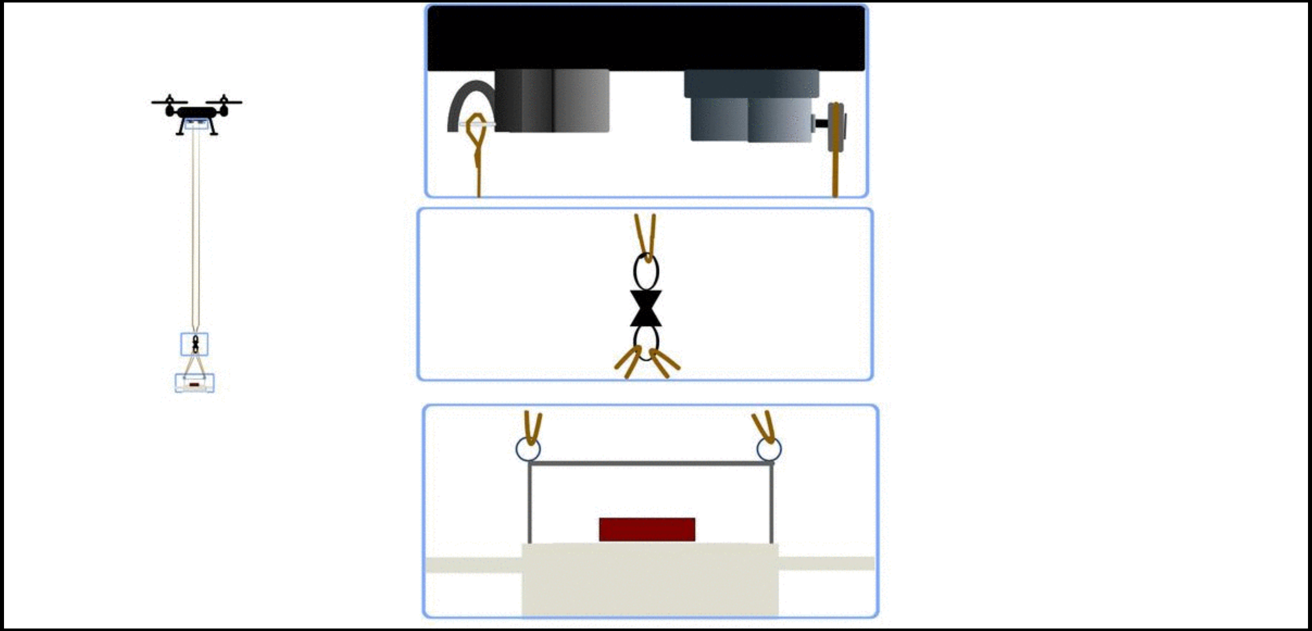
- Unary factors of a single state (initial estimate and external GPS measurements)
- Binary factors relating two states (odometry measurements)

- Potentially observing landmarks from multiple positions induces additional binary factors

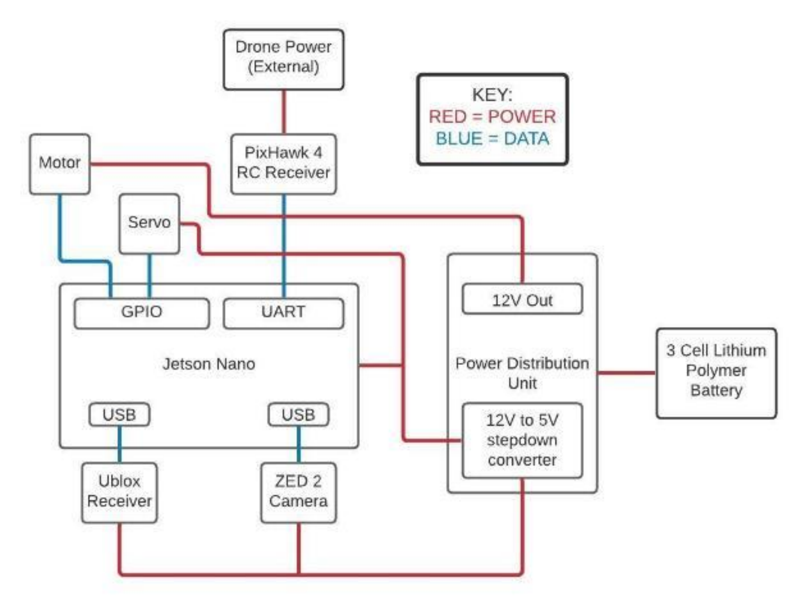




Emergency Release



Power Analysis

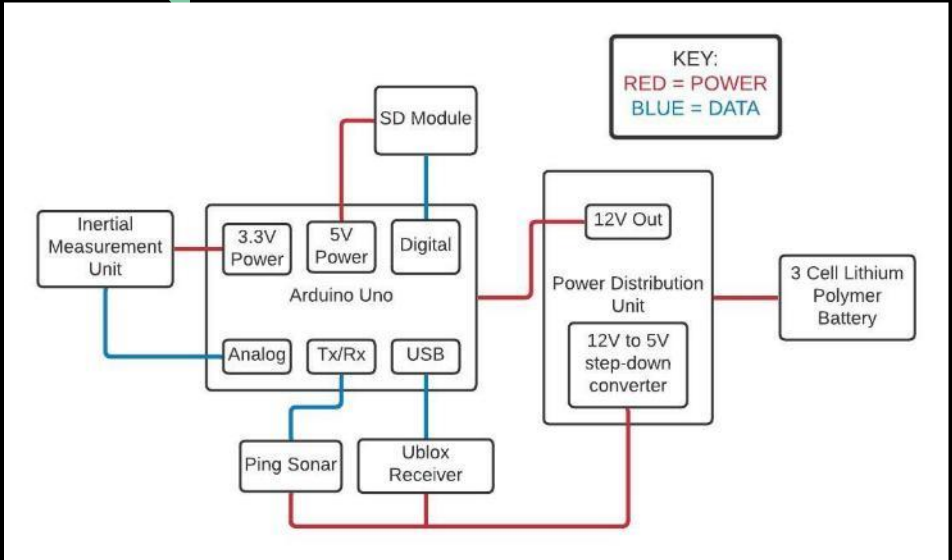


On-Board Power Requirements:
- 12V to power motor
- 2398.5mAh maximum required capacity

On-Board Unit	
Component:	Current flow over time:
Jetson Nano	(4A)(0.5h) = 2000mAh
ZED 2	(380mA)(0.5h) = 190mAh
Ublox Receiver	(67mA)(0.5h) = 33.5mAh
Servo	(250mA)(0.5h) = 125mAh
Motor	(100mA)(0.5h) = 50mAh
Total:	2398.5mAh

Power Subsystem Design:
- 3 cell 3000mAh battery (9.0V - 12.6V)
- 12V to 5V step-down converter to provide constant 5V to Jetson Nano and other instruments
- Direct power to motor (for 12V

Power Analysis

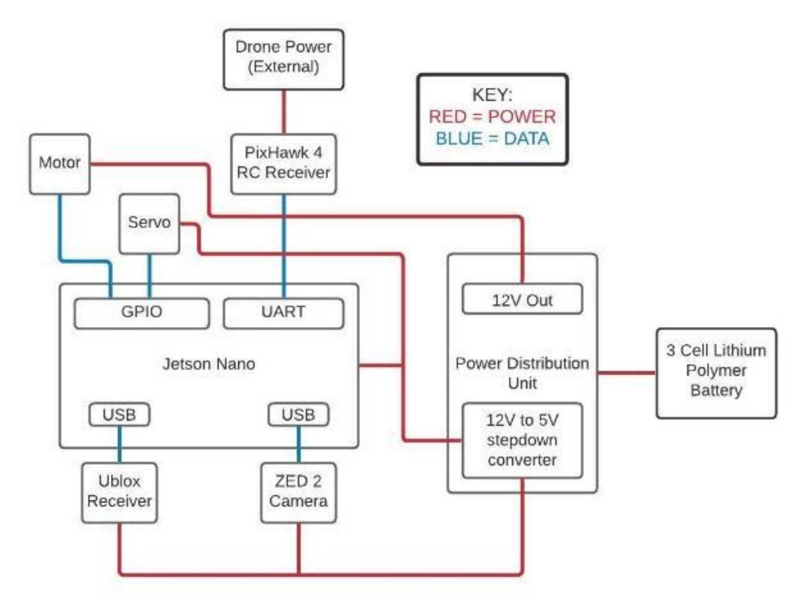


Deployable Unit	
Component:	Current flow over time:
Arduino Uno	(80mA)(0.5h) = 40mAh
Ping Sonar	(100mA)(0.5h) = 50mAh
Ublox Receiver	(67mA)(0.5h) = 33.5mAh
IMU	(12.3mA)(0.5h) = 6.15
Total:	129.65mAh

Power Subsystem Design:
- 3 cell 1000mAh battery (9.0V - 12.6V)
- 12V to 5V step-down converter to provide constant 5V to some instruments so the Arduino doesn't experience current overload
- Direct voltage to Arduino (12V)

Deployable Unit Power Requirements:
- 7-12V to power Arduino
- 129.65mAh capacity

Data Flow Analysis



On-Board Unit	
Component:	Maximum estimated data required
Jetson Nano	6Gb
ZED 2	64Gb
Ublox Receiver	1Gb
Additional Code:	5Gb
Total:	77Gb

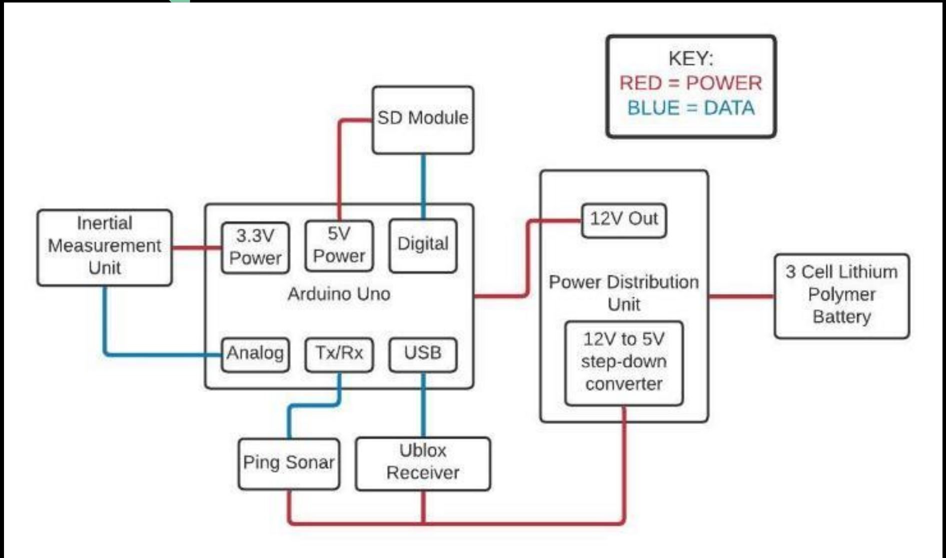
Design solution:

- 128Gb microSD card on Jetson Nano

Underlying Assumptions:

- All components collecting data through entirety of mission
- All data requirements are overestimated, only anticipating all future needs for data storage

Data Flow Analysis



Deployable Unit	
Component:	Maximum estimated data required
Ping Sonar	2Gb
Ublox Receiver	2Gb
IMU	2Gb
Total:	6Gb

Underlying Assumptions:
- All components collecting data through entirety of mission
- All data requirements are overestimated, only anticipating all future needs for data storage

Design Solution
- Minimum of 8Gb microSD card

V&V: Velocity Post-Processing

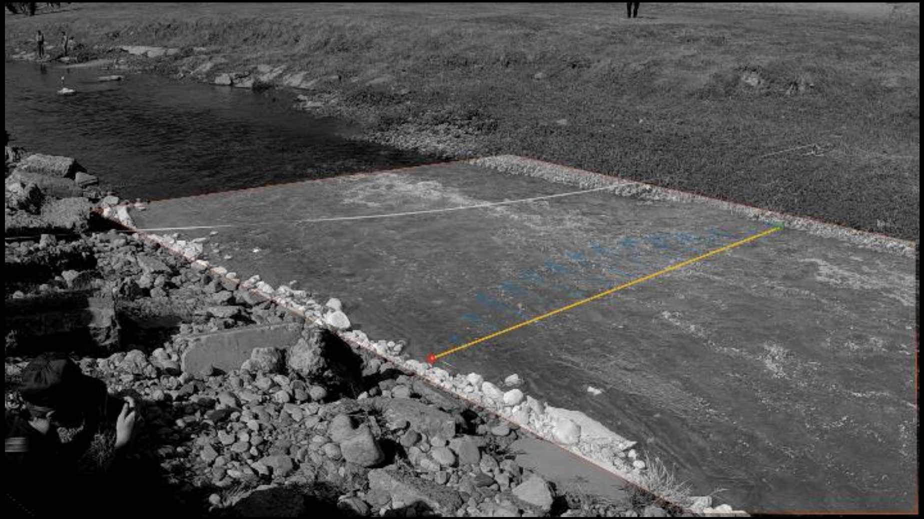
Objective: Show that an accurate velocity field of a river's surface can be extracted from video data using particle image velocimetry

Components Needed for Post-Processing Verification

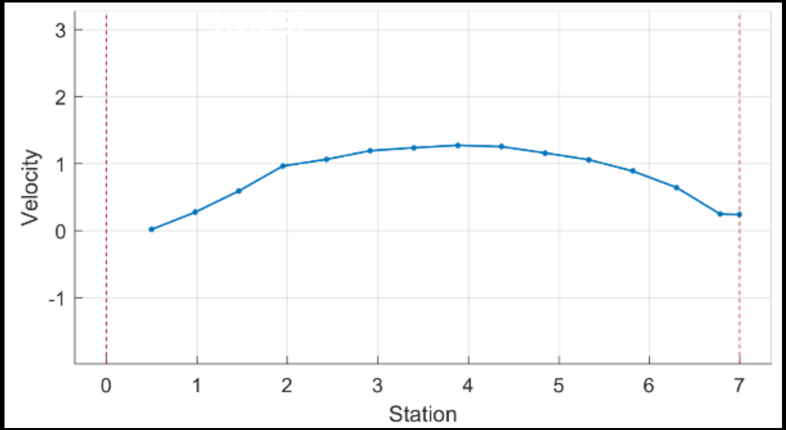
- Top-view video footage of a flowing river
- Ground control points and distance measurements between them
- Computer with Windows 64-bit OS (required for RIVeR)

Velocity Data Gathering

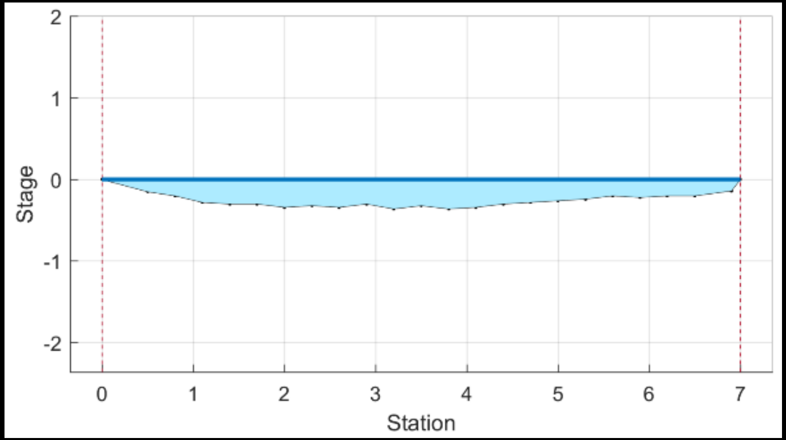
Tutorial Data



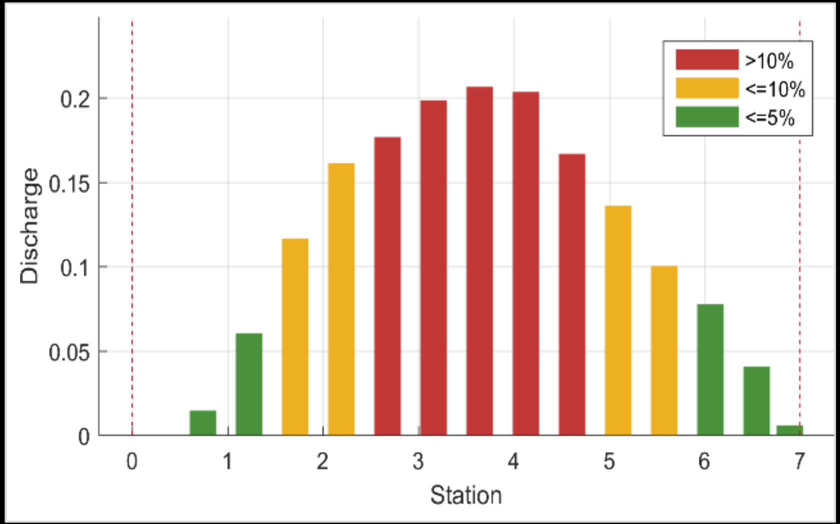
Velocity Chart



Depth Chart [m]

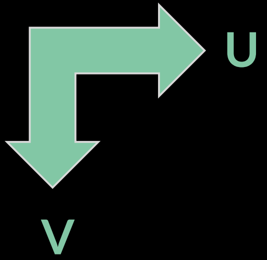


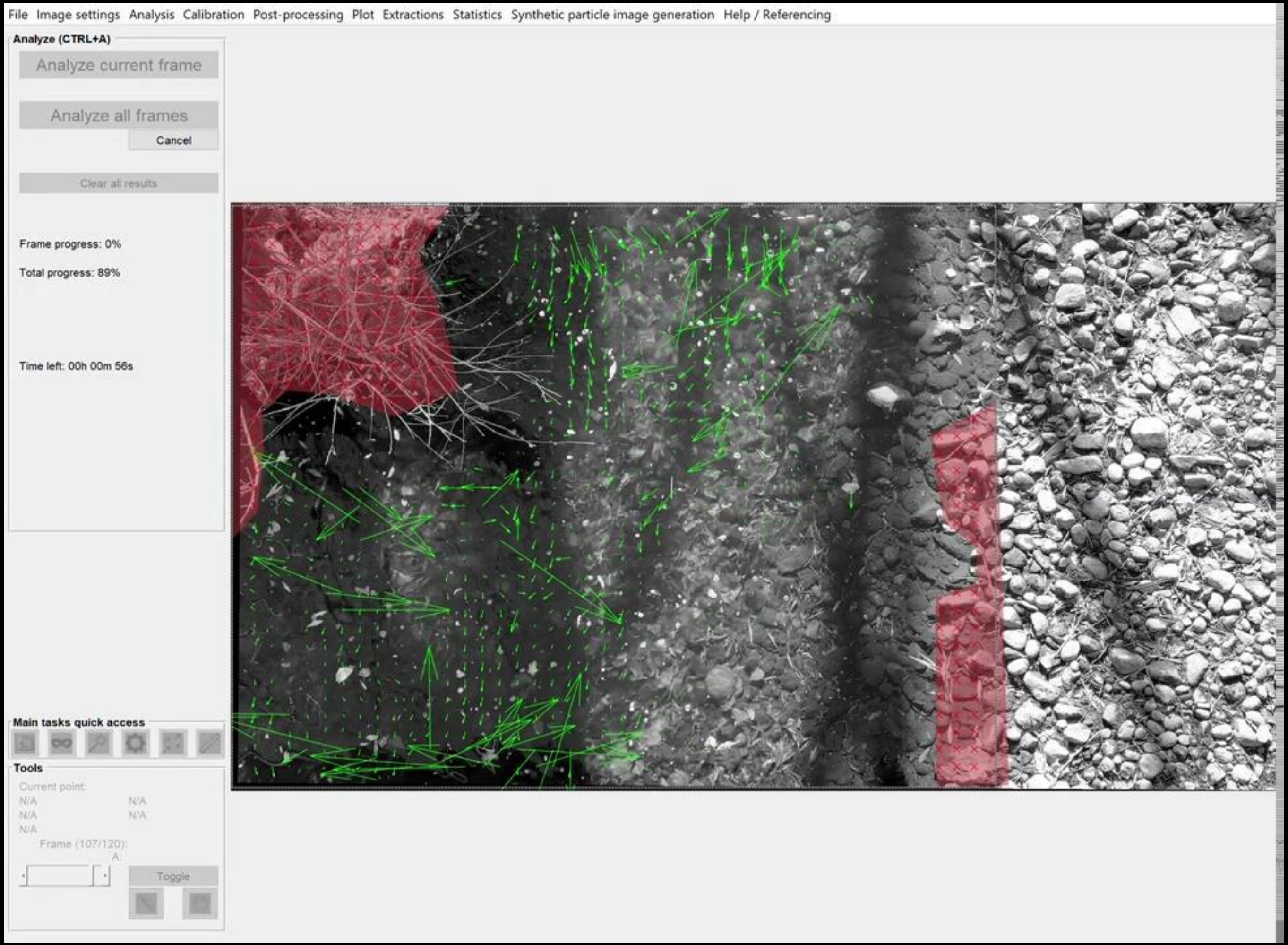
Discharge Chart [m^3/s]



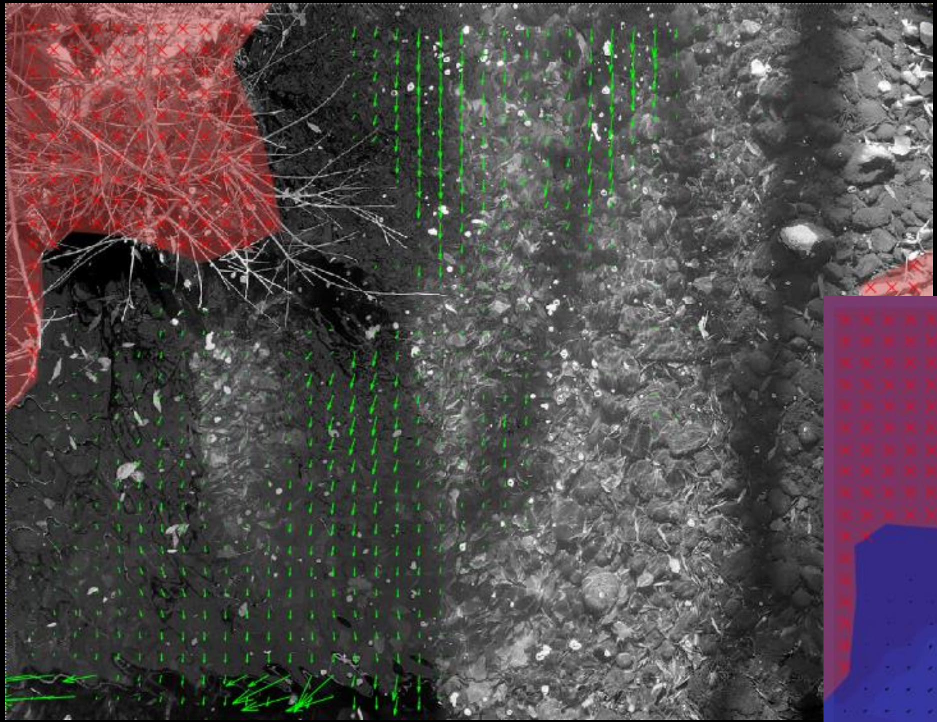
Average Velocity	0.79 m/s
Total Discharge	1.42 m^3/s

Velocity Post-Processing - PIVLab

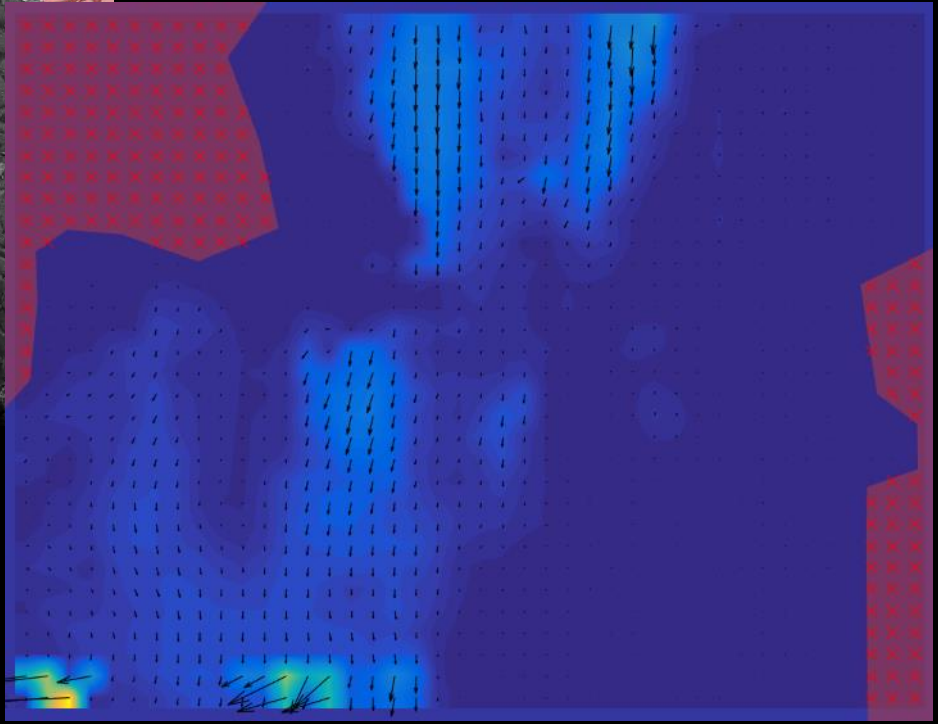

U
V


File Image settings Analysis Calibration Post-processing Plot Extractions Statistics Synthetic particle image generation Help / Referencing
Analyze (CTRL+A)
Analyze current frame
Analyze all frames
Cancel
Clear all results
Frame progress: 0%
Total progress: 89%
Time left: 00h 00m 56s
Main tasks quick access
Tools
Current point:
N/A
N/A
N/A
N/A
N/A
Frame (107/120):
A:
Toggle

Median Velocity Field of all Frames

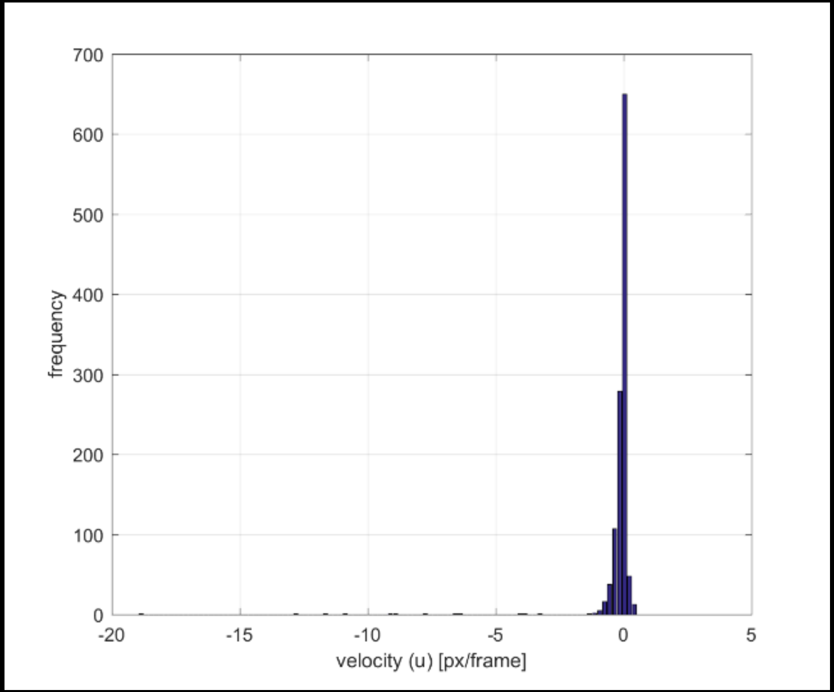


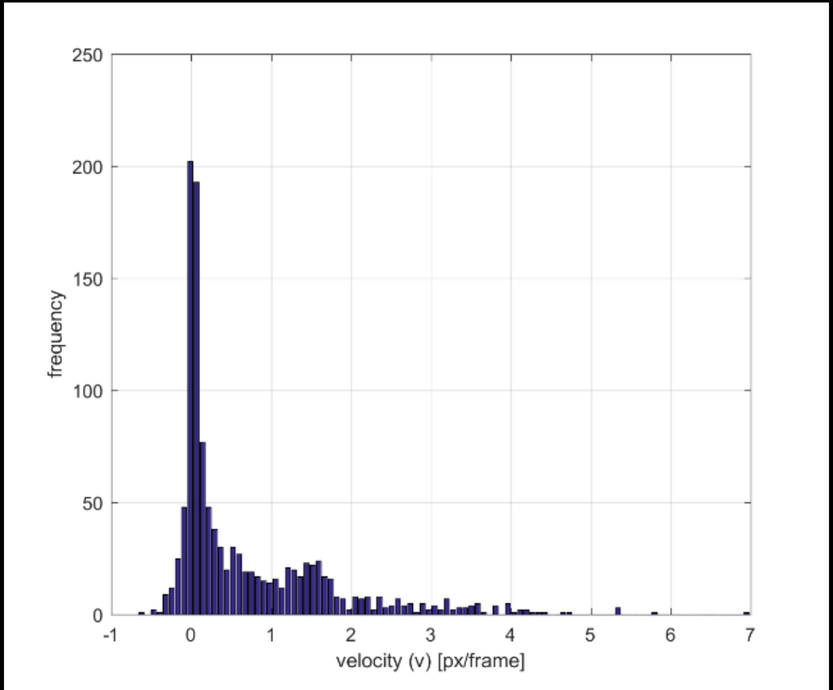
Vectors



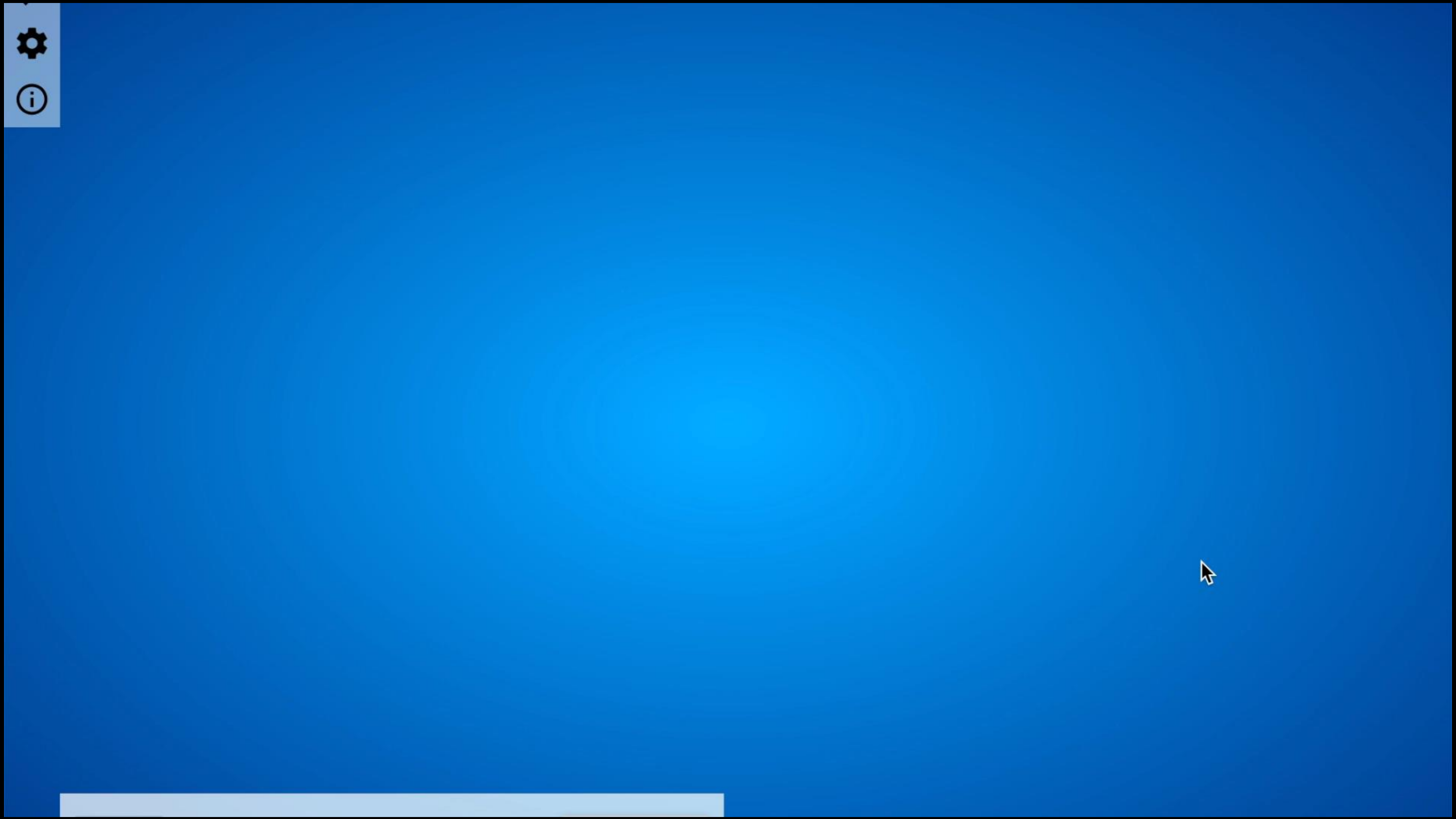
Velocity Magnitude

Velocity Post-Processing Results





Ping Sonar Post-Processing



V&V: Battery Testing

Testing Using Multimeter:

- Configured as Voltmeter:
  - When battery is fully charged, get voltage readings across the battery
  - When battery is completely discharged, get voltage readings across the battery
- Configured as Ammeter:
  - Build simple circuit with known effective resistance equal to the max each avionics unit could draw
  - Measure current in series with circuit to ensure battery can provide necessary amperage

Testing with LiPo Battery Tester:

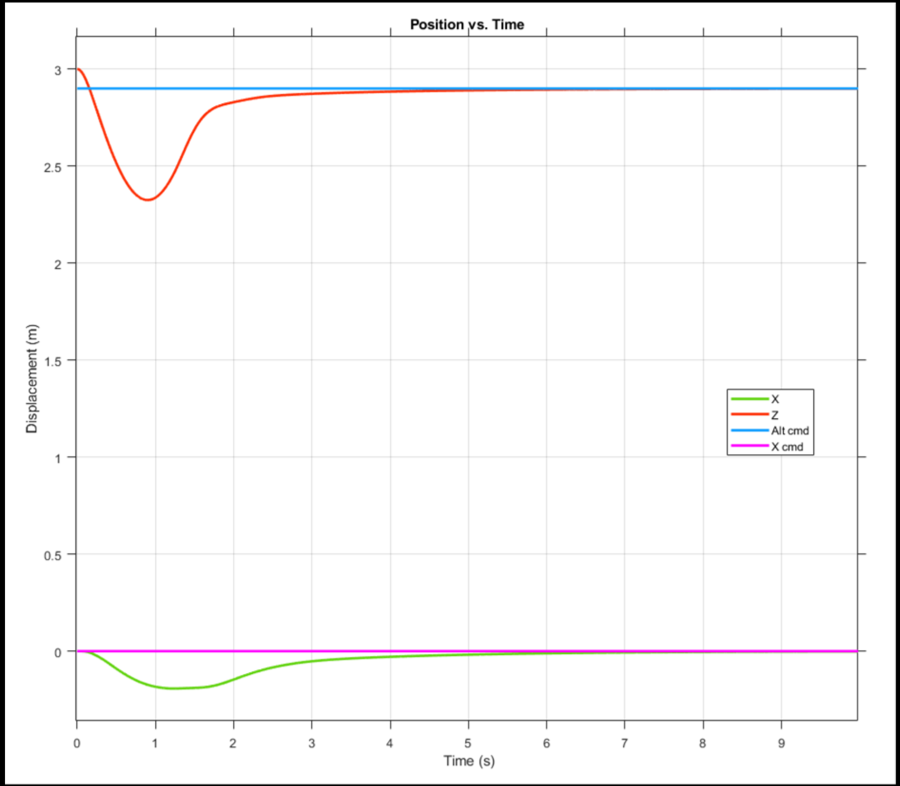
- Ensure each battery is safe with LiPo battery tester

V&V: Avionics Data Collection Testing

- Test each individual sensor on its own
  - Make sure proper data is sent to respective computer and stored on microSD card
- Test PixHawk4 commands with Jetson Nano
  - Send simple test commands from the PixHawk4 remote to Jetson Nano
  - Ensure that commands go through from controller to computer
- Test Jetson Nano commands to specific sensors
  - Have Jetson Nano send data collection initiation commands to all sensors connected to Jetson Nano
  - Ensure commands initiated data collection for all appropriate sensors
- Test Arduino commands to specific sensors
  - Send commands via Arduino to all appropriate sensors
  - Verify that commands initiated data for sensors

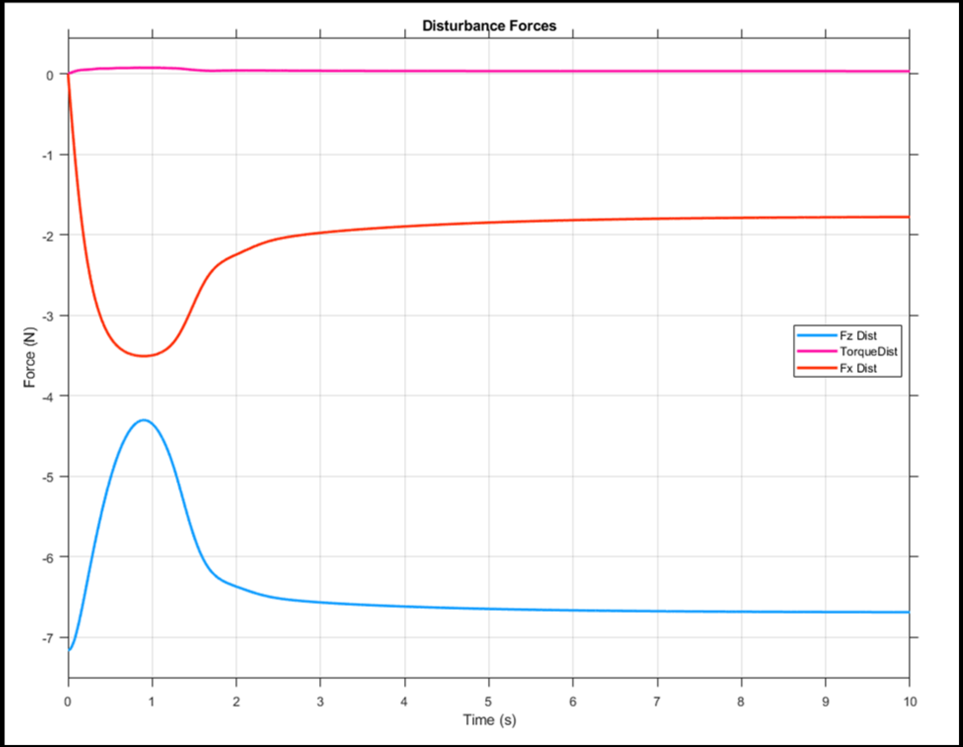
Disturbance Stability Response

- Model is stable to simulated outside disturbance forces and torques
- Simple PID Model, more complex ones will have a better response to

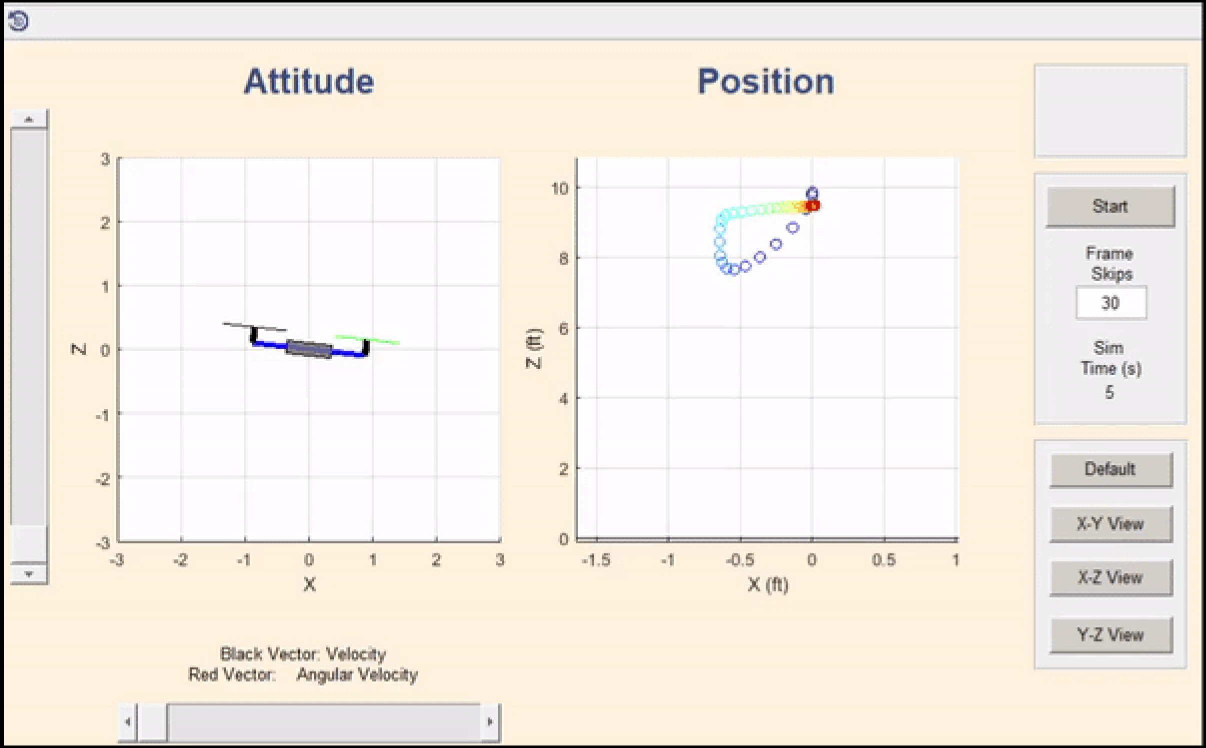


Simulated Disturbances of Float

- Disturbances are simulated assuming a maximum drag force acting on the float at every angle
- This provides a worst case scenario and reducing the forces reduces the overshoot response



Visual Response



Test Type	Test	Location	Date	Related DRs
Performance	Velocimetry Software	Various Rivers	On going	DR7.1
Performance	Sonar Software	N/A	On going	DR7.2
Performance	Float Prototype Stability	Boulder Creek	On going	DR4.2.1-3
Performance	Float Waterproofing	Pool of water	2/1/2020 - 3/1/2020	DR4.2.2
Performance	Deployment Mechanism	TBD	2/1/2020 - 3/1/2020	DR4.3, 4.3.2
Performance	Stereo Camera Velocity Video	Various Rivers	2/1/2020 - 3/1/2020	DR5.1,7.1
Performance	Stereo Camera Depth Measurements	Various Rivers	2/1/2020 - 3/1/2020	DR5.1,7.1
Performance	Sonar Instrument Test	Boulder Creek	2/1/2020 - 3/1/2020	DR4.1.1,2
Performance	Sonar-IMU test	Boulder Creek	2/1/2020 - 3/1/2020	DR4.6,4.6.2,7.4
Performance	GNSS Receivers	Scott Carpenter Park	2/1/2020 - 3/1/2020	DR7.5
Performance	Drone Stability	CU South Campus	2/1/2020 - 3/1/2020	DR3.3,4
Avionics Integration	Jeston Nano Component Integration	TBD	2/1/2020 - 3/1/2020	DR6.1,6.1.1,2
Avionics Integration	Arduino Uno Component Integration	TBD	2/1/2020 - 3/1/2020	DR6.2,6.2.1,2
Avionics Integration	RC Commanding	CU East Campus	2/1/2020 - 3/1/2020	DR4.3, 4.3.1
Avionics Integration	Emergency Release	CU East Campus	2/1/2020 - 3/1/2020	DR4.3.2
Power	Drone Endurance	CU South Campus	2/1/2020 - 3/1/2020	DR1.1
Power	Float System Power	TBD	2/1/2020 - 3/1/2020	DR6.3
Power	Drone-Fixed System Power	TBD	2/1/2020 - 3/1/2020	DR6.3
Drone Integration	Drone-Fixed Integration	CU East Campus	3/1/2020 - 3/29/2020	FR5
Drone Integration	Deployable Unit Integration	CU East Campus	3/1/2020 - 3/29/2020	FR4
Full Mission	Full System DITL	CU South Campus	3/29/2020 - 4/19/2020	ALL

Subsystem	Component	Number of Units	Weight\Unit (g)	Total Weight (g)
Avionics	Arduino Uno	1	25	25
	Jetson Nano	1	140	140
	500mAh Lipo Battery	1	36	36
	2200mAh Lipo Battery	1	203	203
	SD Shield	1	3.43	3.43
	Estimated Wiring	1	15	15
Science	ZED 2	1	124	124
	Ping SONAR	1	135	135
	Sonar Mounting Bracket	1	16.2	16.2
	BNO055	1	3	3
Mechanisms	Servo by Tarot	1	55	55
	Fishing line	1	6	6
	Motor	1	215	215
	Pulley	1	2	2
Structures	Mounting Plate	1	80	80
	Sonar Float	1	640	640
GNC	U-blox C94-M8P	2	35	70
Total Weight System Weight (kg)				1.76863
Total Allowed Weight (kg)				2
Margin (kg)				0.23137