# UAV-deployable Sensor Packages for the Measurement of Hydraulic Parameters

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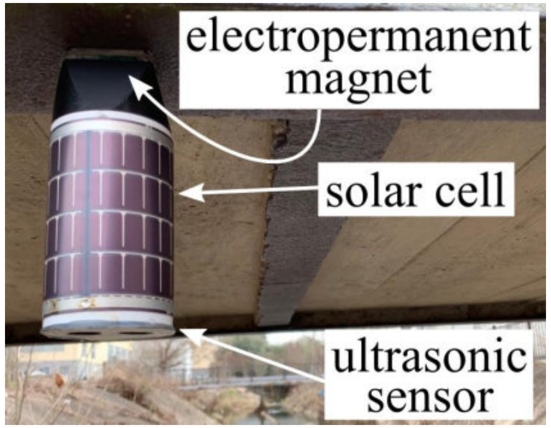
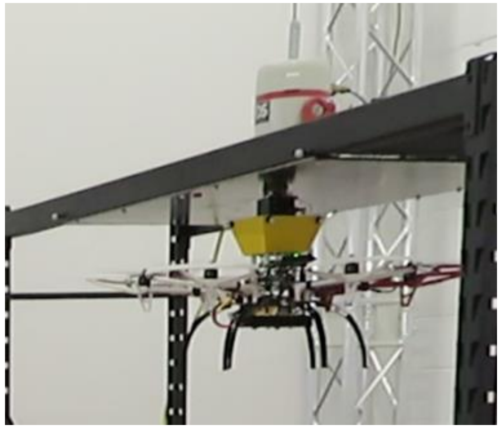
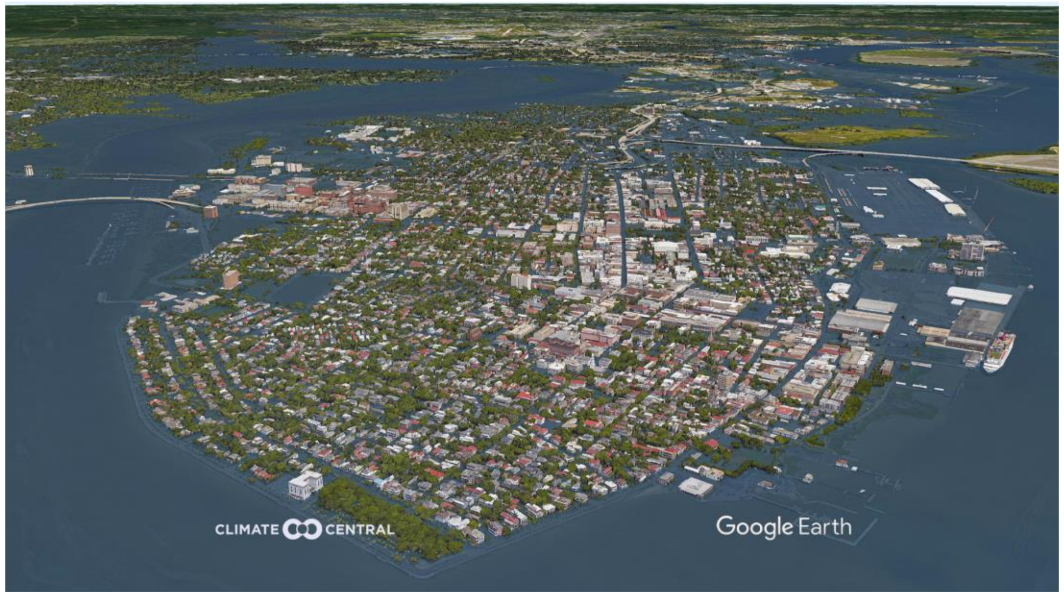
# Outline

- Introduction
- Development of UAV Delivery Systems
- Stage Sensor
- Rain Gauge Sensor
- Power Consumption Challenges
- Conclusion





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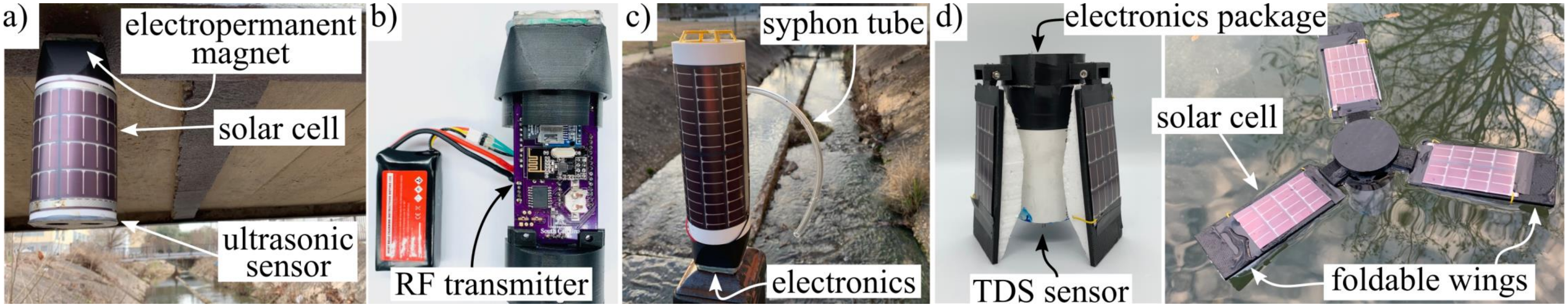
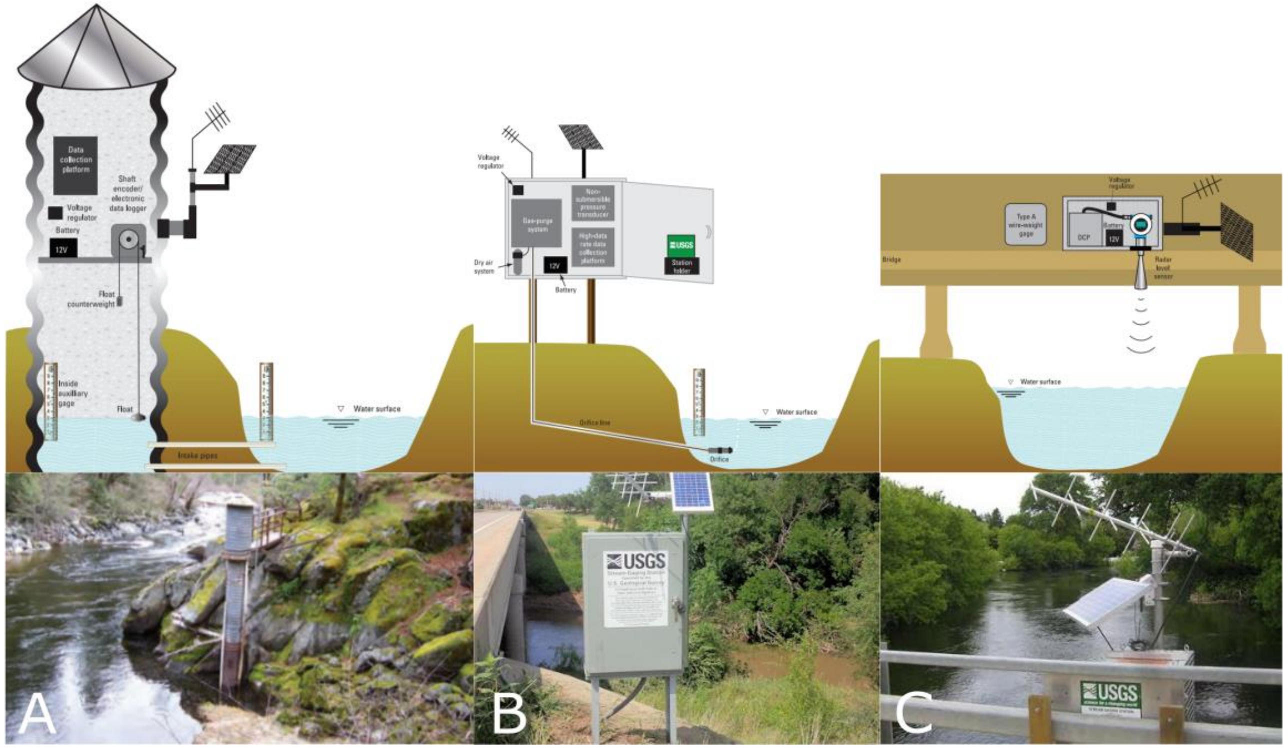
# Purpose

Develop drone-deployable sensor packages for monitoring hydraulic and environmental parameters during wet-weather emergencies.



# Introduction: Stage Sensor

- Stage sensor: device used to measure vertical water height
  - Ultrasonic, radar, pressure
- Main types:
  - stilling well (A) – gage established at water table to measure stage
  - bubble gage (B) – gage uses submerged pressure sensor to determine stage
  - rapid deployable gage (C) – emergency gage measures stage using radar
- Existing stage sensors are large, permanent, expensive

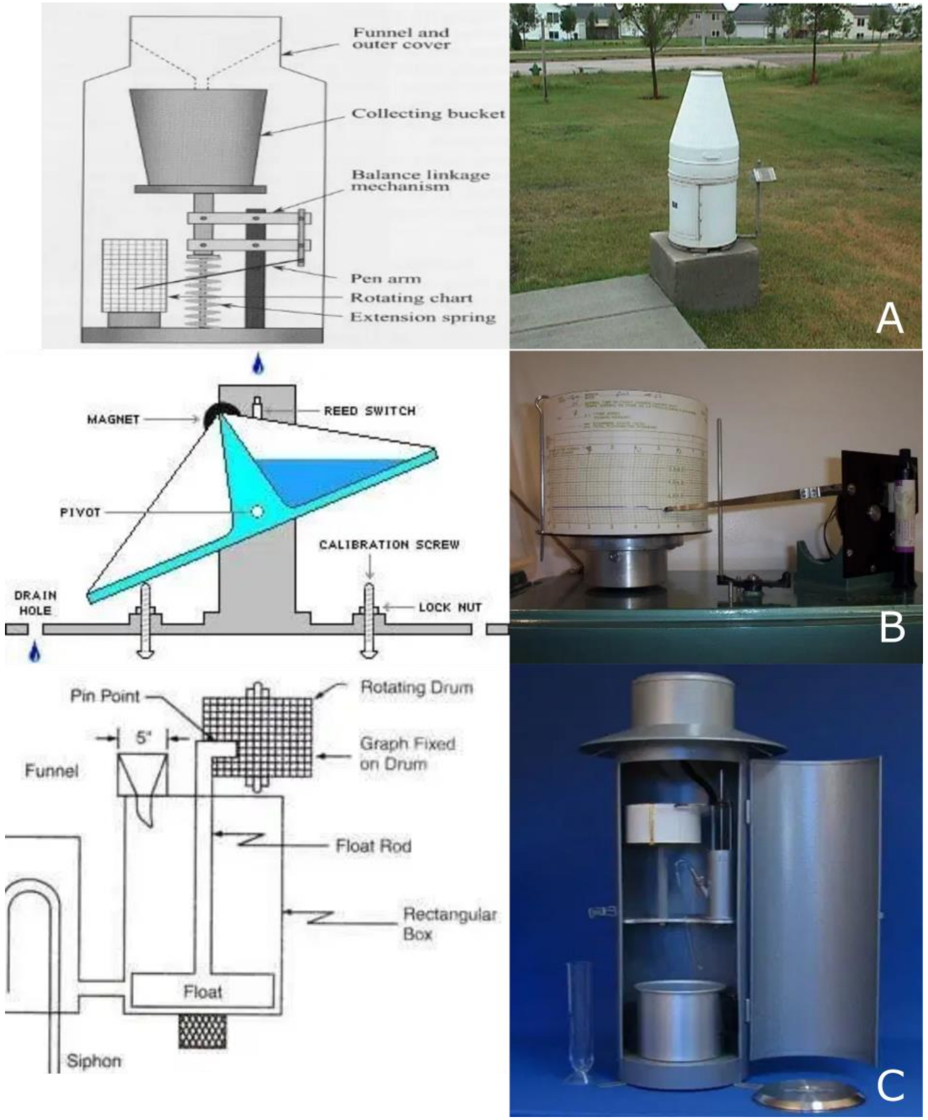





V. Sauer and D. Turnipseed, Stage measurement at gaging stations: U.S. Geological Survey Techniques and Methods. [Online]. Available: https://pubs.usgs.gov/tm/tm3-a7/

# Introduction: Rain Gauge

- Rain gauge: device used to measure precipitation
- Main types:
  - weighing bucket collector (A) – spring measures weight of water
  - tipping bucket collector (B) – two buckets pivot to complete a circuit, which causes the pen to write on the moving drum
  - float system (C) – a float rises with the water level
- Bulky, lots of moving parts




Mishra, Gopal. “Types of Rain Gauges for Measuring Rainfall Data.” *The Constructor*, 6 Sept. 2018, theconstructor.org/water-resources/types-of-rain-gauges/12801/.

# Development of UAV Delivery Systems

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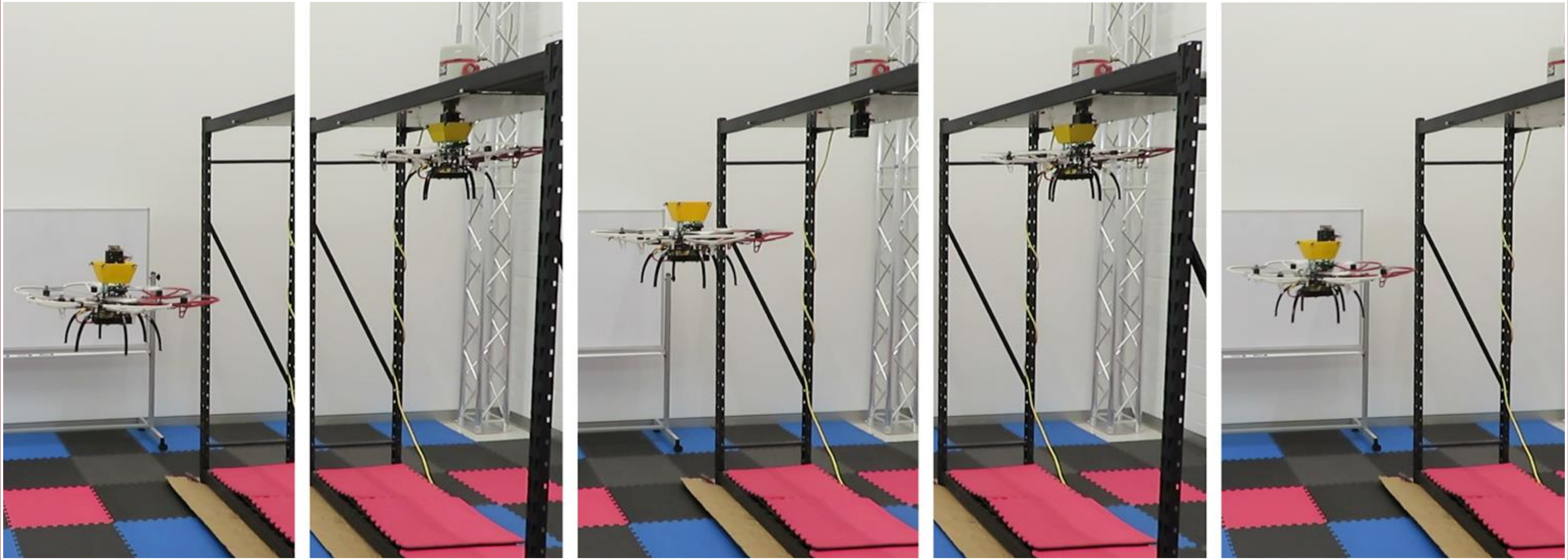
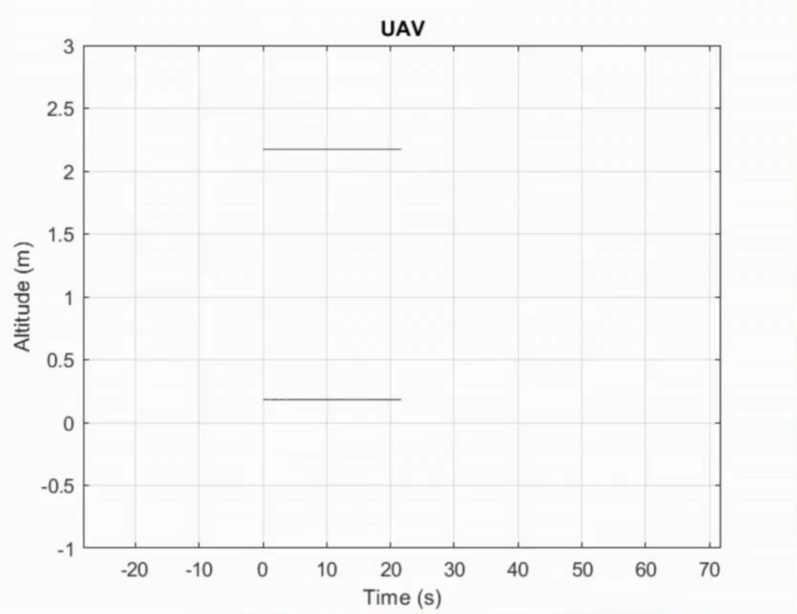
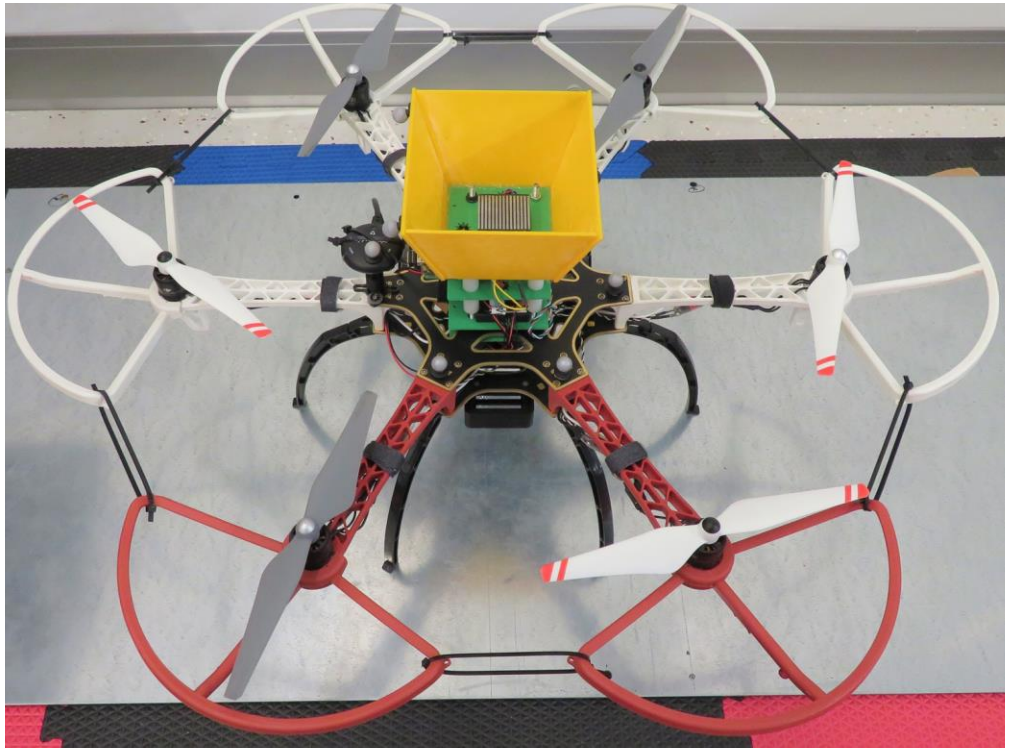
# Experimental Setup: Deployment and Retrieval Flight Test

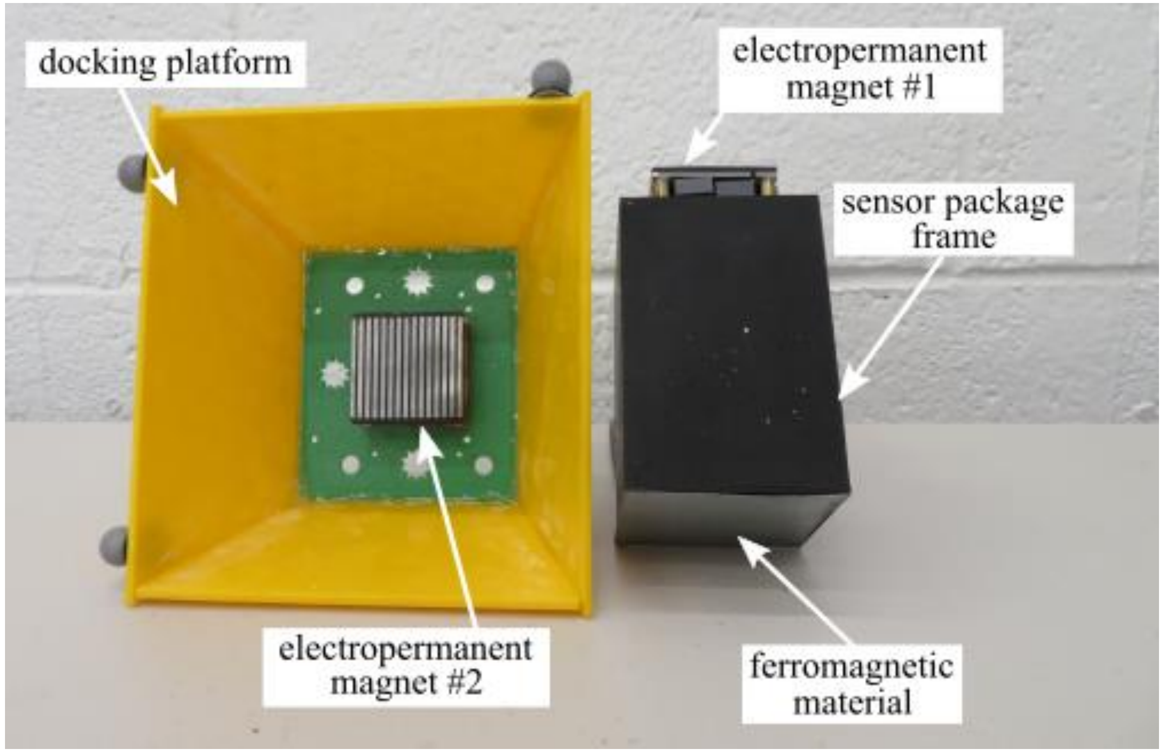


# Flight Test Video




# Development: UAS Platform

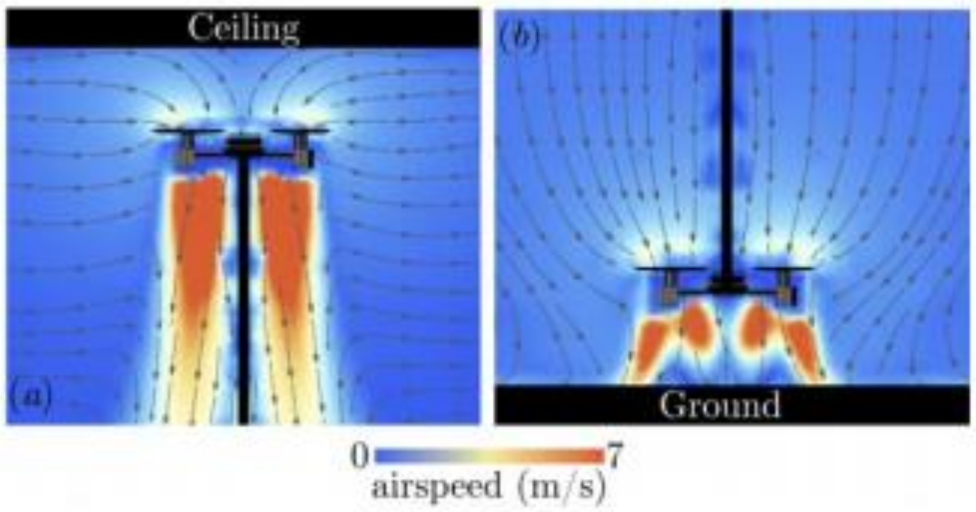





| Electropermanent Magnet #1 | Electropermanent Magnet #2 | Sensor Package | UAS |
|---|---|---|---|
| Unmagnetized | Magnetized | Attached to UAS | At delivery |
| Magnetized | Unmagnetized | Attached to structure | Package deployed |

# Ceiling Effect

- Lift increases as a UAV flies near the ground or ceiling
- Air pressure between the rotors and ceiling decreases
- The UAV will get “sucked” upwards






Gao, Shijie & Di Franco, Carmelo & Carter, Darius & Quinn, Daniel & Bezzo, Nicola. (2019). Exploiting Ground and Ceiling Effects on Autonomous UAV Motion Planning. 10.1109/ICUAS.2019.8798091.

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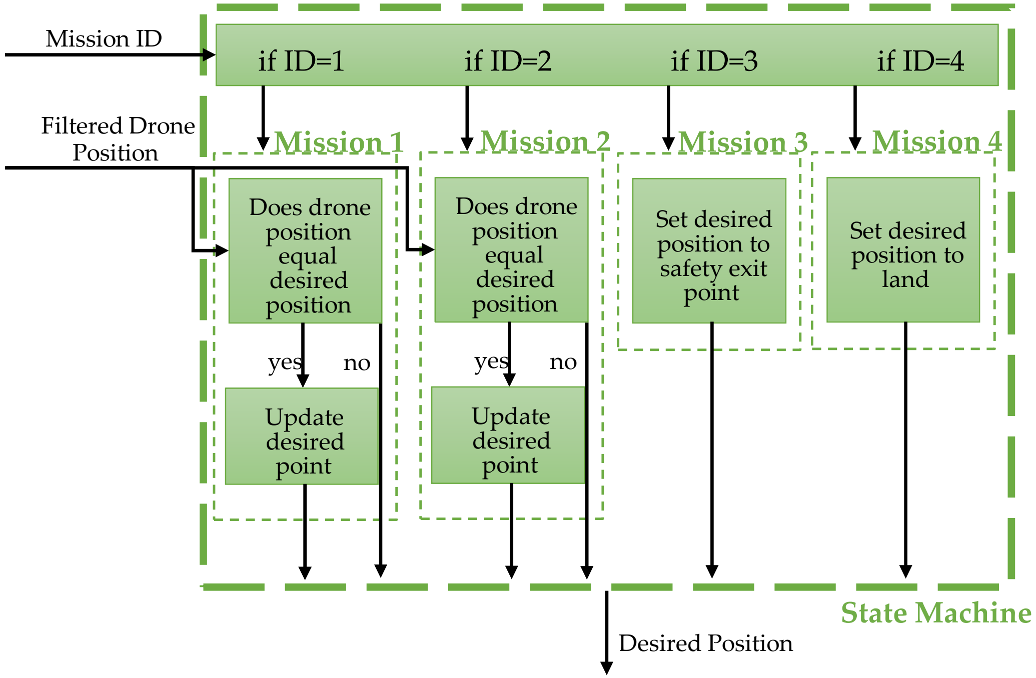
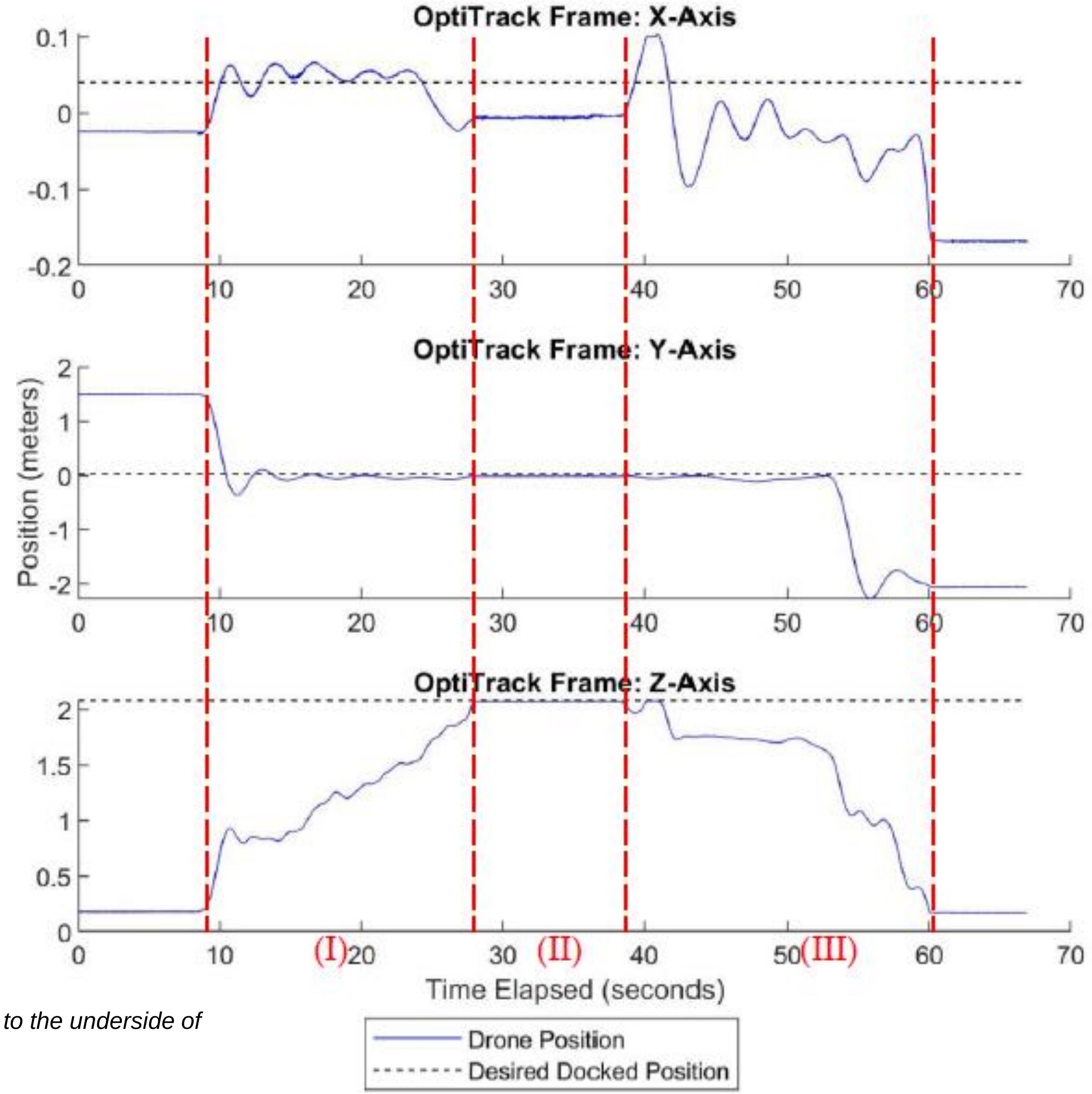
# Control Scheme

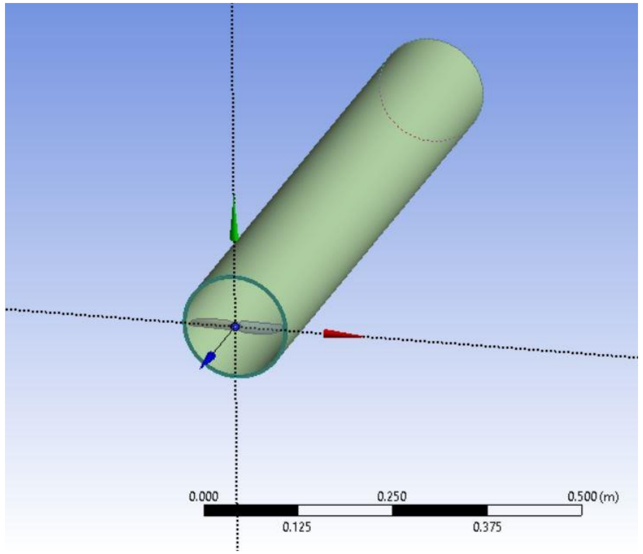


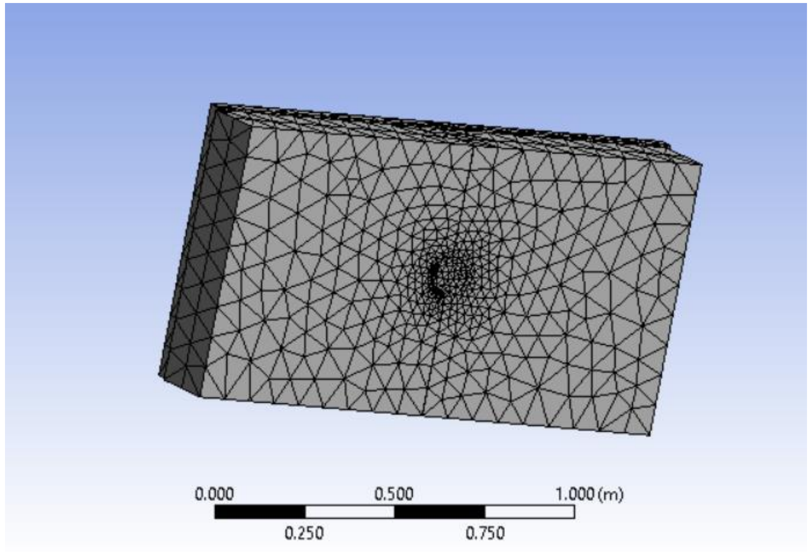

Carrol S. (2020). *Autonomous drone-based sensor package deployment to the underside of structures* [Unpublished Masters Degree]. University of South Carolina.

# Modeling of Ceiling Effect

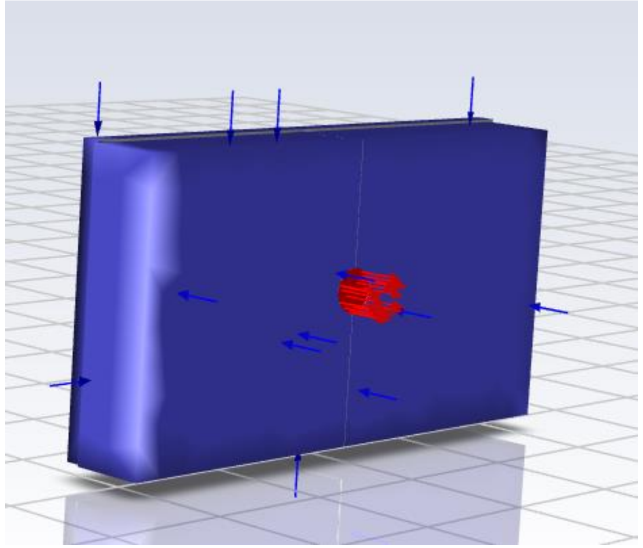
- Ansys CFD model
- Simulates a propellor in a closed boundary surface




Single drone propeller



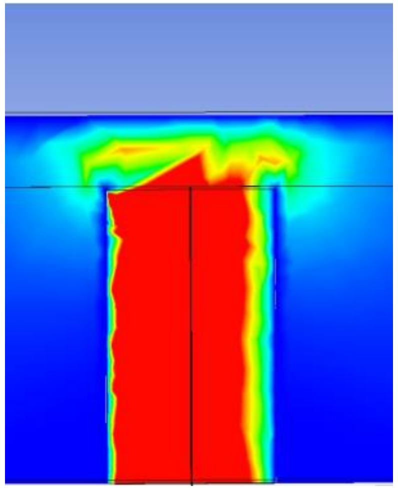

Closed Boundary Surface



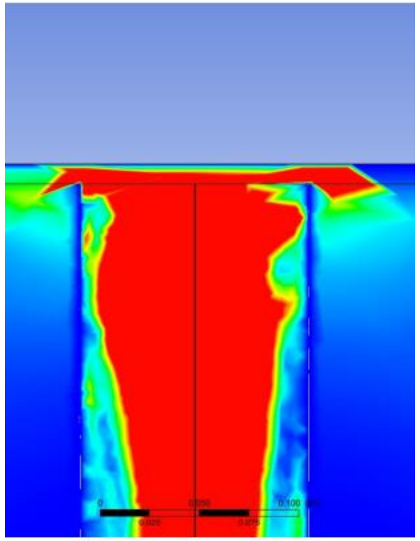
Pressure Results

# Results

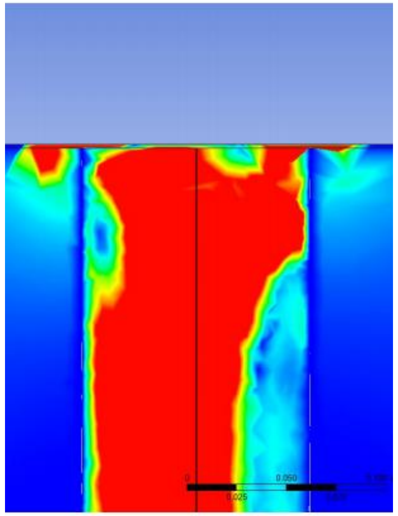
- Velocity profiles were found at set distances from the ceiling
- Velocity at the ceiling increases as distance from ceiling decreases
- Thrust force increases as distance from ceiling decreases



Velocity profile
5 cm distance



Velocity profile
1 cm distance



Velocity profile
0.2 cm distance

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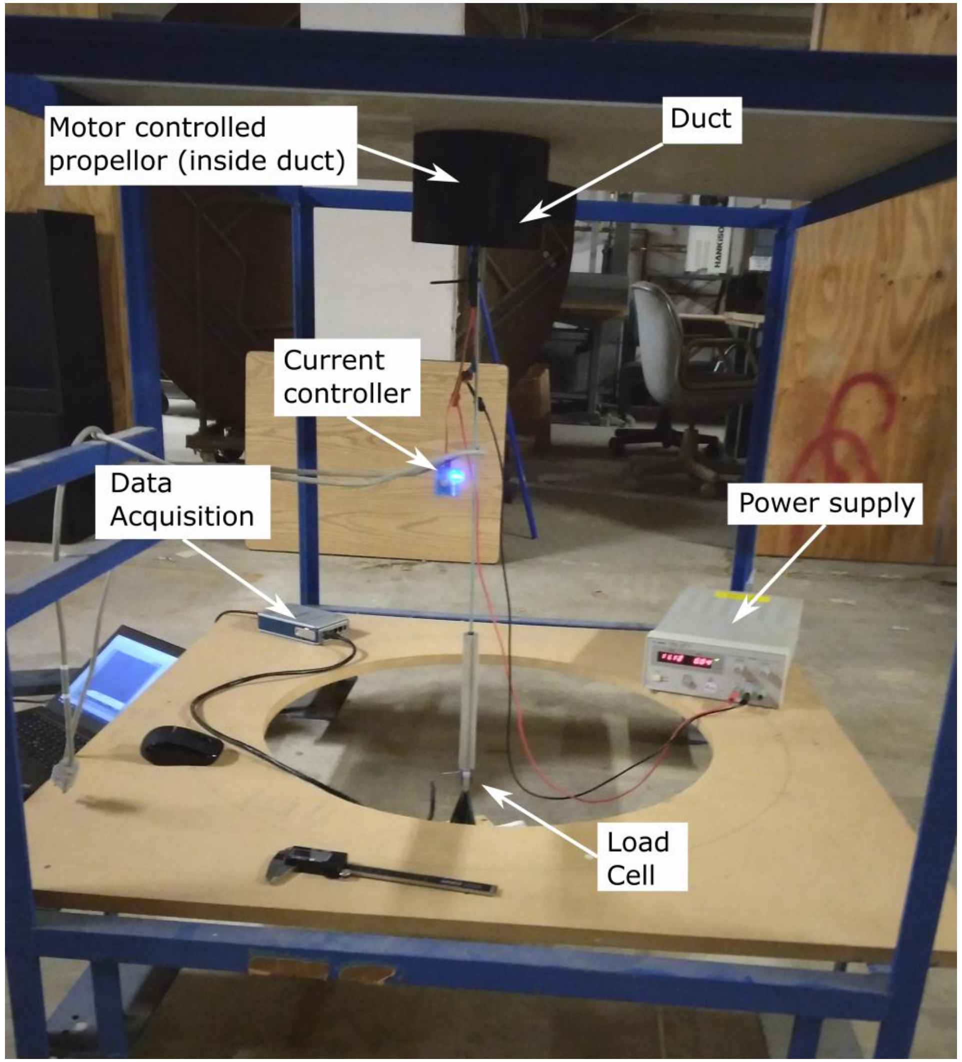
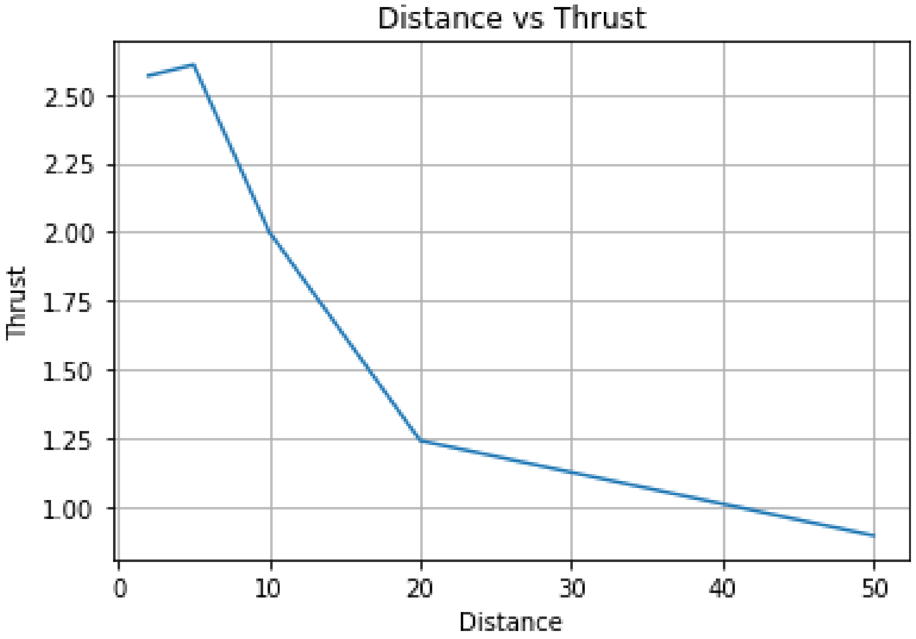
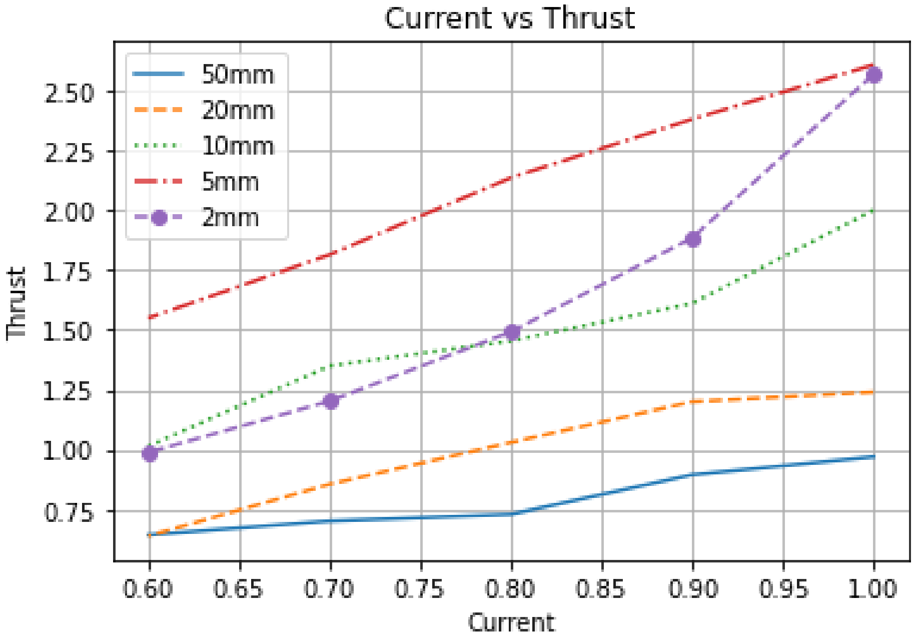
# Experimental Setup



# Stage Sensor

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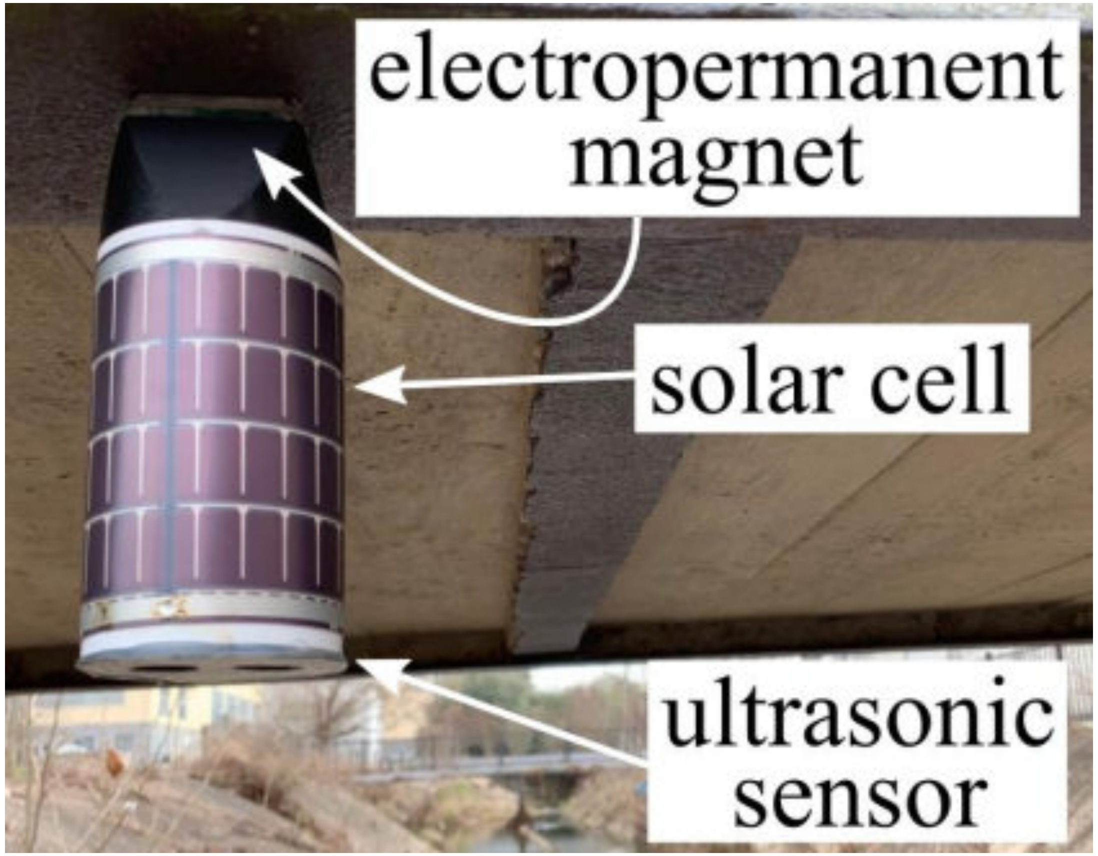
# Hardware Design Goals

1. Low cost per unit ($200) ✔
2. Portable size suitable for UAV deployment (0.5 kg) ✘
3. Low power operation (1 week of operation) ✘
4. Wide range of operating conditions (winds up to 20 km/h) ?
5. Wireless data transfer (100 meters) ✔
6. Comparable accuracy to existing USGS sensors (3 mm) ✘
7. Battery power monitoring (± 5%) ✘

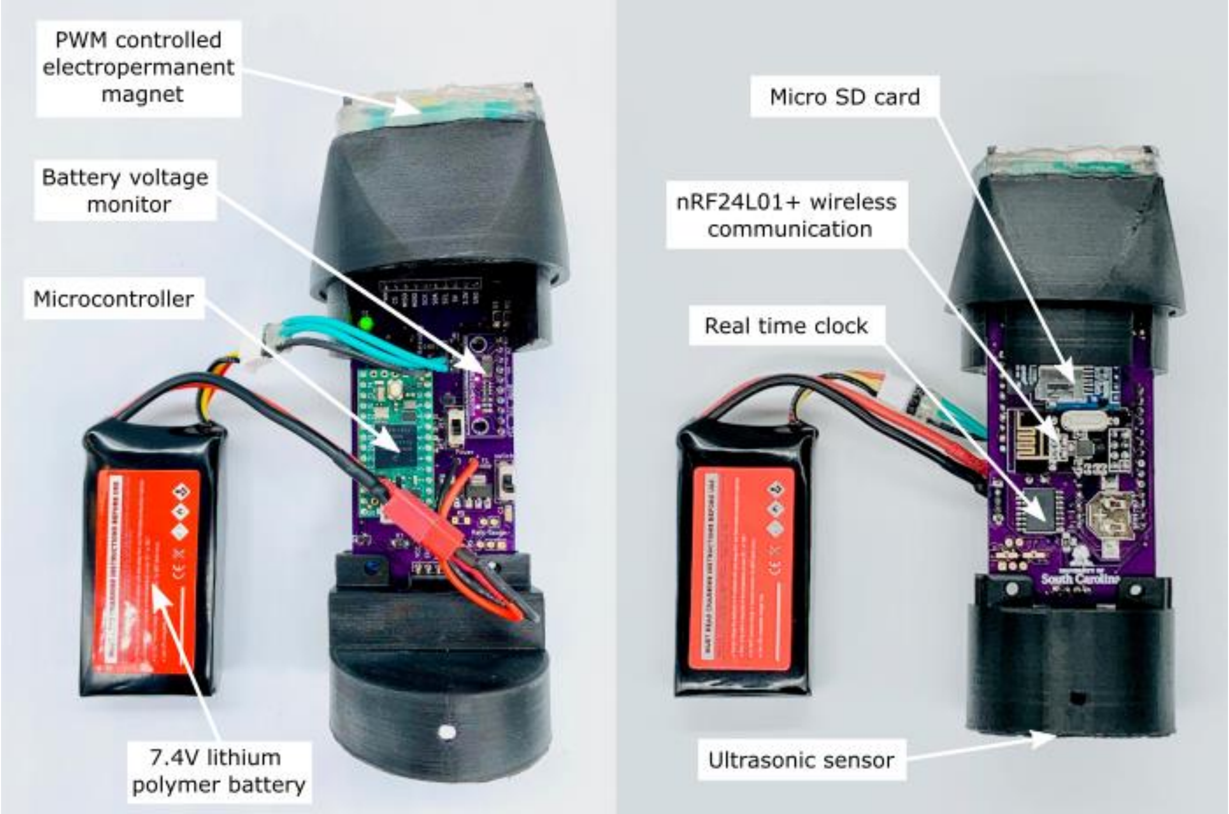
# Hardware Design: Stage Sensor

- Microcontroller based
- EPM allows drone deployment
- Ultrasonic sensor measures stage
- Solar cell helps power package
- 0.83 kg
- Measures up to 4 meters



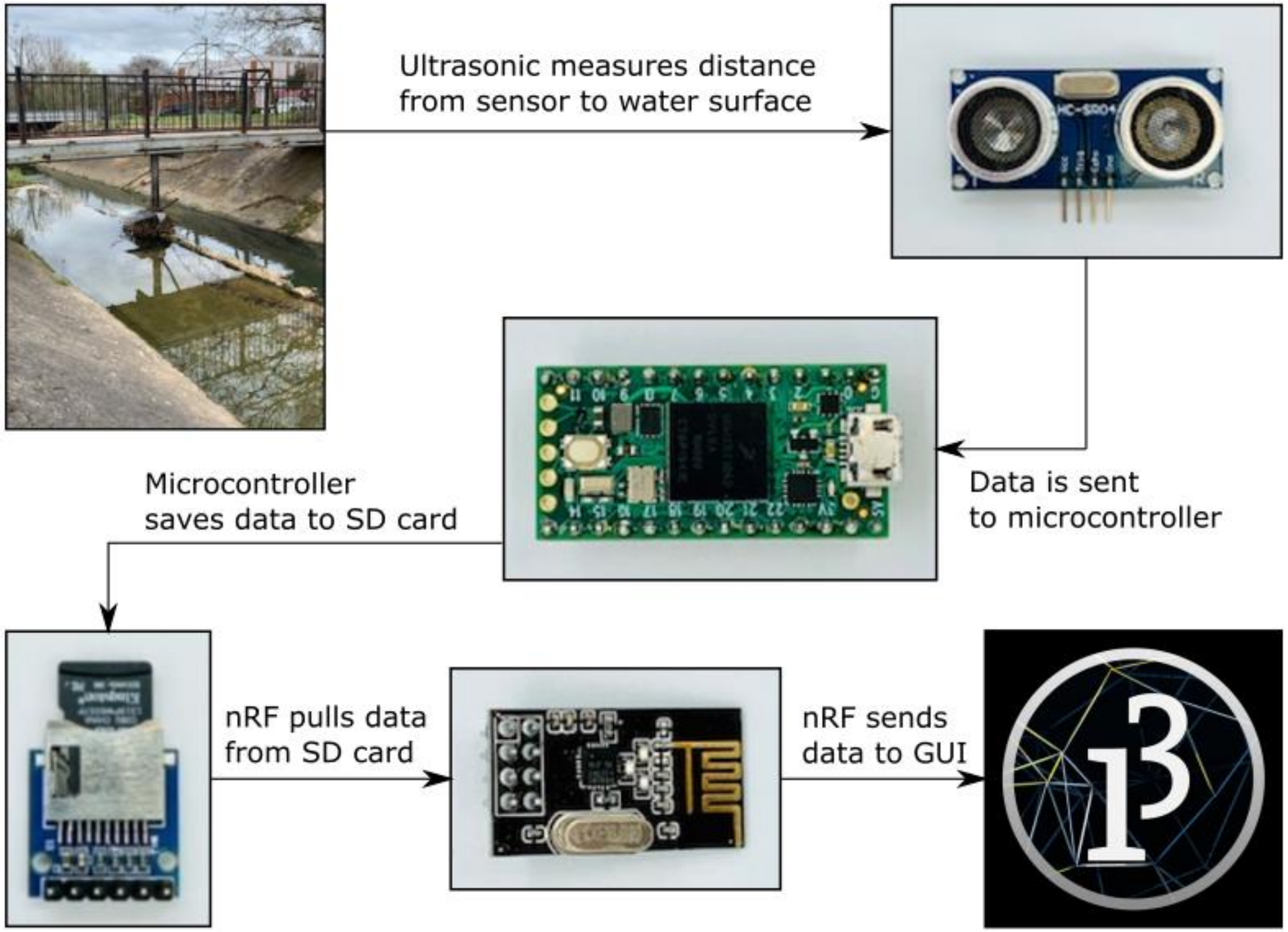
# Package Features

- Teensy 4.0 microcontroller
- EPM V3 R5C electropermanent magnet
- HCSR04 Ultrasonic distance sensor
- Micro SD Card data logger
- DS3231 real time clock
- ADS1115 battery voltage monitoring
- nRF24L01+ wireless RF communication
- GUI integration
- Packages are relatively uniform, just swap sensors

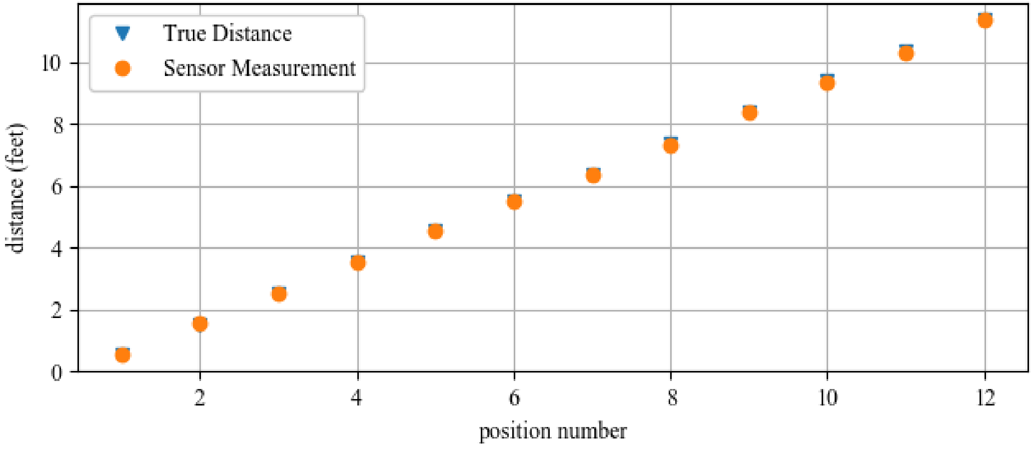


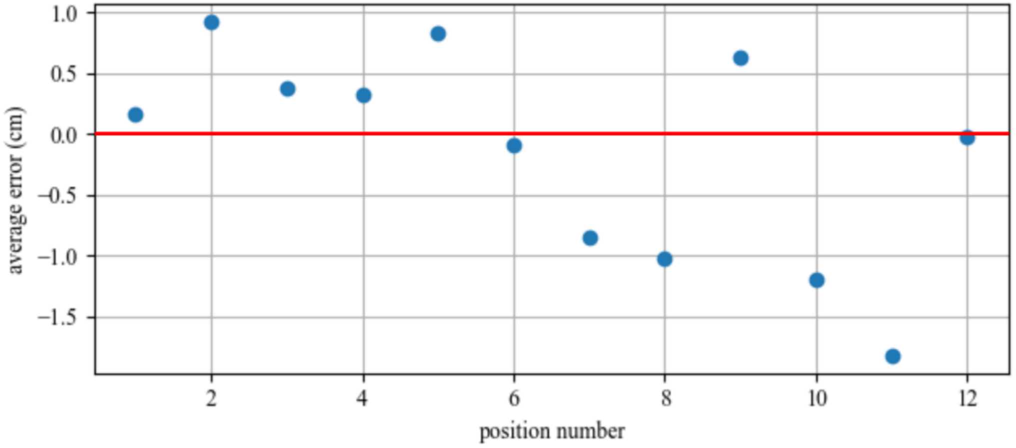
# Software

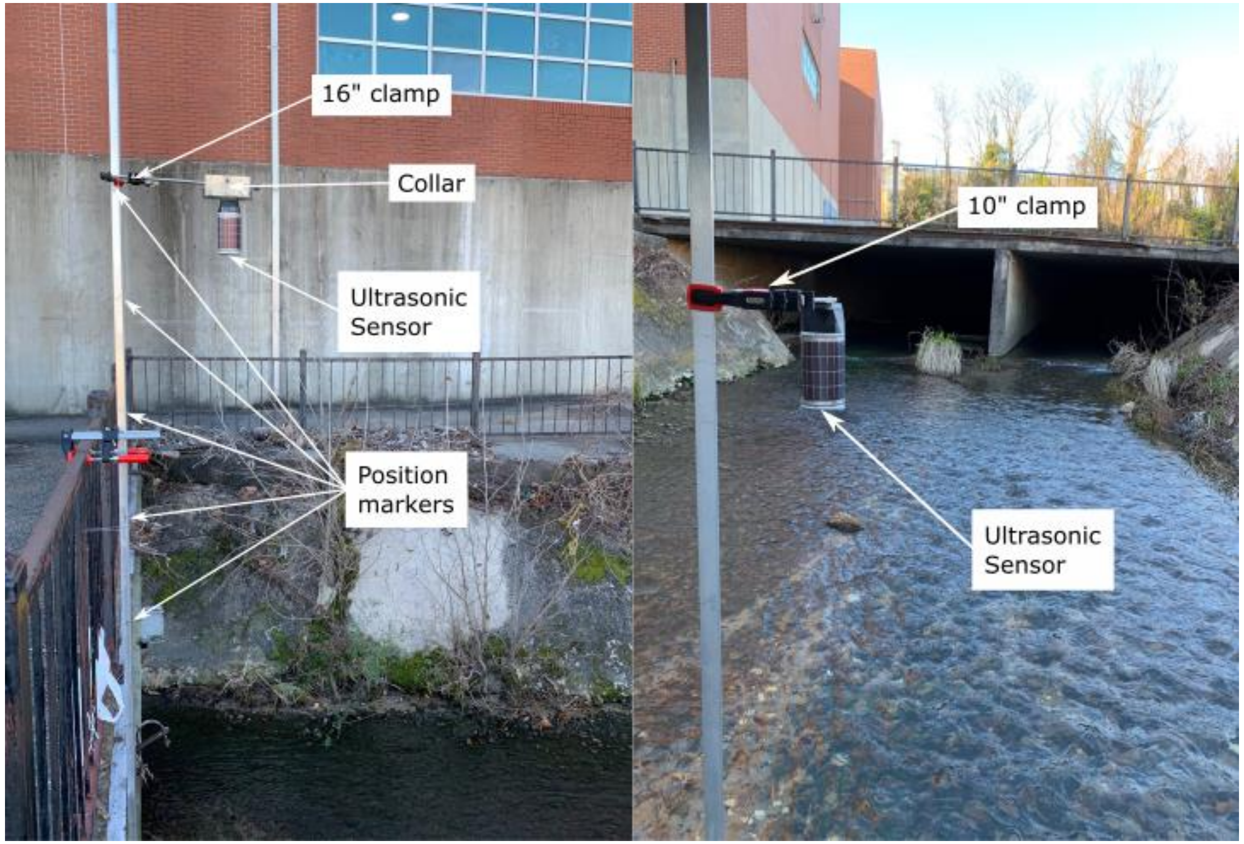
- Arduino language is used for the microcontroller
- Basic data logging processing
- Data is sent wirelessly to a GUI for user access



# Sensor Verification

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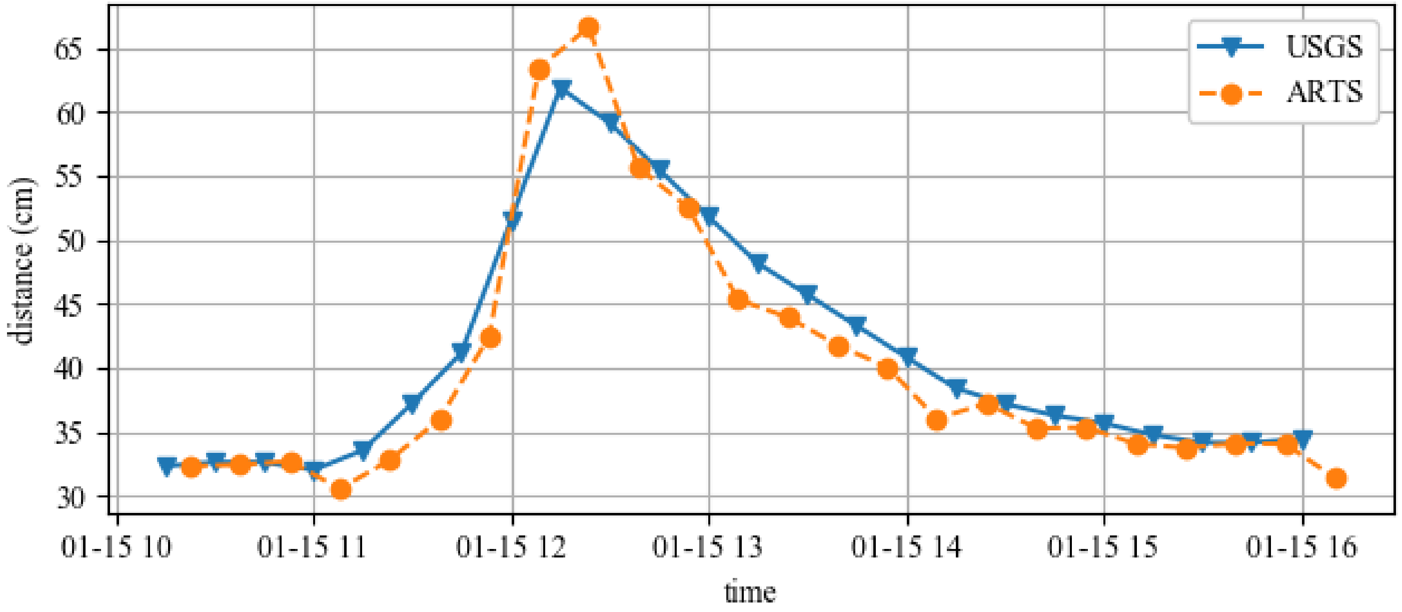
# Field Results

- Sensor package data verified against existing USGS bubble gage data





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# Rain Gauge

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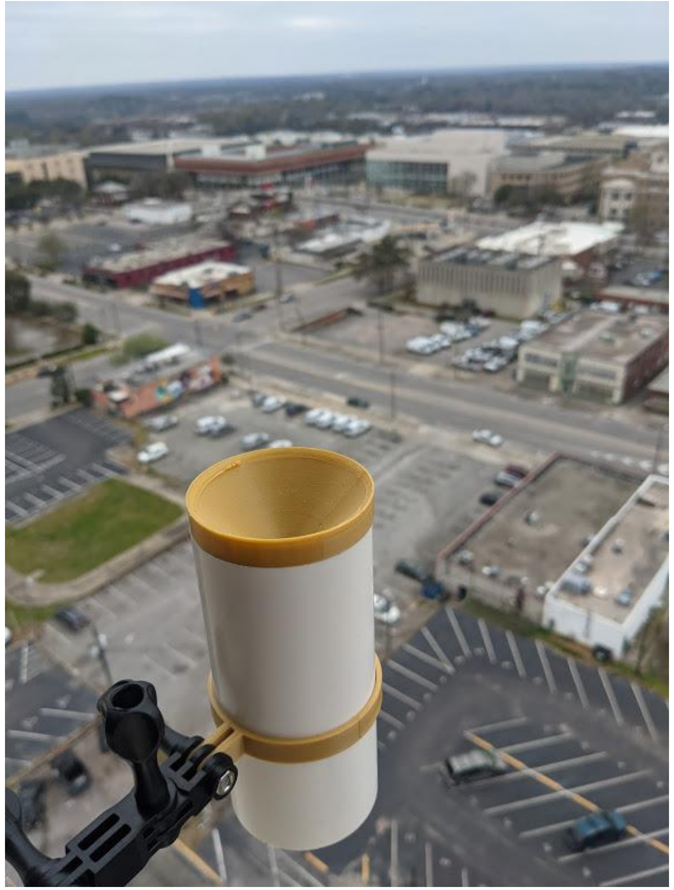
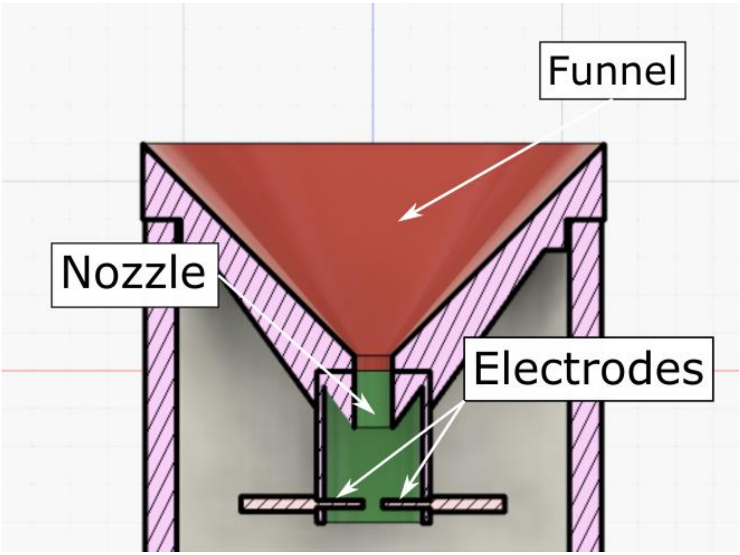
# Hardware Design: Rain Gauge

- Counts the number of individual rain drops per area
- Funnels drops to electrodes and does a binary count
- Same PCB can be used



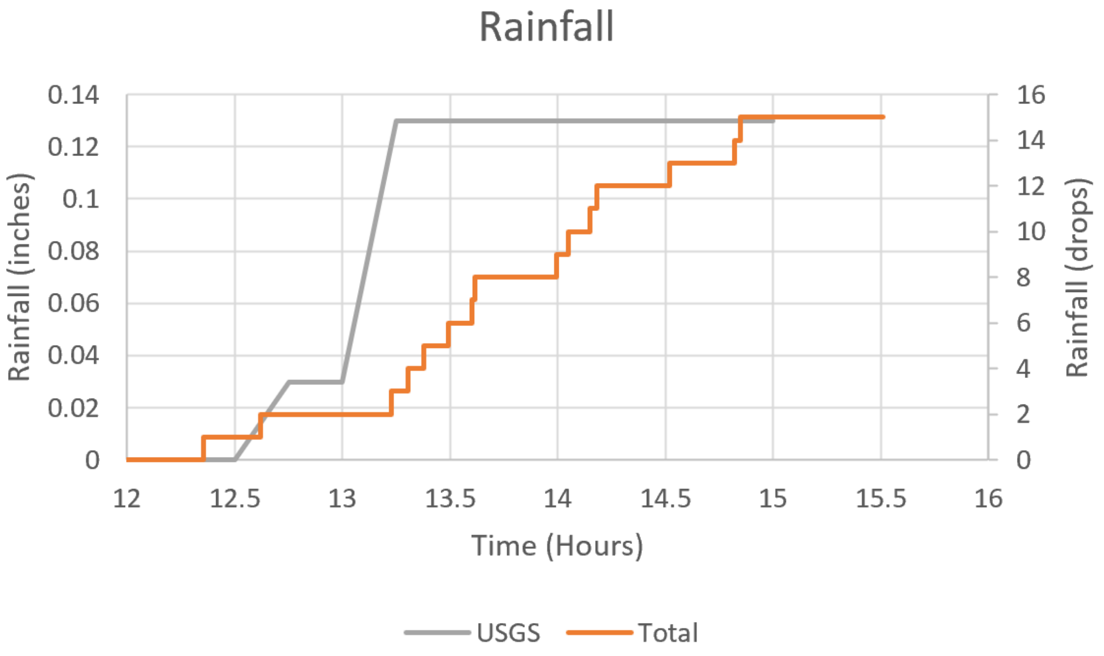


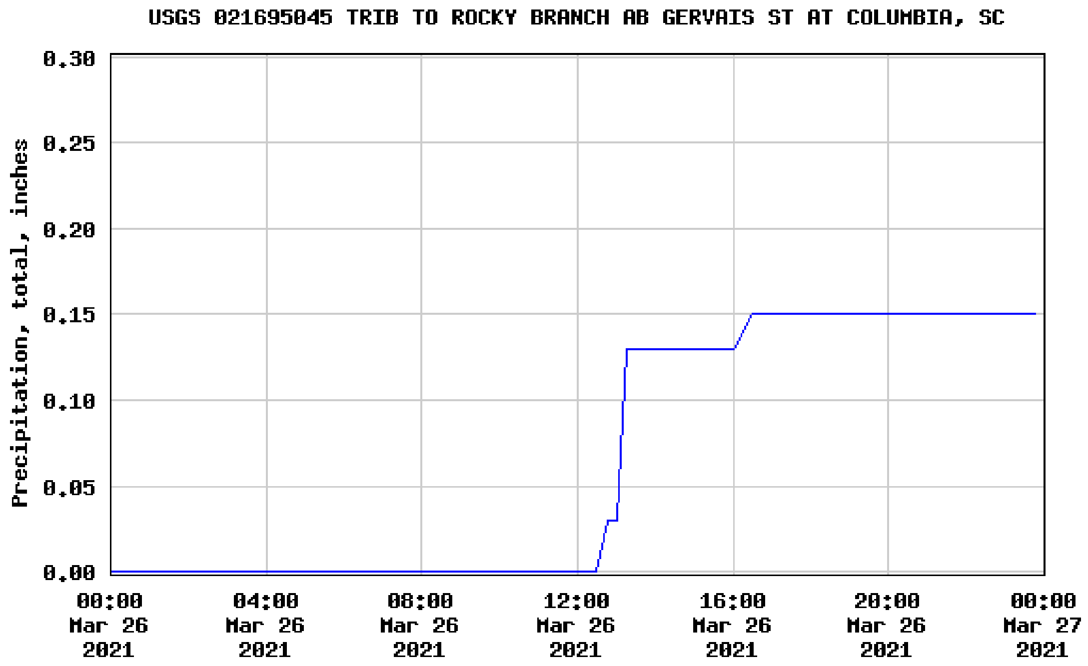
# Design Parameters

- World's maximum rainfall in one hour: 30.5 cm
- The system must process 1 mL of water every 7.75 seconds

# Field Testing

- Tested during a rainfall event in Columbia SC, March 26, 2021
- Higher resolution
- Similar results despite a 1/2-mile separation
- Next step: integrate mobile PCB electronics and test next to USGS rain gauge to correlate

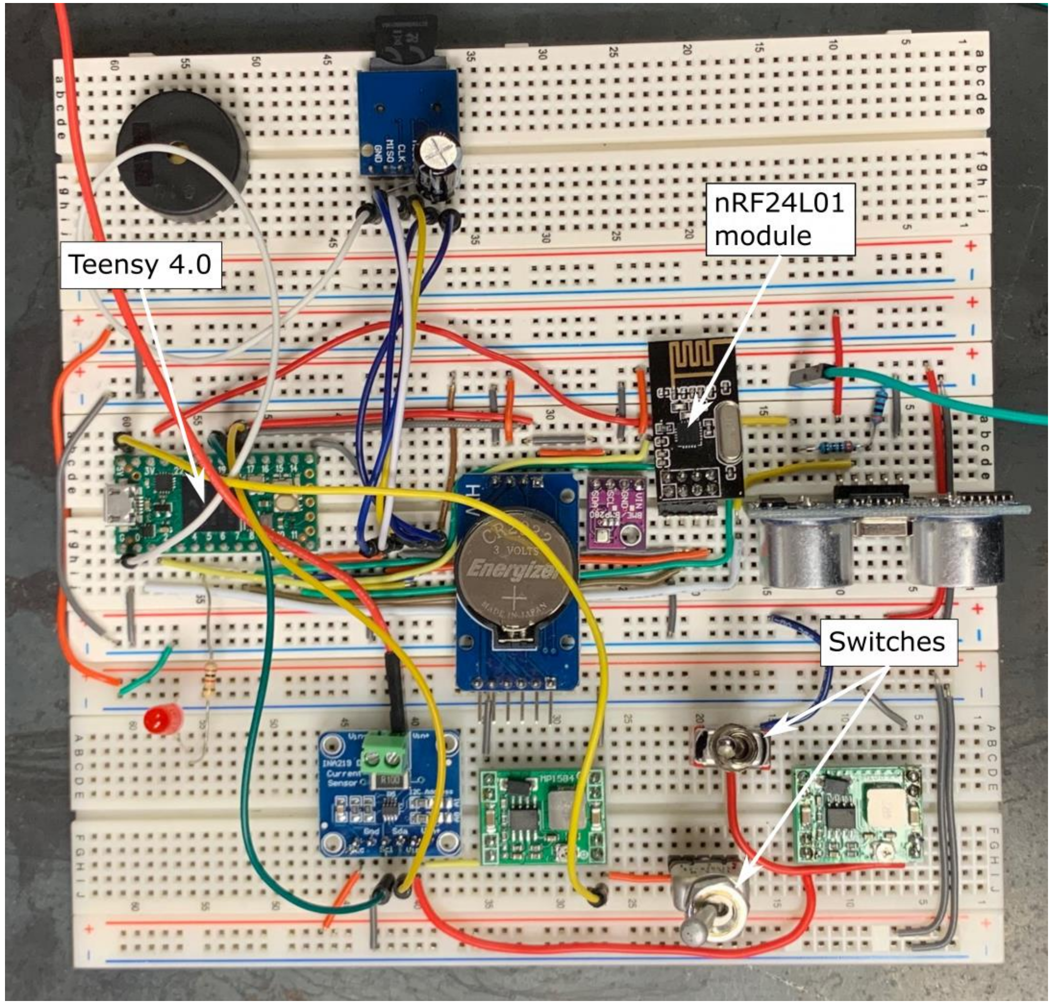


# Power Consumption Challenges

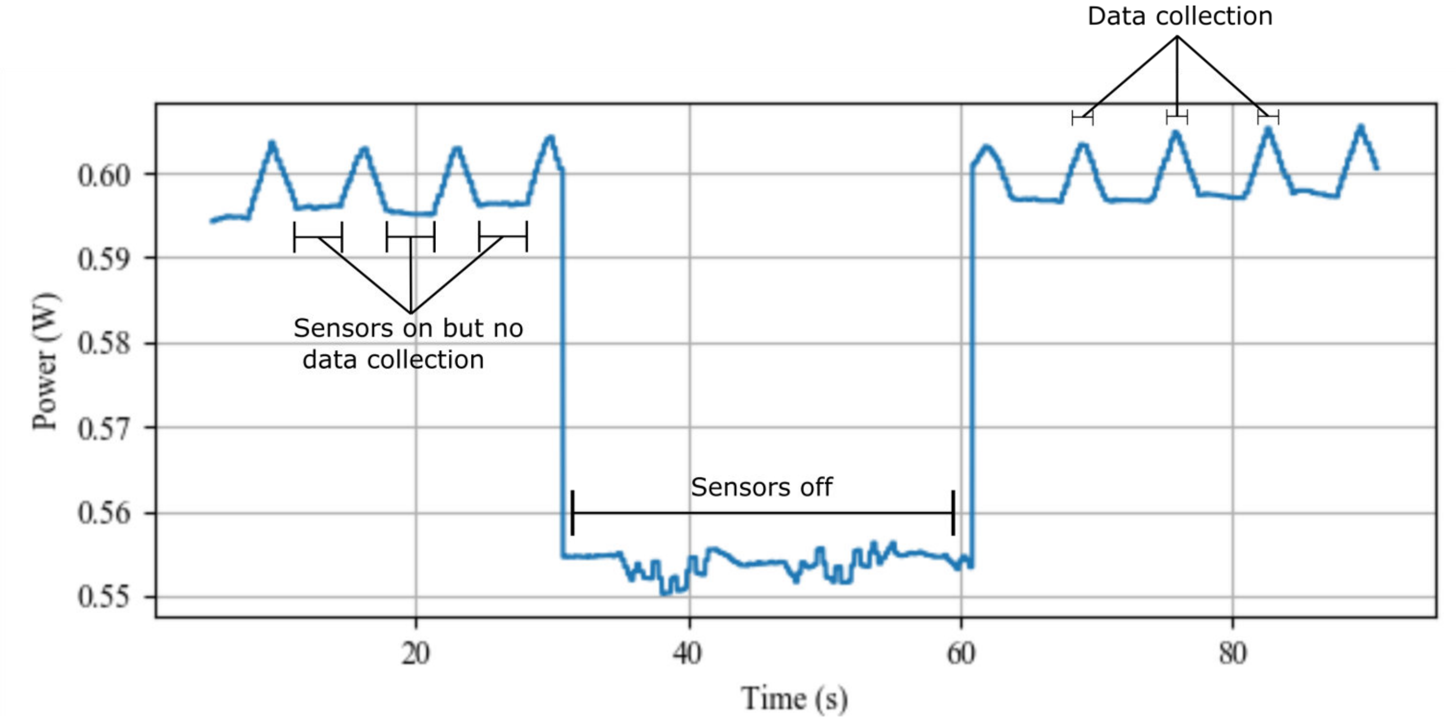
# Power Down Mode

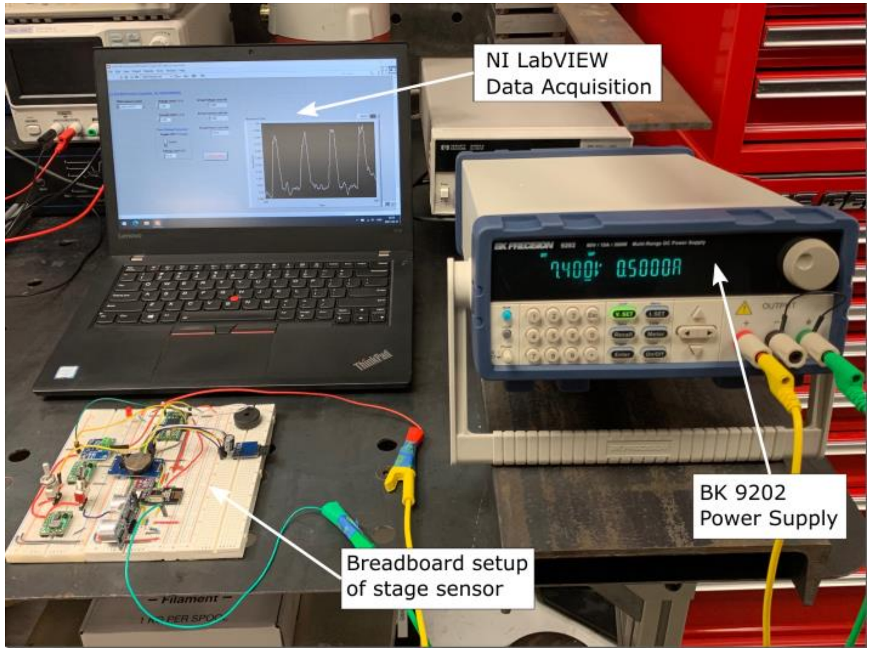
- Idea: use transistors to switch off the sensors on the PCB, excluding the Teensy 4.0 and the nRF24L01+ wireless communication module
- Physical switches were used to simulate transistors



# Power Draw

- 0-30, 60-90 seconds: modules are on
- 30-60 seconds: modules are off
- Total power conserved: 0.055 Watts

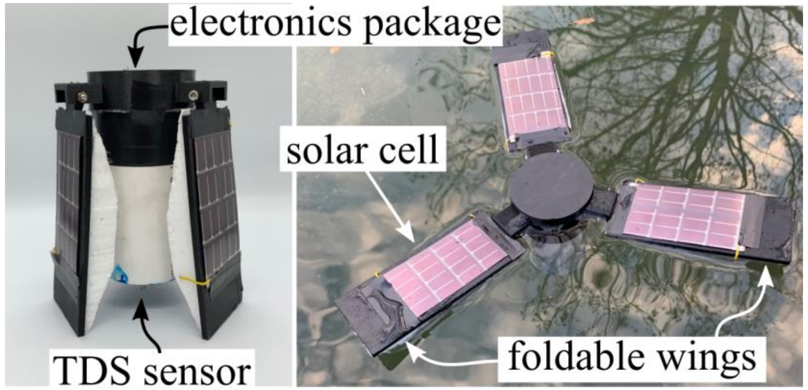


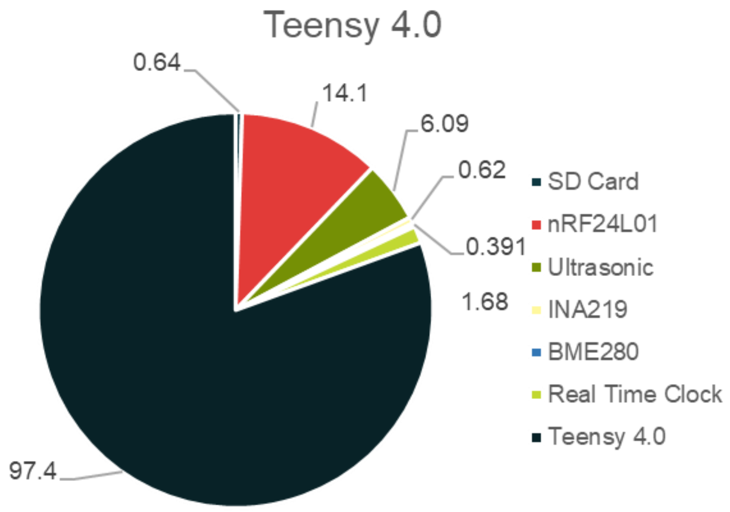




Experimental Setup

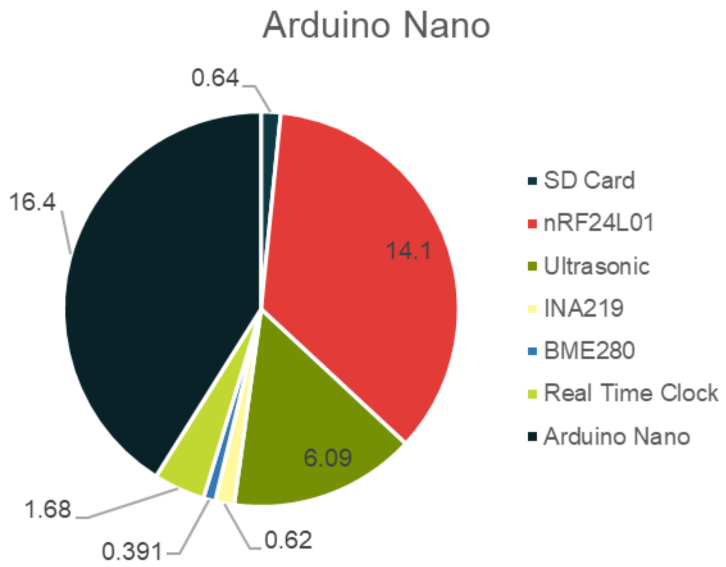
# Current Consumption

- Teensy is most power consuming device



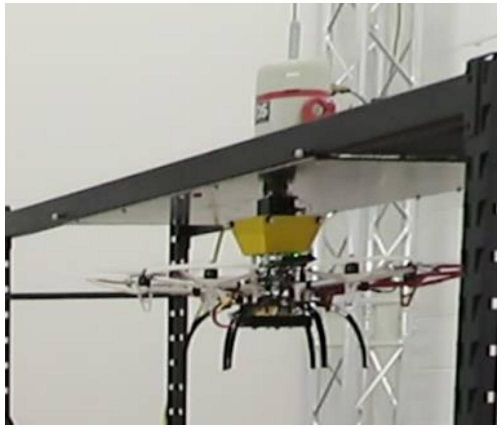

Total draw: 120.9 mA
Ideal lifespan: 12.4 hours

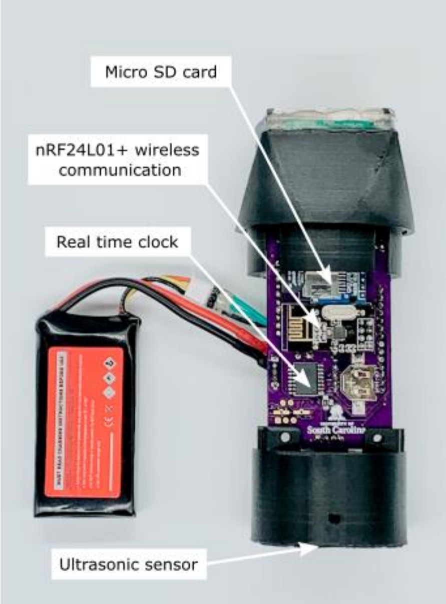


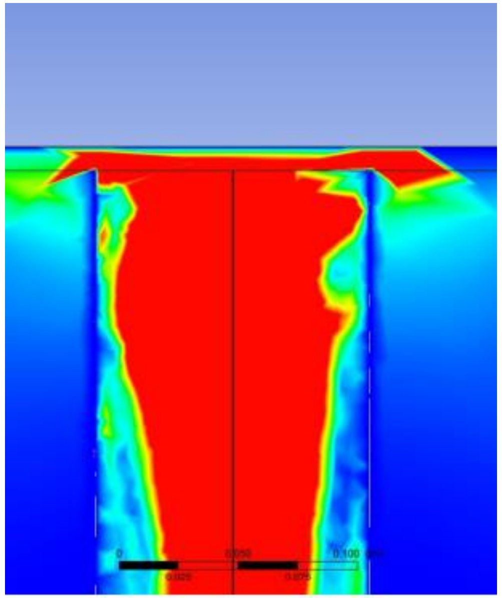

Total draw: 39.92 mA
Ideal lifespan: 37.6 hours

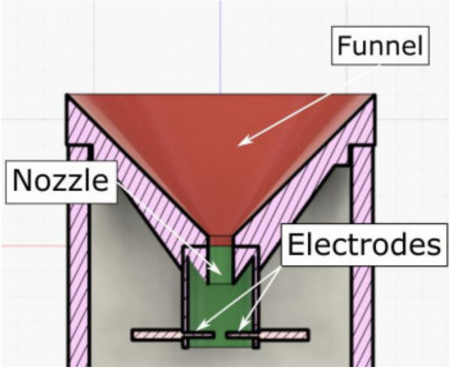
# Conclusions

- UAVs can deliver packages despite ceiling effect
- Stage sensor and rain gauge provide accurate readings of hydrolic parameters
- Need to reduce power consumption
- Use solar panels to prolong battery life







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# QUESTIONS?

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