RAMROD

REMOTE AUTONOMOUS MAPPING OF RADIO FREQUENCY OBSTRUCTION DEVICES

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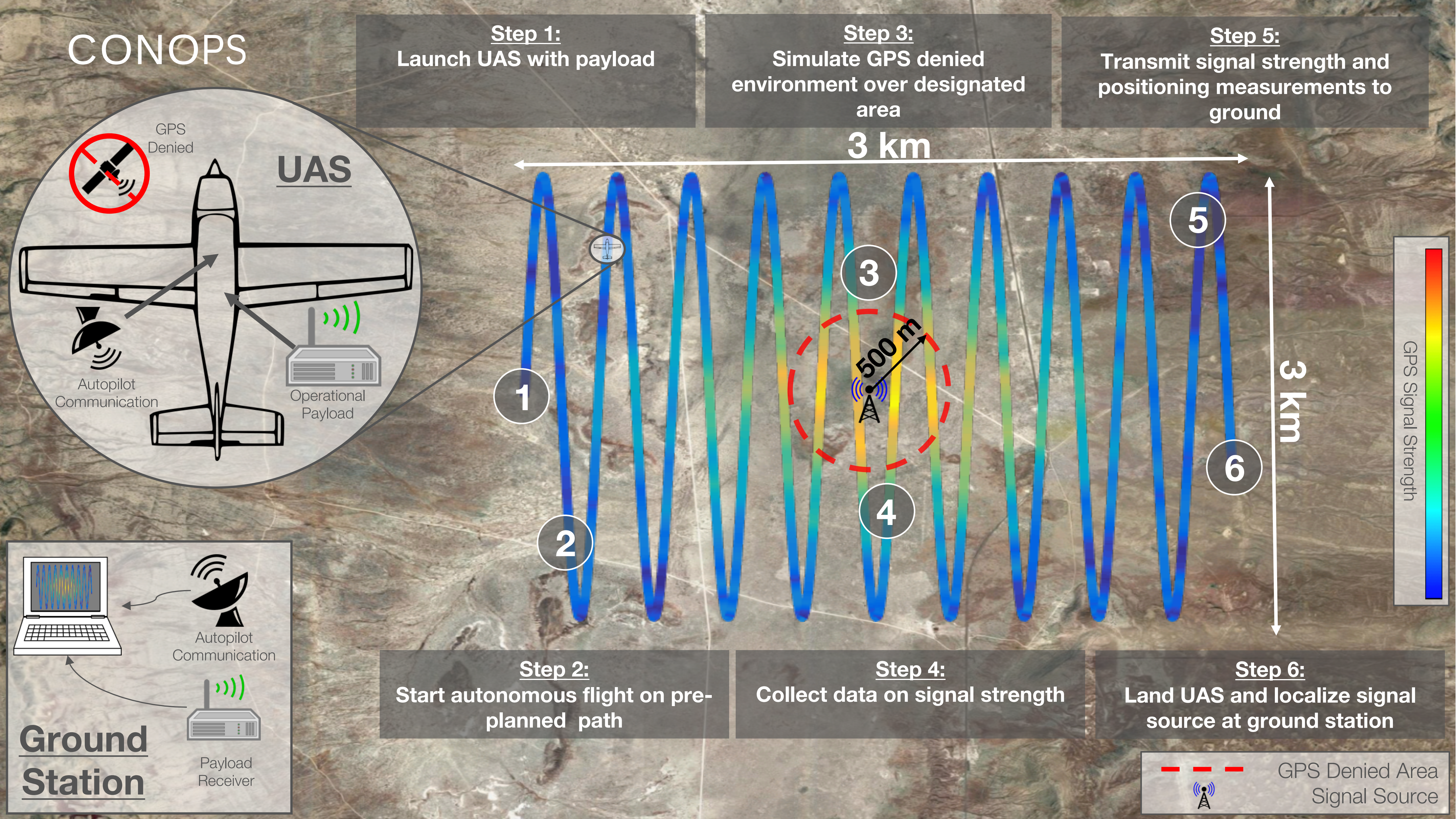
Sponsor: Dennis Akos

Advisor: Jade Morton

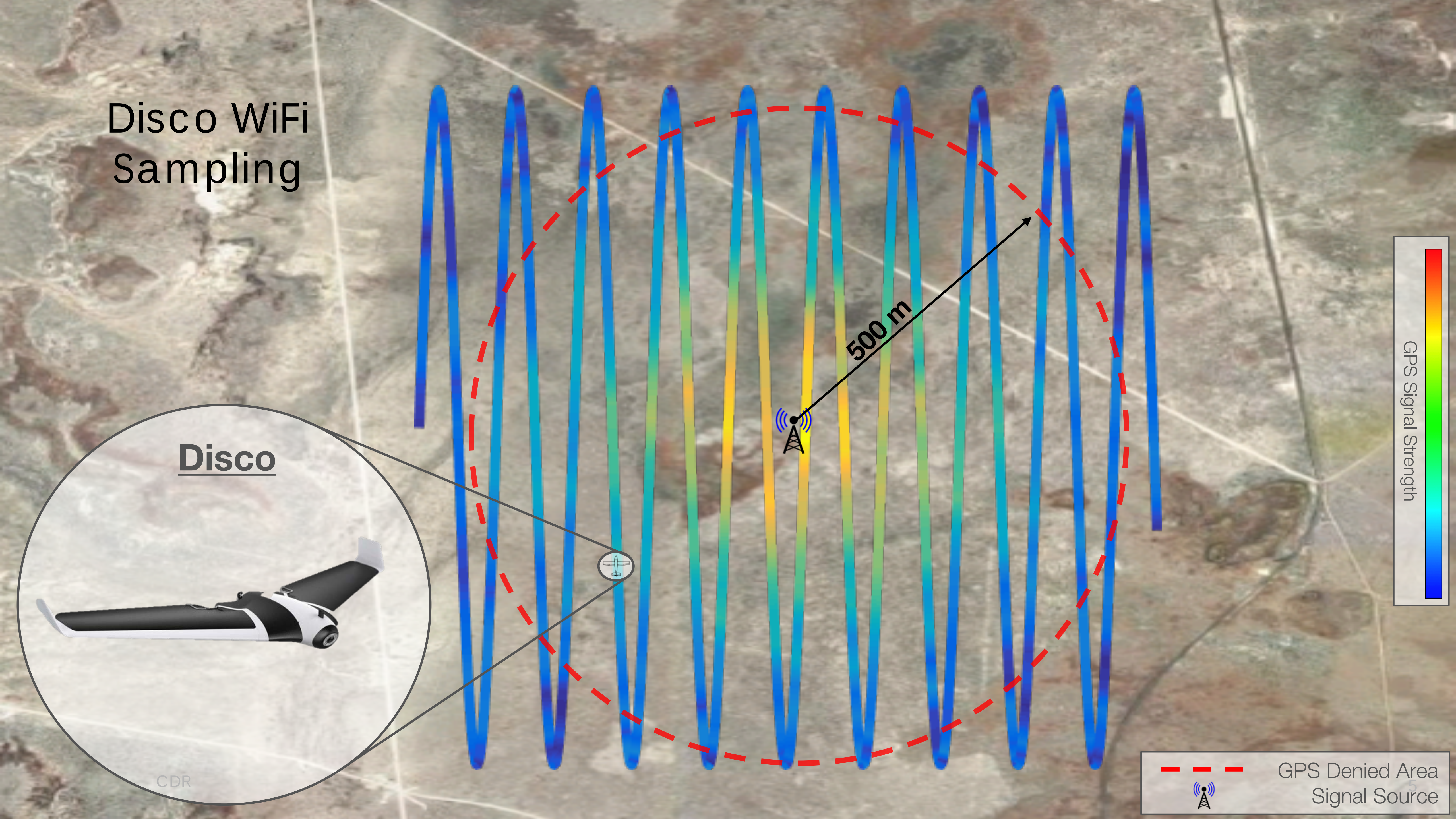

CONOPS
Step 1:
Launch UAS with payload
Step 3:
Simulate GPS denied environment over designated area
Step 5:
Transmit signal strength and positioning measurements to ground
GPS Denied
UAS
Autopilot Communication
Operational Payload
3 km
500 m
3 km
1
2
3
4
5
6
GPS Signal Strength
Autopilot Communication
Payload Receiver
Ground Station
Step 2:
Start autonomous flight on pre-planned path
Step 4:
Collect data on signal strength
Step 6:
Land UAS and localize signal source at ground station
GPS Denied Area
Signal Source

INTEGRATIVE TESTING PROBLEMS

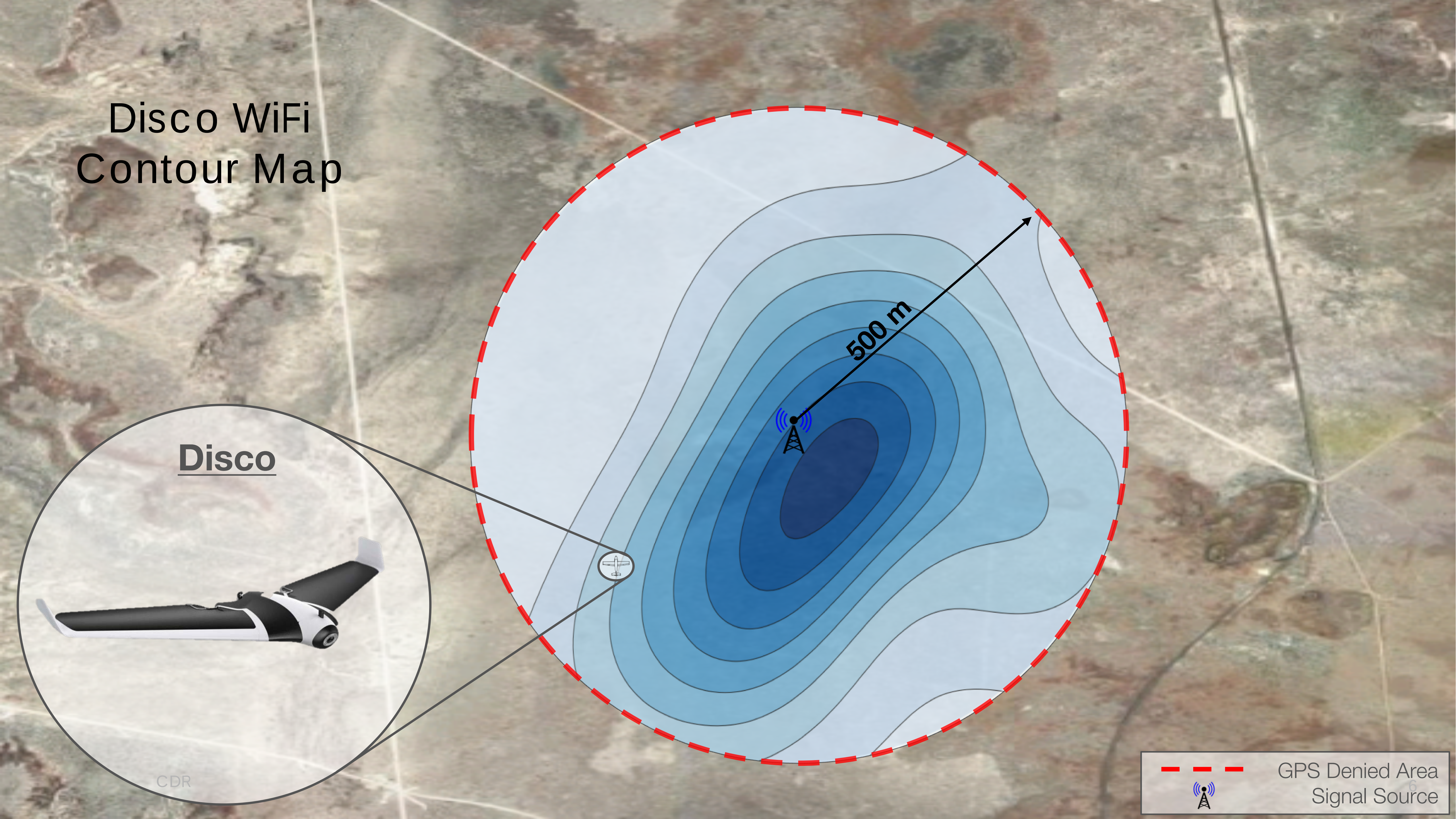
Problem	The use of GPS jammers is illegal	The Talon will not mesaure frequencies outside of the GPS band
Solution	Use a WiFi signal to simulate GPS jammer	The “Disco” UAS will be used to sample WiFi power over the GPS denied area

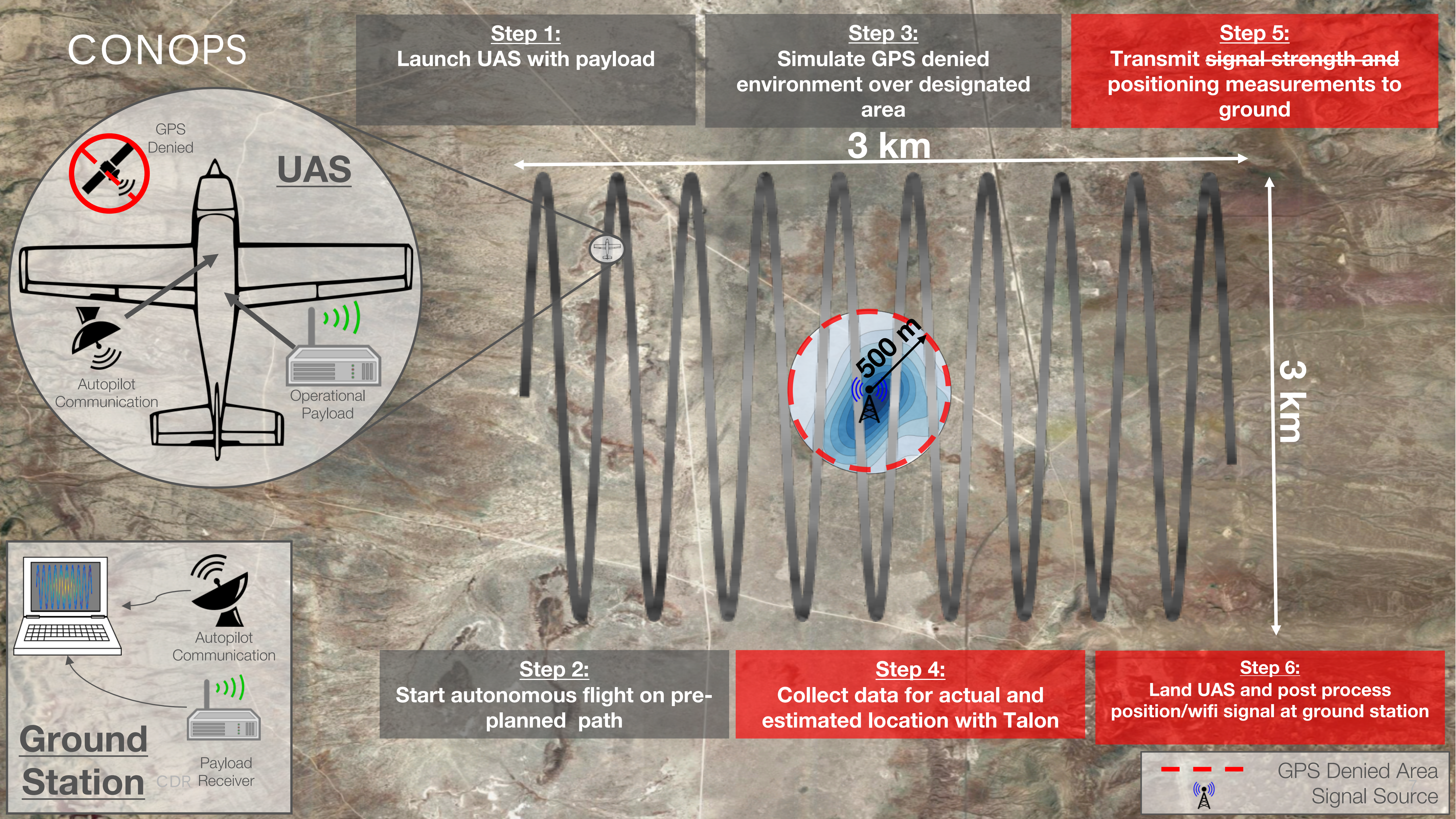
PARROT DISCO UAS

- Given to team RAMROD by customer
- Already proven capable of sampling WiFi power
- Will be used to create contour plot of signal power


Disco WiFi Sampling
Disco
500 m
GPS Signal Strength
GPS Denied Area
Signal Source

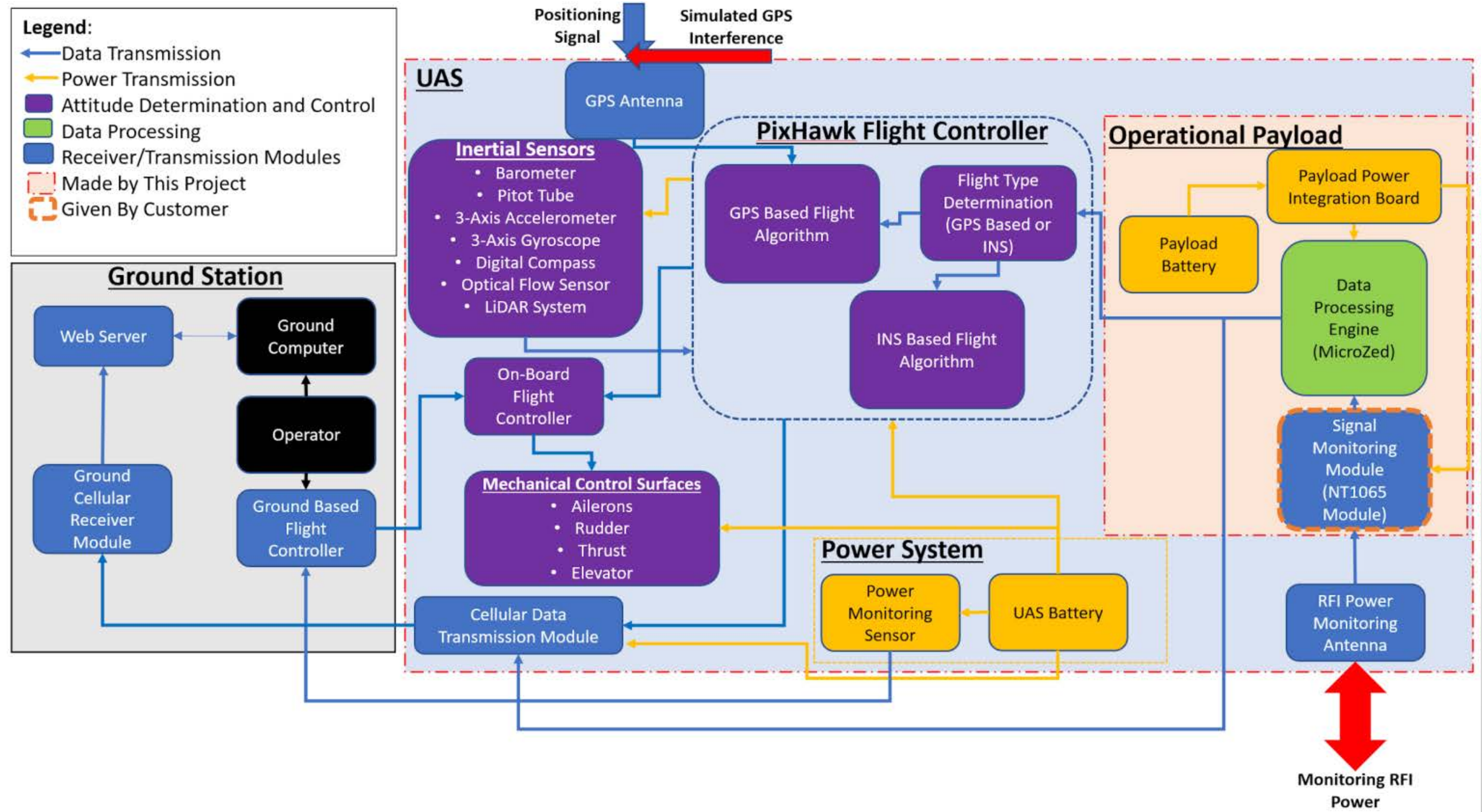
Disco WiFi Contour Map





CONOPS
Step 1:
Launch UAS with payload
Step 3:
Simulate GPS denied environment over designated area
Step 5:
Transmit ~~signal strength and~~ positioning measurements to ground
3 km
GPS Denied
UAS
Autopilot Communication
Operational Payload
500 m
3 km
Ground Station
Autopilot Communication
Payload Receiver
CDR
Step 2:
Start autonomous flight on pre-planned path
Step 4:
Collect data for actual and estimated location with Talon
Step 6:
Land UAS and post process position/wifi signal at ground station
GPS Denied Area
Signal Source

FUNCTIONAL BLOCK DIAGRAM



CRITICAL PROJECT ELEMENTS

CPE	Description	Reason
GPS Denied Flight Software	Maintain autonomous flight while in a simulated GPS denied environment for up to 200 seconds at a time	A PPD or ET will cause GPS data to be inaccurate.
UAS	Use the Talon to fly in a simulated GPS denied environment while housing the operational payload made by team RAMROD	A UAS capable of supporting the necessary sensors would be the best means of covering the required area.
Payload	Self-powered sensor payload that can monitor, store and transmit RFI signal data while interfaced with the UAS platform	To measure the RF source all necessary sensors must be integrated together. By customer request the payload must be capable of taking RF measurements without UAS integration

LEVELS OF SUCCESS

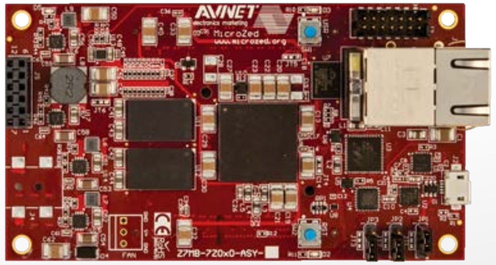
	Operational Payload	UAS Platform	GPS Denied Flight Software	RF Localization
Level 1	-Collect and store power measurements for a full 60 minutes	-Shall use manual flight to achieve a minimum total flight time of 60 minutes while containing the full payload	-Autopilot switches seamlessly to GPS denied flight	-Shall be able to establish an RFI power profile
	power data with PixHawk			
Level 3		-Shall have the ability to fly autonomously for 10 minutes with GPS denied	-Shall allow for turning manuevers in GPS denied conditions -Shall keep positional error less than 30m after 2km of GPS denied flight	-Localize RFI source within 40 m

On Track for Level 3 Success

BASELINE DESIGN

Basic Components of Importance:

Flight Controller (PixHawk)

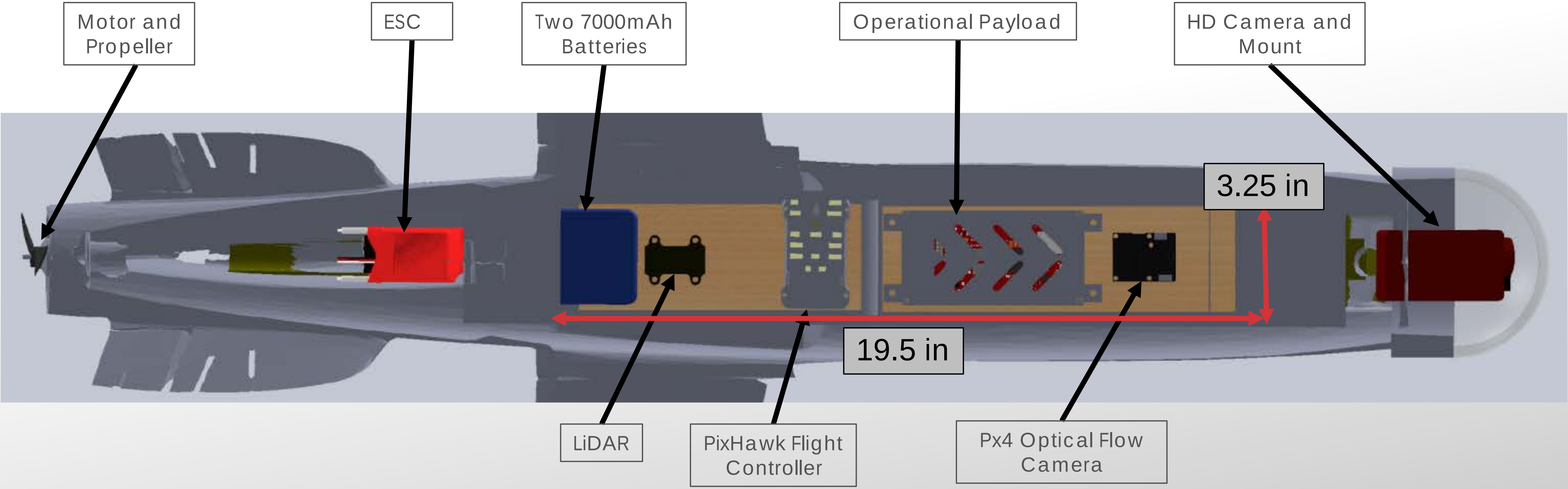


Microprocessor (MicroZed)

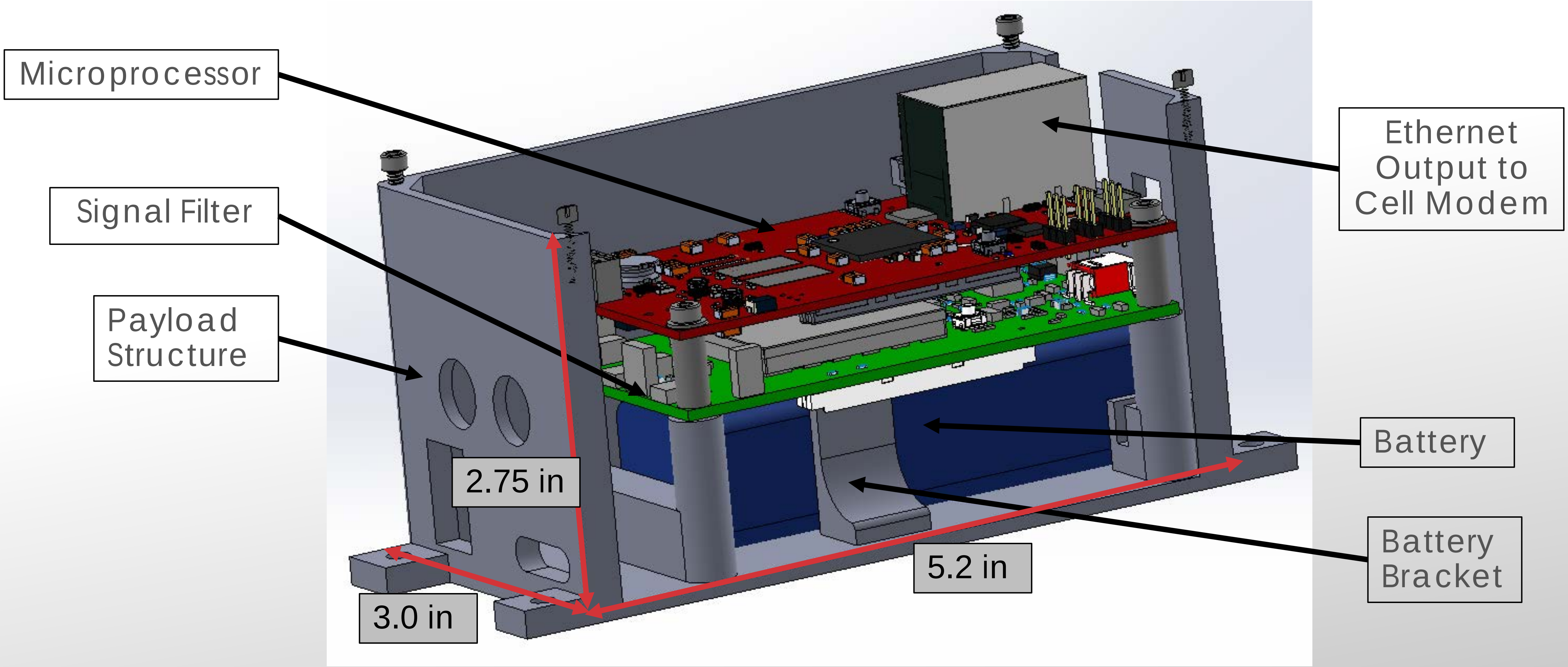
Inertial Measurement Unit (DMU11)

Signal Filter (NT1065)

TALON BASELINE DESIGN



PAYLOAD BASELINE DESIGN

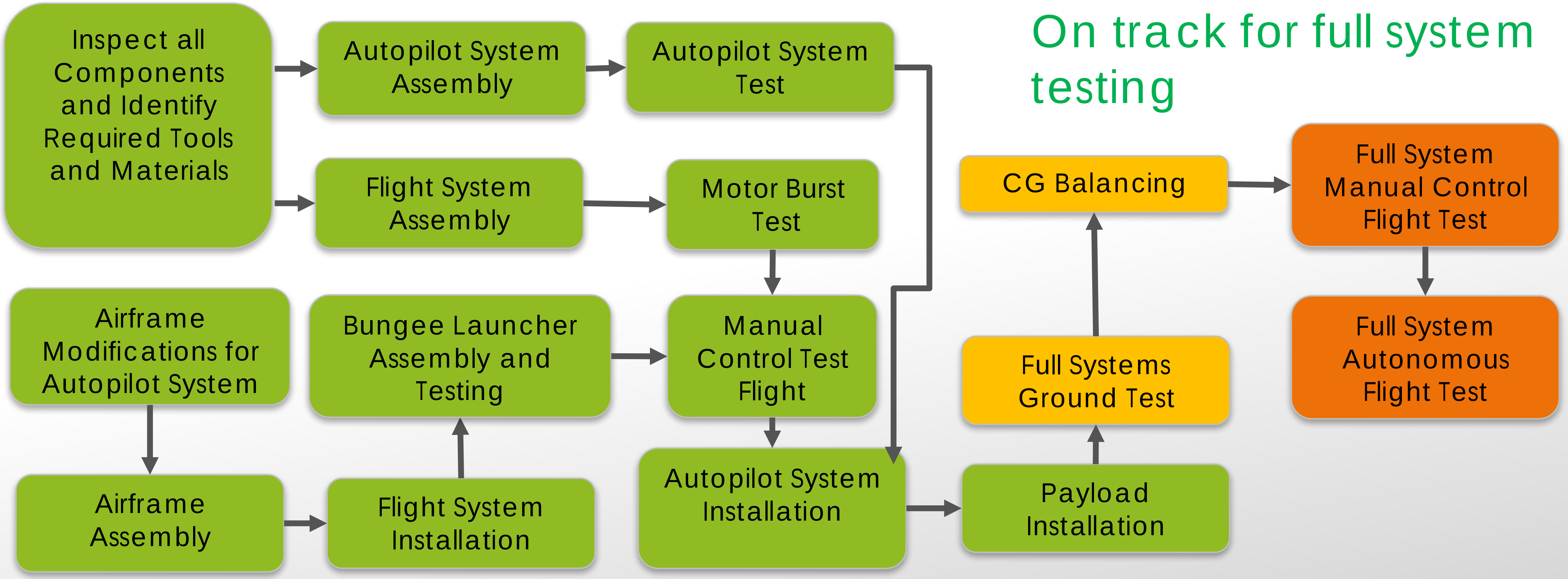


TESTING COLOR SCHEME

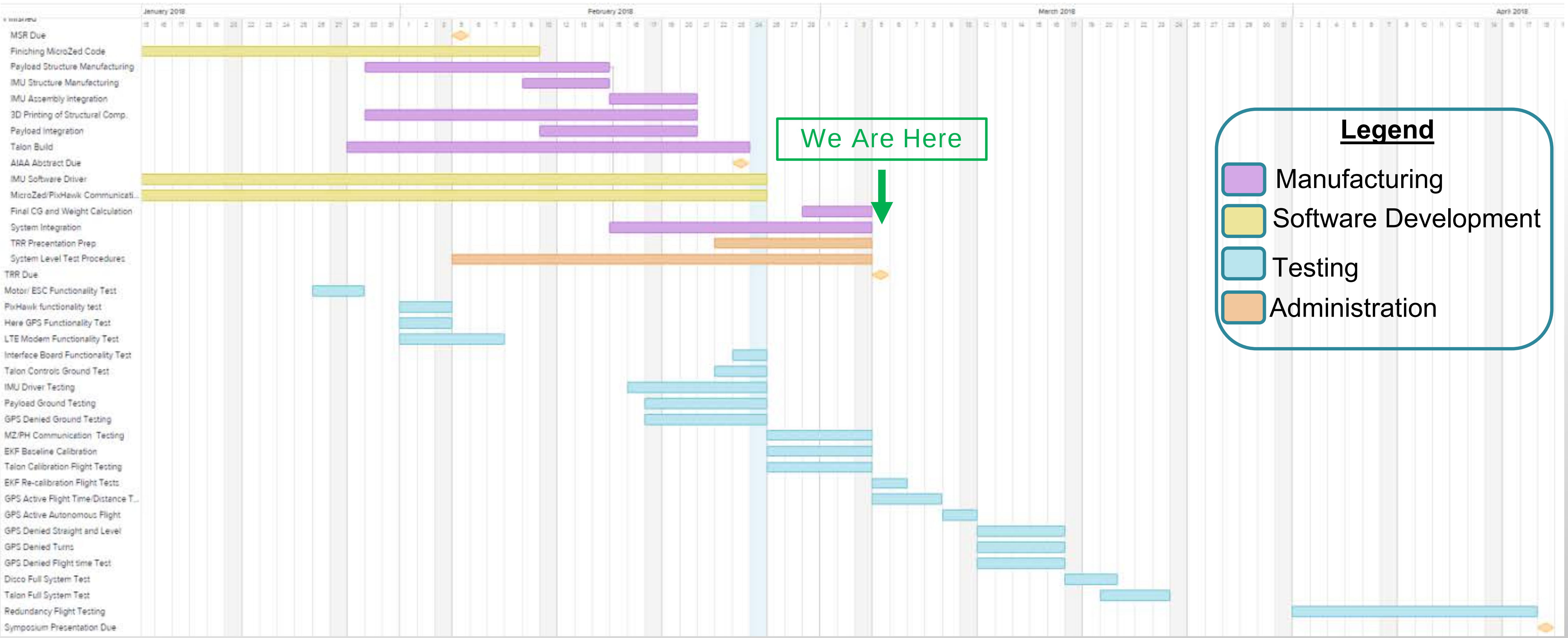
Complete → In Progress → Not Started

FULL SYSTEM INTEGRATION

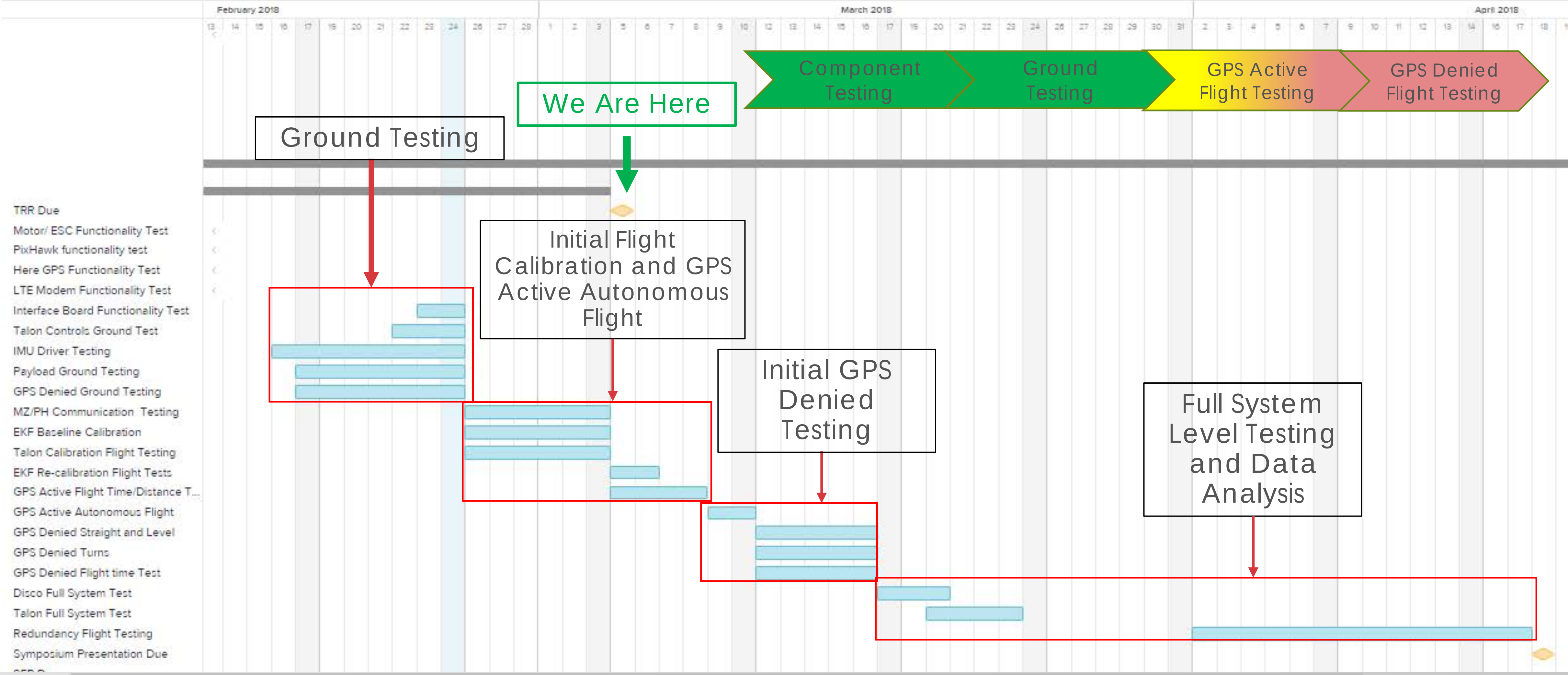
On track for full system testing



SPRING SCHEDULE



TESTING SCHEDULE



TEST PLAN

Level 1

Test	Date (2018)
❑ Talon Hardware Calibration	March 6
❑ Payload Functional Ground and Downlink Testing	February 17-24
❑ Autopilot Software Modification	February 20-28

Level 2

Test	Date (2018)
❑ Talon EKF Calibration	March 6-15
❑ GPS Guided Autonomous Flight Test	March 6-15
❑ GPS Denied Flight (Straight and Level)	March 15-24

Mission Level

Test	Date (2018)
❑ Autonomous Flight GPS Denied	March 15-31
❑ Mission Level Flight Test and Localization	March 19-30
❑ Redundant Tests	April 1-14

LEVEL 1 TESTING

Talon Calibration

- Verify Talon UAV basic flight capabilities
- Verify unmodified Autopilot software
- Verify CG placement
- Verify FR 1, 2, 4, 5 ,6

Payload Functional Ground & Downlink

- Ensure payload components are functional
- Verify structural requirements
- Verify data acquisition on ground
- Verify LTE Downlink capabilities
- Verify FR 9 & 11

Autopilot Software Modifications

- Verify modifications to Autopilot software function in simulation
- Verify Autopilot software integrates with hardware
- Verify FR 8

Test Plan Created → Test Scheduled → Test Conducted → Results Analyzed

MANUAL FLIGHT TEST RESULTS

- Initial calibration attempted on March 2
- Manual flight ended with tree impact due to pilot error
- Talon airframe critically damaged
- Replacement airframe assembled and tested

Takeaways:

1. Move to a more open testing location at CUSB
2. Talon was tail-heavy due to CG shift at launch
3. Talon flight hardware is functional

PAYLOAD TESTING

Data Collection & Storage

- Objective: Verify the payload receives data from the signal filter and stores data to USB
- Status: Completed

Cellular Data Test

- Objective: Verify the payload downlinks data via cellular connection
- Status: Completed

Flight Controller Interface

- Objective: Verify the payload sends data to the flight controller and the data is received correctly
- Status: In Progress

Battery Power Test

- Objective: Verify the battery can power the system for 60 minutes
- Status: Completed

Payload Fit Check

- Objective: Verify the payload box and electronic components interface correctly
- Status: Completed

Full Payload Integration

- Objective: Verify the payload integrates with flight system and functions correctly
- Status: Not Started

AUTOPILOT MODIFICATION MODEL AND VERIFICATION

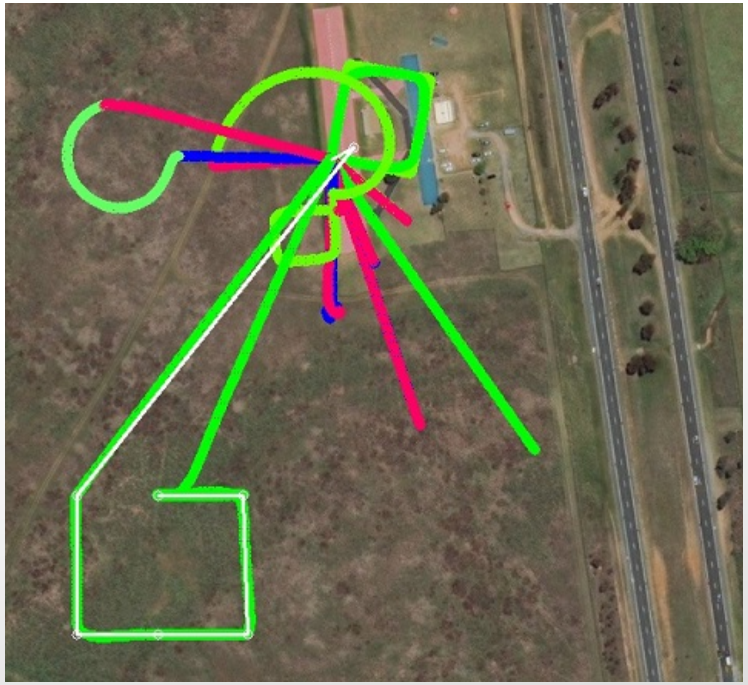
✓ 1. Use SITL simulation to verify software functions with RAMROD modifications

✓ 2. Use HIL simulation to ensure software integrates & functions with PixHawk hardware

✓ 3. Ensure RAMROD autopilot software is ready for GPS denied flight

✓ 4. Verification: Run build through Autotest framework used to verify stable ArduPilot builds

AutoTest Simulation



Legend

1 – Testing flight modes

2 – Testing telemetry loss

3 – Failsafe testing

✓Build passed

LEVEL 2 TESTING

Autonomous Flight

- Verify Autopilot software functions in GPS Enabled state
- Gather IMU data during GPS guided flight
- Ensure successful flight plan
- Verify FR 7

Talon EKF Calibration

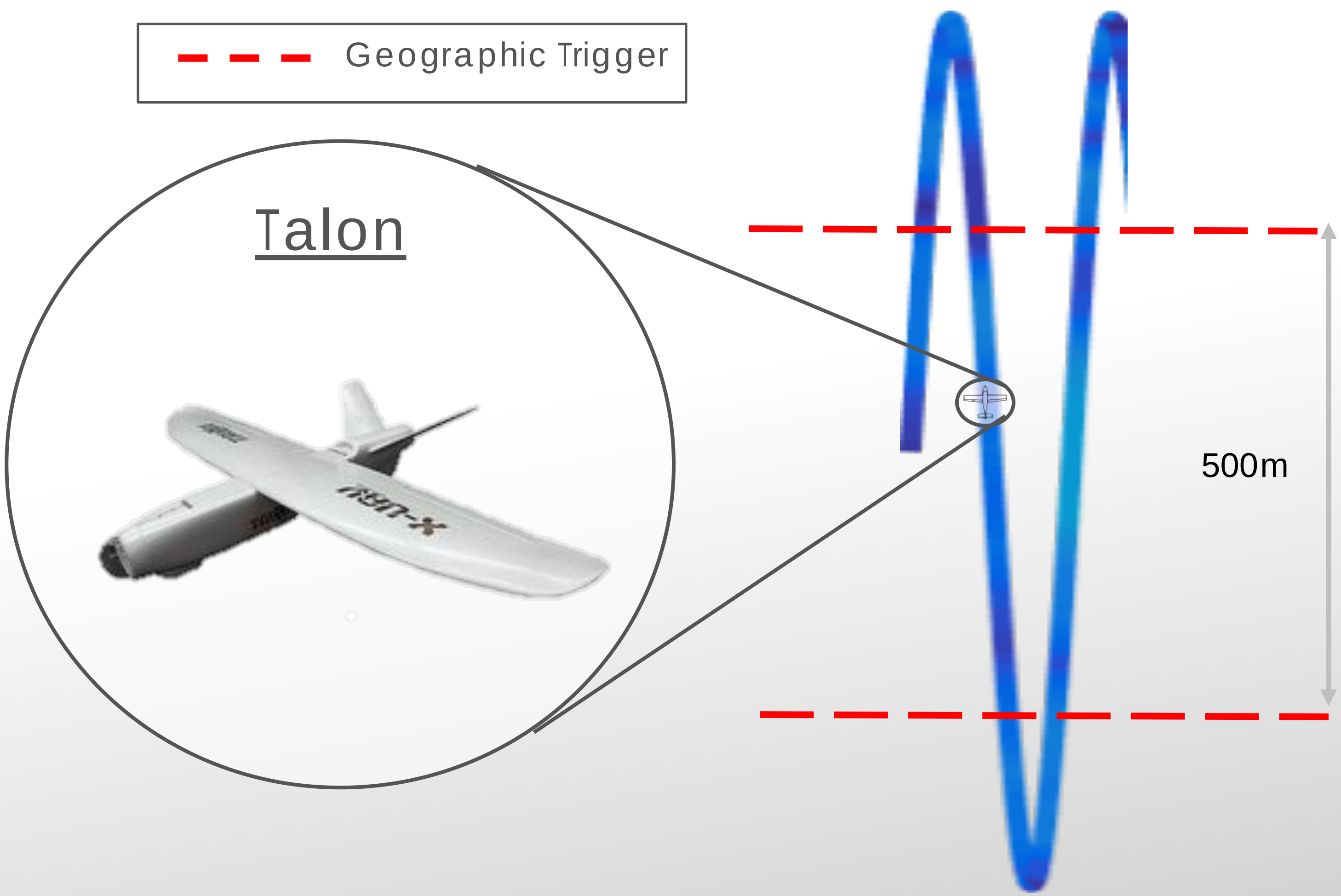
- Tune EKF based on flight performance
- Verify modified autopilot functionality
- Collect raw IMU and position data
- Verify DR 3.2, DR 3.3

GPS Denied Flight

- Verify modifications to Autopilot software function in simulation in GPS Denied state
- Verify INS drift is within localization threshold
- Verify FR 8

Test Plan Created → Test Scheduled → Test Conducted → Results Analyzed

INITIAL GPS DENIED FLIGHT



Geographic Location triggers switch to GPS Denied flight mode

Talon flies straight for 200 seconds with inertial navigation

Autopilot switched back to GPS enabled state and completes flight plan guided with GPS

MISSION LEVEL TESTING

Autonomous Flight GPS Denied

- Verify navigation and maneuvering in GPS denied state
- Ensure successful flight plan in GPS denied state
- Verify inertial drift is within threshold value
- Verify FR 7,8

Localization & Power Profile

- Utilize Disco to gain AGC data on WiFi band
- Verify PDOA algorithm can localize with WiFi data within 40m
- Generate power profile
- Verify FR 10, 12

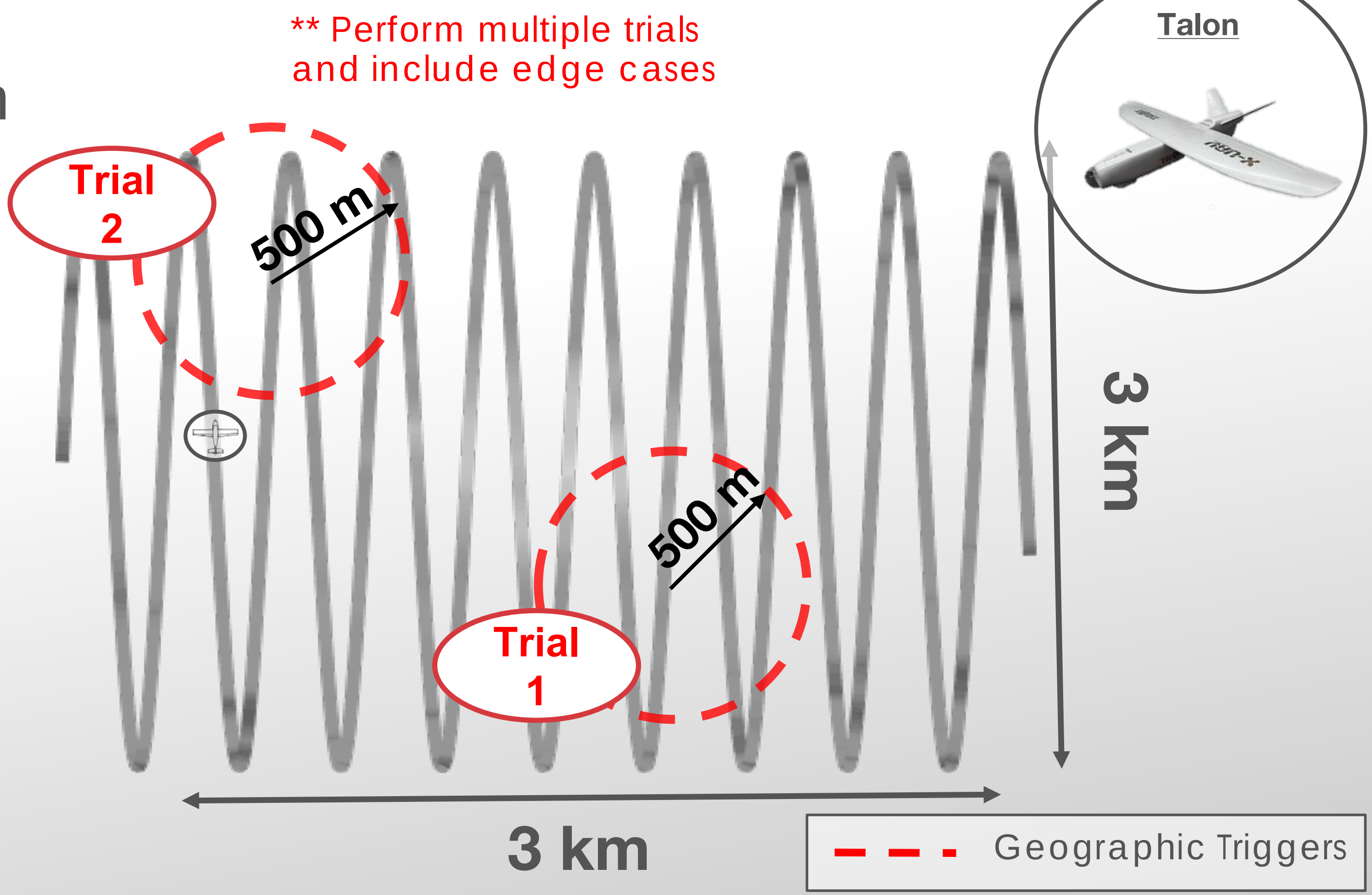
Redundant Tests

- Ensure quality and consistent success of full system functionality
- Conduct at least 5 mission level flights and analyze results

Test Plan Created → **Test Scheduled** → **Test Conducted** → **Results Analyzed**

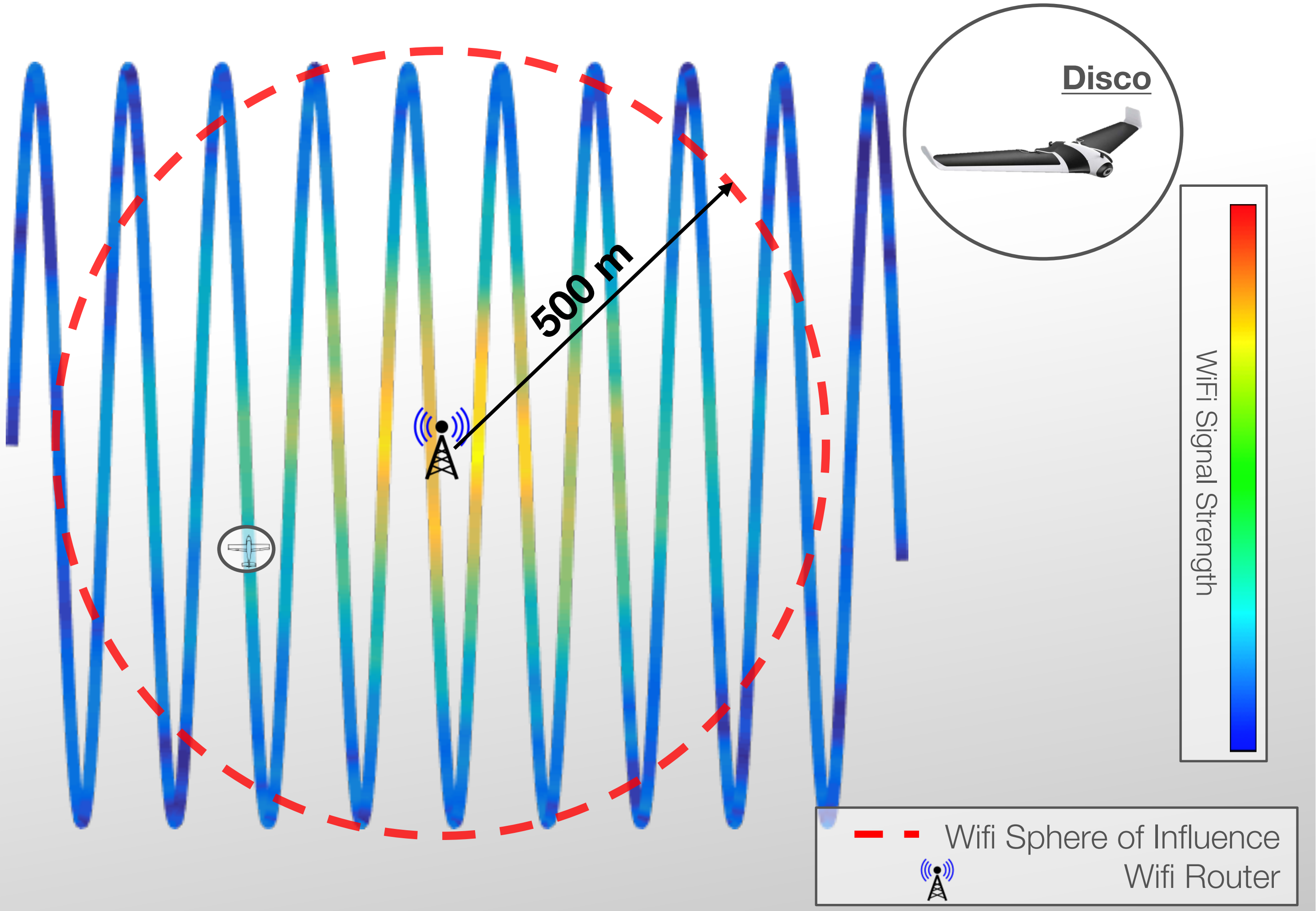
AUTONOMOUS MANEUVERS IN GPS DENIED

- Problem: Can RAMROD Talon execute banked turns and navigate around waypoints in GPS denied state?
- Verification: Fly autonomous flight plan and deny GPS in 500 meter sphere in multiple locations on grid. Ensure inertial drift is within 40m threshold during maneuvers.



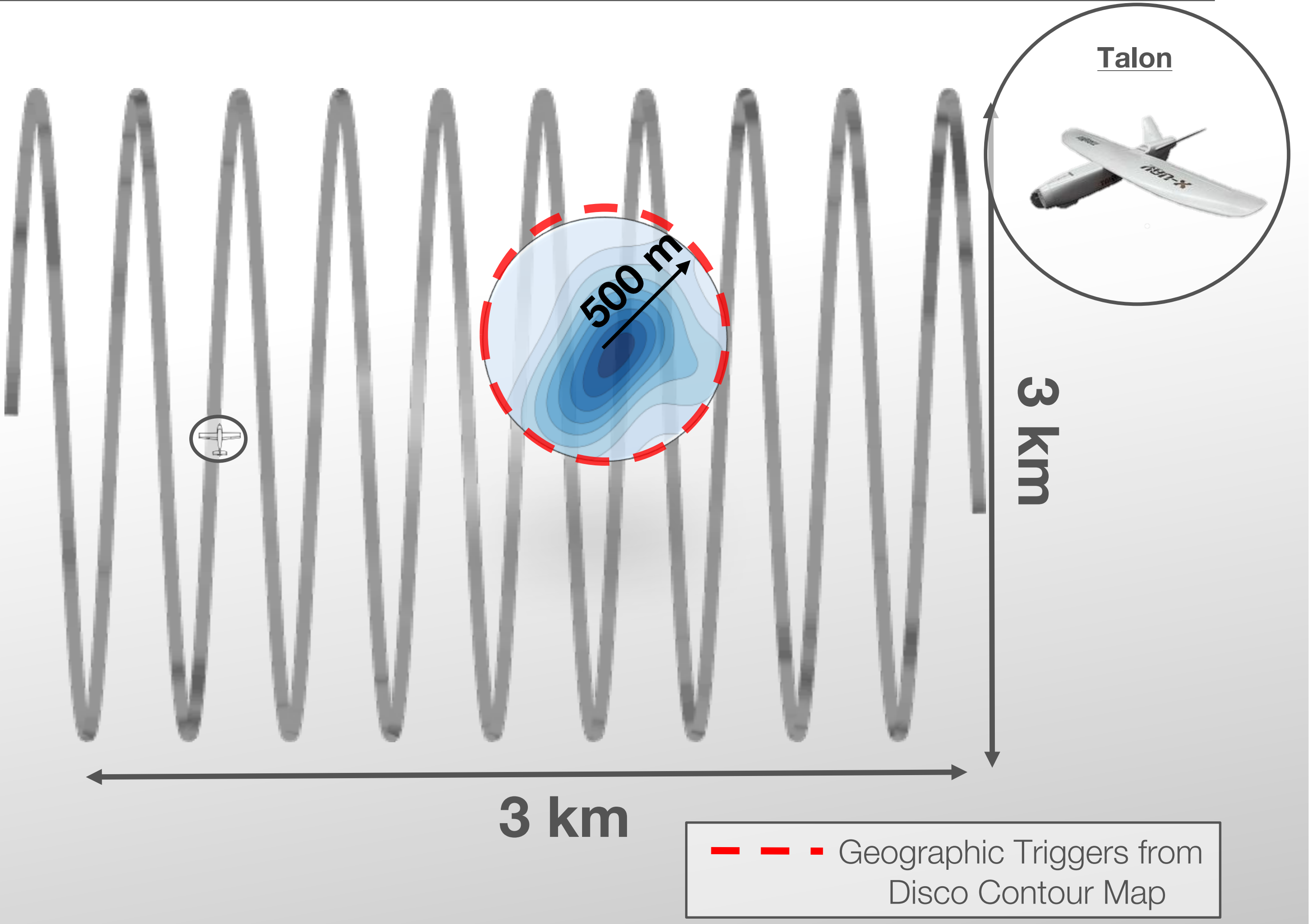
LOCALIZATION FLIGHT: DISCO

- Problem: RAMROD requires power data and GPS position data to switch from GPS to inertial guided flight
- Solution: Use disco UAS to create a contour map of sphere of influence by:
  1. Sample power on 2.4 GHz band over 500km square area and sample at rate 1 Hz
  2. Collect GPS position data
  3. Use minimum 300 samples over 3 separate flights to create contour power profile

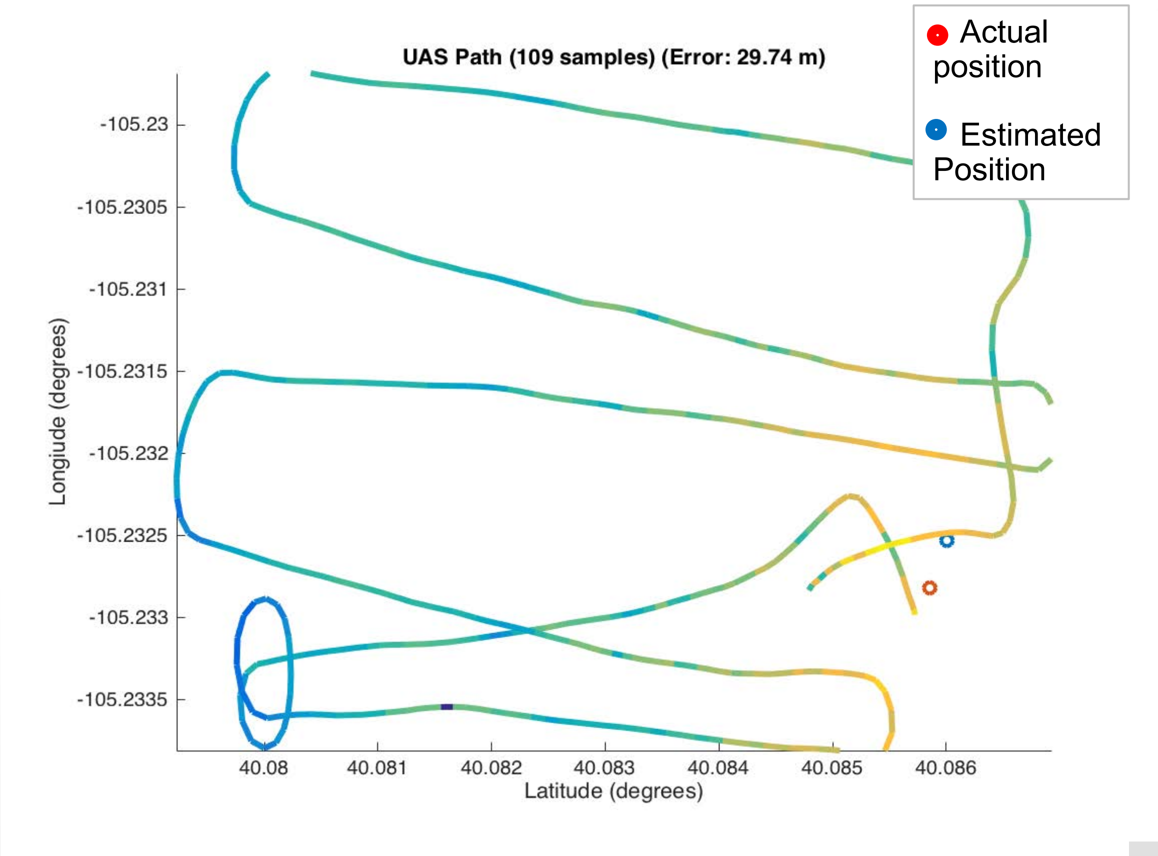


LOCALIZATION FLIGHT: TALON

- Problem: RAMROD Talon requires power data to switch flight modes but cannot detect the 2.4GHz band
- Verification: Use power contour map to create geographic triggers for RAMROD flight mode switch by:
  1. Fly RAMROD Talon over 3km square area
  2. Sample GPS position for entire flight at 1Hz
  3. Measure estimated position in GPS denied state
  4. Perform 3 redundant flights



LOCALIZATION INTEGRATION



AGC Data + True Position Data (GPS)

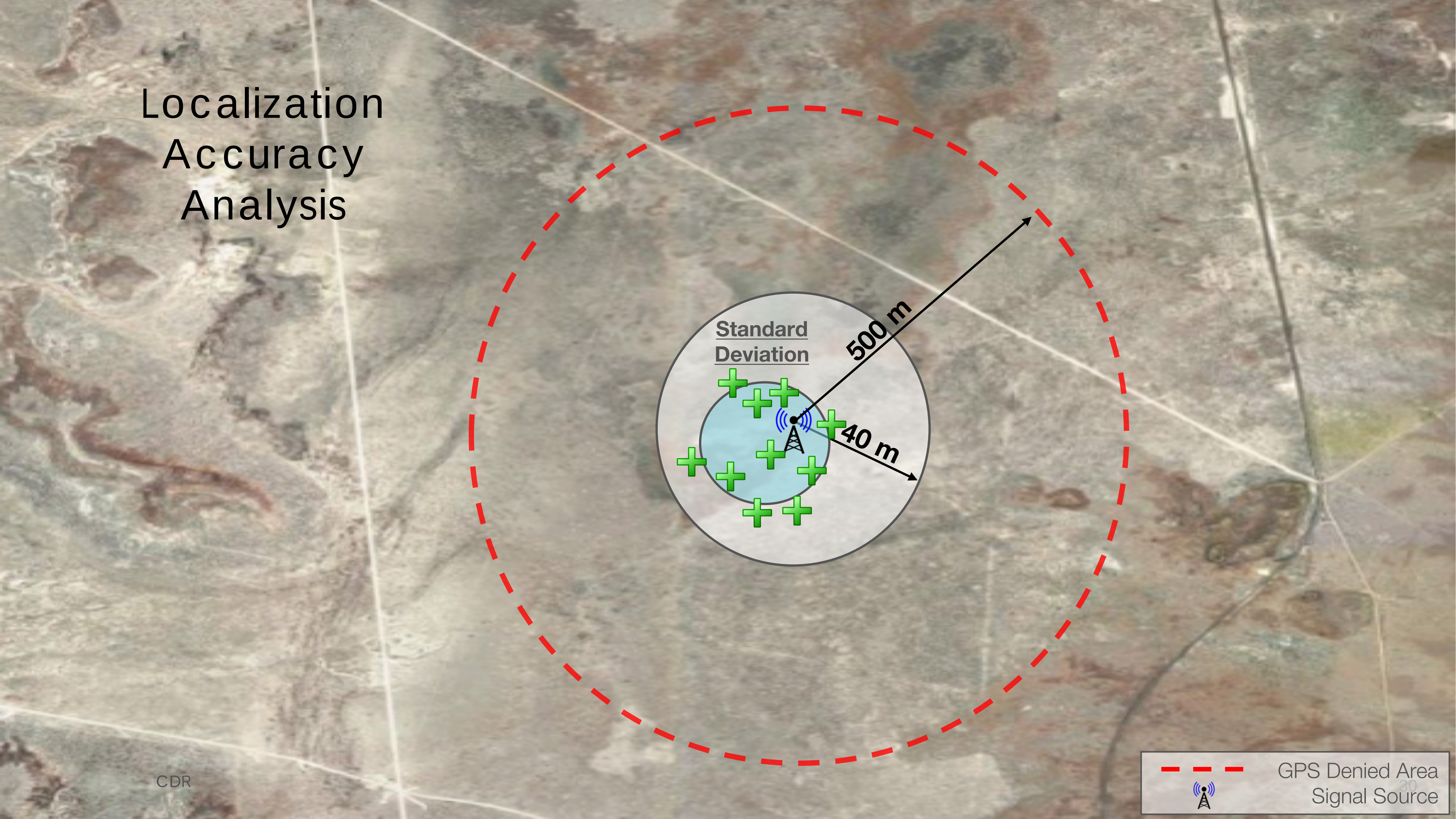
True Position Data (GPS) + Estimated Position (IMU)

Power Profile + Sphere of Influence Map

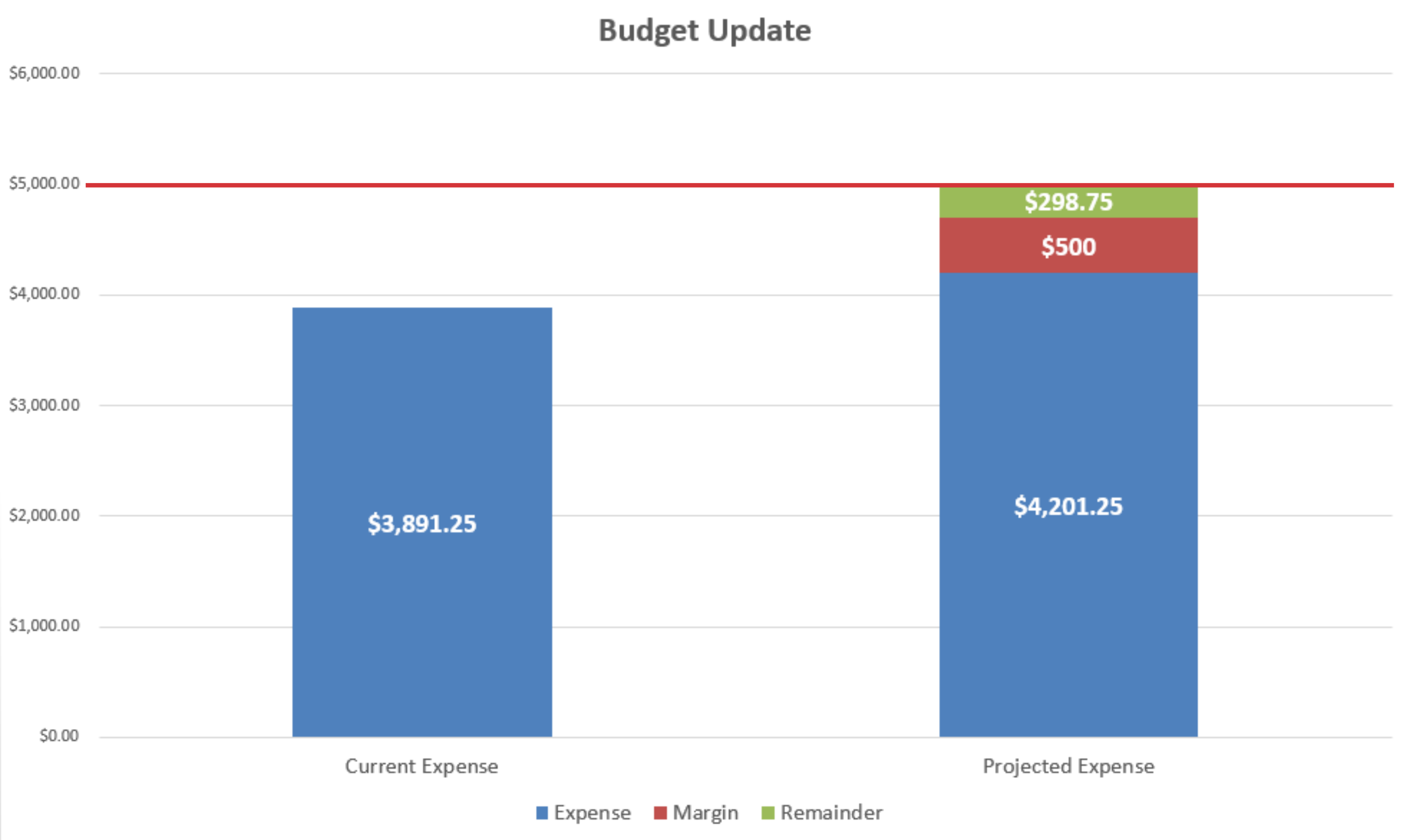
Position Error within Sphere of Influence

RFI Power Profile + Localization

Localization Accuracy Analysis



CURRENT EXPENSES AND PROCURMENT OVERVIEW



Obtained

- All UAS Components
- Transmitter and Receiver
- All Launcher Components
- Interface board, Microcontroller, Signal Filter

In Progress

- 3rd Backup Airframe
  (Expect Arrival: Mar 9)
- 2nd LTE Modem
  (Expected Arrival: Mar 5)
- Back-Up ESC
  (Expected Arrival: Mar 12)
- Replacement Batteries
  (Expected Arrival: Mar 12-15)

QUESTIONS?

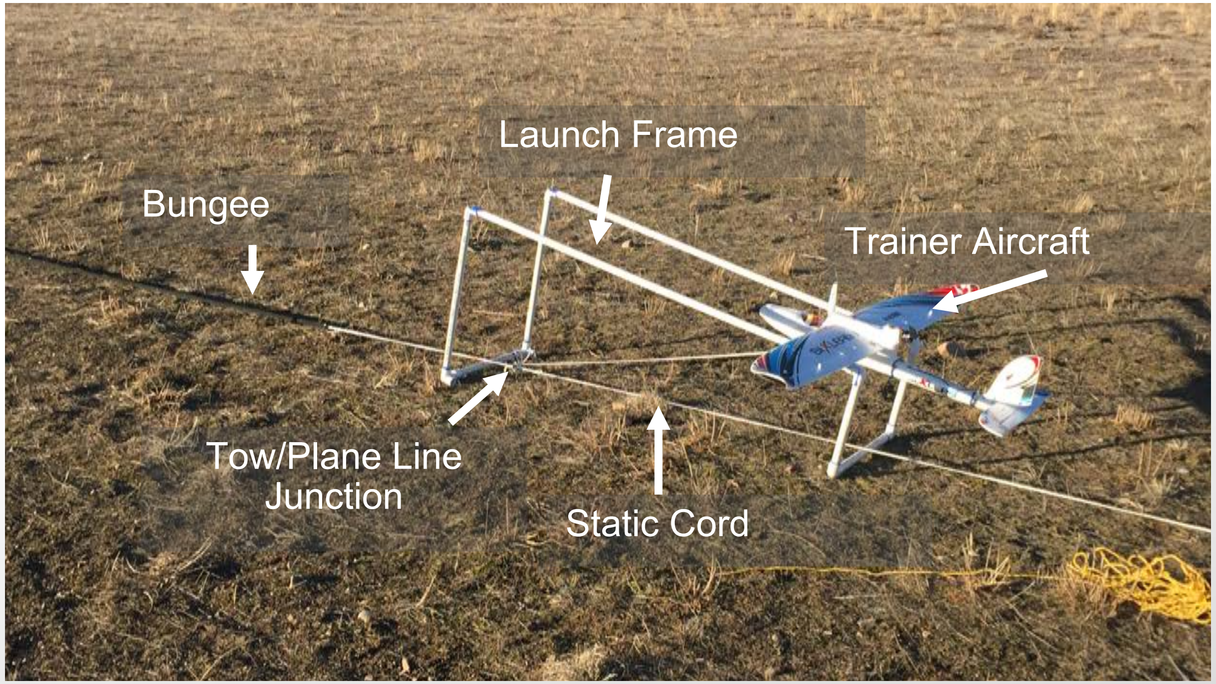
Back Up Slides

Talon launch Method

Bungee Launch

Force Gauge & Quick Release

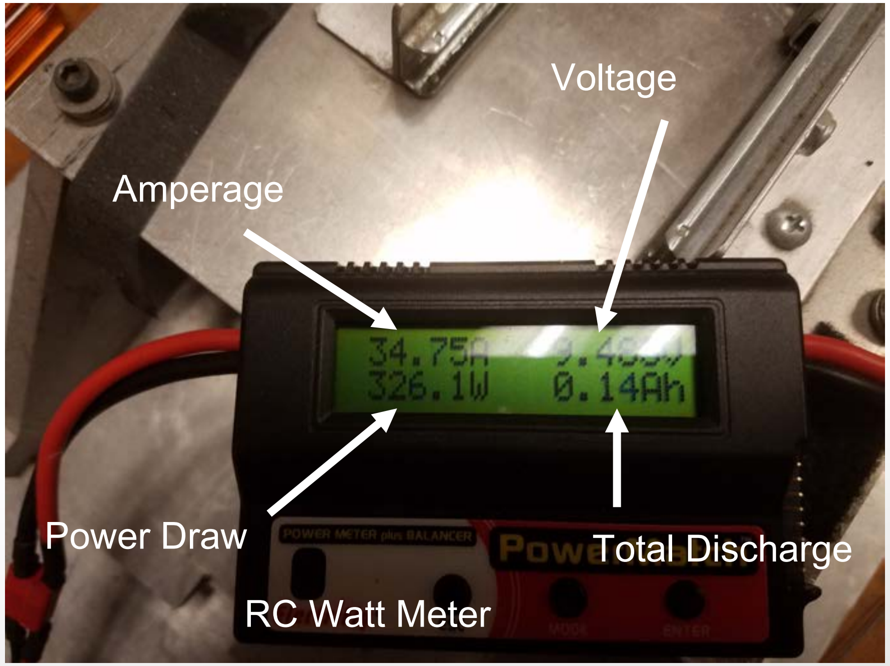
- Accurate Bungee Force
- Operate From Safe Distance
- Tensioned to ~5x aircraft weight (~35 lbs)



- Static Cord Junction allows no tension on aircraft until release
- 12 deg launch angle

Status: In Progress, completed with trainer aircraft, awaiting flight test with Talon

Motor burst test

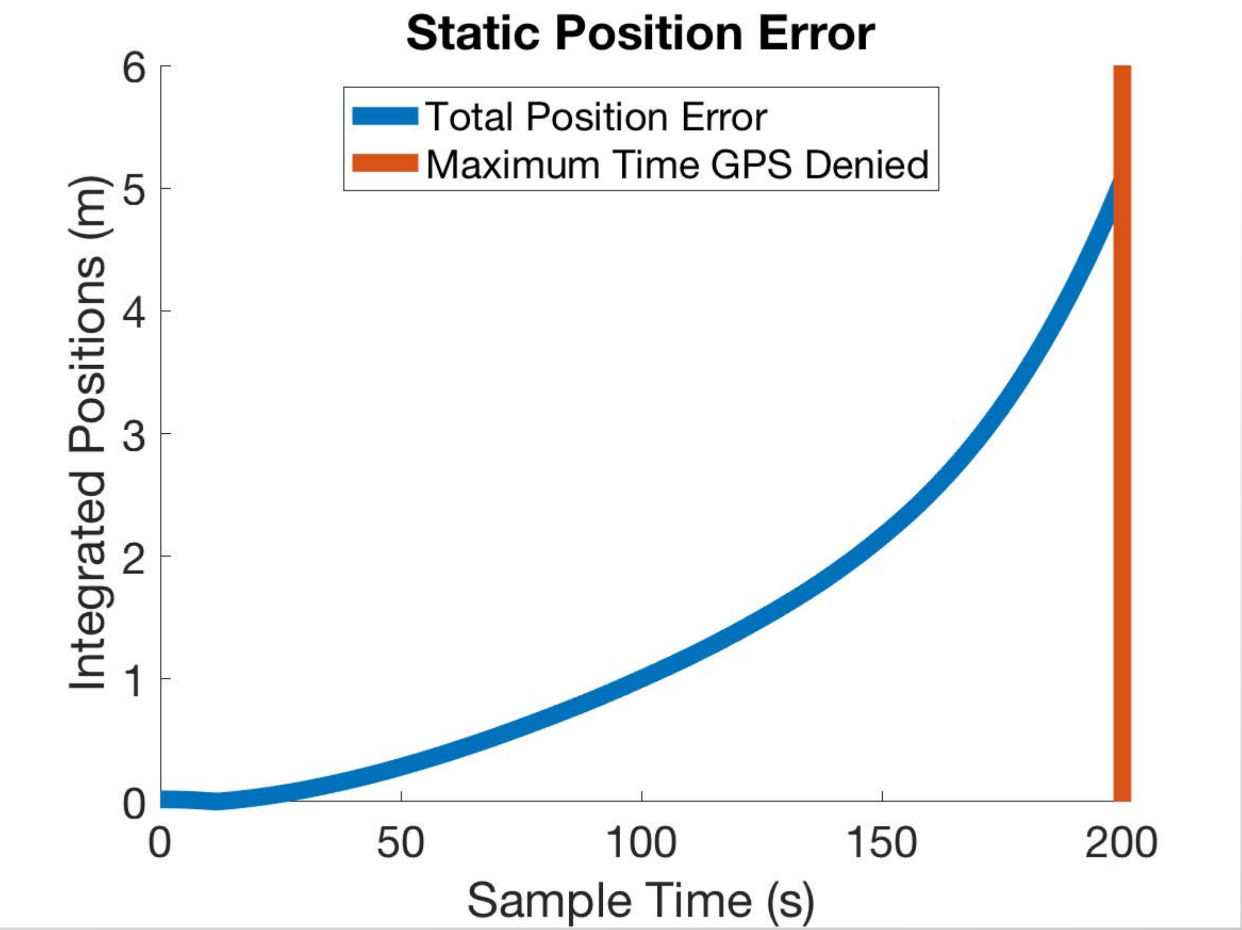


- Verifies that motor can provide at least 671 W at takeoff
  $PR_{TO,max} = PR_{D,max} + PR_{L,max} + PR_{climb}$
- Provides battery discharge info, validates flight model and Requirement 1

Status: Completed, but must retest because batteries were not charged resulting in much lower power than expected

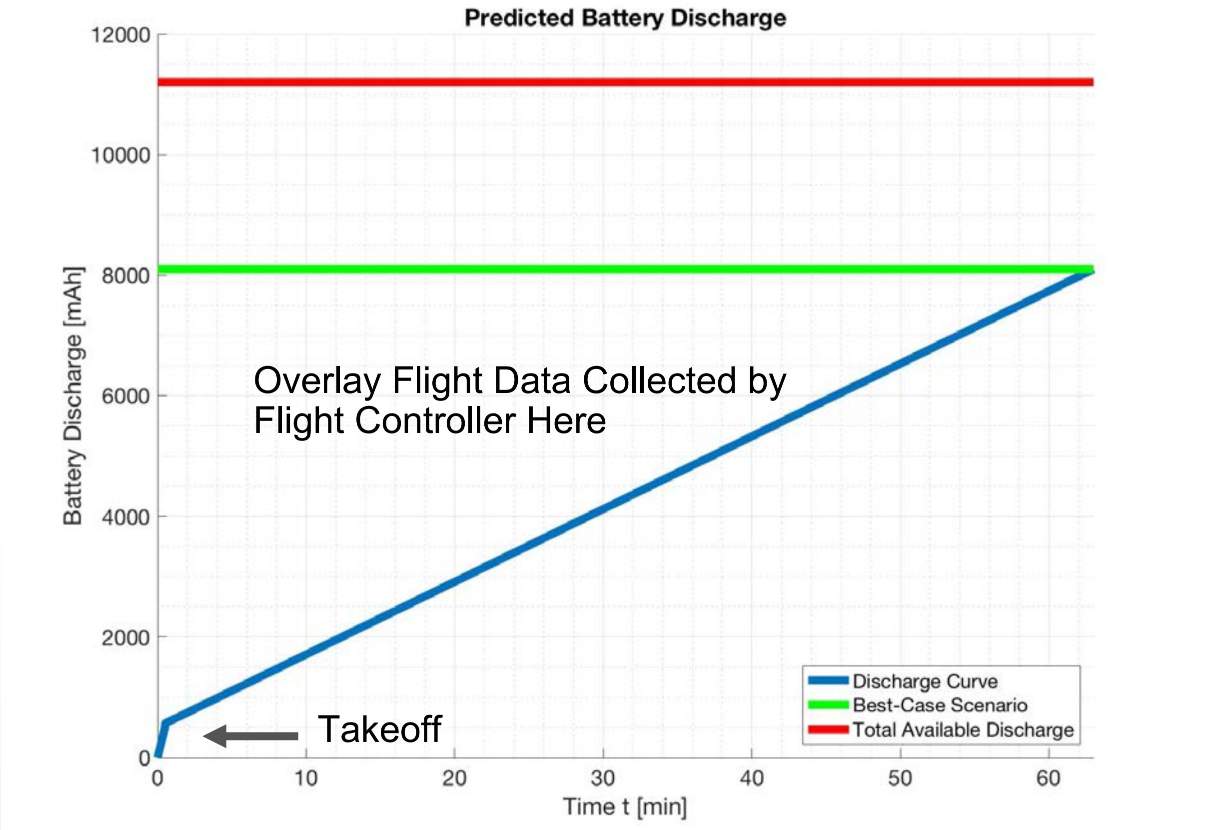
STATIC IMU TESTING

- Static testing shows error in position well below 40 m requirement.
- Performs better than previously modeled.
- Will improve with filtering and full sensor integration.



Flight Model Validation

Validates that aircraft can stay in the air for 60 minutes



- Will use battery info from Flight Controller to validate Flight Model
- Expecting 8100/14000 mAh discharge
- Will Compare:
  - Power Required @ Takeoff
  - Power Required during Flight
  - Total Flight Time
  - Battery Discharge
  - Flight Weight

To validate flight model

Status: Incomplete, awaiting full flight test for data

Talon hardware verification

Component	Fly-Ready?	Required for Flight-Readiness	Test
Motor	Y		Burst Test, Full Flight
Batteries	Y		Charge Cycle, Full Flight
Receiver/Servos	Y		Deflection by Inspection
Speed Controller	Y		
LiDAR Rangefinder	N	Calibration, Installation	Range Test, Full Flight
Optical Flow Sensor	N	Calibration, installation	Ground Test, Full Flight
Airspeed Sensor	Y		
GPS Module	Y		
Inertial Sensor	N	Calibration, Drivers, Installation	Ground Test, Flight Test
MicroZed	N	Calibration, Drivers, Installation	Ground Test, Flight Test
Telemetry Antenna	Y		
PixHawk Flight Controller	Y		

Talon Launch Method

Bungee Launcher

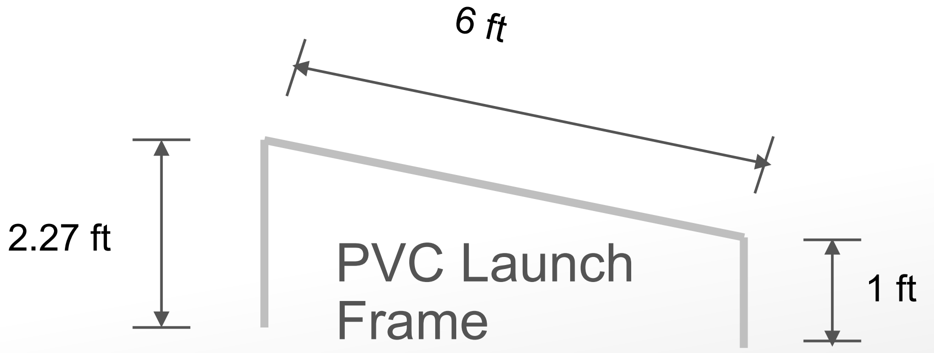
Elastic cord used to launch aircraft

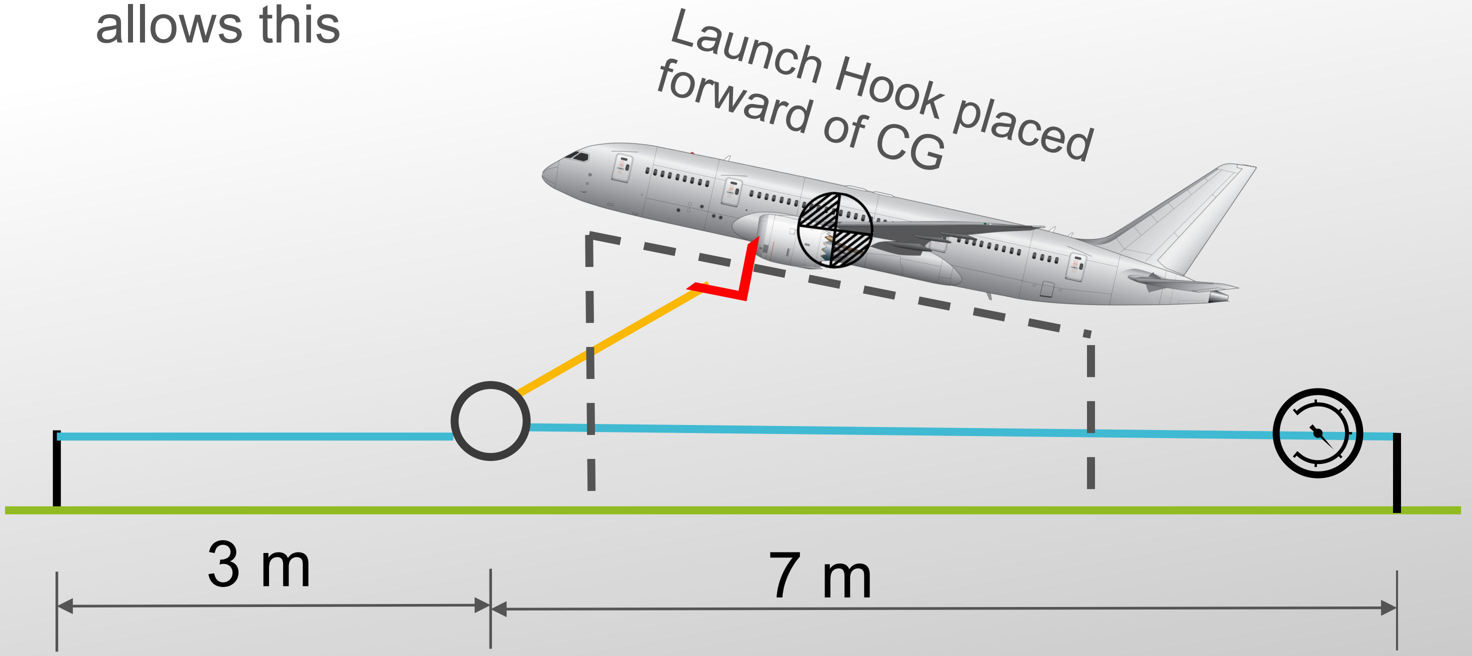
- cord junction
- launch frame
- elastic cord
- inelastic para-cord
- ground
- ground stakes
- force gauge
- launch hook

Aircraft must leave launch frame at V_{stall}

↓

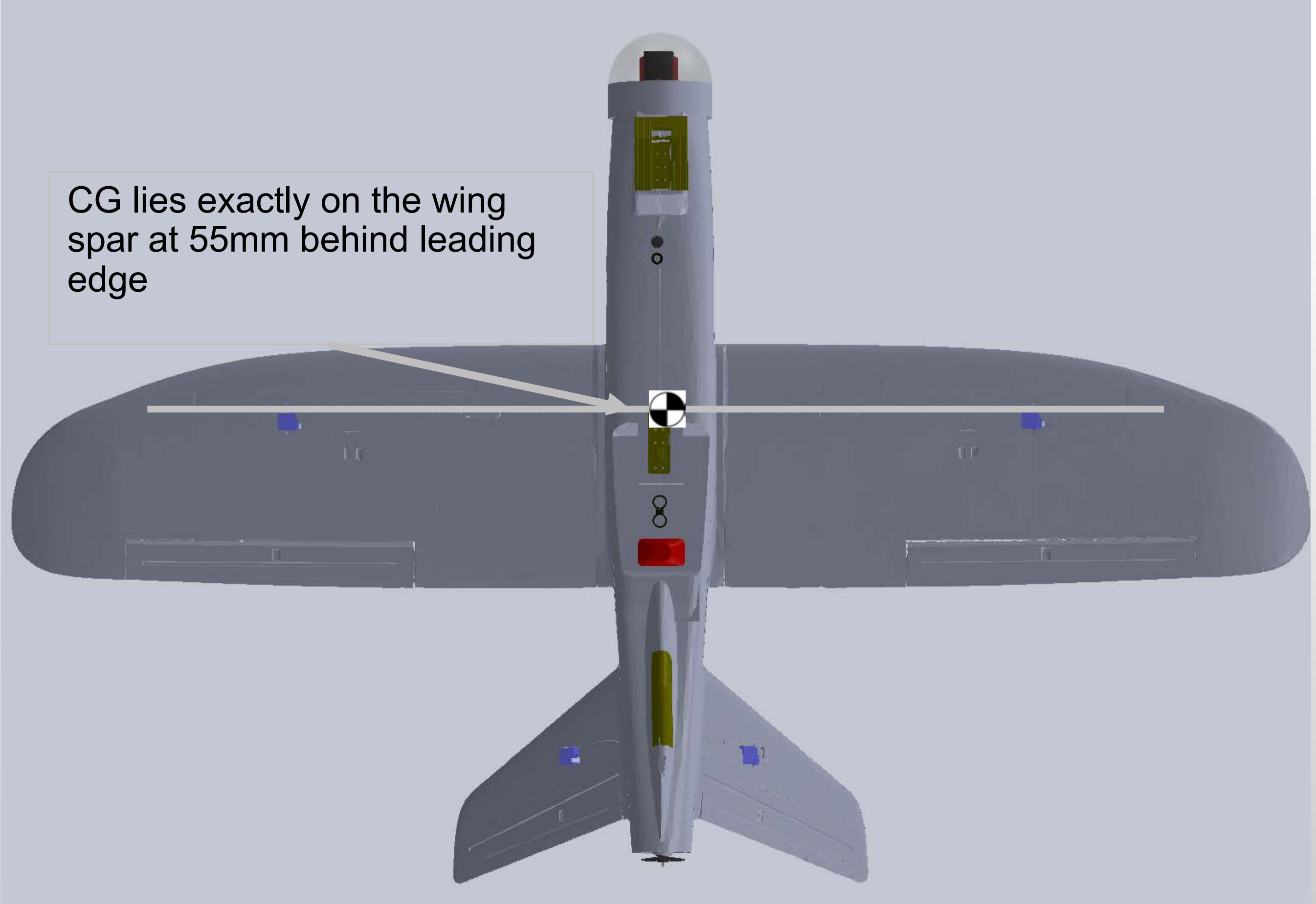
Cord stretched to tension force that allows this





CG Verification

- Will use CG stand on wing spar to test CG
- All components will be ensured secure before flight
- Susceptible to tail-heaviness



EKF2 Tuning

- Pitot Tube
  - EK2_EAS_NOISE
  - EK2_EAS_GATE
- Optical Flow
  - EK2_MAX_FLOW
  - EK2_FLOW_NOISE
  - EK2_FLOW_GATE
  - EK2_FLOW_DELAY
- IMU
  - EK2_GYRO_PNOISE
  - EK2_ACC_PNOISE
  - EK2_GBIAS_PNOISE
  - EKF2_GSCL_PNOISE
  - EK2_ABIAS_PNOISE

EKF2 States

- Attitude (Quaternions)
- Velocity (North, East, Down)
- Position (North, East, Down)
- Gyro bias offsets (X,Y,Z)
- Gyro bias factors (X,Y,Z)
- Z acceleration bias
- Earth magnetic field (X,Y,Z)
- Body magnetic field (X,Y,Z)
- Wind velocity (North, East)

Back

IMU Hardware

DMU11 From Silicon Sensing

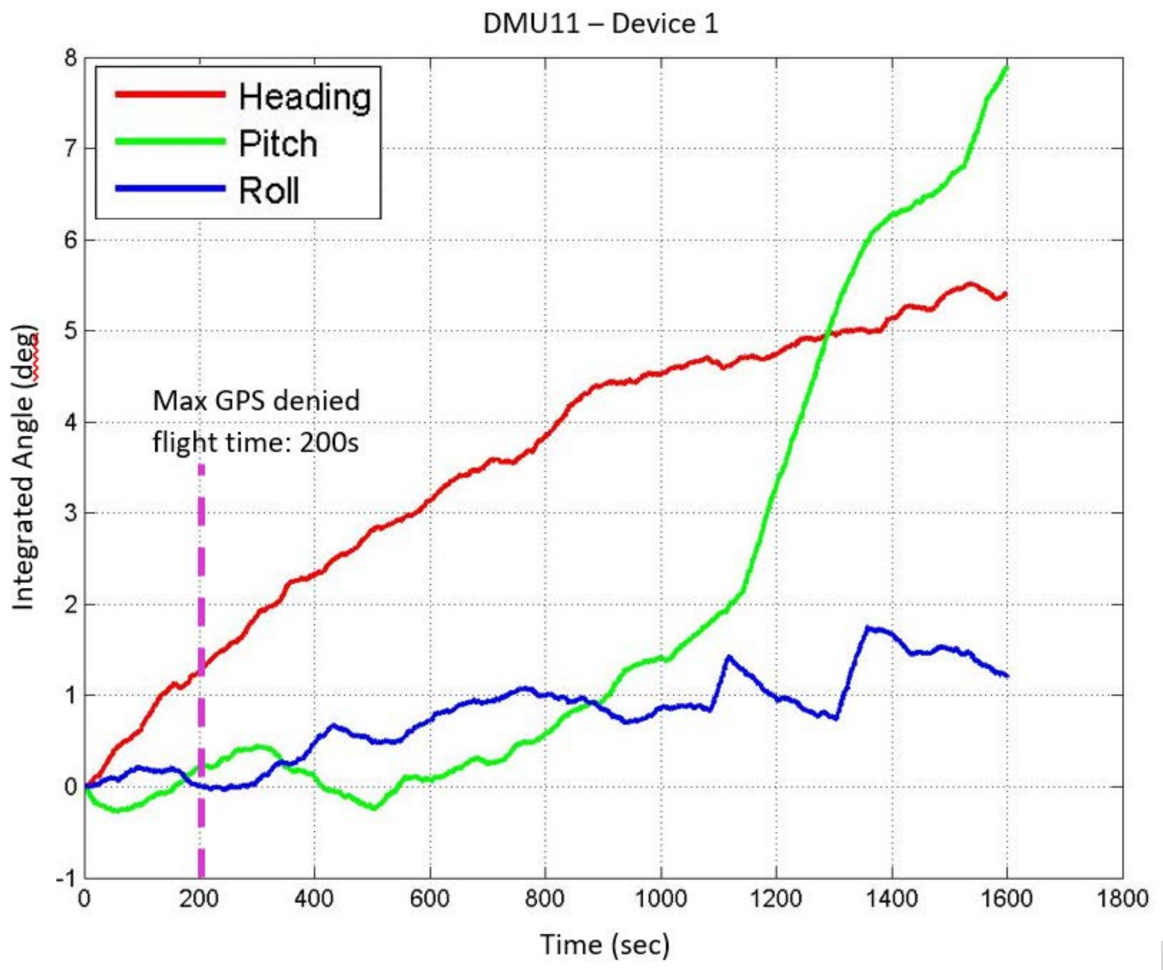
- Gyro bias = +/- 0.25 deg/s
- Gyro bias drift = +/- 0.025 deg/s
- Gyro bias instability < 10 deg/hr
- ARW < 0.4 deg/sqrt(hr)
- Acc. bias = +/- 3.0 mg
- Acc. bias drift = +/- 1.0 mg
- Acc. bias instability < 0.05 mg
- VRW < 0.05 m/s/sqrt(hr)
- Size: 22 x 22 x 10.6 mm
- Mass: 24 g
- Cost: $359.00 (including evaluation kit)

Initial Flight Software Calibration

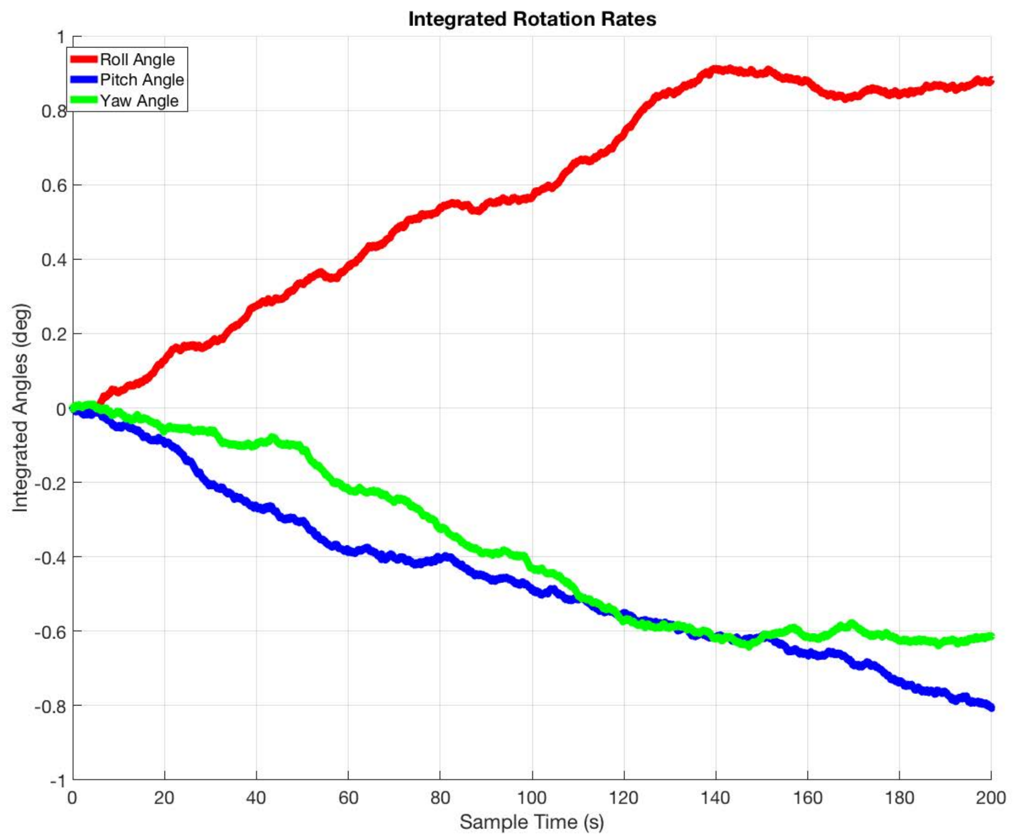
- Airspeed Sensor – crucial for all future autonomous flights and tuning
  - Automatic tuning mode, 5 minute loiter flight is all that is needed
- Ardupilot AUTOTUNE – allows the flight software to learn key values for pitch and roll tuning and control surface outputs.
  - 20 minute manual flight with many sharp attitude changes
- NAVL1_PERIOD – Sets the sharpness of aircraft turns, manually set
- PITCH2SRV_RLL – how much elevator is used in turns to hold altitude

IMU Performance

Manufacturer Provided Data



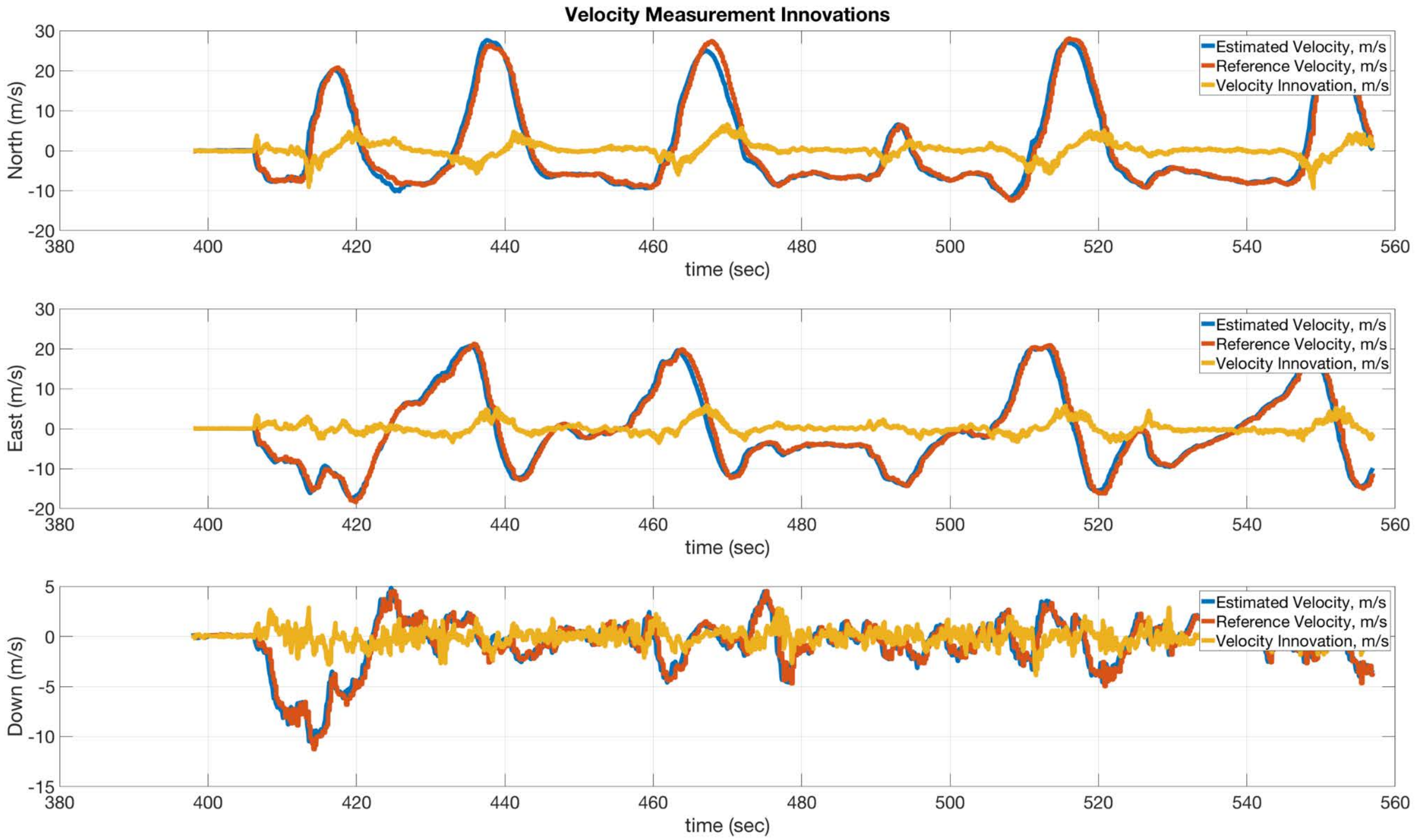
RAMROD Verified Data



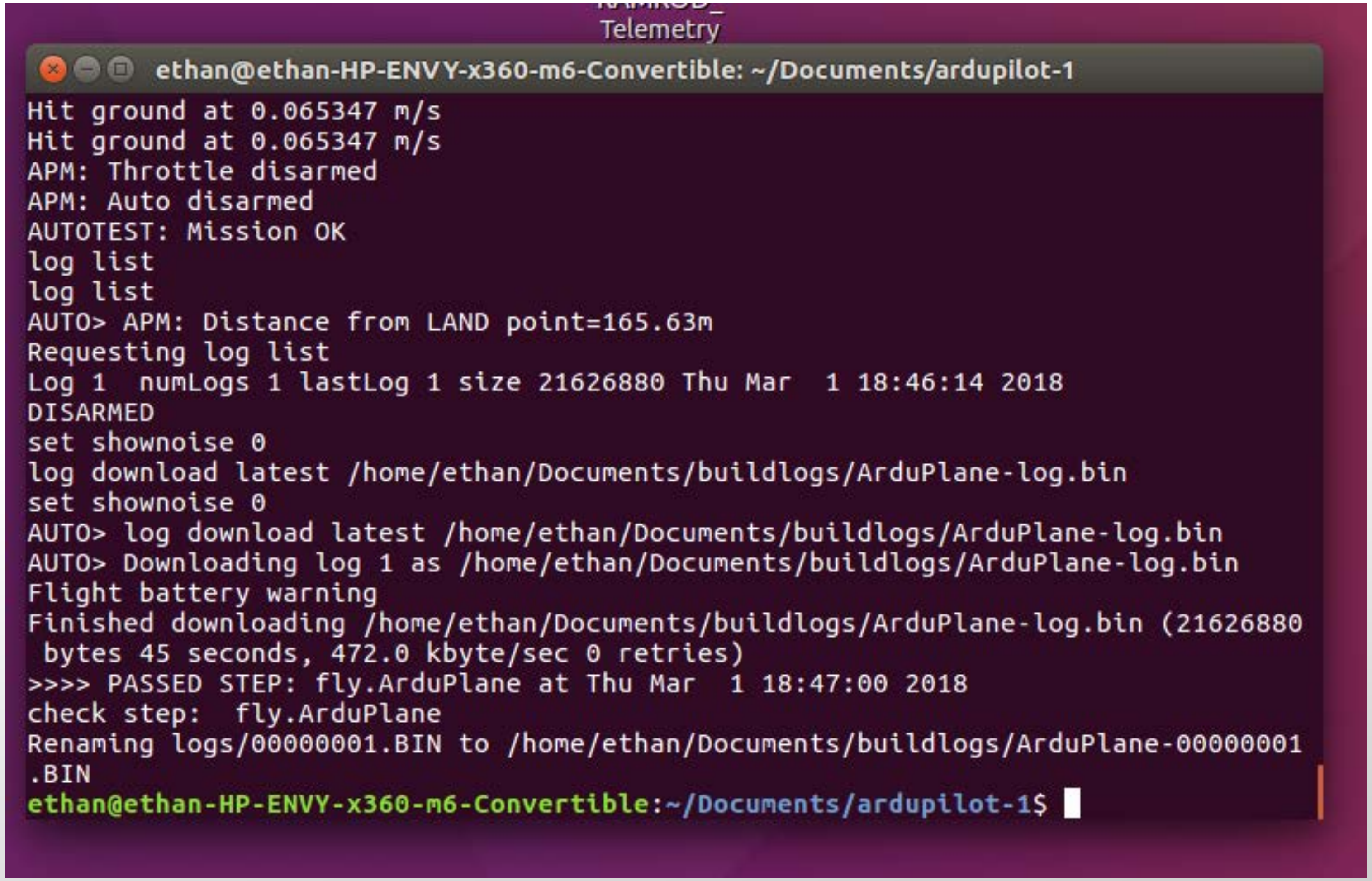
Kalman Filter Tuning

- Default tune built around stock PixHawk sensors. A higher quality IMU, as well as a pitot tube, and optical flow sensor are to be added.
- Tuning for new IMU
  - Static baseline test
  - Utilize Mission Planner to analyze telemetry logs, view filter innovations
  - Update Parameters
  - Repeat
- Flight testing to follow static ground tests
  - Allow for pitot tube and optical flow tuning

Kalman Filter Tuning

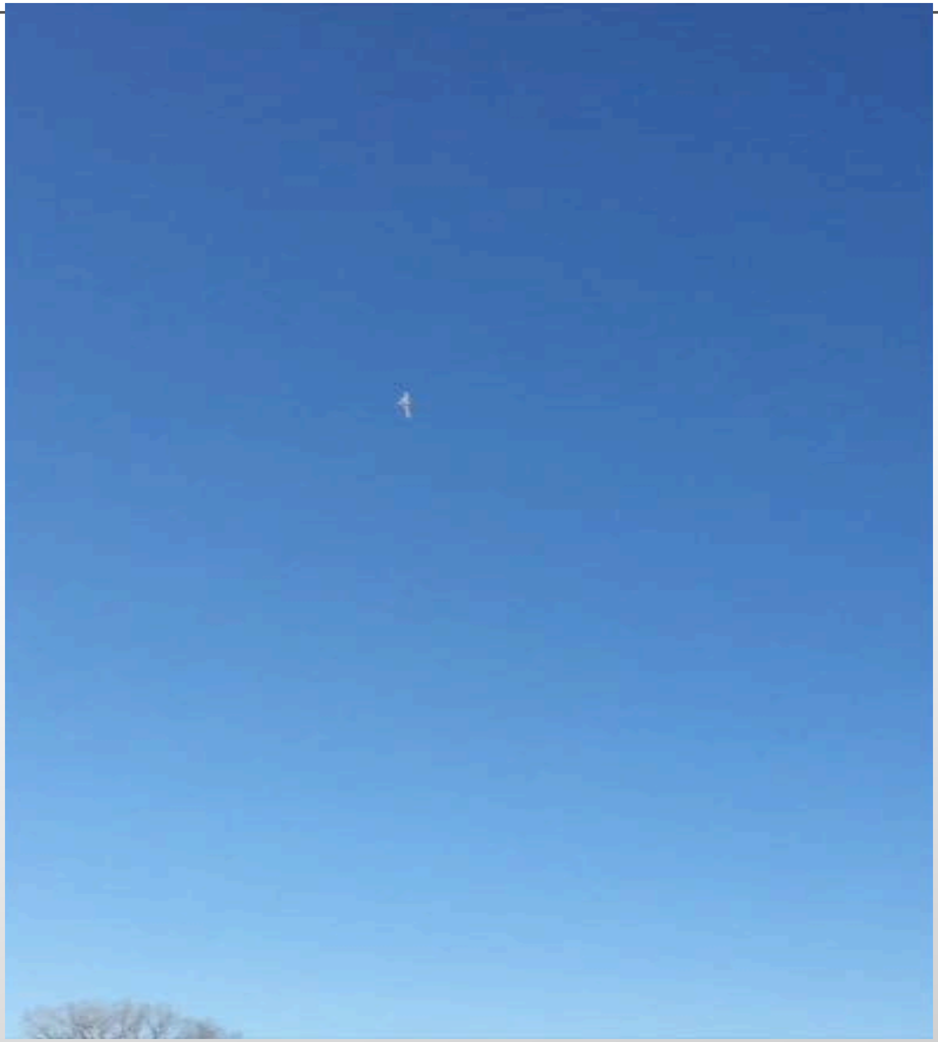


BACKUP – Ardupilot autotest



```
ethan@ethan-HP-ENVY-x360-m6-Convertible: ~/Documents/ardupilot-1
Hit ground at 0.065347 m/s
Hit ground at 0.065347 m/s
APM: Throttle disarmed
APM: Auto disarmed
AUTOTEST: Mission OK
log list
log list
AUTO> APM: Distance from LAND point=165.63m
Requesting log list
Log 1  numLogs 1 lastLog 1 size 21626880 Thu Mar  1 18:46:14 2018
DISARMED
set shownoise 0
log download latest /home/ethan/Documents/buildlogs/ArduPlane-log.bin
set shownoise 0
AUTO> log download latest /home/ethan/Documents/buildlogs/ArduPlane-log.bin
AUTO> Downloading log 1 as /home/ethan/Documents/buildlogs/ArduPlane-log.bin
Flight battery warning
Finished downloading /home/ethan/Documents/buildlogs/ArduPlane-log.bin (21626880
 bytes 45 seconds, 472.0 kbyte/sec 0 retries)
>>>> PASSED STEP: fly.ArduPlane at Thu Mar  1 18:47:00 2018
check step:  fly.ArduPlane
Renaming logs/00000001.BIN to /home/ethan/Documents/buildlogs/ArduPlane-00000001
.BIN
ethan@ethan-HP-ENVY-x360-m6-Convertible:~/Documents/ardupilot-1$
```

Talon manual flight video



Bungee Launcher vs hand launch

BACKGROUND AND MOTIVATION

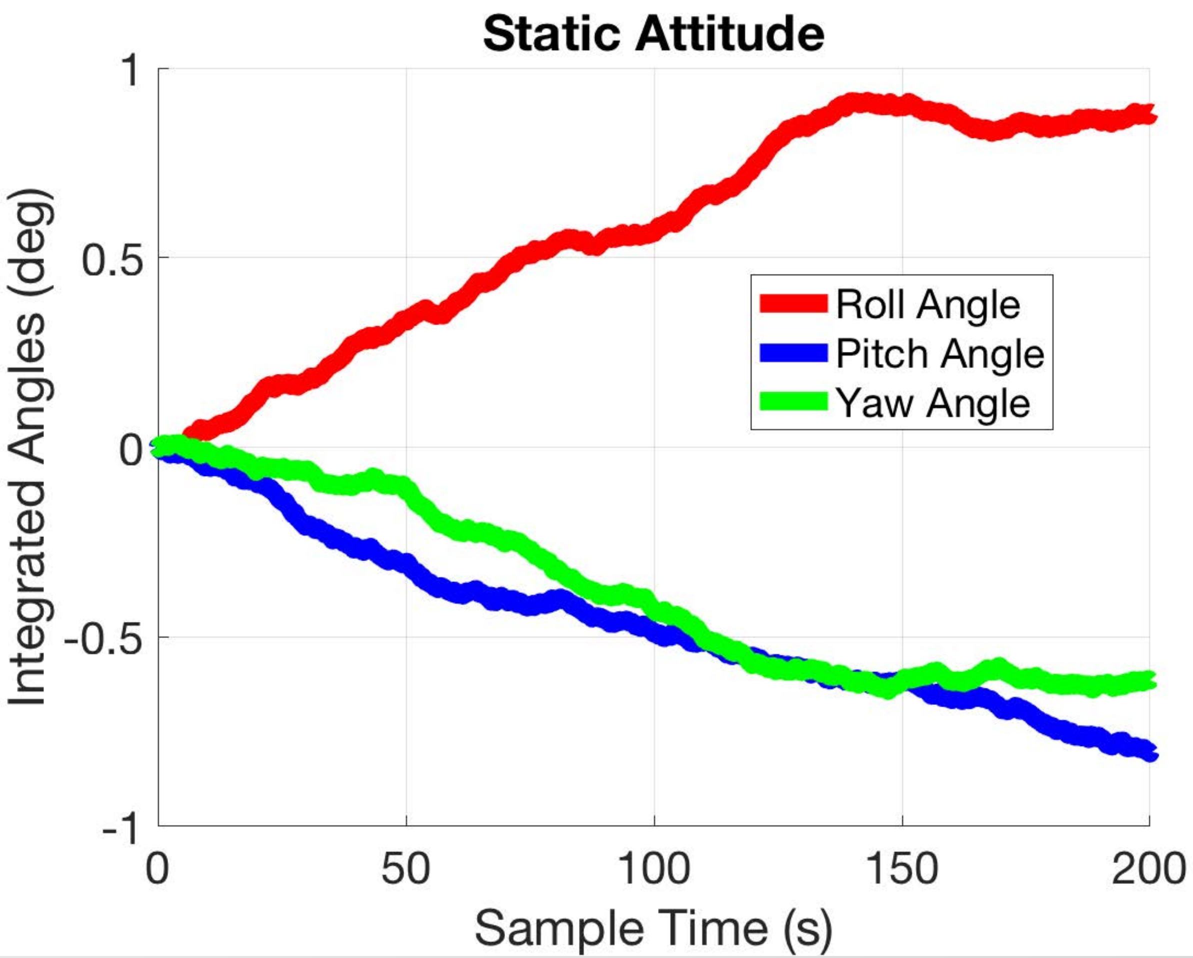
RAMROD will utilize an autonomous UAS and self-contained sensor payload to localize Radio Frequency Interference and Emerging Threat sources in a GPS-denied environment to allow civilian and military GNSS endeavors to continue without disruption.

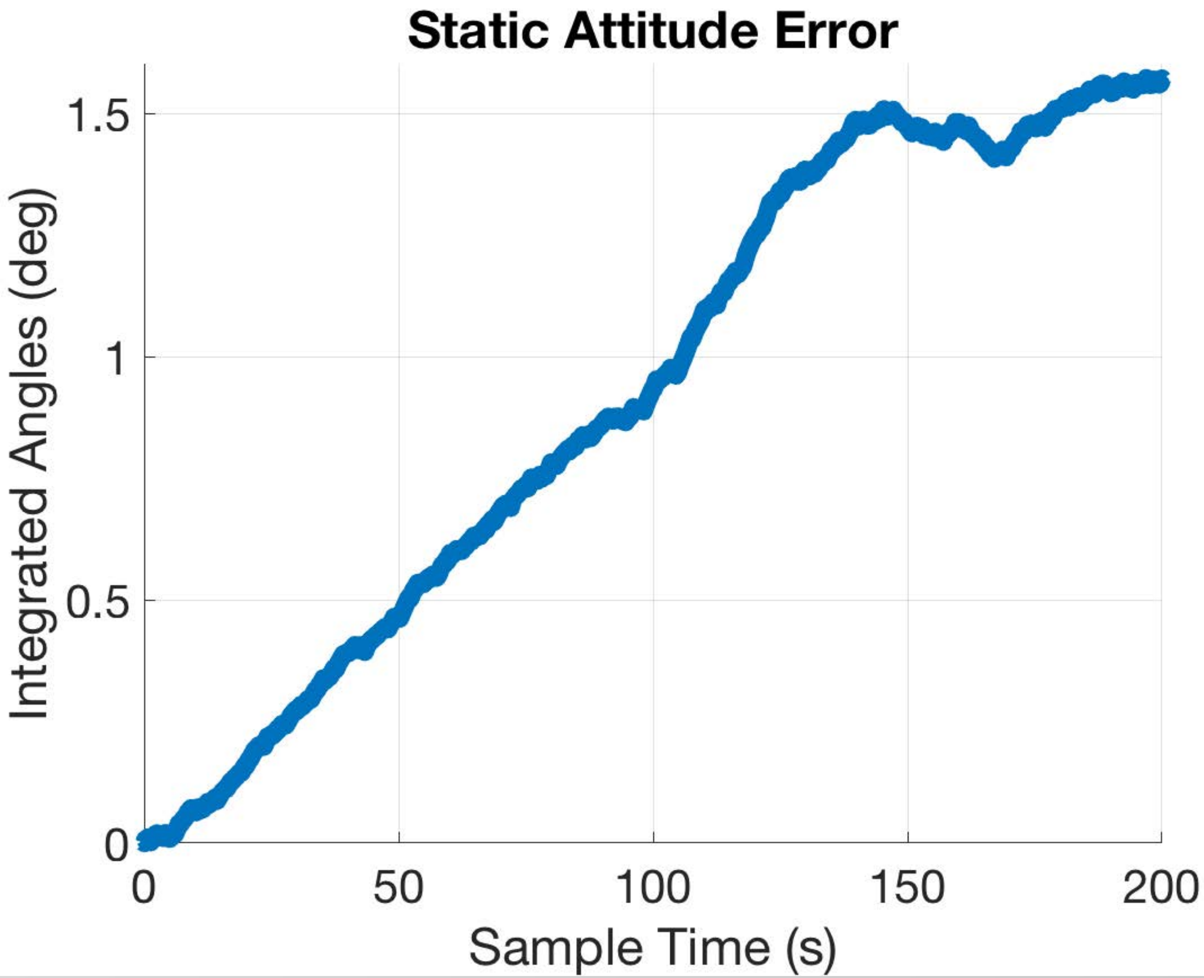
GPS Jammer

GPS Spoofer

- Personal Privacy Devices and Emerging Threats (spoofers) are interrupting civilian and military GNSS endeavors
- Utilizing a UAS is the most efficient method for rapidly localizing these RFI sources
- Flying a UAS in GPS-denied conditions is problematic due to most autopilots reliance on GNSS

DMU Static Attitude (Backup)





DMU Static Position