# Radio Tracking Fish with Small Unmanned Aircraft Systems (sUAS)

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# 1. Project Background

- Proposal funded through the USGS Innovation Center
- Collaborators:
  - USGS: CERC, FORT, NUPO, L&RS Program
  - WWR Development
  - NanoElectromagnetics LLC
  - NASA-Ames Research Center
  - DOI-Office of Aviation Services, UAS Division
  - Missouri Department of Conservation

# 1. Project Background

- Personnel:
  - NASA:
    - Bob Dahlgren, Dave Satterfield, Jonas Jonnsson, Ethan Pinsker
  - USGS:
    - Karl Anderson, Leanne Hanson, Joe Deters, Patrick Kroboth
  - WWR Development:
    - Dave Witten
  - DOI-OAS:
    - Rich Thurau

# 1. Project Background

- Concept of Operations
  - Assess UAV payload capacity
  - COTS telemetry equipment too heavy for UAV
  - Select airframe
  - Develop and test telemetry payload (receiver and antenna)
  - Integrate UAV and telemetry payload
  - Airworthiness review and flight tests with telemetry payload
  - Field data collection using UAV with telemetry payload

# 1. Project Background


# 1. Project Background

- **Advancing UAV in natural resources**
- **Successful demonstration**
- **of UAV-deployed telemetry**
- **system will expand demand and increase applicability of technology**

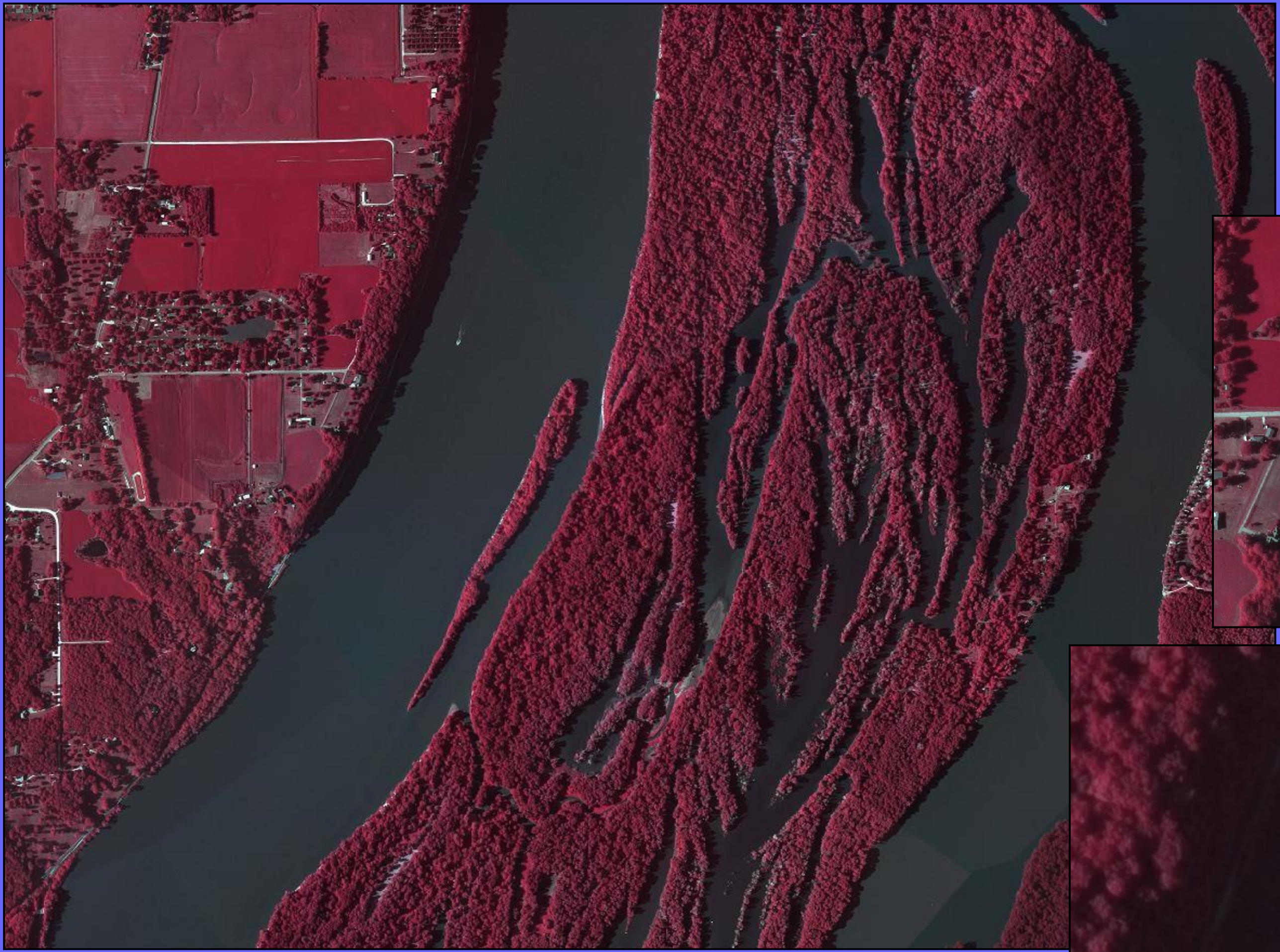
*Moving telemetry forward…*

# 1. Project Background

- The ability to track invasive Asian carp is critical for control efforts.
  -
- This is a time-consuming task
-
- Carp frequent areas inaccessible by boat causing gaps in tracking data

# 1. Project Background

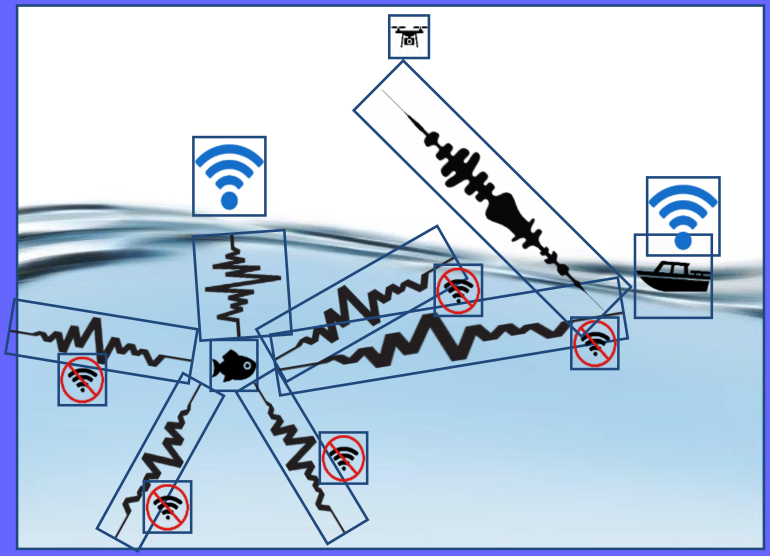
Mississippi River
~2 miles wide and
~20 foot long speed
boat shown for scale



Burlington Island complex, Mississippi River. USDA-NAIP image.

# 1. Project Background

- Radio signal propagation underwater
  - Radio signal drops over distance underwater (conductivity and depth)
  - Strongest signal is above fish (less water to go through).
  - Signal comes out of water in a cone shape.
  - sUAS altitude permits signal reception at further distance



- UAV equipped with a receiver should be able to more efficiently direct us to the tagged Asian carp.

# 1. Project Background

- Goals:
  - Develop and test telemetry receiver and antenna affixed to UAV to detect fish tags in river environment
  - Marine operations of UAV

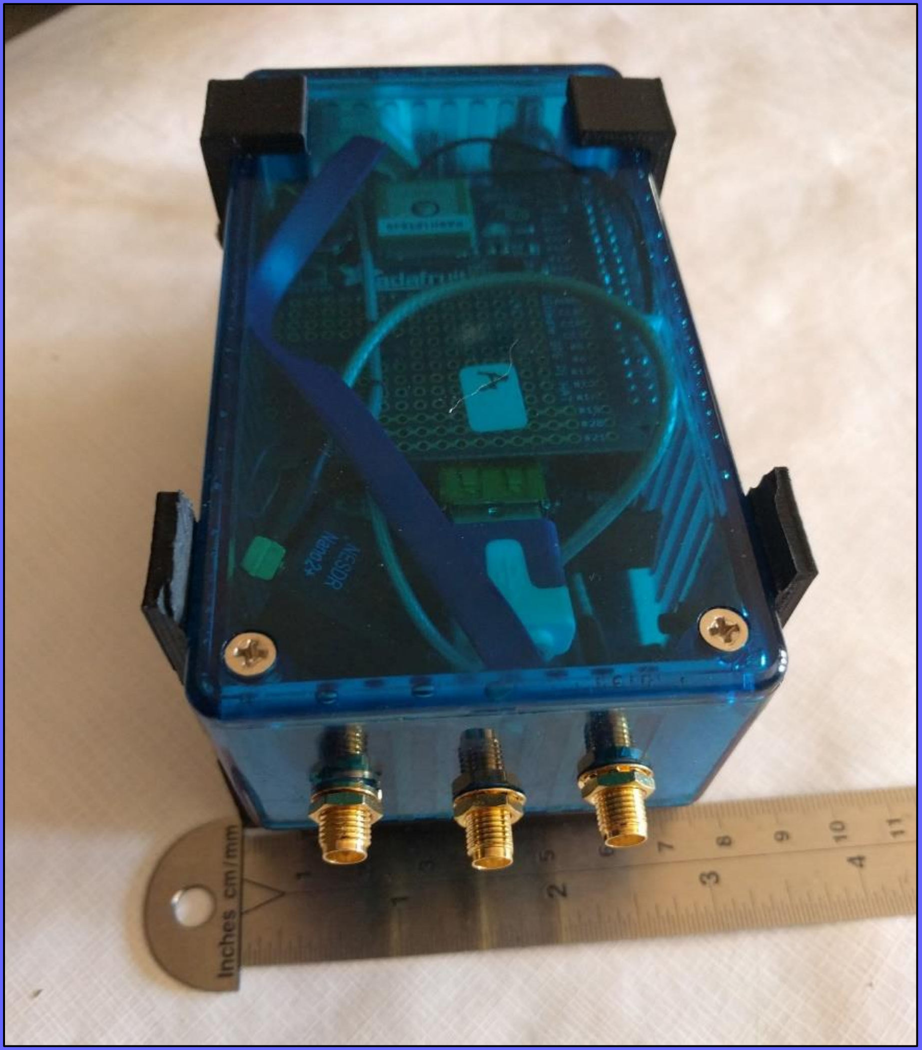
## Potential Problems:

- Harsh environment (heat, wind, humidity, etc.)
- River conductivity and turbidity
- Equipment failure
- Loss of UAV

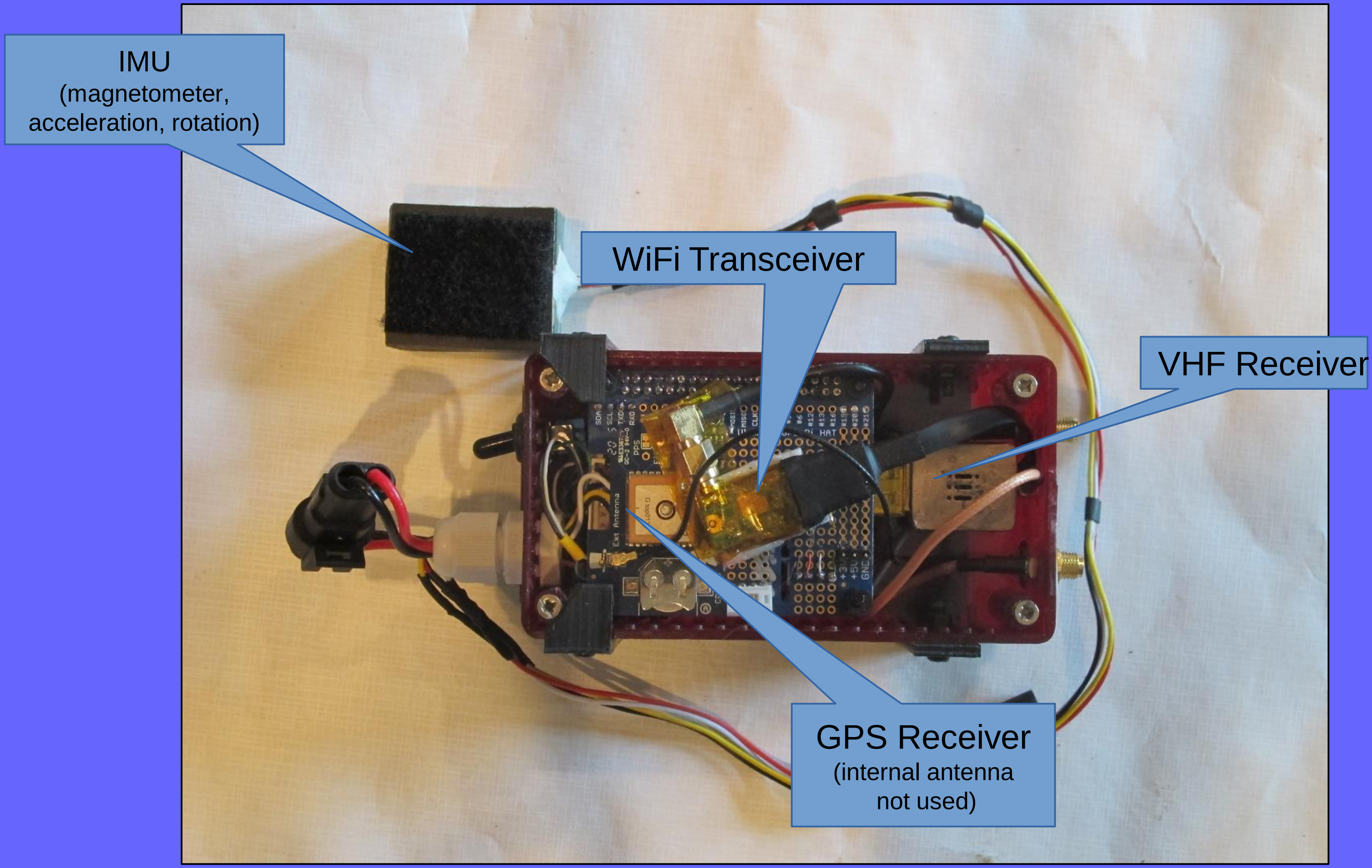
# 2. Payload Development

- Desired requirements:
  - Receive Tag Signal in *real time*
  - Lotek Tag submerged in river water
  - Signal is extremely narrow band OOK modulated pulse emitted every 3-5 seconds
  - 
- Correlate Tag Signal with Position and Bearing
  - Time of arrival of pulse must be correlated with data from GPS (latitude, longitude, time stamp), IMU (magnetometer, accelerometer, gyroscope) Signal Strength (VHF receiver)
  - 
- Transmit Position, Bearing, and Signal Strength to Ground Station in real time
- 

# 2. Payload Development



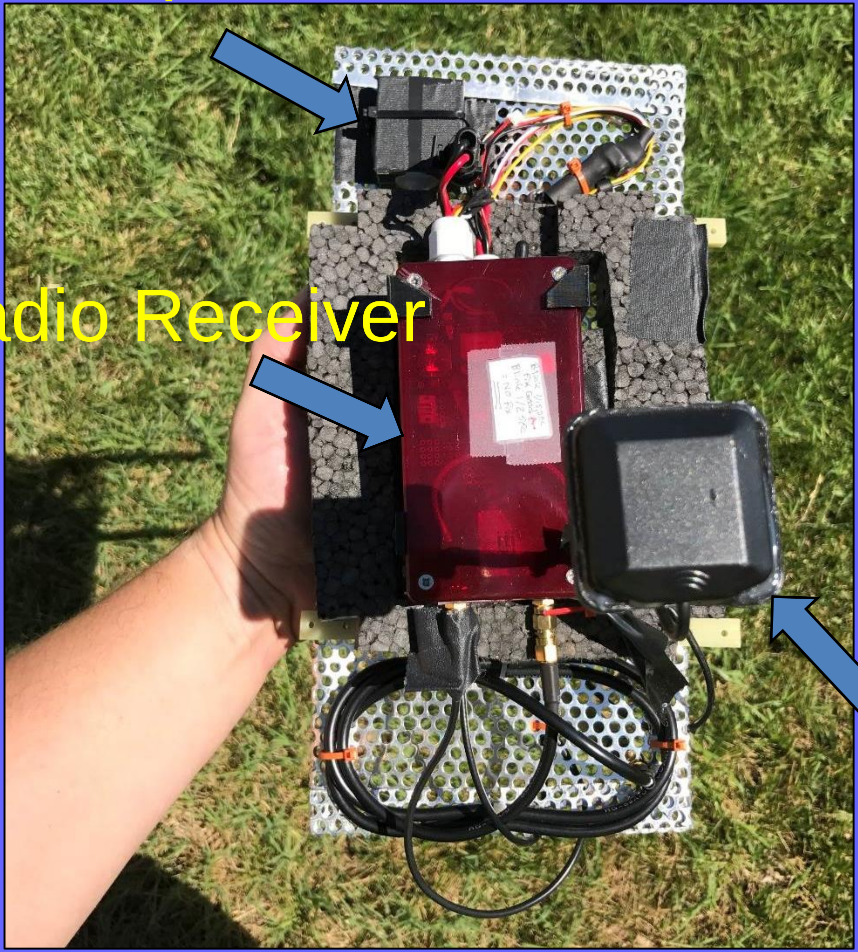
# 2. Payload Development



# 2. Payload Development

Directional Antenna (underneath) Facing Direction

Compass

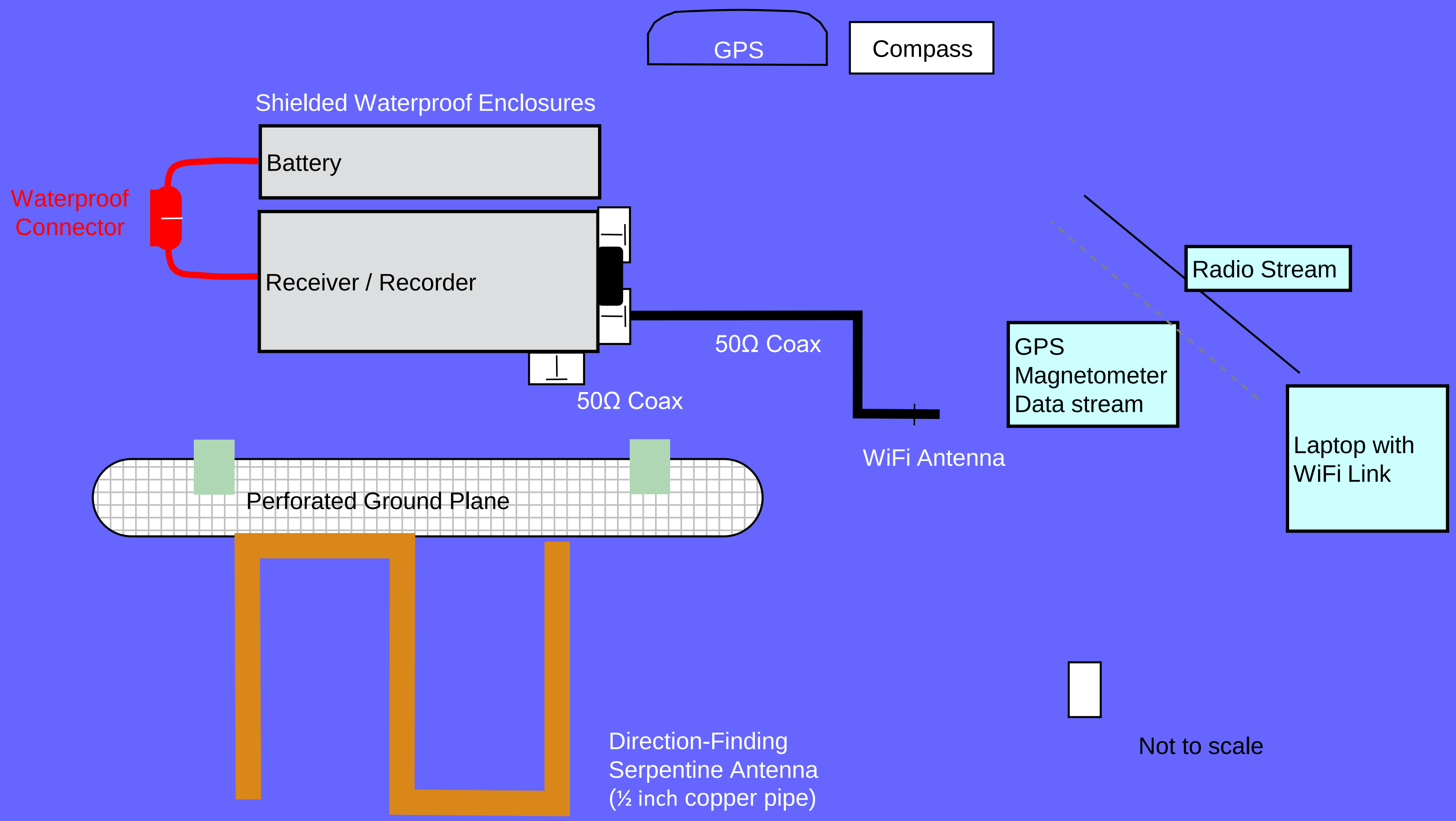


Radio Receiver

GPS

1.2kg total wt.

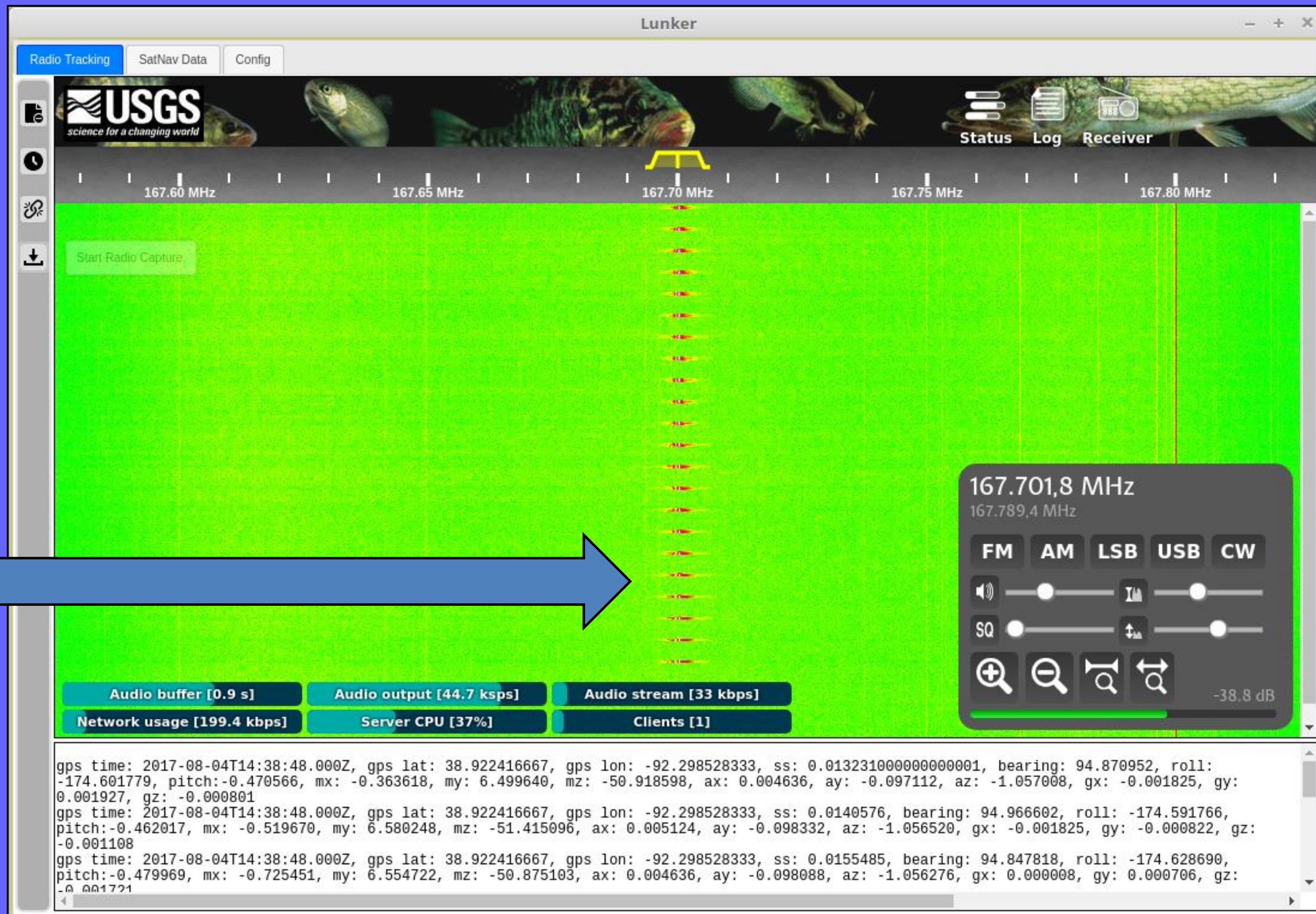
# 2. Payload Development



# 2. Payload Development

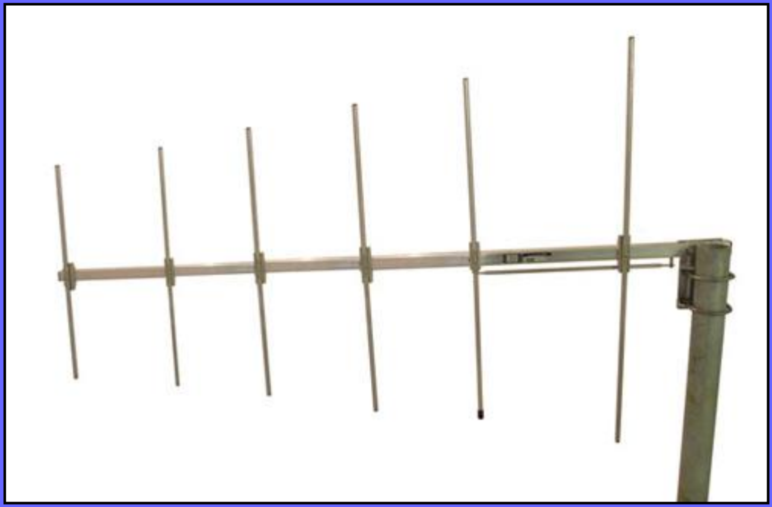
- **Software includes a waterfall diagram**

Radio tag signal



# 2. Payload Development

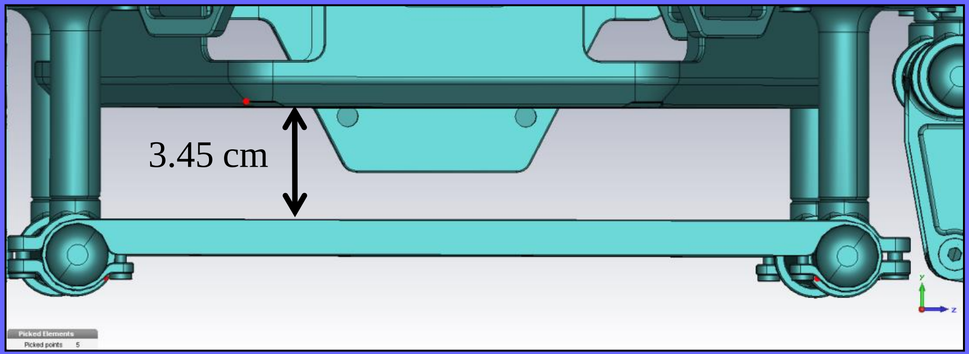
- **Antenna desired requirements:**
- **VHF band**
  - **Tag signal at 167.7 MHz**
  - **Wavelength at 167.7 MHz is ~1.78 m**
- **Drone mountable**
  - **Reduce weight**
  - **Fit within the payload envelope of the DJI Matrice 600**
  - **Minimize interference from drone and radio equipment**
- **Directional**
  - **Main lobe pointing along the horizon**
  - **Minimal side lobes**
- **Polarization**
  - **Vertically polarized**

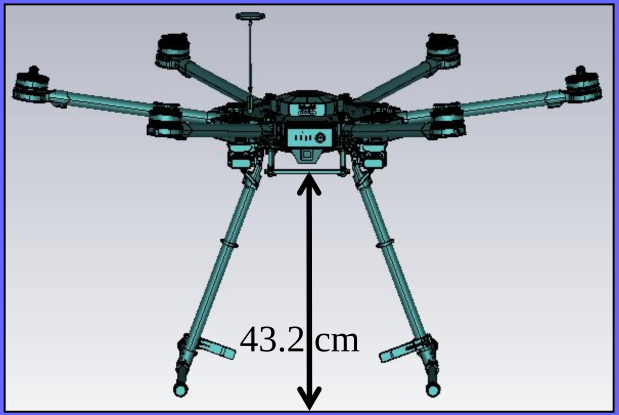


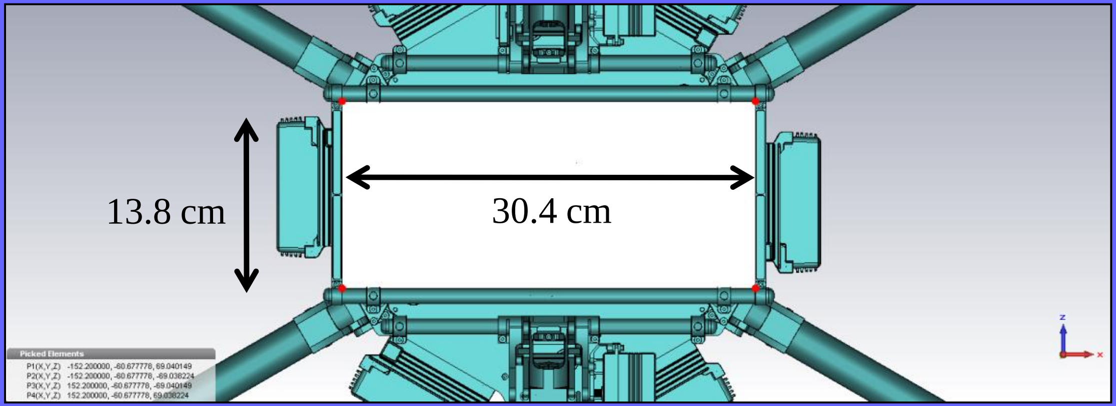
Wade Antenna 6YLV VHF Yagi
typically used for boat-based tracking
Length: 214 cm

# 2. Payload Development

- **sUAS Platform: DJI Matrice 600**
  - **Incorporated Matrice 600 into 3D electromagnetic simulations**
  - **Drone dimensions determined maximum antenna dimensions**
  - **Drone carbon fiber modeled as conductor to simulate effects of the platform**

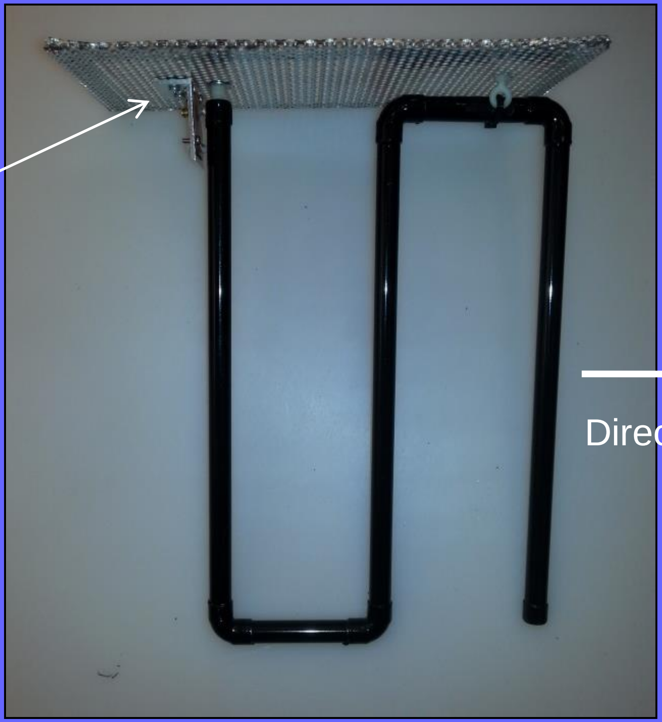


# 2. Payload Development

- **Meandered conductor**
  - **Reduced height below drone to fit within landing gear**
  - **Ground plane improves isolation of antenna from drone and radio**
  - **Vertical polarization**
  - **Directional toward 'front' of drone**

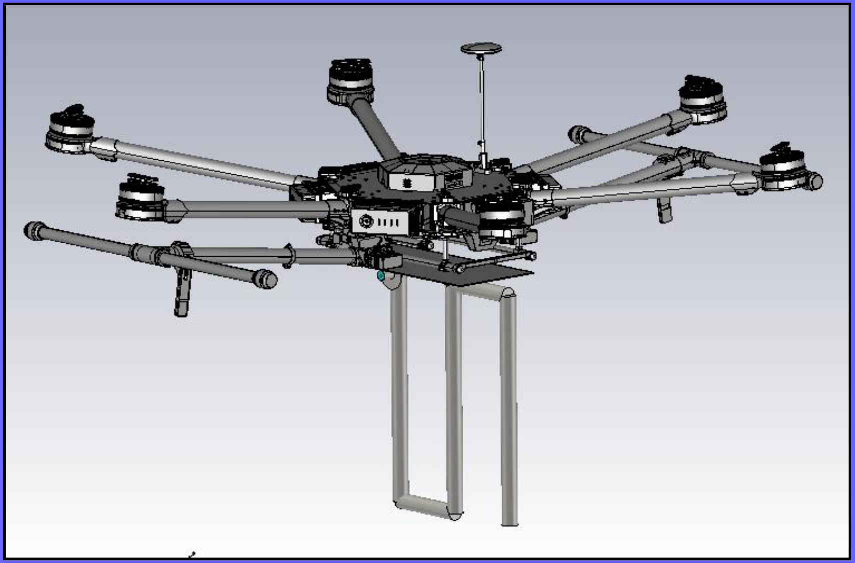


RF connection

Direction of vertically polarized main lobe

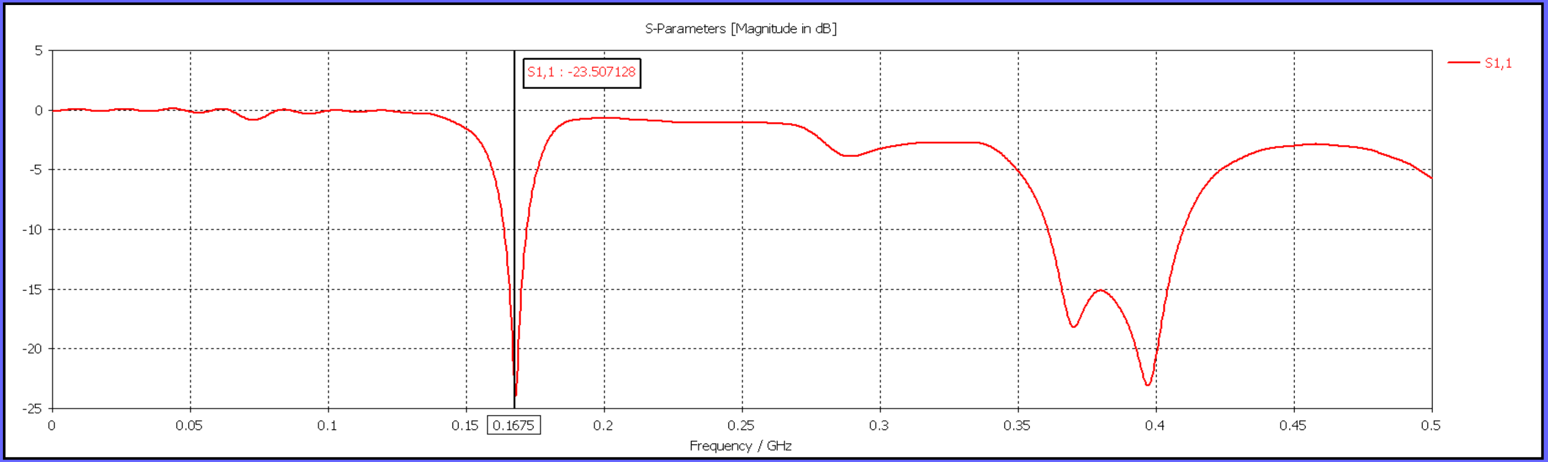
# 2. Payload Development

- CST Microwave Studio
- Simulated with drone – landing gear up
- Good reception at tag frequency



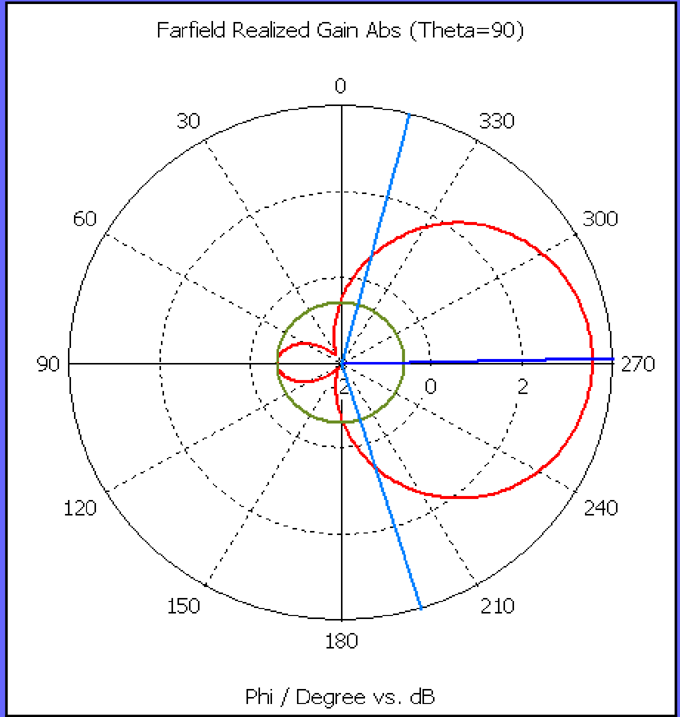
Impedance well matched at 167.7 MHz

$S_{11}$



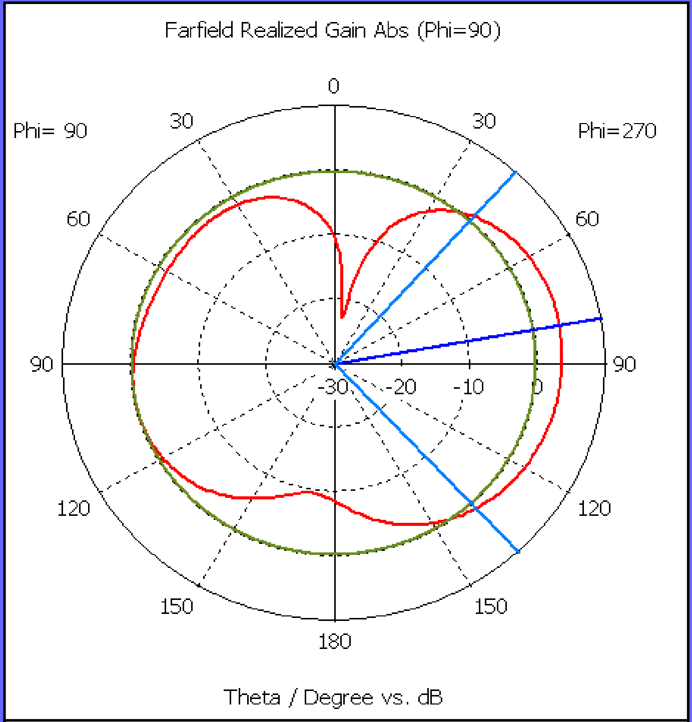
# 2. Payload Development

Horizontal Plane



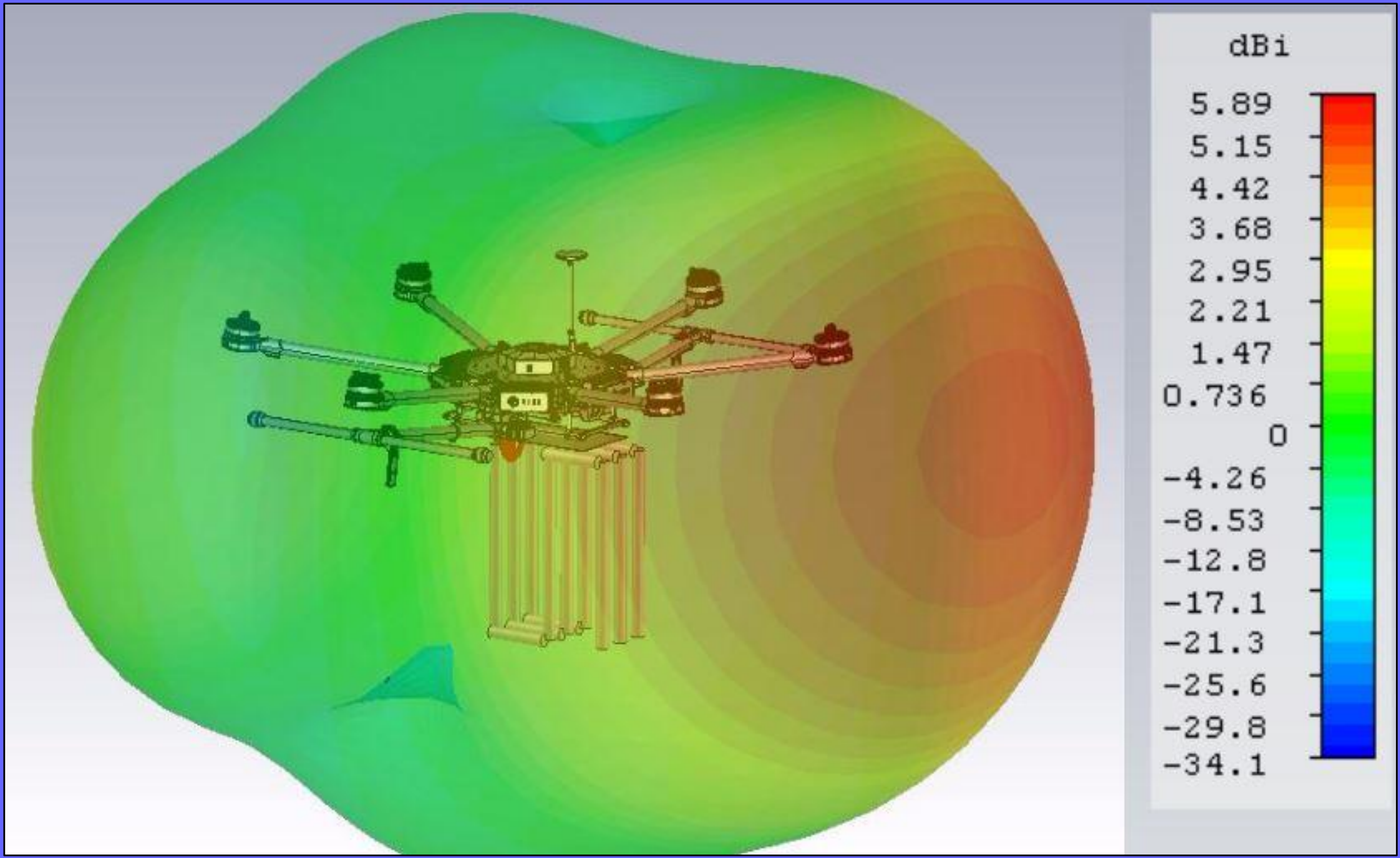

Frequency = 0.167
Main lobe magnitude = 3.54 dB
Main lobe direction = 271.0 deg.
Angular width (3 dB) = 148.1 deg.
Side lobe level = -4.1 dB

Vertical Plane




Frequency = 0.167
Main lobe magnitude = 3.65 dB
Main lobe direction = 80.0 deg.
Angular width (3 dB) = 95.2 deg.
Side lobe level = -3.9 dB

# 2. Payload Development



# 3. Aircraft, Integration, and Review

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| Overview | |
|---|---|
| Manufacturer | DJI Innovations |
| **Configuration** | **HexaCopter (6-rotor)** |
| **Aircraft Dimensions** | |
| Arm Length | 44.5 cm |
| Center Frame Diameter | 32.7 cm |
| Height (landing gear down) | 55.4 cm |
| **Batteries** | TB47S Li-Ion Polymer |
| Configuration, Voltage | 6S, 22.2 VDC |
| Maximum energy per cell | 99.9 Wh |
| Maximum charge per cell | 4500 mAh |
| Operating Temperature | 14°F to 104°F |

| Weight | |
|---|---|
| Aircraft Weight (with 6 batteries) | 9.1 kg |
| Maximum Acceptable Gross Takeoff Weight | 15.1 kg |
| Maximum Payload | 6.0 kg |
| USGS Receiver | 1.2 kg (21%) |

| Propulsion | 6 dual-bladed electric motors |
|---|---|
| Peak Motor Power | 1,300 W |
| Peak Motor RPM | 6,800 RPM |
| Motor Model | DJI 6010 |
| Rotor Specifications | DJI 2170 (21 × 7 in) |

| Flight Parameters | |
|---|---|
| Max Speed, (no wind) | 18 m/s (~40.3 mph, 35 kt) |
| Max. transmission Distance | 5 km (3.1 mi) |
| Expected Flight Time | 1-16 min. |
| Maximum Hover Time (6.0 kg takeoff weight) | 16 min. |
| Operating Altitude | 10-500ft |

# 3. Aircraft, Integration, Review

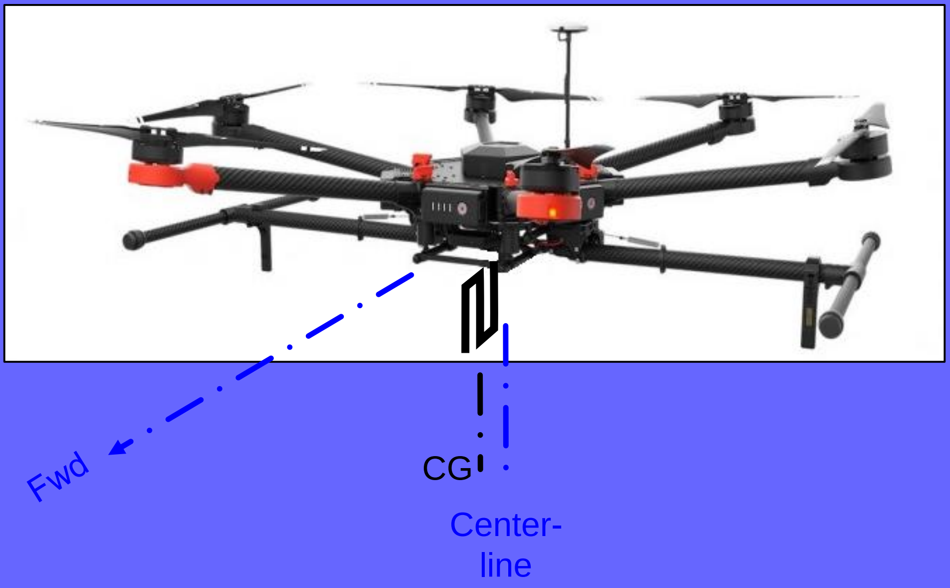
## Weight and Endurance

At 1.2 kg the USGS receiver system is only 20% of the rated payload capacity of the M600.
The 1.2 kg payload has an unrated flight time of 30 min, a 100% margin for a 15 minute mission.

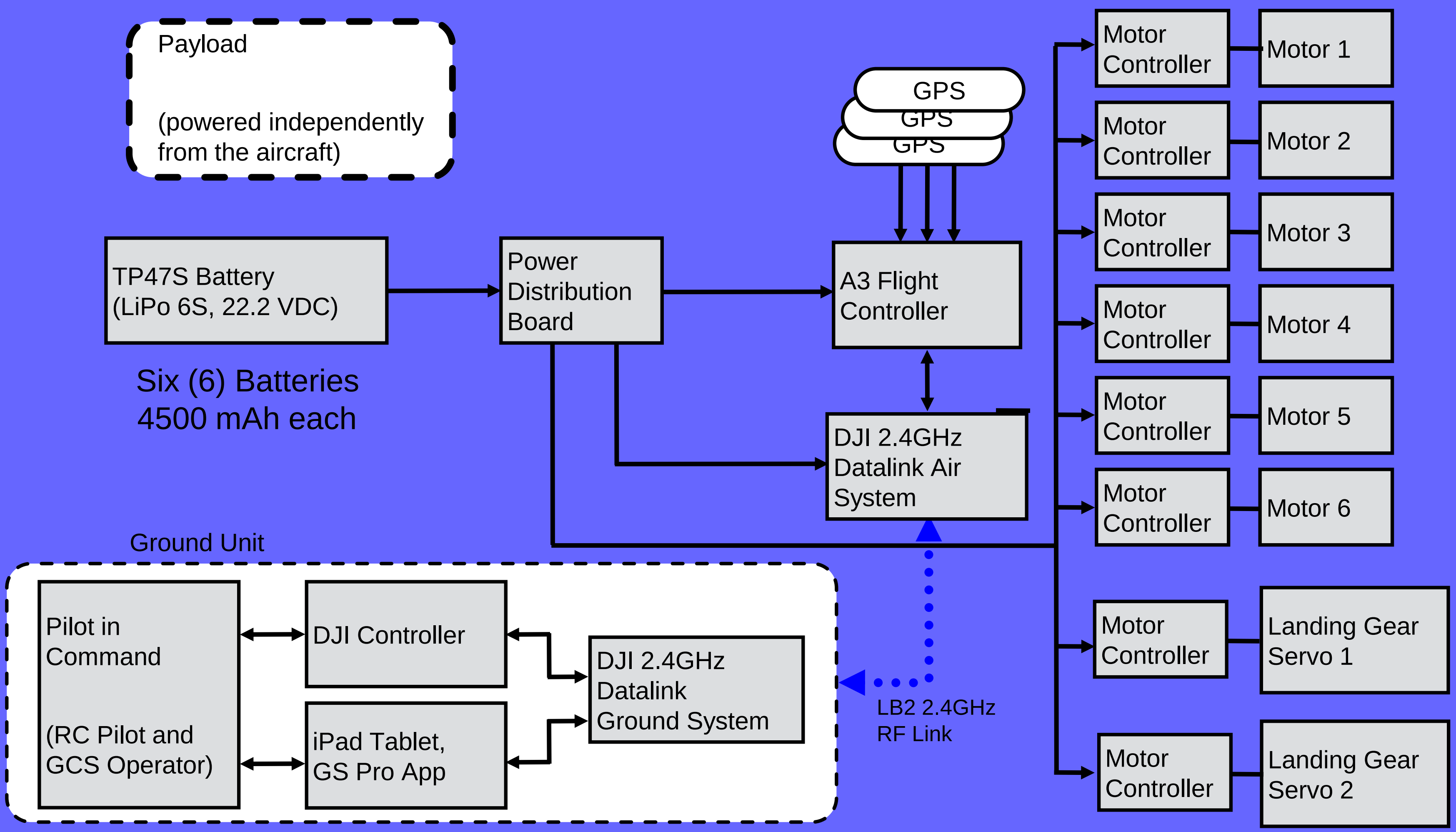
## Center of Gravity (Balance)

The DJI M600's centerline is indicated by the blue line through the center of the aircraft. The payload is approximately symmetrically mounted underneath the M600, and the new CG is located along the black dashed line. The margin of error is approximately 3 cm (assuming a 12 kg gross take-off weight). Ballast to restore CG, if needed, is not included in weight budget.
Checks of the CG with payload will be included in all pre-flight checklists. Pre-flight hovering tests will ensure that the aircraft is properly balanced under control of both the autopilot and RC pilot.

| Weight Budget | |
|---|---|
| Aircraft Weight (w/battery) | 9.1 kg |
| USGS Payload | 1.2 kg |
| **Total Gross Weight** | **10.3kg** |
| Maximum Acceptable Gross Take-off Weight | 15.1 kg |



# 3. Aircraft, Integration, Review



# 3. Aircraft, Integration, Review

- Contingency analysis showed risk of water landing
  - Developed and tested FDH maneuver
  - Added water-activated floatation device
  - Issues with DJI's definition of "GeoFence"
  - What DJI calls the geofence are the Do Not Fly zones
  - The user-defined geofence is called "Virtual Fence"
  - Virtual Fence only functions in manual mode


- NASA Increased risk posture for LiPo batteries
  - Accidents at JPL and another NASA center
  - Added items to risk matrix, checklists, and SMP
  - Constantly-changing shipping rules
- ***Update DJI Aircraft are grounded as of 8-14-2017***
  - ***Cybersecurity issue identified by the US Navy***

# 4. Methods and Results

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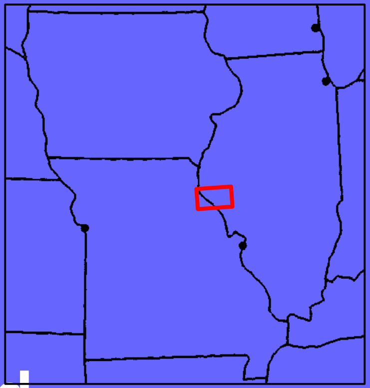
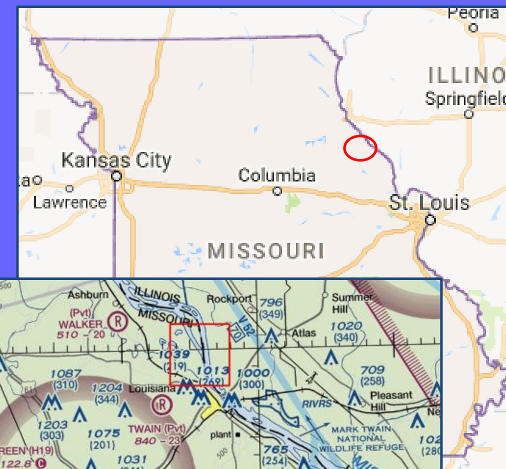


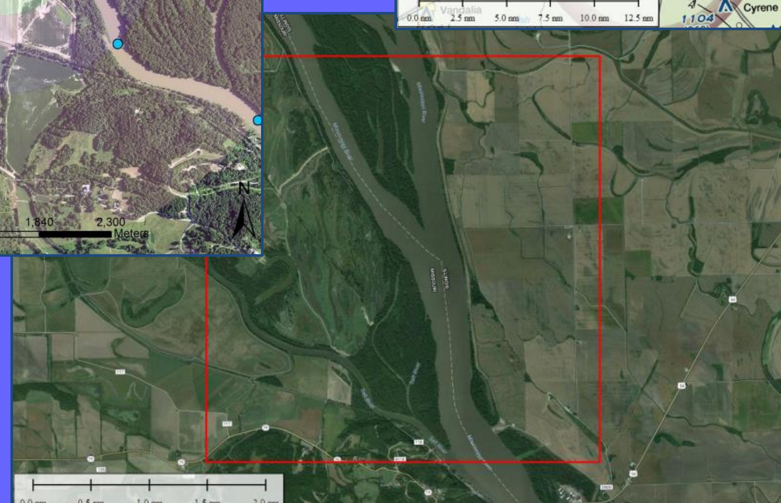
- 
- Concept of Operations
  - Multicopter with direction-finding payload
  - Identify location of radio-emitting underwater tag
  - UAS flight over river, shore, and wooded area
    - Constant 100 m altitude (328 ft AGL)
    - Triangular flight path as specified by three predefined waypoints, total distance approximately 434 m
    - Hover-in-place at each vertex, then rotate 360° while taking data before proceeding to the next vertex
    - Flight time typically 10min for a 434 m perimeter flight path
    - Real-time and post-flight analysis to ID tag location
  - Flight operations from onshore area
    - Takeoff and landing from flat, vegetation-free area
    - Takeoff and landing from deck of boat (manual control only)

# 4. Methods and Results

## Field Site: Ted Shanks Conservation Area near Louisiana, Missouri

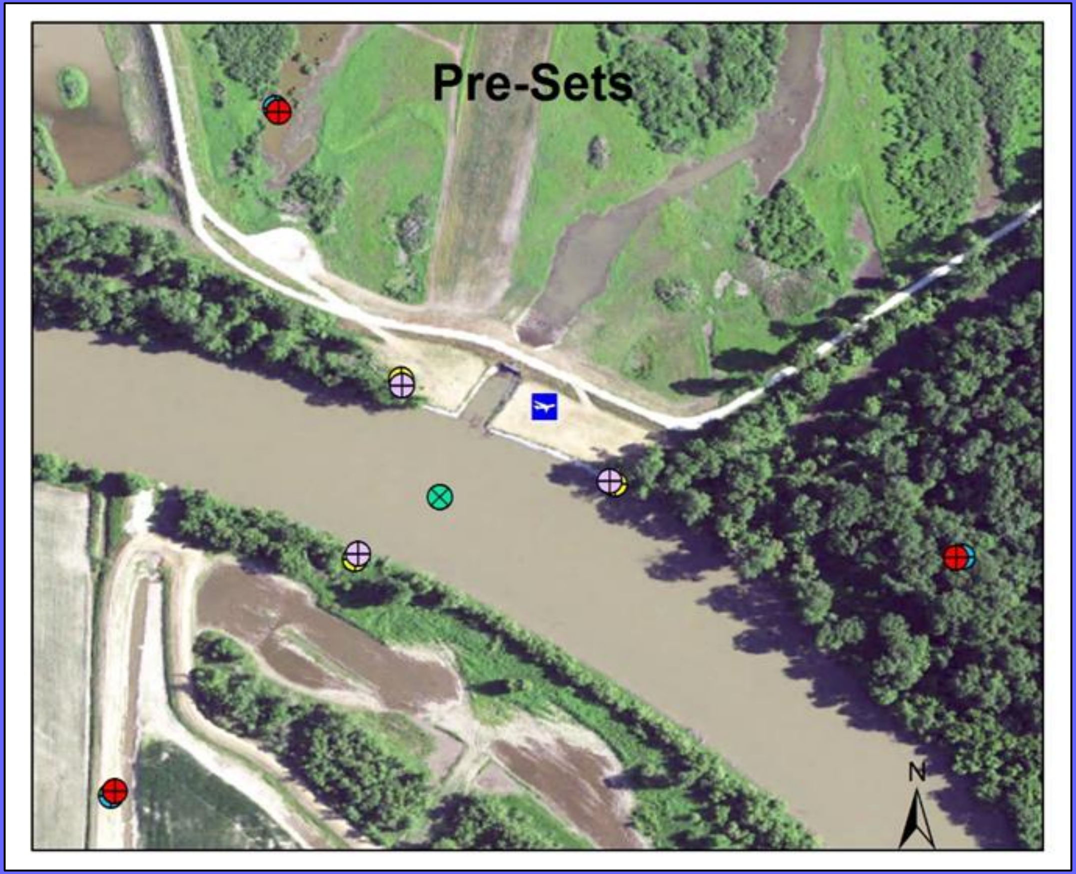







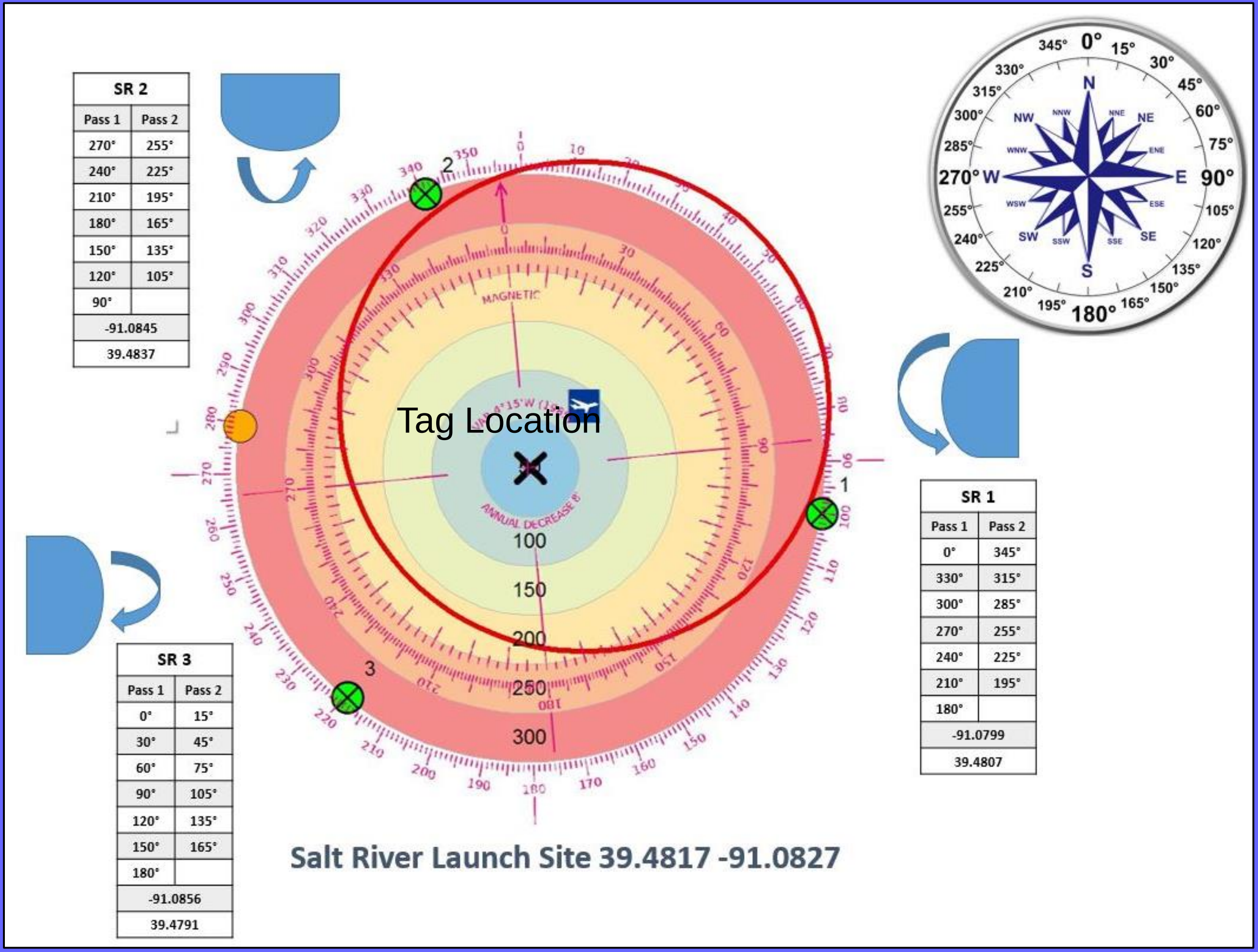
# 4. Methods and Results

- Triangulation Flight Plan
  - 300m distance from tag at each point in the triangle at 100m elevation
  - 
  - 100m distance from tag at each point in the triangle at 100m elevation.



# 4. Methods and Results

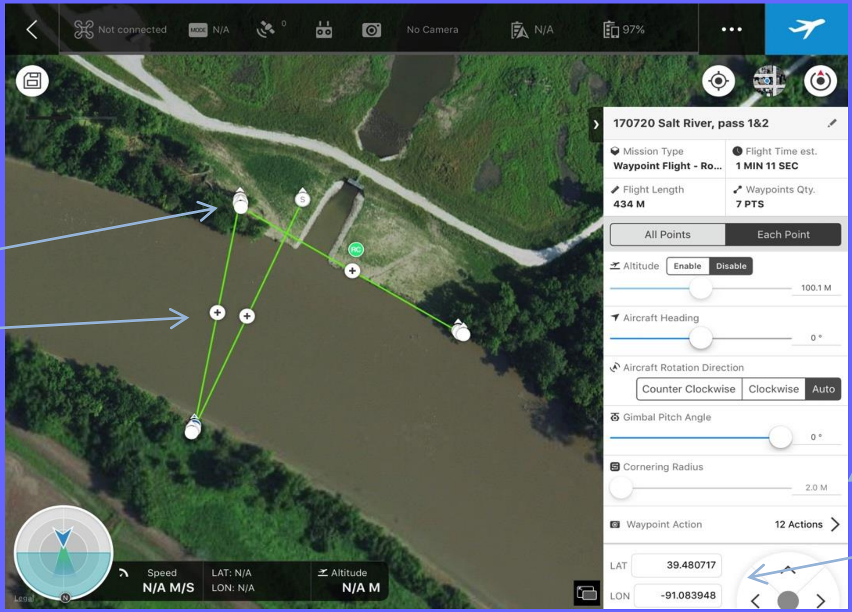
- Triangulation Flight Plan
  - UAV pause at each bearing for 10 seconds



# 4. Methods and Results

## Flight 4, Flight Plan from DJI GS Pro:

- Waypoints
- Planned flight tracks




Flight parameter settings

- Altitude
- Heading
- Actions at each waypoint
- Waypoint coordinate

- Flight execution
  - Flight status bar
  - Multi-rotor position
  - Flown track
  - Track to fly
  - Home point
  - RC position


- Flight progress
- Multi-rotor position

# 4. Methods and Results

## Goal 1: Relay Radio signal from tag to UAV to boat.

- **Success!**
  - **UAV can pick up the radio tag**

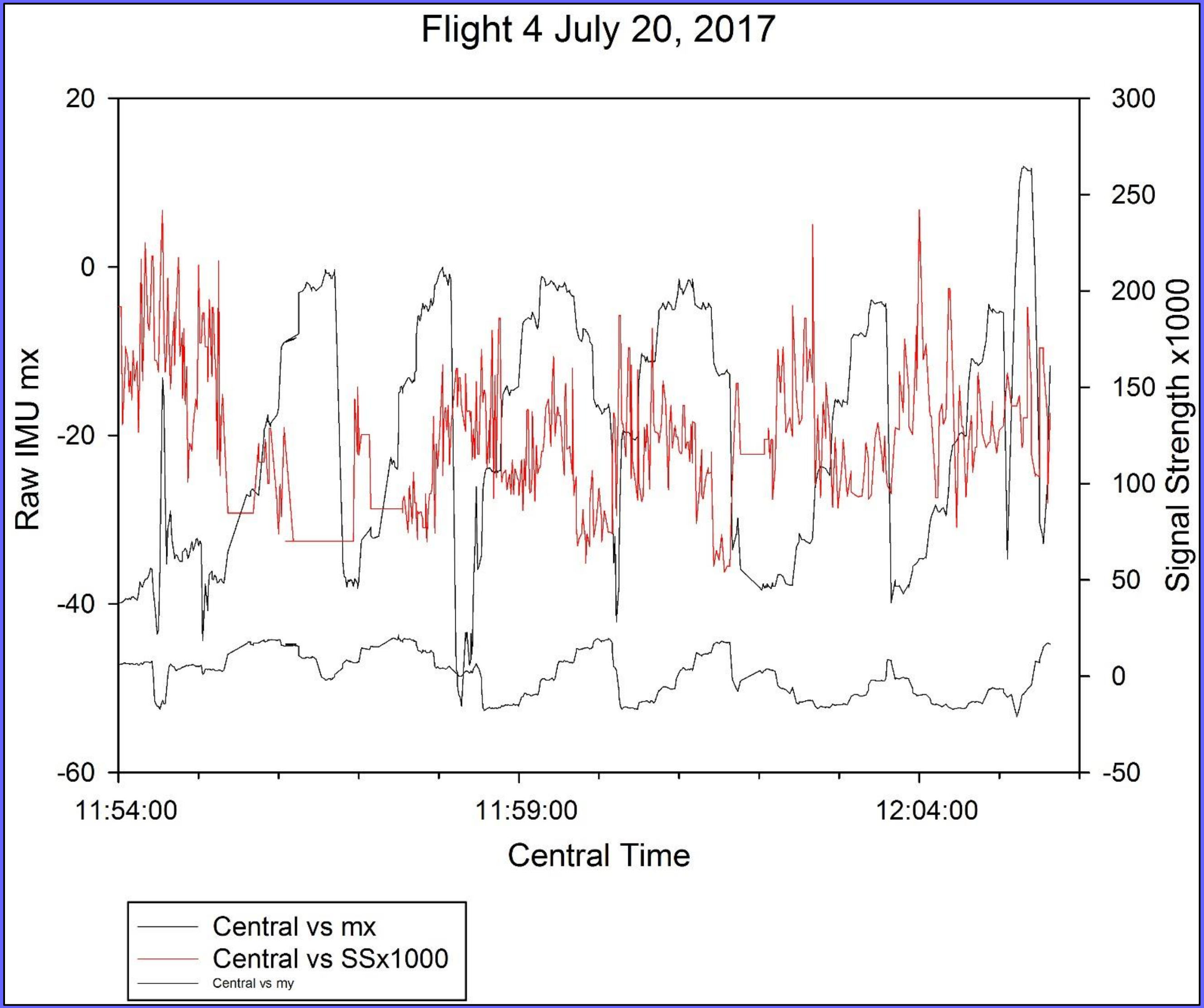
UAV
100m elevation
300m dist.

Radio Tag

# 4. Methods and Results

- **Results:**
-
  - **Conducted 8 flights**
  -
    - **Flights 1-3**
      - **300m distance**
      - **All flights data stream locked after waypoints 1 and 2**
      -
    - **Flights 4-7**
      - **100m distance**
      - **Flight 4 maintained data stream throughout**
      - **Flights 5-7 radio signal locked (many reasons why)**
      -
    - **Flight 8**
      - **Test UAV launch from boat**

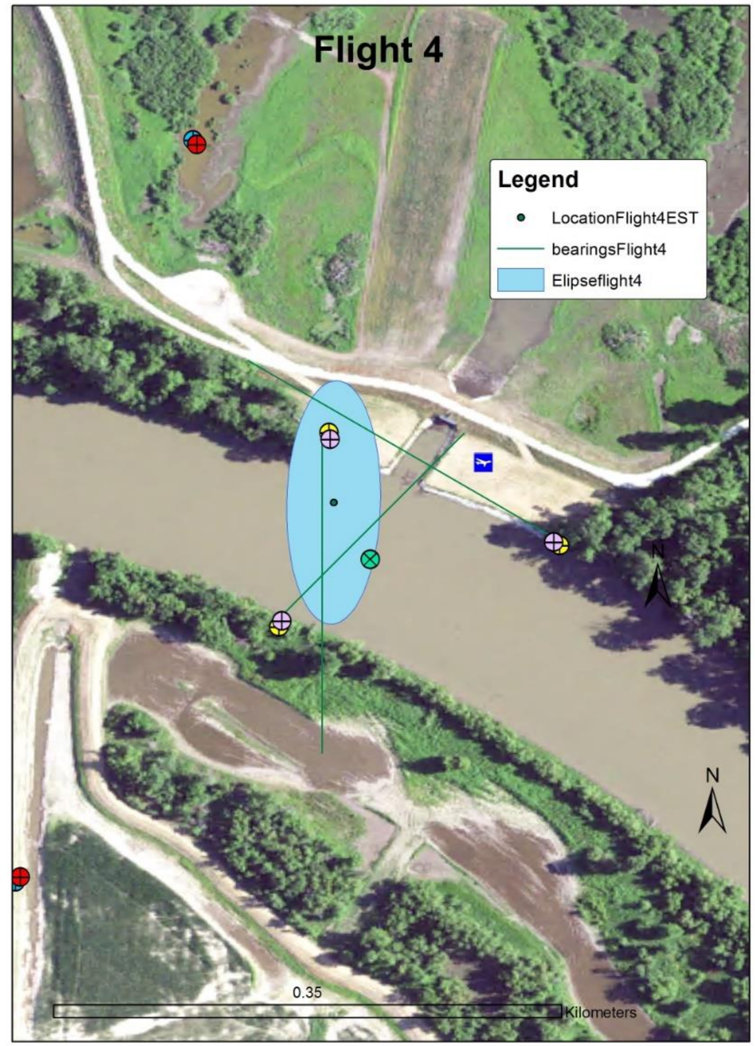
# 4. Methods and Results



# 4. Methods and Results

**Flight 4**

- Triangulation
  - Estimate bearing based on graph data.
    - WP1 45°
    - WP2 180°
    - WP3 300°
  - Off by 44m to estimated tag location
  - Within 95% confidence ellipse



# 4. Methods and Results


- **Flight 8**
- **Launch and Land on the Yi Bolu.**

# 4. Methods and Results

- Magnetometer Noise
  - Bearing switches from – to + in less than a second.
  - Incorrect bearings readings
    - Major shifts in bearing from one second to next i.e. more than 100° in some cases
  - Possible causes:
    - Heat – Heat index was 114° with base temp being 100°
    - Interference from UAV control commands
    - Insufficient shielding from metal parts
    - Platform motion may be too much for the chip.
  - Fixes:
    - Use UAV bearing and match waypoints
    - Vents in receiver housing to reduce heat.

# 5. Discussion and Future Improvements

# 5. Discussion and Future Improvements

- **Discussion**
  - **Successful mission**
    - **All goals achieved**
      - **Relay Radio signal from tag to UAV to boat.**
      - **Get a measure of tag reception range at set UAV height.**
        - **100m range good reception**
        - **300m range weak reception**
          - Frequent signal loss
          - Can be improved
        - **Triangulate a tag location**
      - **Launch UAV from boat and land on boat**
      -
  - **Field test showed weaknesses are in the receiver's systems**
  -
      - **Magnetometer**
      - **Waterfall data stream**
      - **Heat both for both equipment and persons.**

# 5. Discussion and Future Improvements

- Future Improvements
  -

# Acknowledgements

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