RAMROD

REMOTE AUTONOMOUS MAPPING OF RADIO FREQUENCY OBSTRUCTION DEVICES

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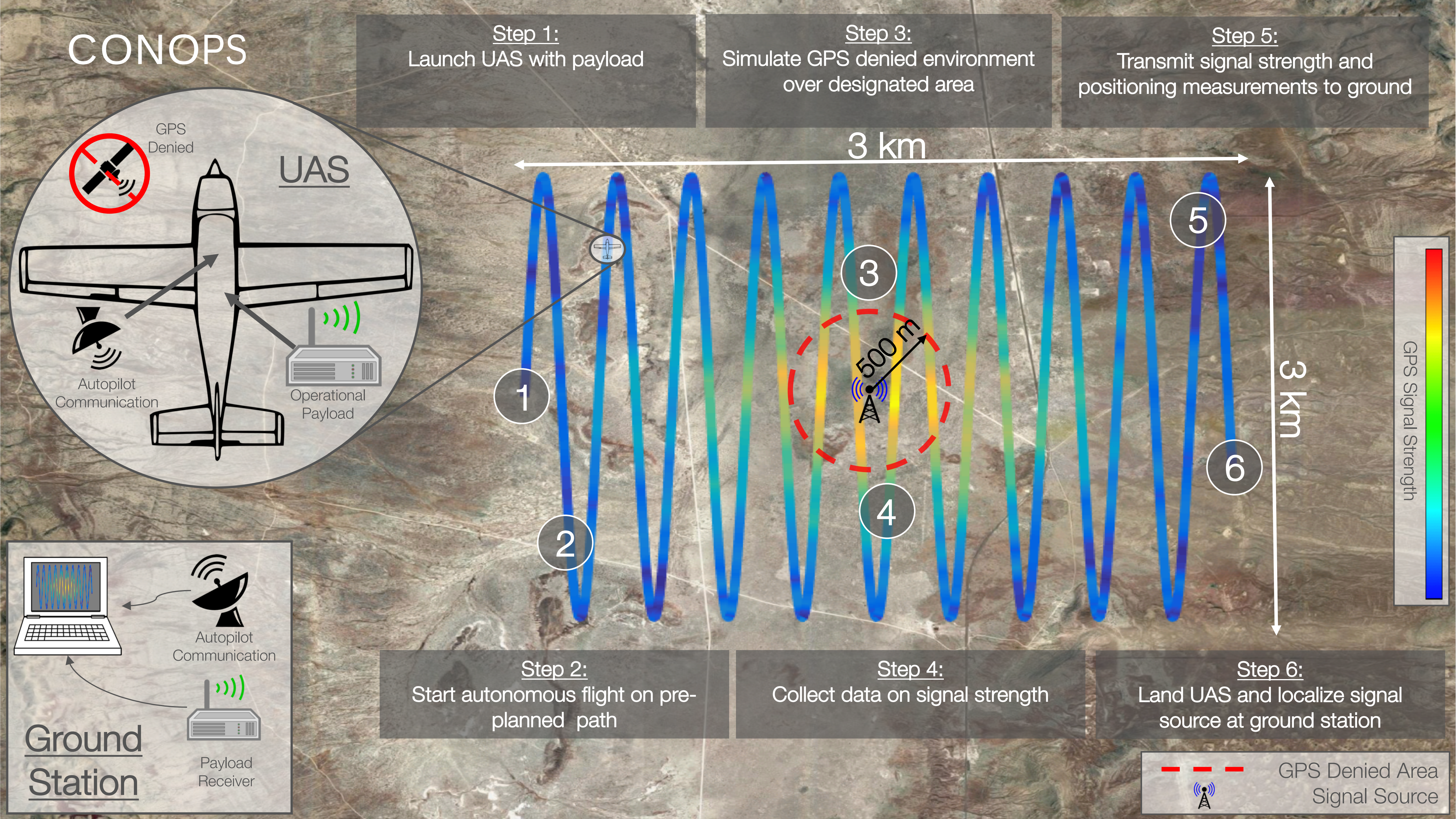


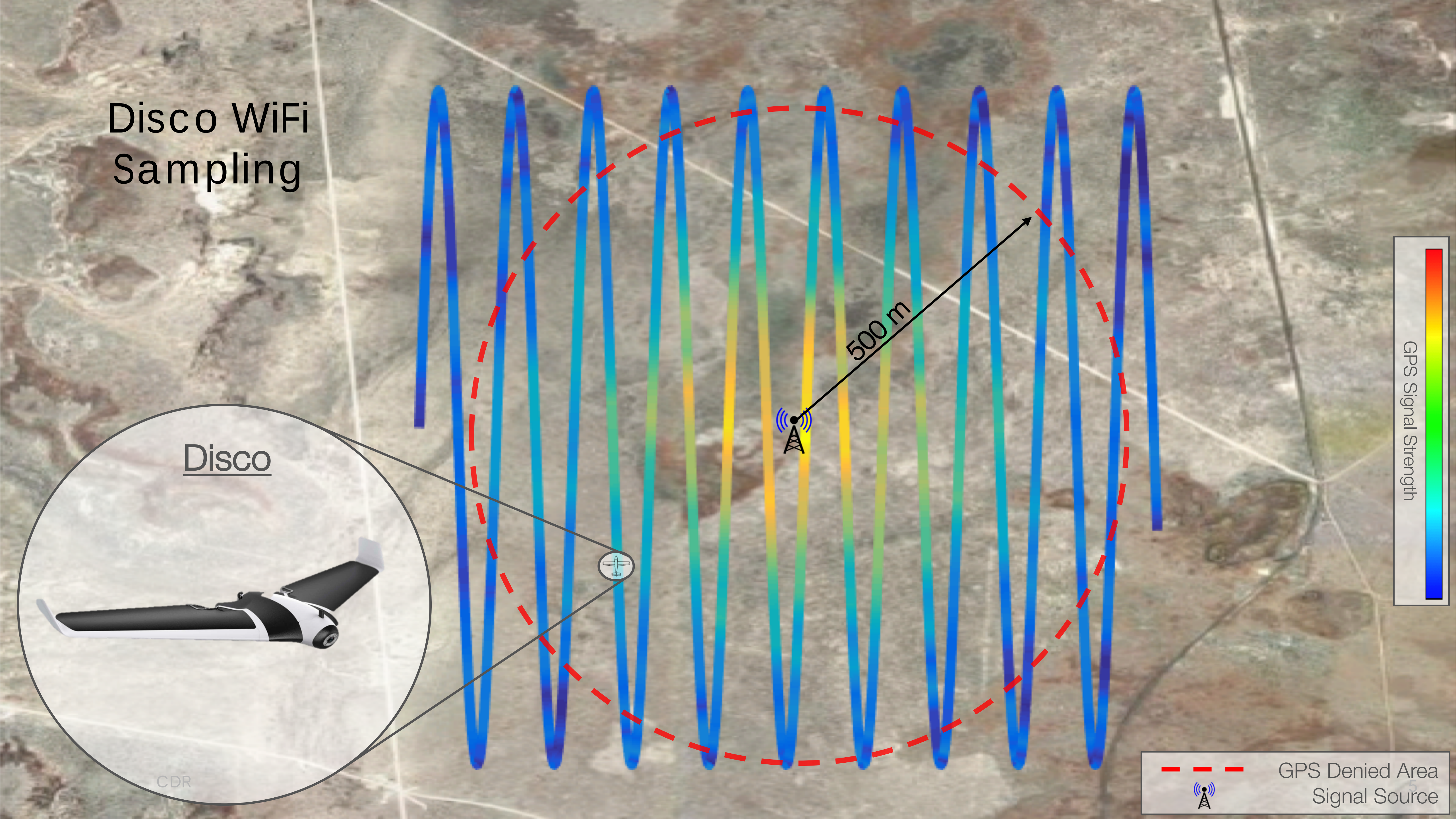
CONOPS
Step 1:
Launch UAS with payload
Step 3:
Simulate GPS denied environment over designated area
Step 5:
Transmit signal strength and positioning measurements to ground
GPS Denied
UAS
Autopilot Communication
Operational Payload
3 km
3 km
500 m
1
2
3
4
5
6
GPS Signal Strength
Autopilot Communication
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

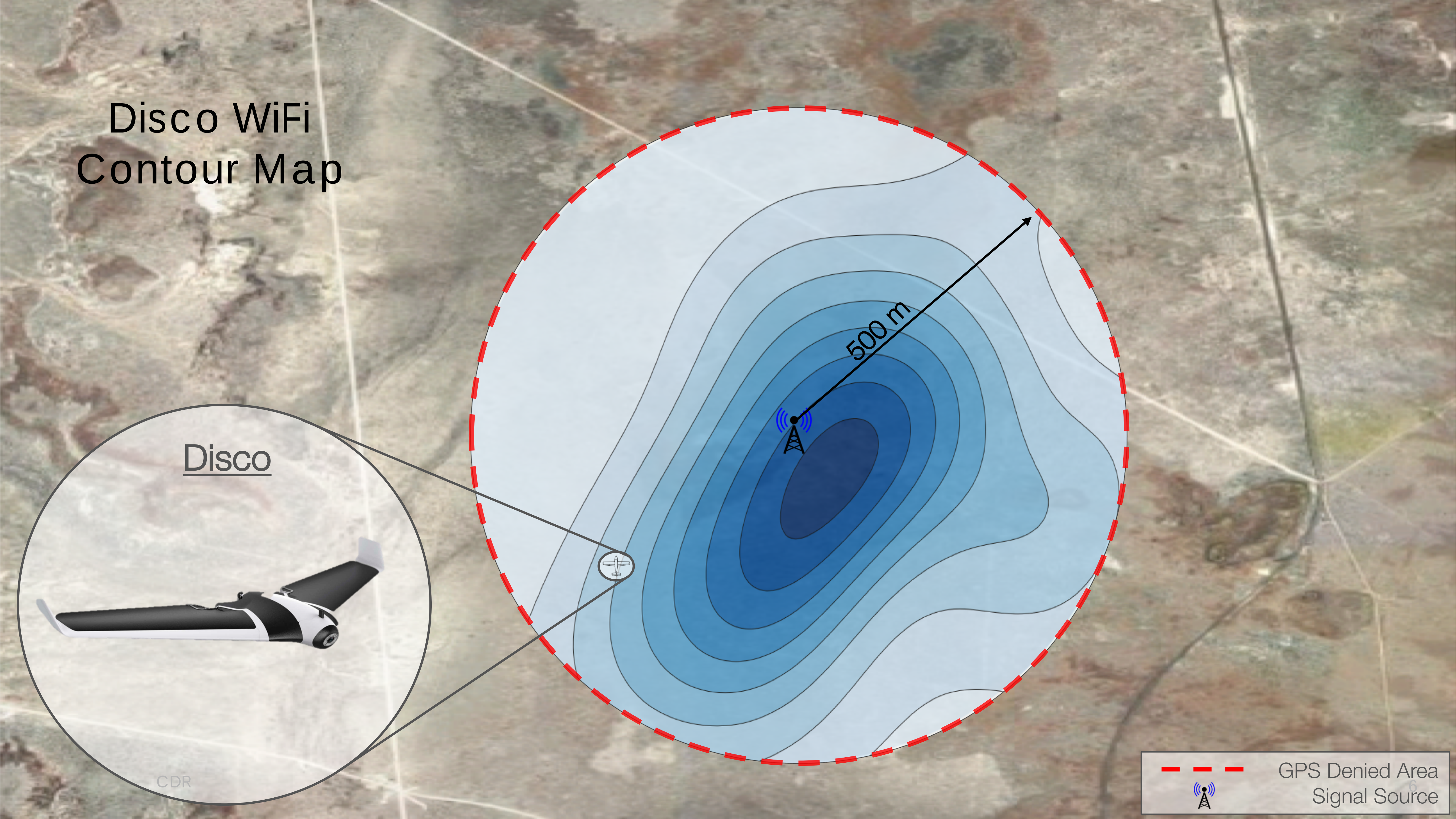
PARROT DISCO UAS

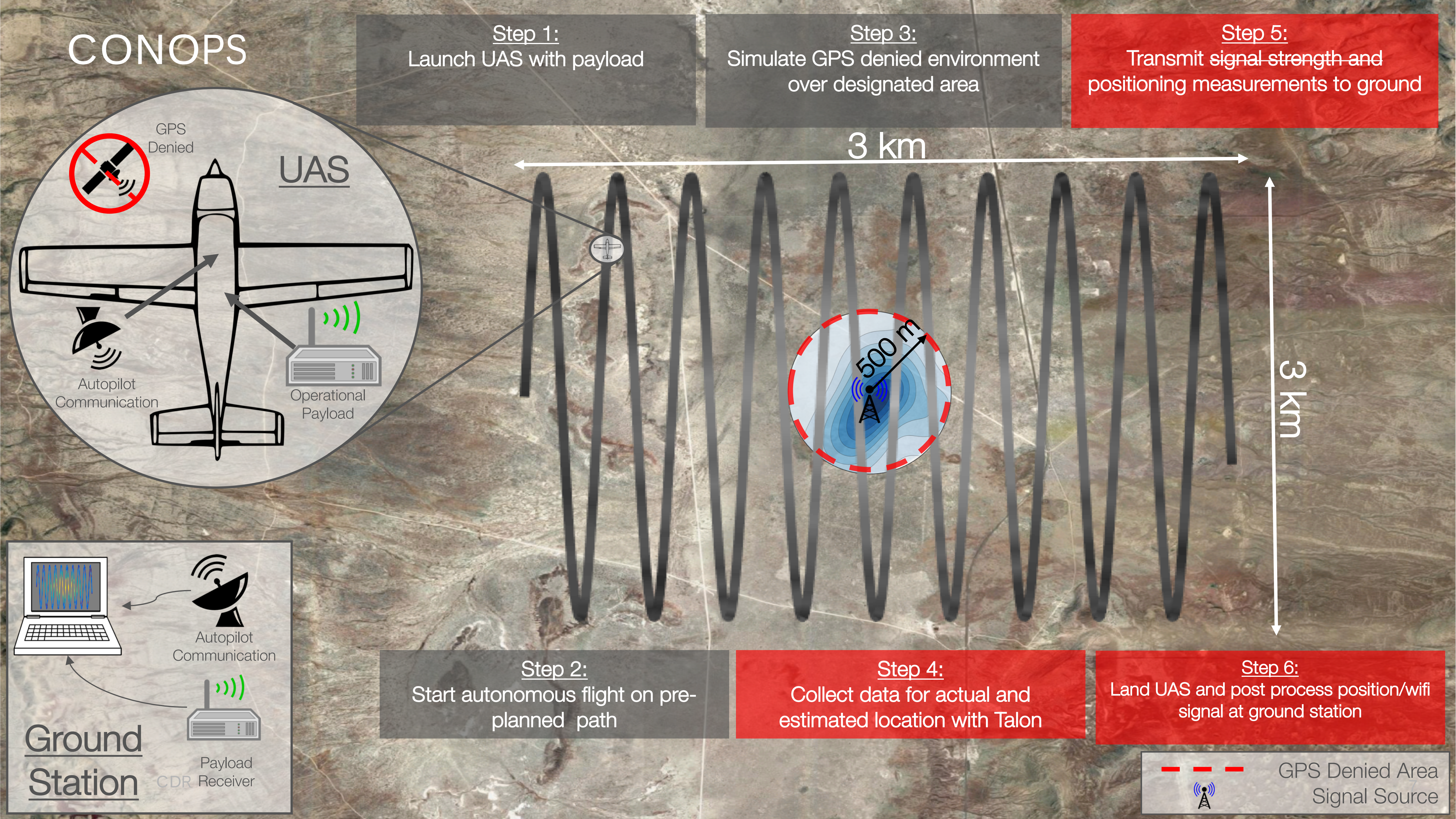
- Given to team RAMROD by customer
- Already proven capable of sampling WiFi power
- Will be used to create contour plot of signal power



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

Disco WiFi Contour Map

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Step 5:
Transmit ~~signal strength and~~ positioning measurements to ground
3 km
3 km
500 m
GPS Denied
UAS
Autopilot Communication
Operational Payload
Ground Station
Autopilot Communication
Payload Receiver
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

CRITICAL PROJECT ELEMENTS

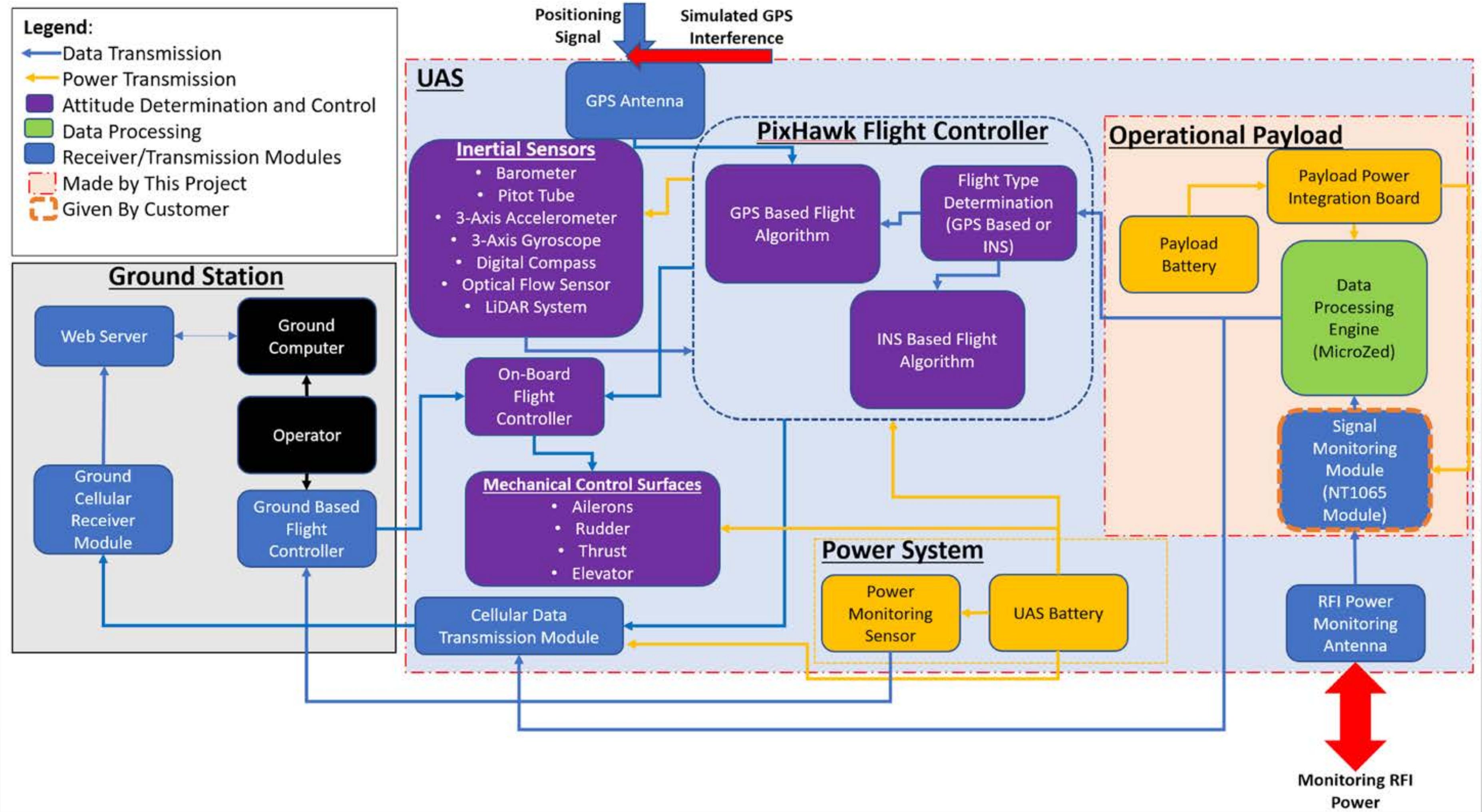
CPE	Description	Reason
GPS Denied Flight Software	Maintain autonomous flight while in a simulated GPS denied environment for up to 200 seconds at a time	A PPD or ET will cause GPS data to be inaccurate.
UAS	Use the Talon to fly in a simulated GPS denied environment while housing the operational payload 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
Level 2	-Transmit data up to 4.25 km using LTE connection. -Communicate power data with PixHawk	-Shall have the ability to fly autonomously for 60 minutes with GPS active	-Shall allow for maintained straight and level GPS denied flight for 1 km	-Localize RFI source within 100 m
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

DESIGN

FUNCTIONAL BLOCK DIAGRAM



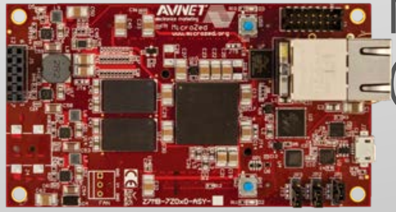
CRITICAL FOR MISSION SUCCESS

Critical Component	Components Chosen	Reason Component is Mission Critical
Flight Controller	PixHawk 2.1	• Controls all flight characteristics and manages autonomous flight • Contains modified GPS-Denied Flight Mode
Inertial Measurement Unit	DMU11	• Main component for minimizing positional error in GPS-Denied Flight Mode
Signal Filter	NT1065	• Collects raw power data on L1 and L2 bands and filters it into usable data for microprocessor
Microprocessor	MicroZed	• Sends all power and position data to the ground • Stores all power data • Indicates flight mode switch

Flight Controller (PixHawk)

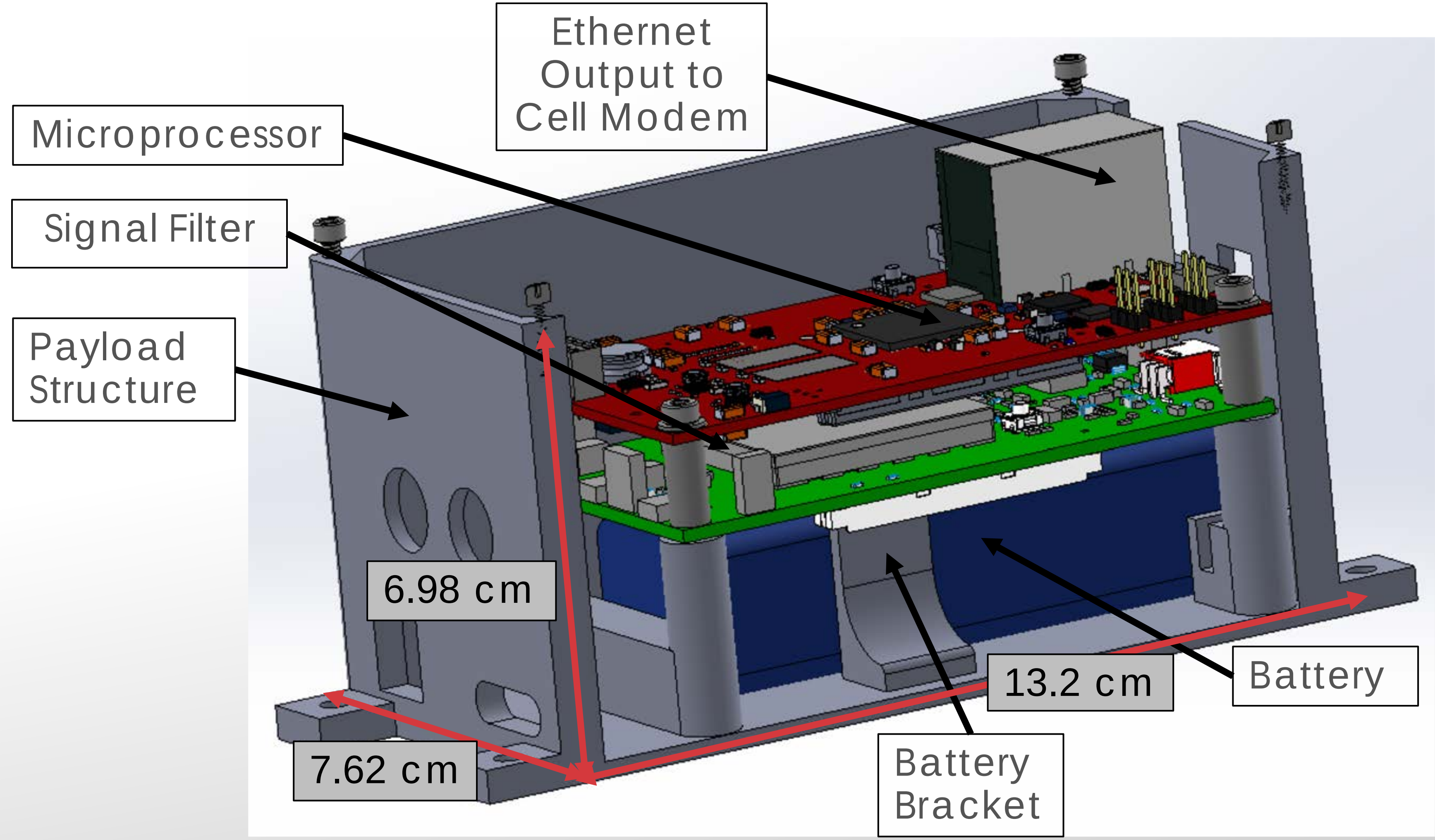
Inertial Measurement Unit (DMU11)

Signal Filter (NT1065)



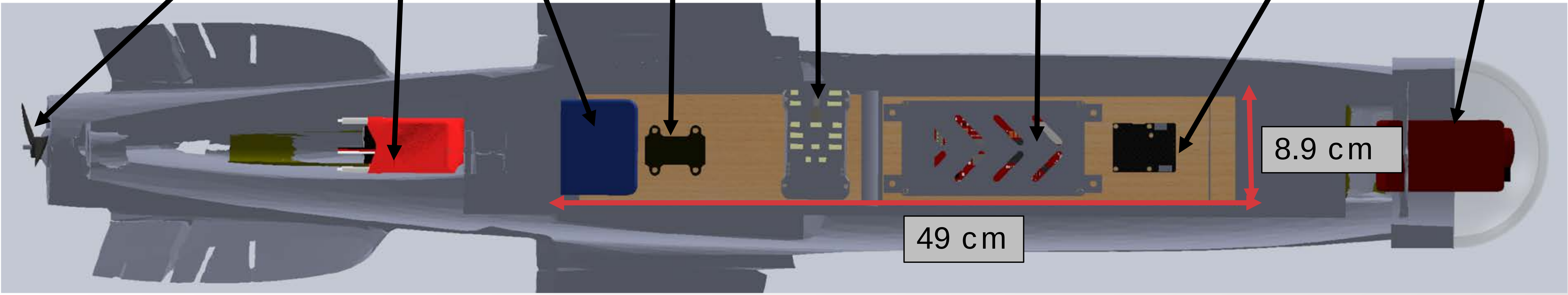
Microprocessor (MicroZed)

PAYLOAD BASELINE DESIGN



Key Parameter	Value
Size (cm)	7.62x13.21x6.98
Mass (g)	450
Avg. Data Transmission Rate (Mbps)	Upload: 7.64 Download: 6.67

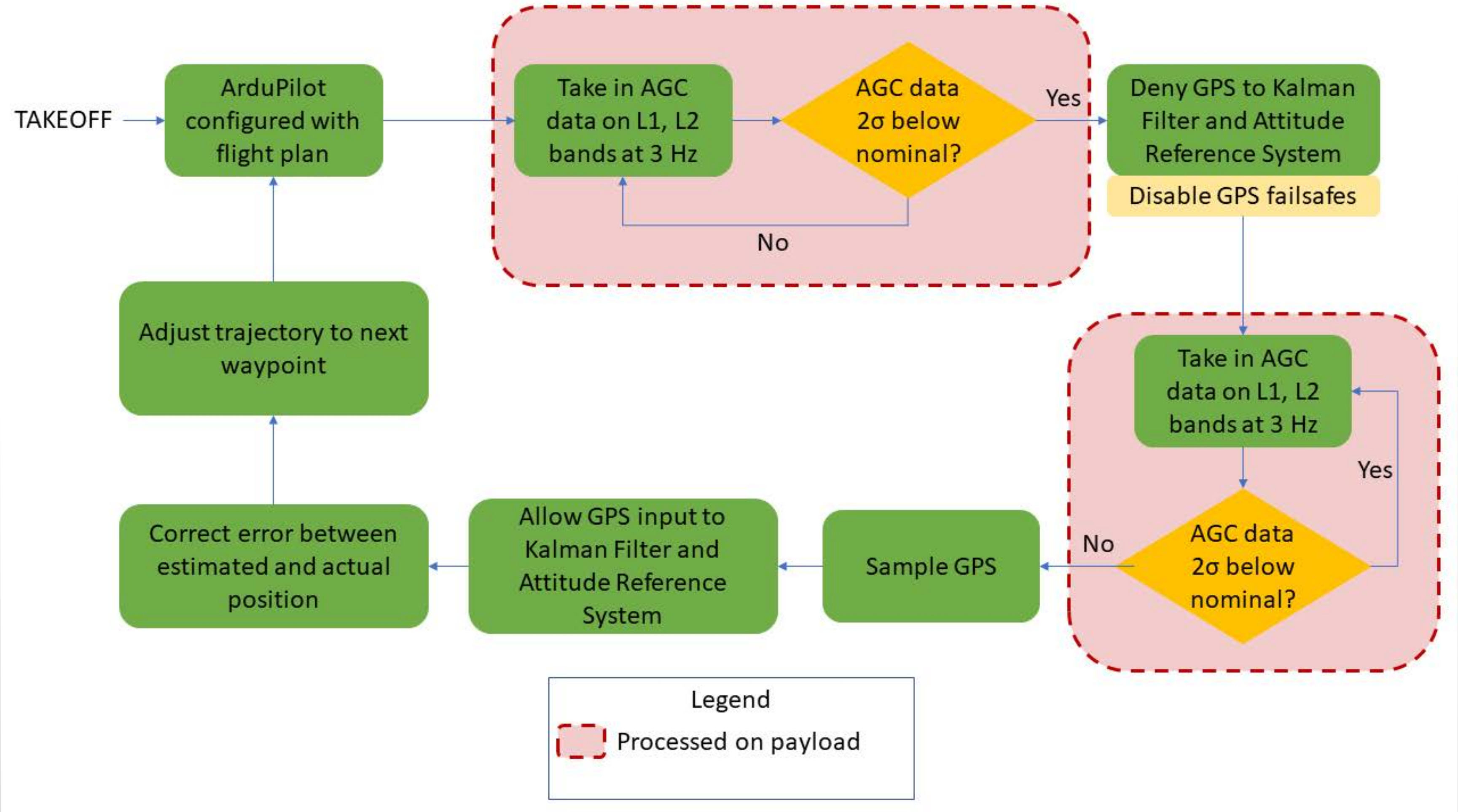
UAS BASELINE DESIGN



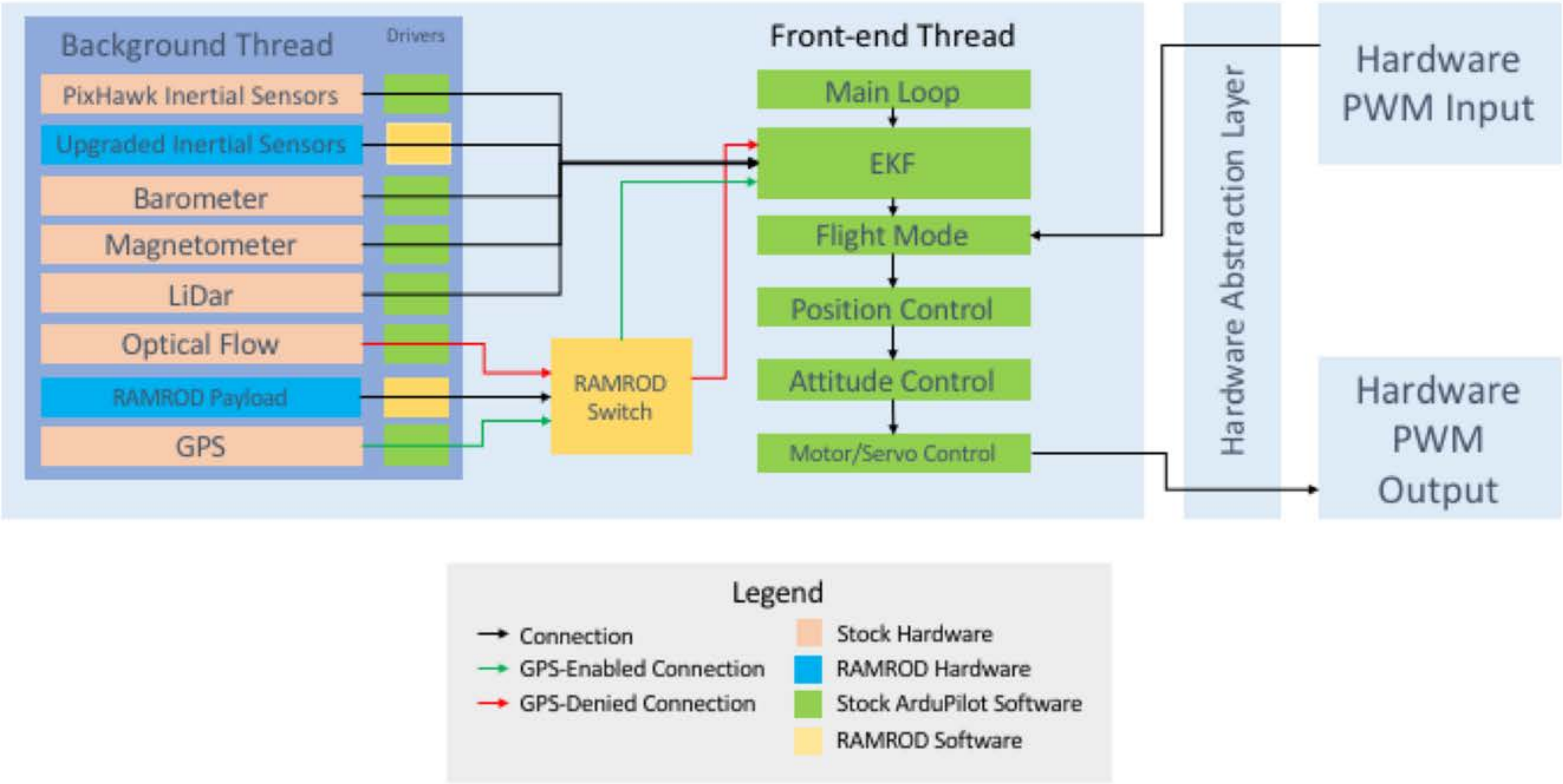
Key Parameter	Value
Wingspan (m)	1.7
Body Length (m)	1.1
Payload Bay Dimensions (cm)	49x8.9x10

Key Parameter	Value
Final CG Location	55 mm aft of leading edge
Final Mass (kg)	3.2
Maximum Flight Time (min)	67

SOFTWARE BASELINE DESIGN
FLIGHT MODE SWITCH



SOFTWARE BASELINE DESIGN
MODIFIED AUTOPILOT

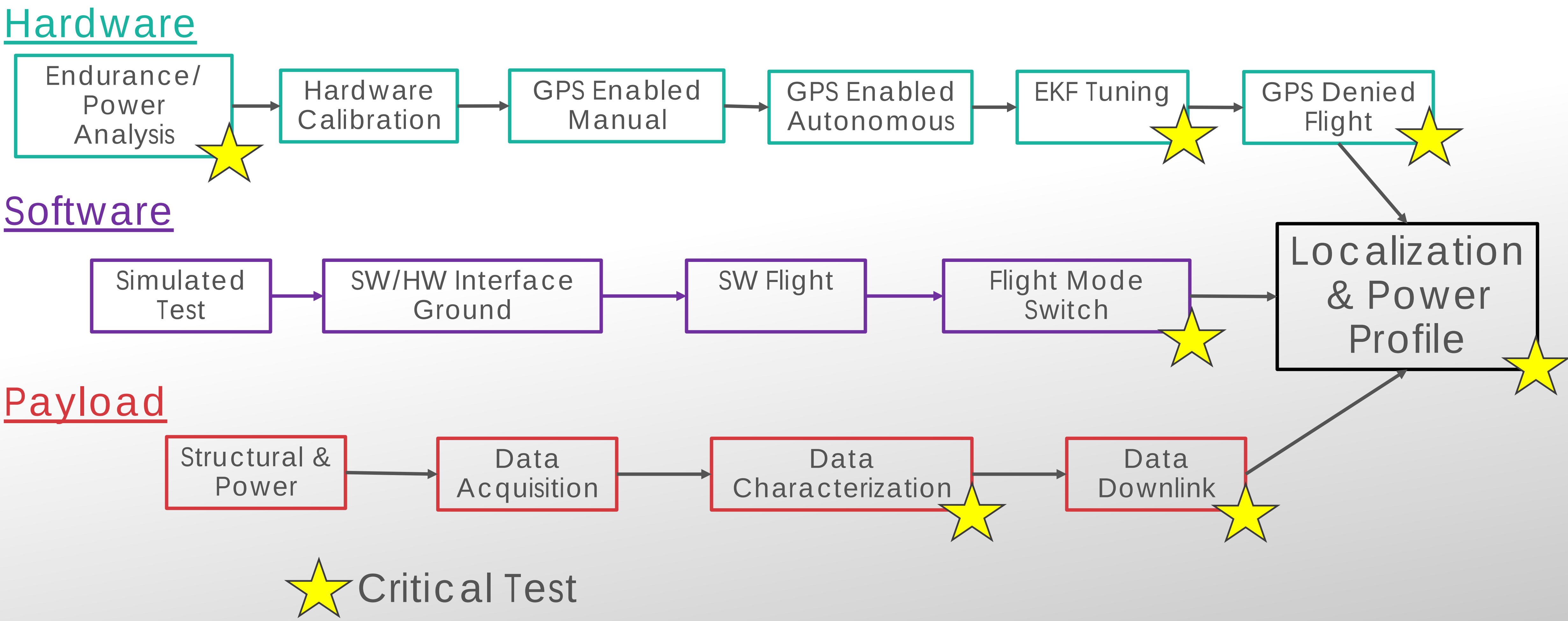


BASELINE DESIGN CHANGES

Design Change	Reason for Change	Impact on Design
Optical flow camera and LiDAR not used for testing	Not confident in landings. Rough landing environment.	Other sensors used for positional estimations were sufficient to minimize error therefore there was no major effect from this design change
Solid nose cone was used for final testing	Original nose cone (clear plastic and foam) was destroyed on a failed take off attempt and 3-D printing a replacement was faster than ordering a new cone	Since the solid nose cone is opaque, the HD camera could no longer be used, but that does not effect mission success
Main wing spar was replaced with brass rod	Original spar was damaged on rough landing and a replacement could not be ordered in time	20g increase in final mass and better structural stability of the wing.

TEST OVERVIEW

TEST FLOW DOWN



TESTING SETBACKS

Flight Testing Issues

Testing Attempts	Successful Flights	Weather Delayed	Hardware Failure	Vehicle Crash	Schedule Conflict	Success Rate
30	5	12	5	4	4	17 %

Main Setbacks for Testing

1. Weather
2. Scheduling
3. Test Location
4. Hardware failures

PAYLOAD AGC CHARACTERIZATION TESTS

Test Descriptions
5 minute tests at 3 different locations
60 min flight test with battery pack
Simulated GPS interference test

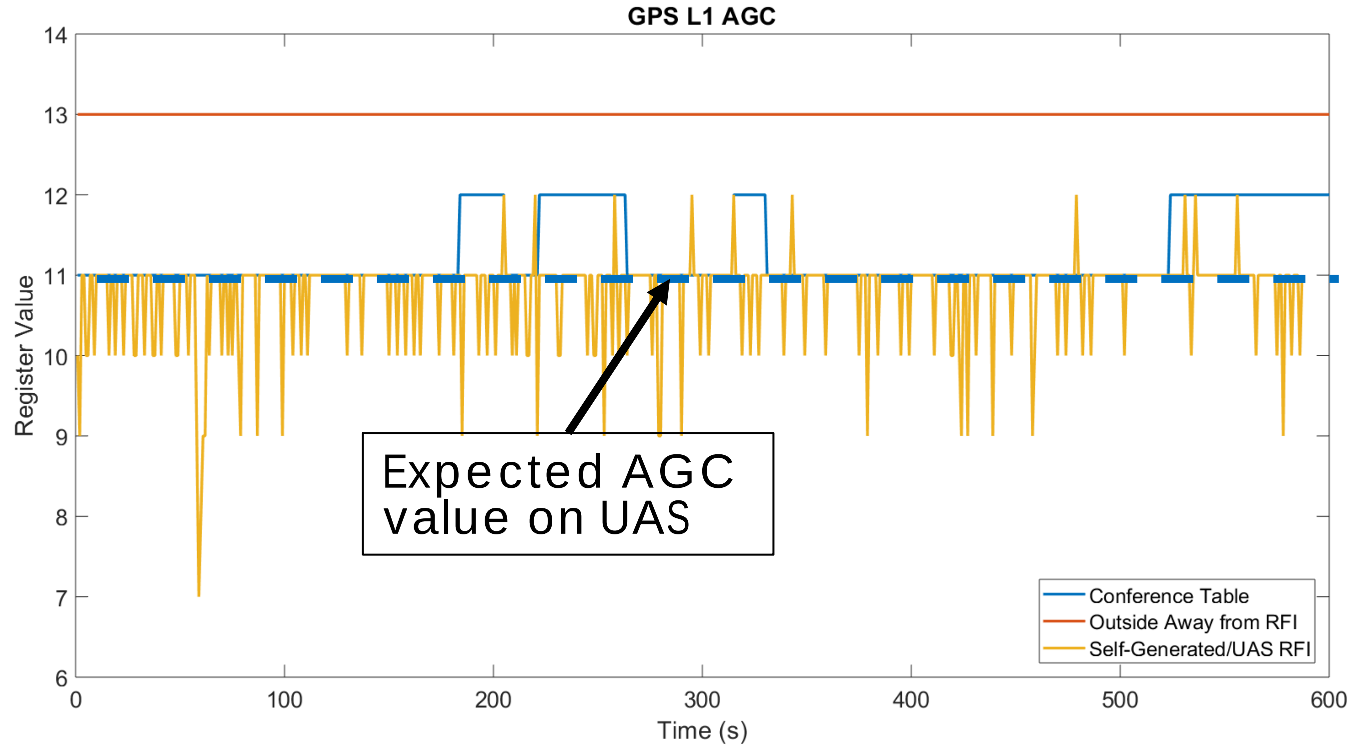
Purpose
Provide accurate GPS-denied threshold
Define when GPS is unreliable

Systems Used
Payload Components

Metric for Success
Capable of running and storing data for 60 minutes
Understand the self-generated RFI on the UAS and when AGC data is unreliable

AGC CHARACTERIZATION TESTS

AGC data from 5-minute Tests in 3 different Locations



Average AGC value on UAS: 10-11

Purpose

- Understand AGC data collected on UAS

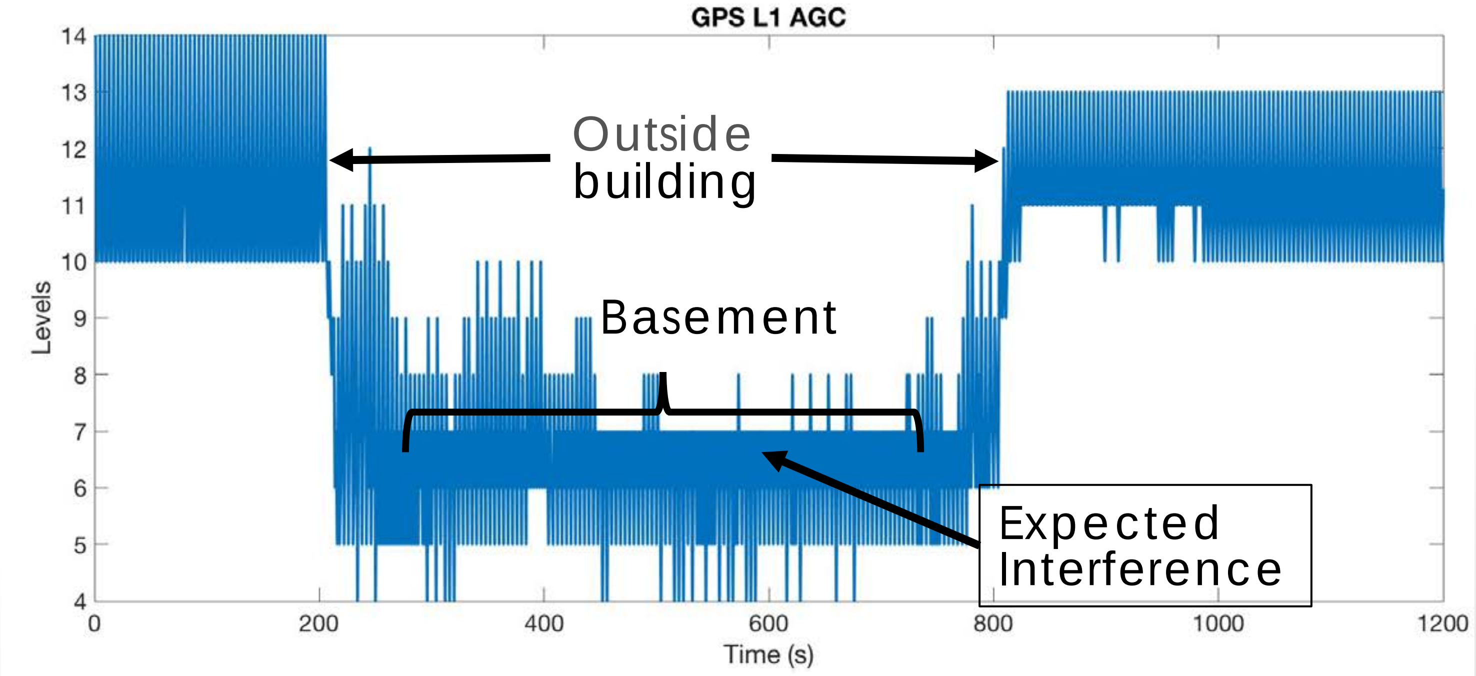
Setup

- LM Room
- CUSB
- UAS

Results

- Average AGC value on UAS: 10.5±0.5

AGC CHARACTERIZATION TESTS



Purpose

- Identify when GPS is unreliable

Setup

- Walked into basement of BESC, simulating unreliable GPS

Results

- Average unreliable GPS value: 6.5±1
- GPS cannot be trusted when AGC < 8

Mission Success Impact

- Creation of power profile map
- Localization of an RFI source
- Reliable flight mode switching
- Satisfies All of FR/DR 12, part of FR/DR 10

POWER AND ENDURANCE TEST

Objective:

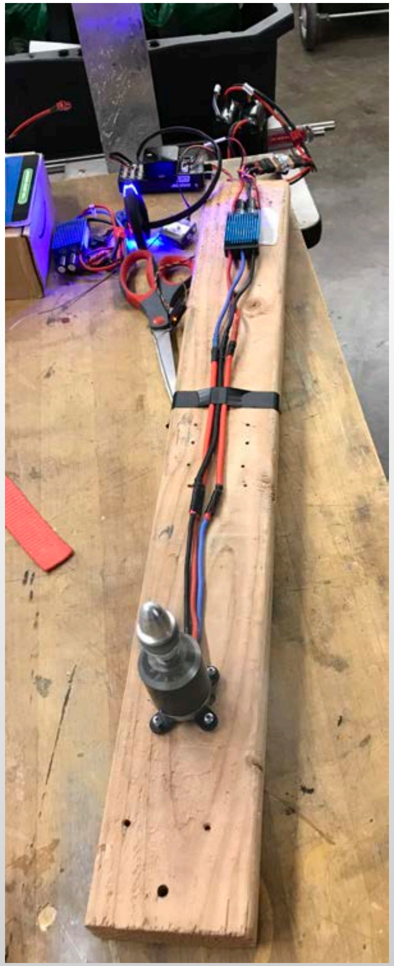
- Verify the UAS is capable of flying for 60 minutes in 30 kph wind
- Confirm UAS efficiency and validate power model

Description

- Static thrust test draining the batteries by 85% capacity
- 35% throttle (30% used for cruise at 60 kph)

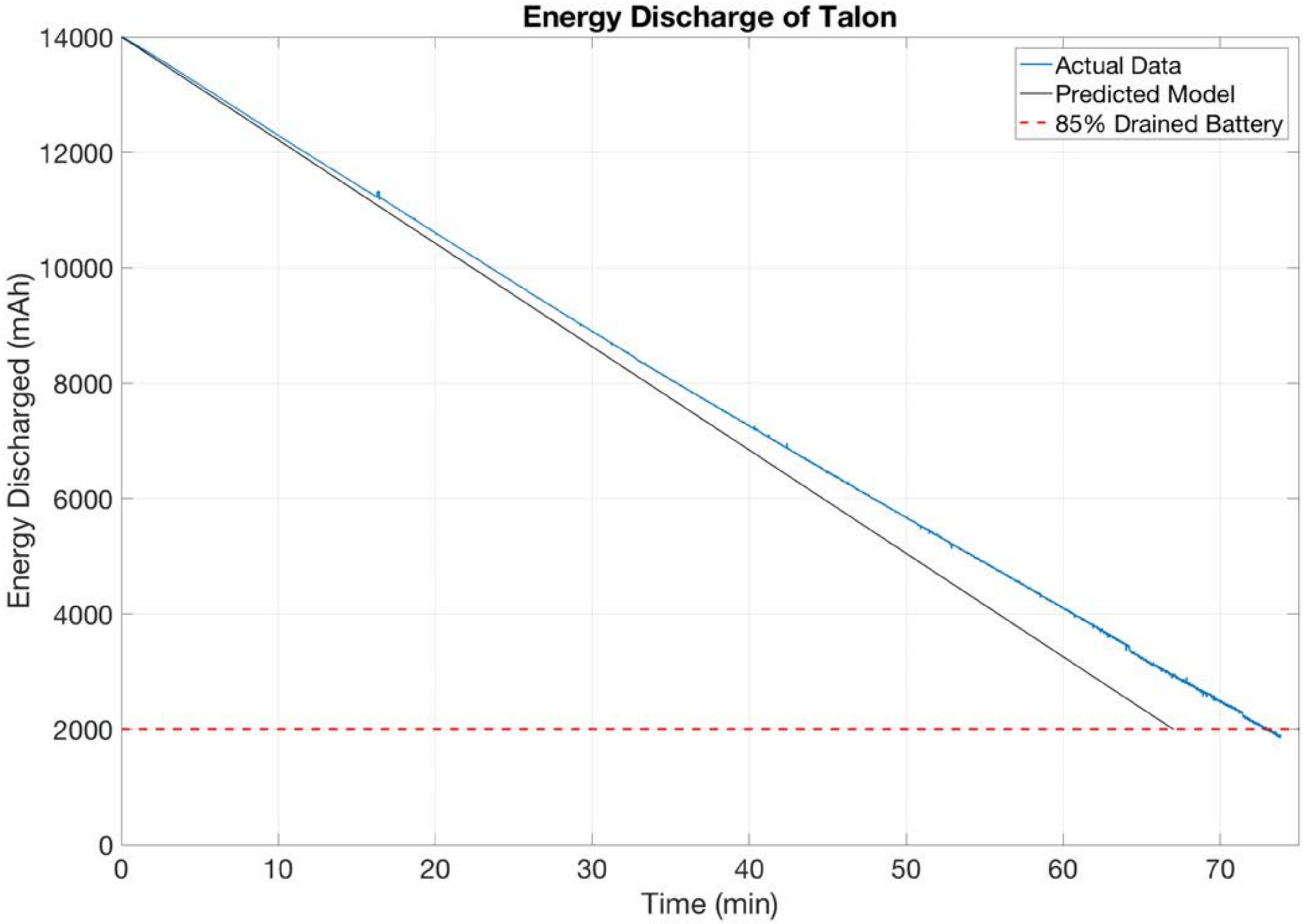
Measurements:

- Recorded using flight controller power module
- Sent over telemetry and logged on ground station
- Voltage (V), Current (A), Discharge (mAh)
- Total Discharge Time (s)



POWER AND ENDURANCE TEST

Expected	Actual
67 minutes	72 minutes



POWER AND ENDURANCE TEST

Verification

- FR 1: The UAS shall sustain flight for 60 minutes
- FR 2: The UAS shall be capable of flying in 30 kph wind
- FR 4: The UAS shall be capable of flying the payload

Confidence

- Capable of sustaining flight for the required time in required wind conditions
- Capable of carrying all payload sensors

EKF FLIGHT TESTING AND TUNING

Description

- Five 10-20 minute flight tests
- Initially manual control, later moving to autonomous flight plans
- Collect EKF position estimates without GPS aided filter, with GPS aided sensors

Systems Used

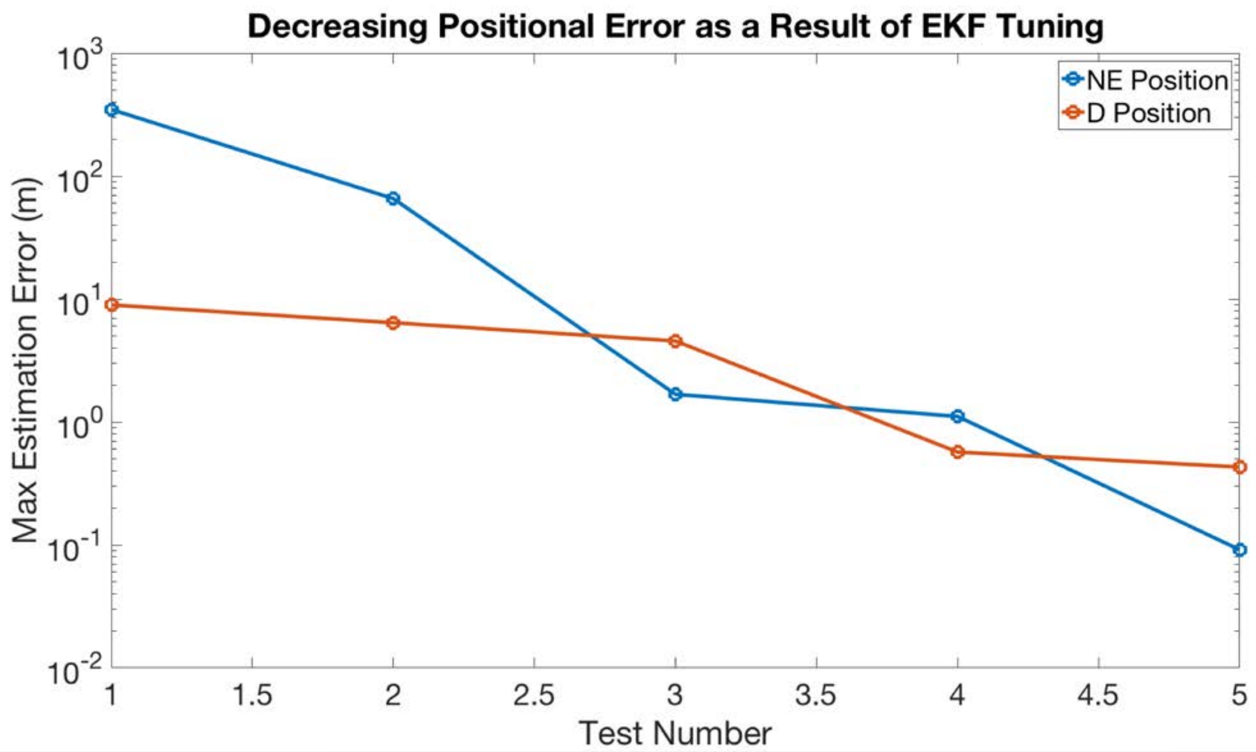
- UAS with all sensors (except payload) integrated

EKF FLIGHT TESTING AND TUNING

Goal: Reduce the estimated positional error through EKF tuning.

- EKF not given GPS position or velocity. IMU and Magnetometer measurements corrected with GPS
- NE positional error reduced from 25.8 m to 0.17 m as a result of EKF tuning
- Truly GPS denied ground testing has shown 37.4 m after ~100 seconds

Metric of Success: The positional error will decrease with tuning, eventually resulting in under 40 m of horizontal error



NE and D Position error for 5 discrete tests. Note the log scale on the y-axis

GPS DENIED FLIGHT TESTING

Objectives:

- Verify ability of UAS to sustain flight in GPS denied state
- Continue tuning EKF
- Achieve level 2 success

Straight and level GPS Denied flight

- 200 m linear distance through GPS denied region
- GPS denied region set using geographic triggers
- 10 passes through GPS denied region

Major systems used in testing:		Metric for Success	Data Collected
Software	• Modified autopilot	• Flight mode switches from GPS guided flight to inertial guided flight	• EKF innovations and estimated position
UAS	• Full flight system • Inertial navigation instruments	• UAS maintains straight & level flight with <40 m drift	• GPS position

DATA LOOKS TOO GOOD

Problem:

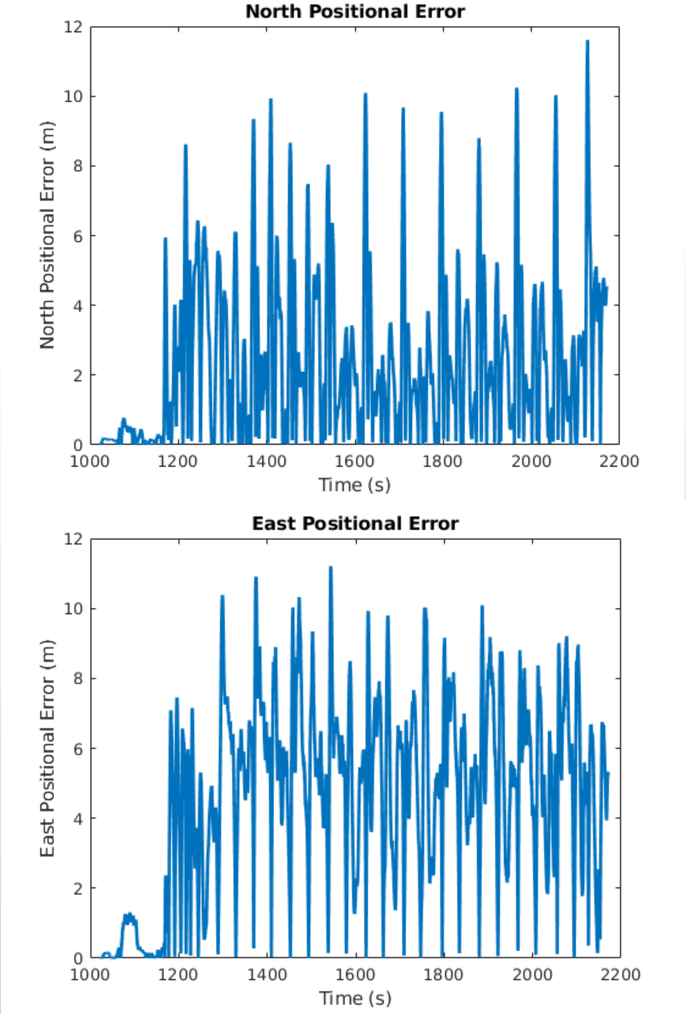
- Upon inspection, positional error was bounded when exponential error was expected
- <10 meter error after 20 minutes

Reason:

- EKF was fully GPS-denied
- However, inertial sensors were being constantly calibrated using GPS drift estimate

Result:

- Autopilot software re-visited to truly deny GPS to all state estimation

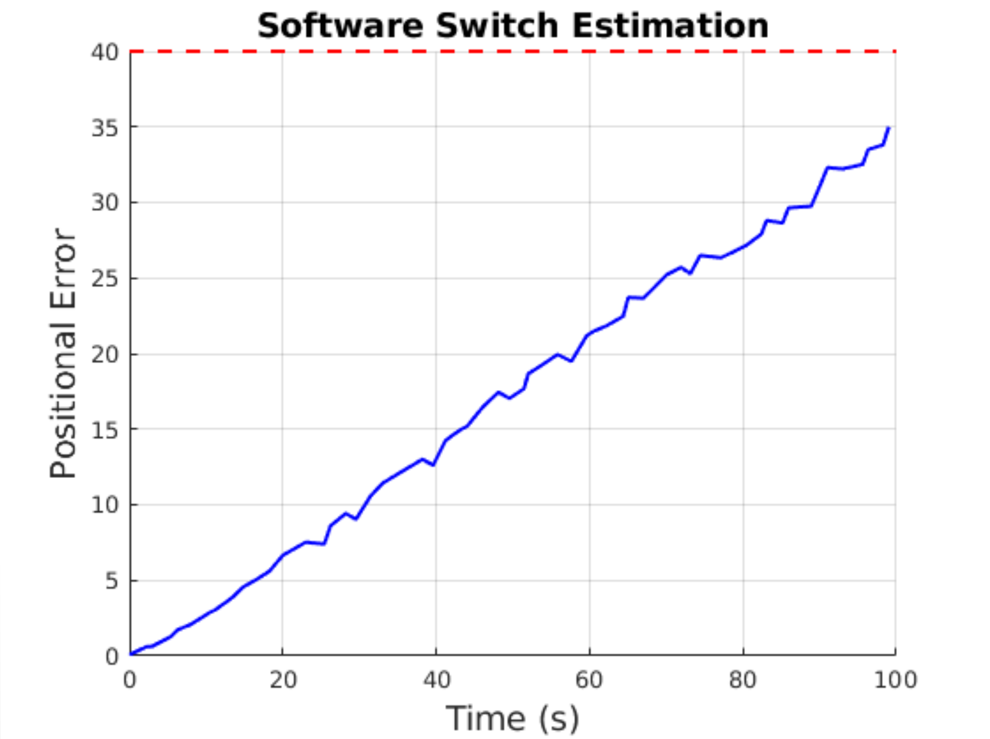


FLIGHT MODE SWITCH GROUND TEST

- Objective:
  - Verify ability for autopilot software to switch from GPS guided to inertial guided flight using geographic trigger
- Test Details:
  - Ground Test: walking
  - Conducted on business field at CU
  - Total of 3 passes with GPS unconnected
  - Total of 12 passes with GPS connected
  - Analyzed data in post processing

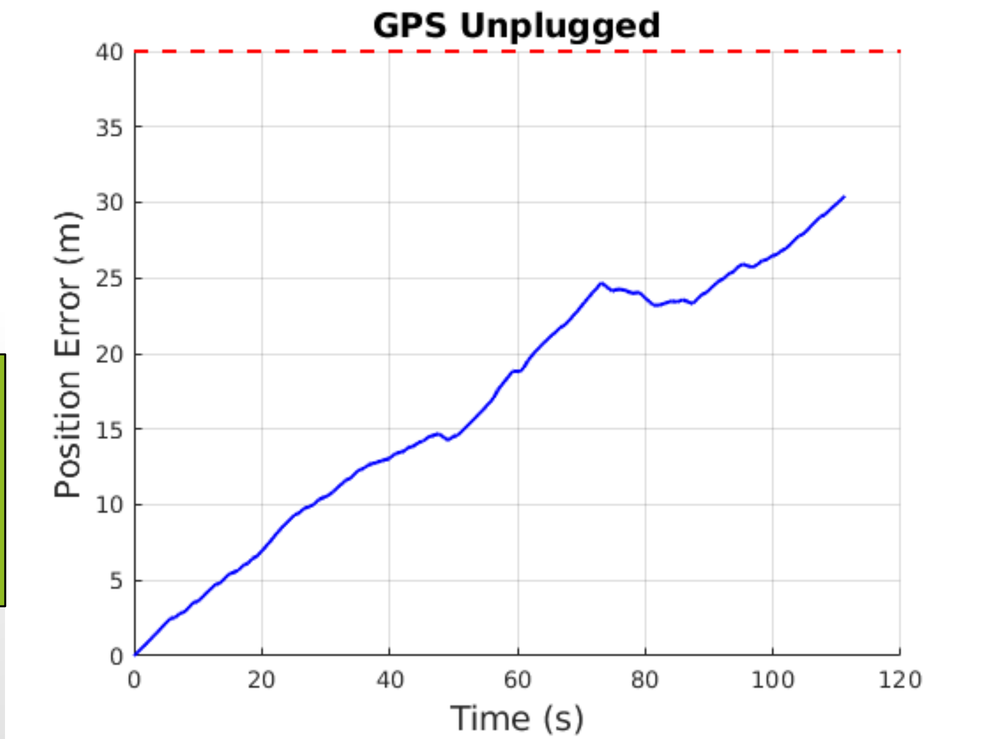
Major systems used in testing:		Metric for Success	Data Collected
Software	• Modified autopilot software	• Average error between GPS connected/ unconnected within 10 m • Matching growth trends in positional error	• EKF estimated latitude and longitude
UAS	• PixHawk flight controller • GPS receiver	• Testbed for software	• GPS position

GPS SWITCH VERIFICATION



Verified

Accuracy requirement: error difference < 10 m



Over 12 Passes:

- Average Max Error: 37.4 m
- Average Time: 103.6 s

Over 3 Passes:

- Average Max Error: 30.43 m
- Average Time: 111.3 s

HARDWARE FAILURE

Problem:

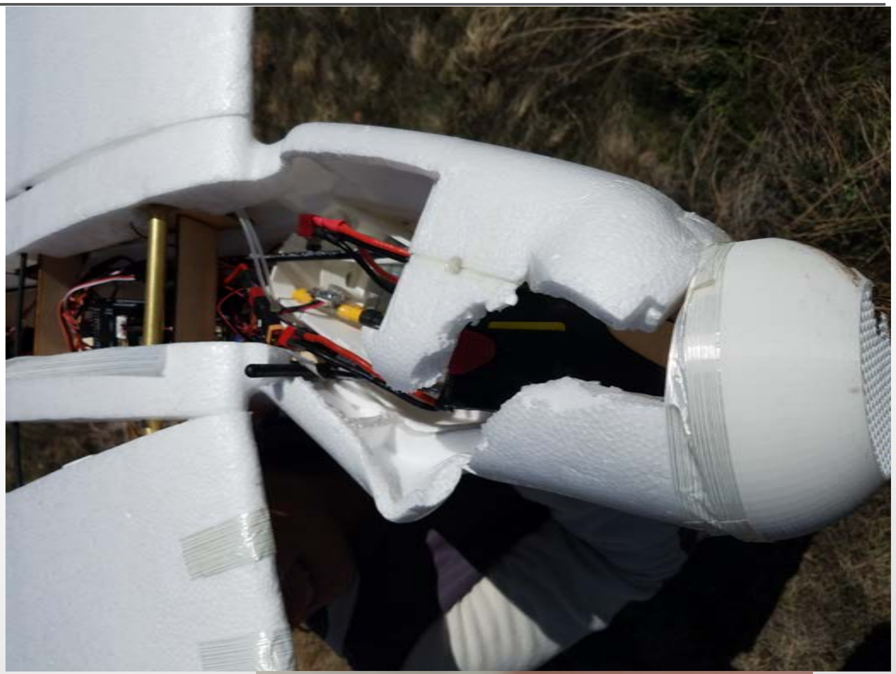
- PixHawk flight controller failed mid-flight due to power loss
- Catastrophophic damage to airframe

Analysis: Caused by broken connector

- Connector briefly disconnected and reconnected, causing a system reboot
- PixHawk could not re-arm during flight

Future Mitigation:

- Inspect hardware prior to every flight



GPS DENIED FLIGHT TEST RESULTS

GPS Denied flight testing was not successful; included in future testing plan

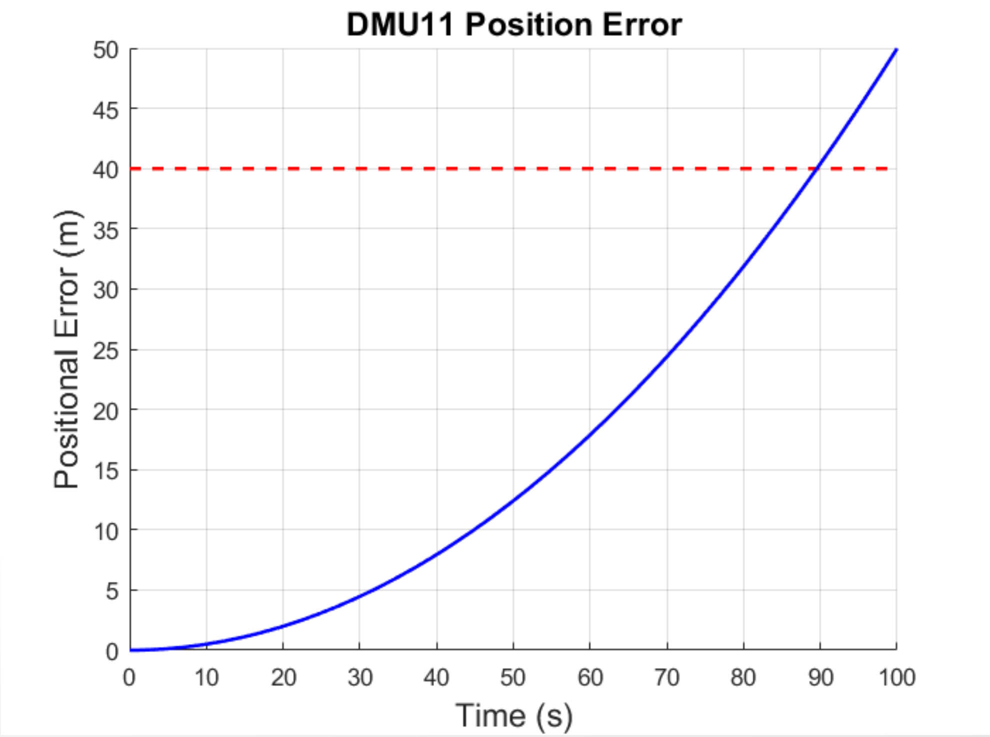
Functional Requirement / Level of Success Validation	
FR 3: The system shall fly and navigate in GPS denied region for linear distance of 1km	NOT Verified
Level 2 Success: The UAS shall allow for maintained straight and level GPS denied flight for 1 km	NOT Verified
Level 3 Success: The UAS shall allow for turning maneuvers in GPS denied conditions and shall keep positional error less than 40 m after 2km of GPS denied flight	NOT Verified

GPS DENIED PERFORMANCE GROUND TEST

- Objective:
  - Analyze performance of inertial sensors in GPS denied conditions
- Test Details:
  - Ground Test: walking
  - Conducted on business field at CU
  - Total of 2 trials (12 passes) within a GPS denied region
  - Analyzed data in post processing

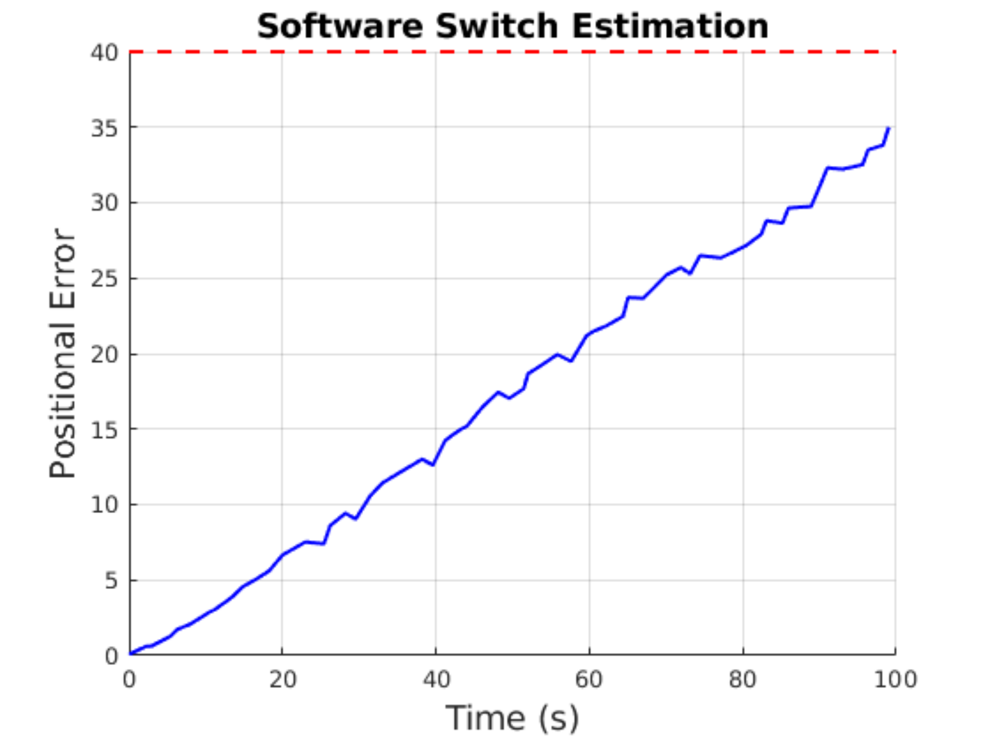
Major systems used in testing:		Metric for Success	Data Collected
Software	• Modified autopilot software		• EKF Estimated latitude and longitude
UAS	• PixHawk flight controller • GPS receiver	• Inertial sensor produce positional error within 40 m after 100 seconds within GPS denied	• GPS position

GPS DENIED PERFORMANCE



Verified

Accuracy requirement: positional error < 40 m



Predicted Error: 49.98 m
Time: 100 s

Over 12 Passes:

- Max Error: 69.02 m
- Average Error: 37.4 m
- Average Time: 103.6 s

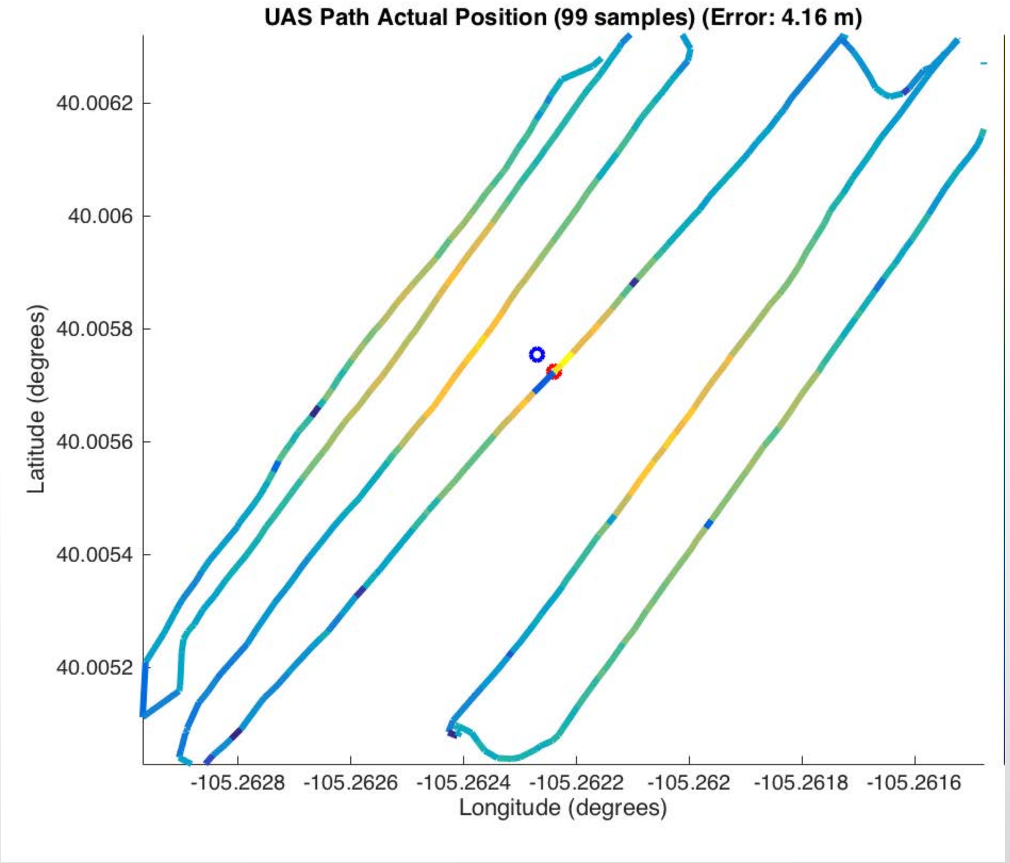
LOCALIZATION OVERVIEW

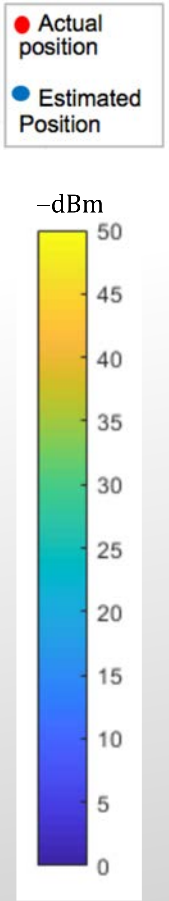
- Test Details:
  - Ground Test: walking
  - Conducted on business field at CU
  - Total of two trials (12 passes)
  - Collected data from Parrot Disco and RAMROD system
  - Performed localization in post-processing
- Functionalities verified:
  - Ability to detect and measure signal from an RFI source
  - Ability to measure estimated position data from EKF in GPS denied

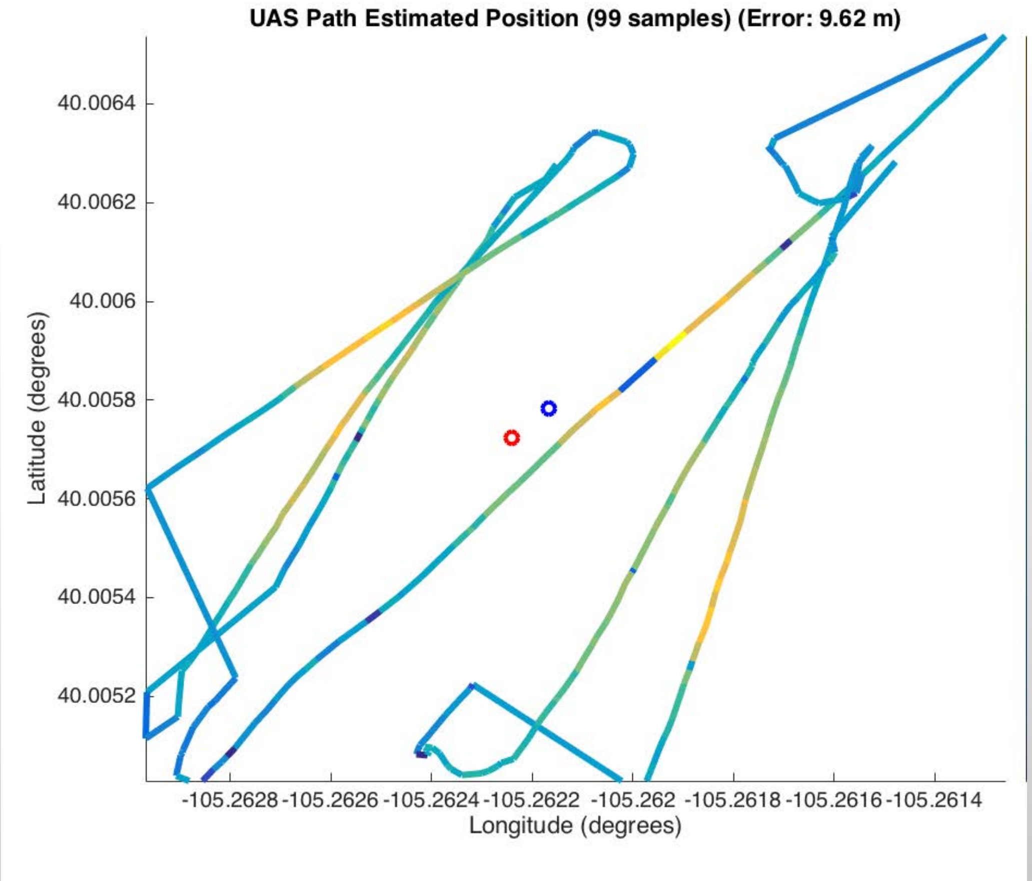
Major systems used in testing:		Metric for Success
Software	• Talon flight software, • Estimated position (EKF output) • Localization algorithm	Localize with 40 m accuracy
UAS	• Full flight system • Inertial navigation instruments	Positional error < 40 m
Parrot Disco	• 2.4GHz receiver	Measure power data on 2.4 GHz band

LOCALIZATION RESULTS

Localization using GPS Position Average Error 6.4 m ⟷ Localization using Estimated Position Average Error: 8.35 m

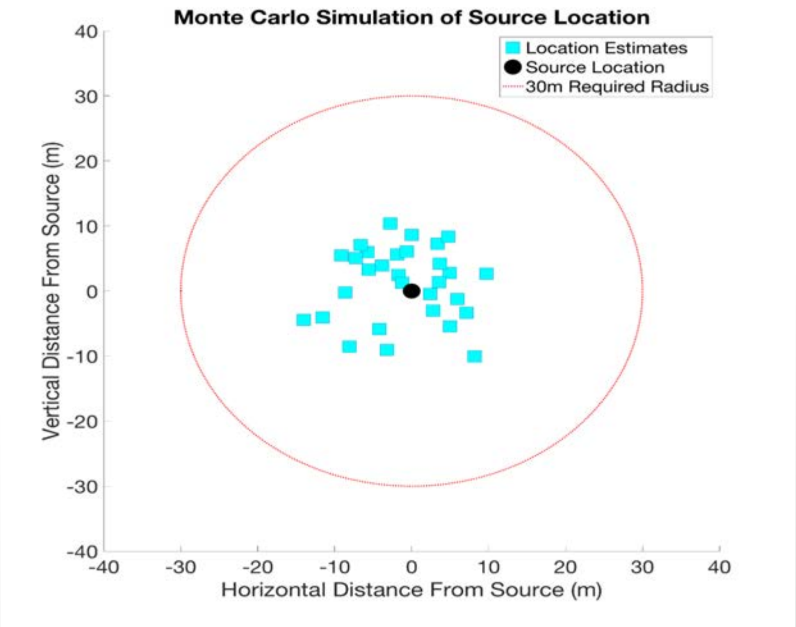






LOCALIZATION MODEL VALIDATION

Localization Model:



- Samples: 100
- Trials: 30
- Accuracy: 8.03 m

Accuracy requirement: error < 40 m

RAMROD Localization Results

Localization with Estimated Position Results	
Trial 1	9.62 m
Trial 2	7.08 m
Average	8.35 m

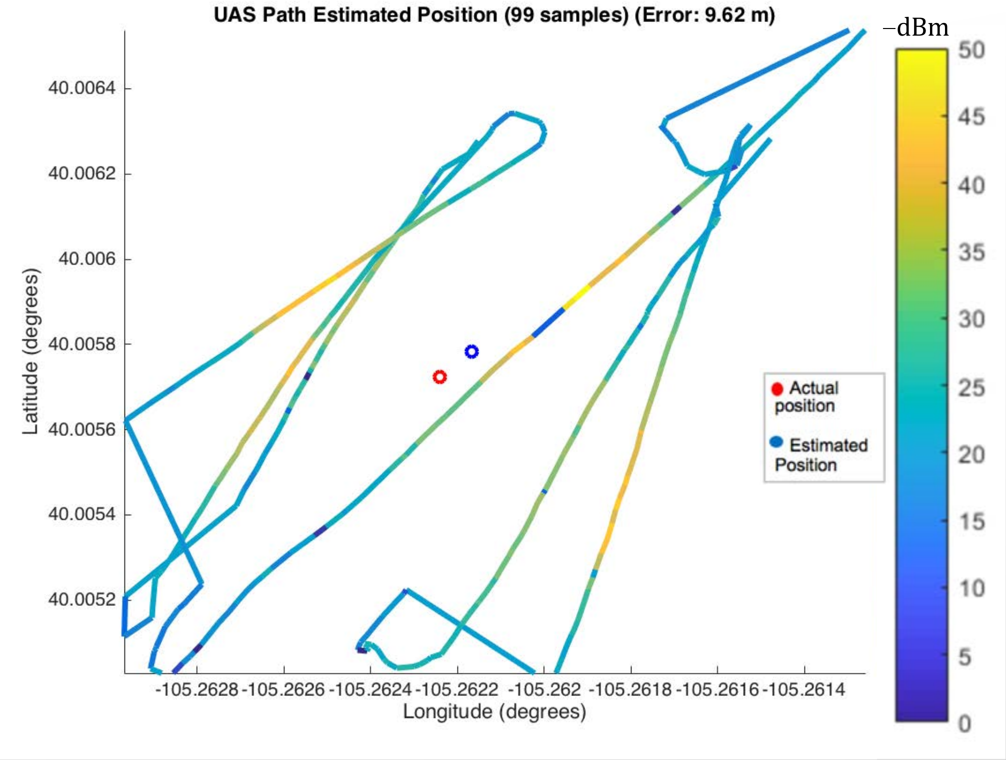
- Samples: 99
- Trials: 2
- Average Accuracy: 8.35 m

LOCALIZATION TEST RESULTS & POWER PROFILE

Localization testing was successful!

Functional Requirement/ Level of Success Validation	
FR 10: The RAMROD system shall generate a power profile of the search area	Verified ✔
FR 12: The Ramrod system shall measure and localize an RF source	Partially Verified
Level 3 Success: The system shall localize within 40m accuracy	Partially Verified

RAMROD Power Profile



FUTURE TESTING

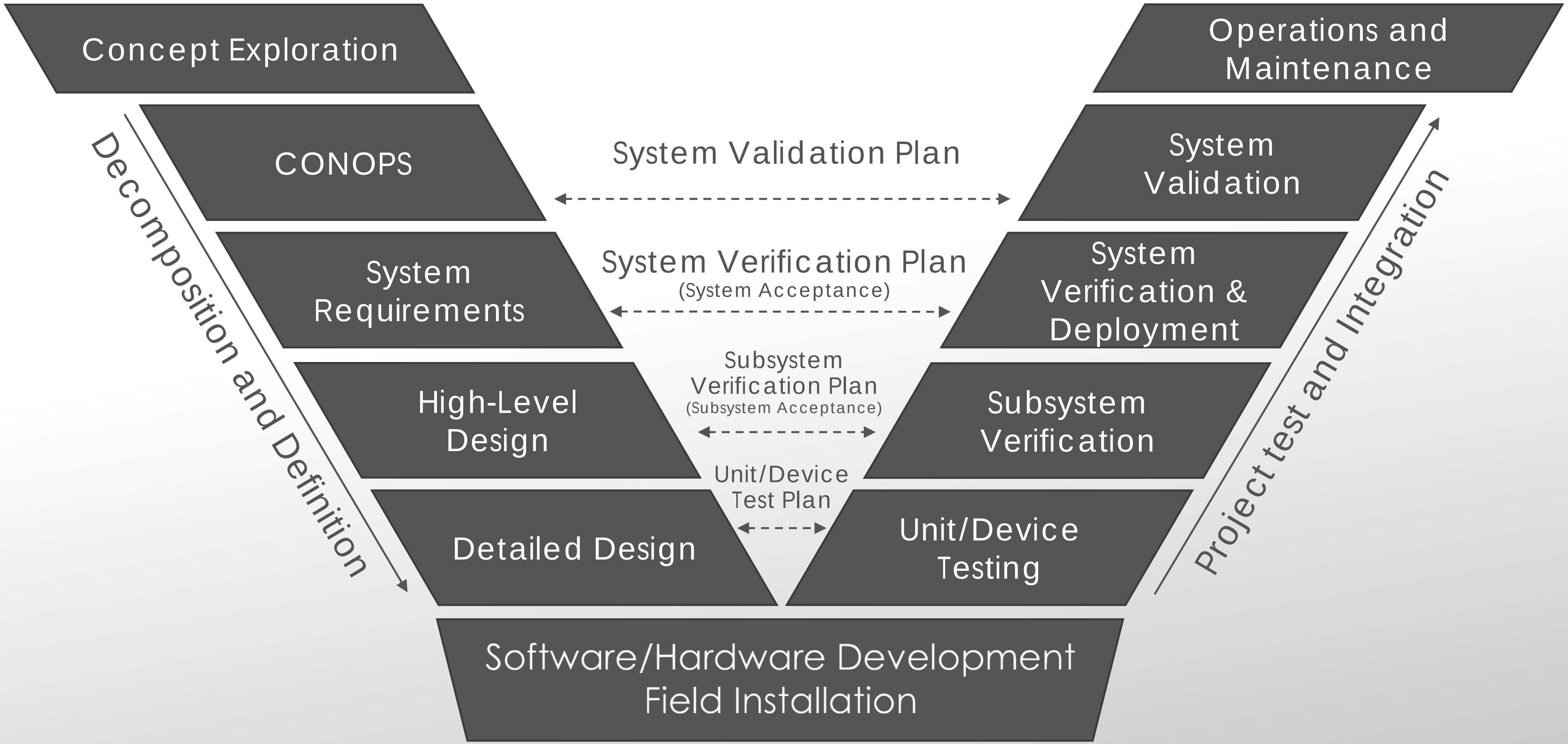
Agenda:

1. Full scale testing over 3km x 3km search area
2. True GPS denied flight (straight & level)
3. Maneuvers in GPS Denied

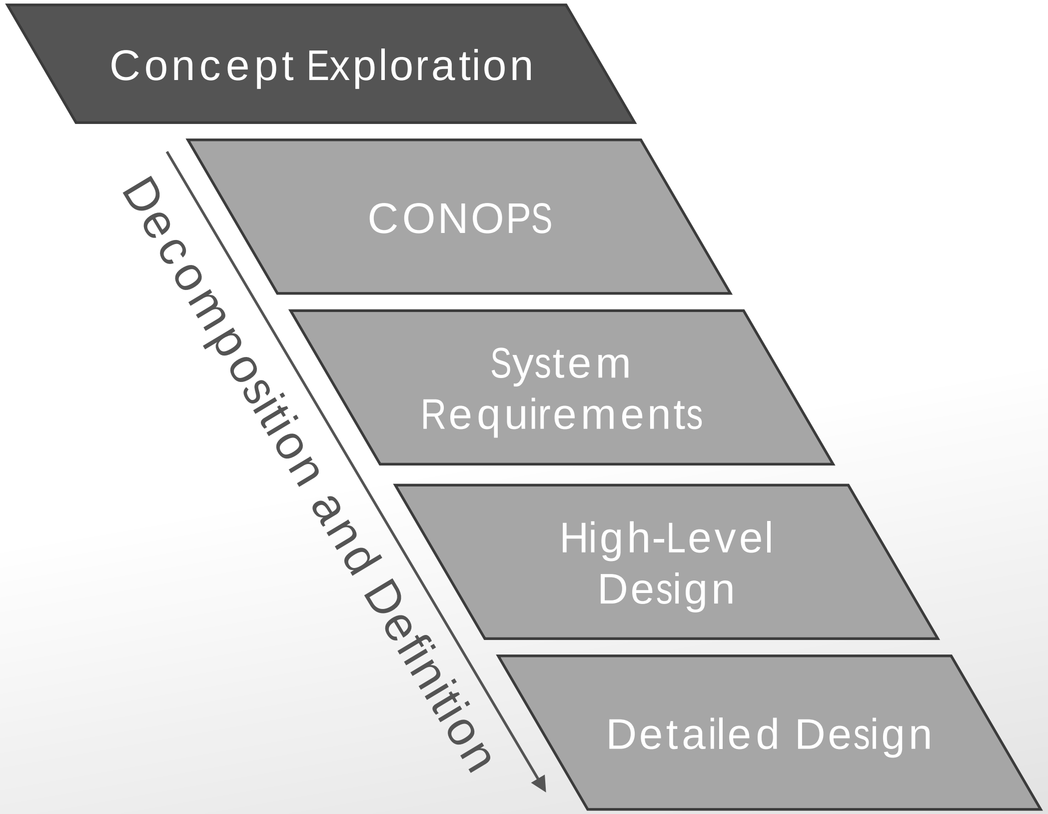
Functional Requirement/ Level of Success Future Validation	
FR 1: The UAS shall sustain flight for at least 60 minutes	Partially Verified
FR 3: The system shall fly and navigate in GPS denied region for linear distance of 1km	NOT Verified
Level 2 Success: The UAS shall have the ability to fly autonomously for 60 minutes with GPS active	Partially Verified
Level 2 Success: Shall allow for maintained straight and level GPS denied flight for 1 km	NOT Verified
Level 3 Success: The UAS shall allow for turning maneuvers in GPS denied conditions and shall keep positional error less than 40m after 2 km of GPS denied flight	NOT Verified

SYSTEMS ENGINEERING

SYSTEMS ENGINEERING V MODEL



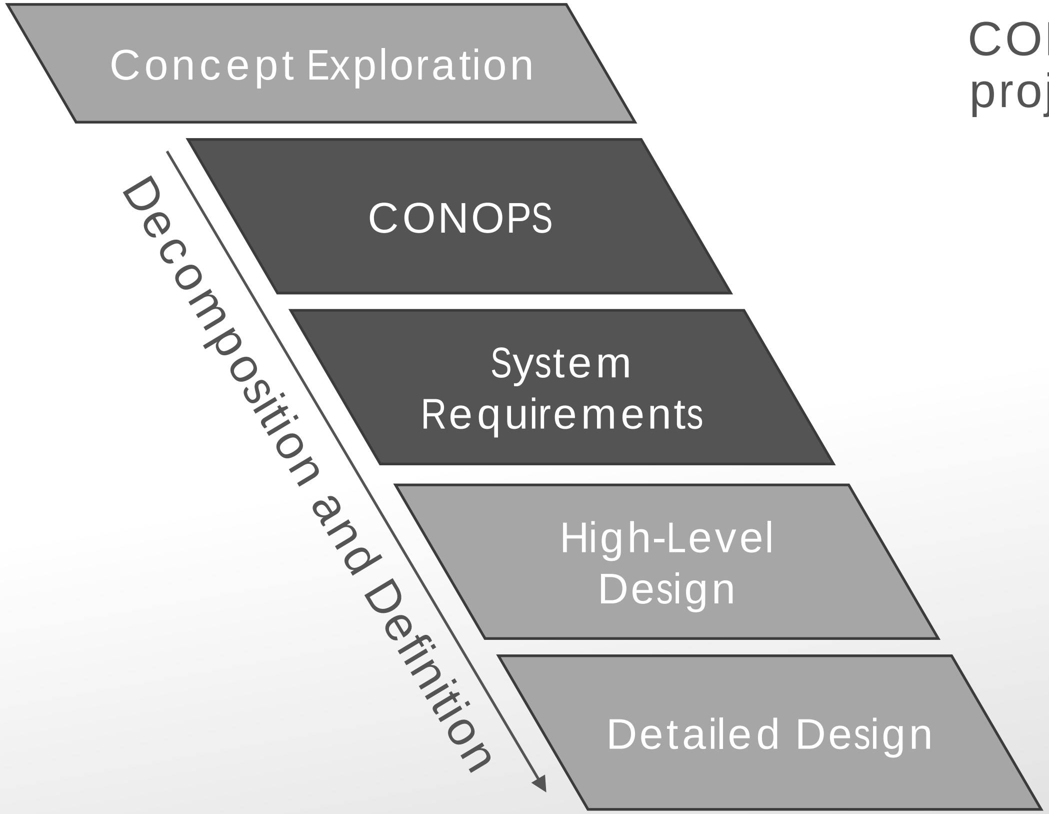
CONCEPT EXPLORATION



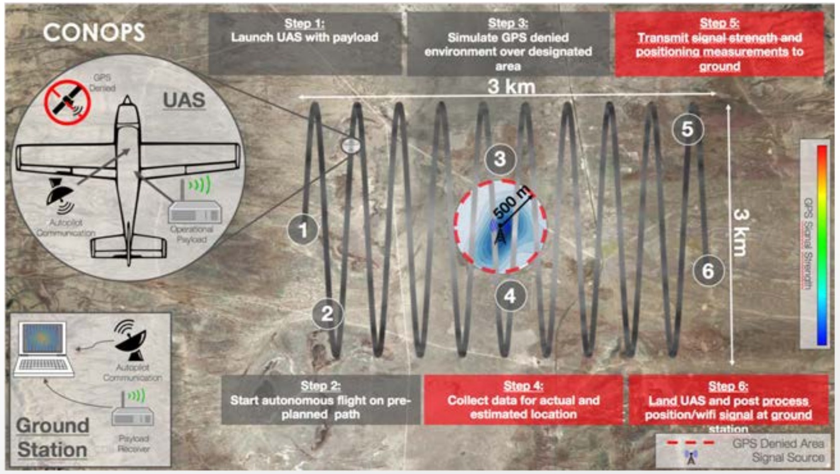
Basic Functional Objectives:

- Fly in GPS denied environment
  - Created need to detect when GPS is cut
- Localize RFI device
  - Created requirement for downlinking data
- One hour flight time
  - Created need for efficient flight platform

CONOPS & SYSTEM REQUIREMENTS



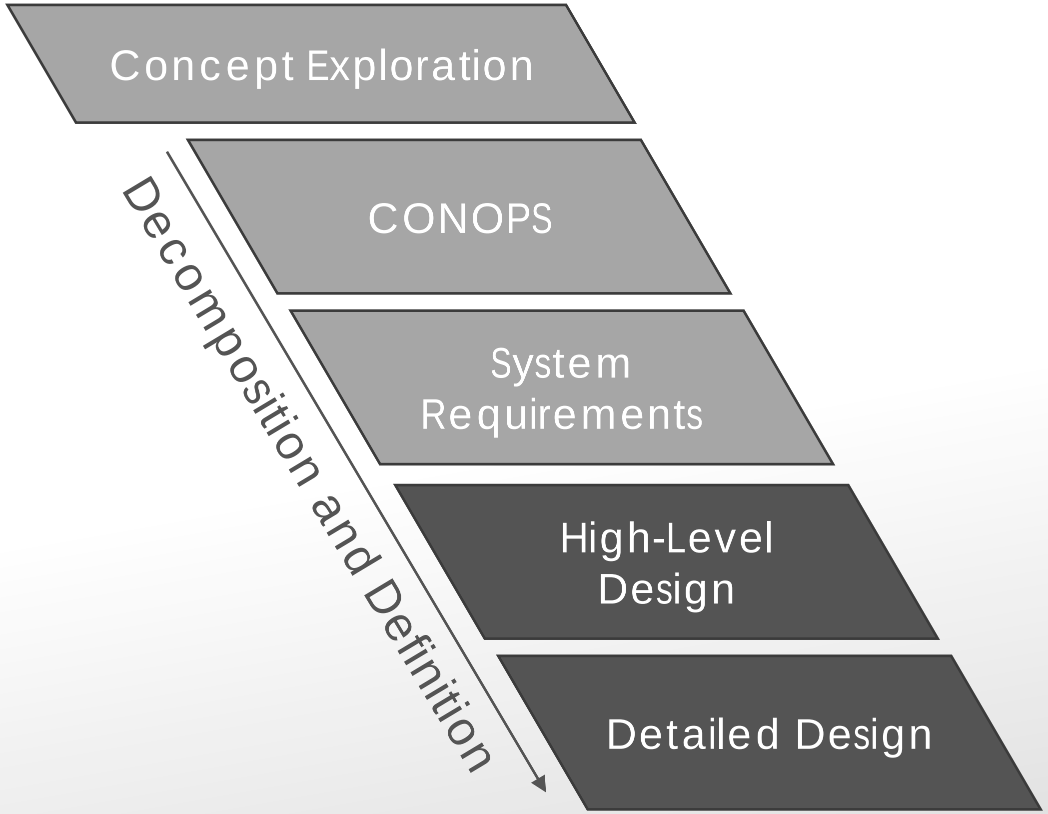
CONOPS was critical for project definition



Requirements Development:

- Requirements stemmed from CONOPS
- Trade Studies
- Derived from each subsystem

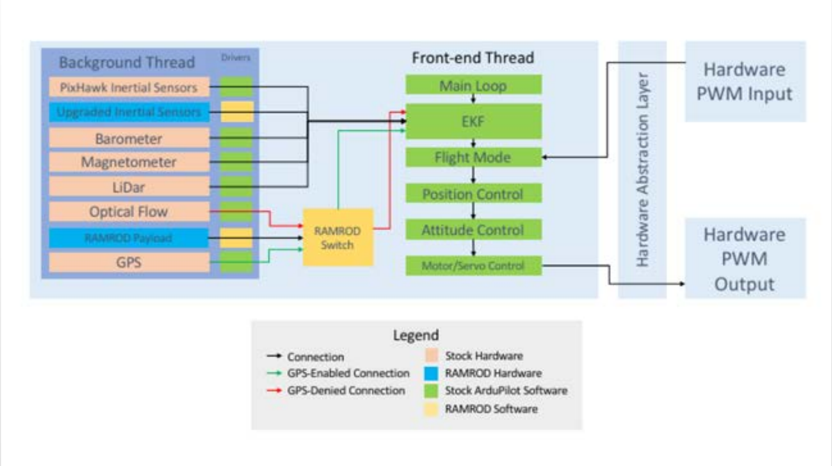
PROJECT DESIGN



Key Trade Study: GPS Denied Guidance

1. Dead Reckoning w/ Inertial Navigation System – light weight, not computationally expensive
2. LiDAR based Localization and Mapping – expensive, computationally expensive
3. LTE Localization – only estimates 2D, high position error

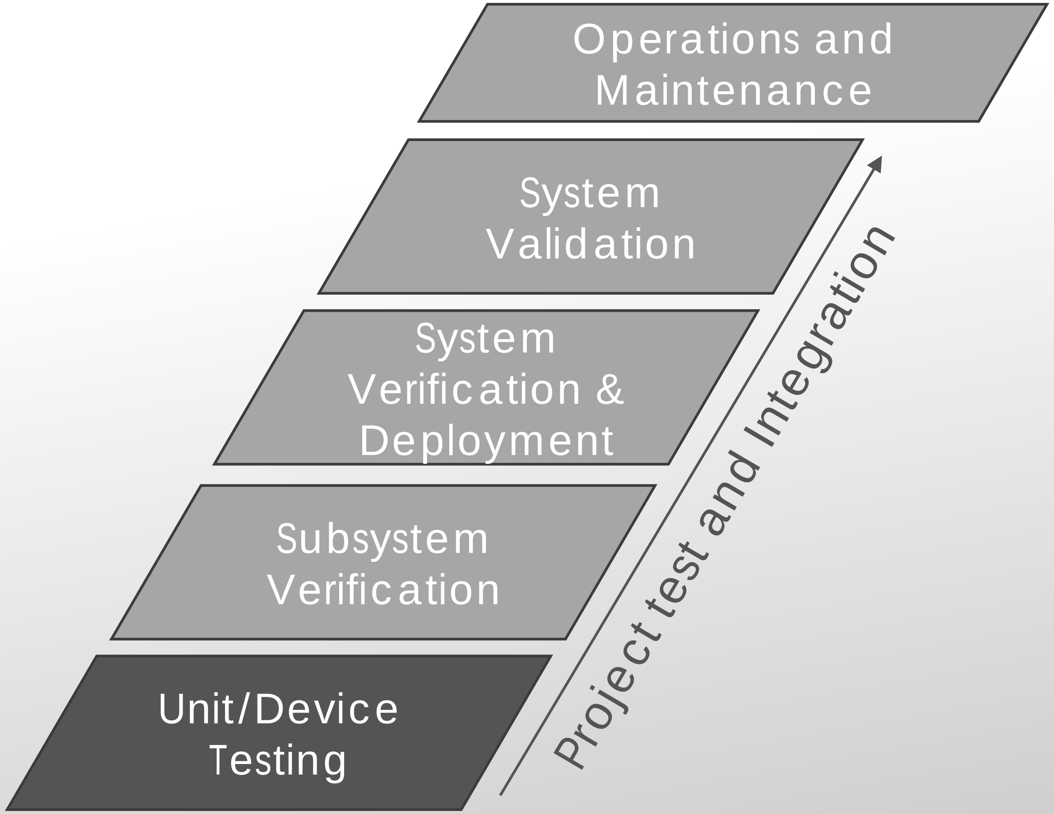
Detailed Design:



UNIT/DEVICE TESTING

Unit Testing:

1. Motor Test
2. Static Ground Test with IMU
   - Verify the specifications from the manufacturer
3. CG Placement
   - Verify that the CG is in the correct location for flight tests

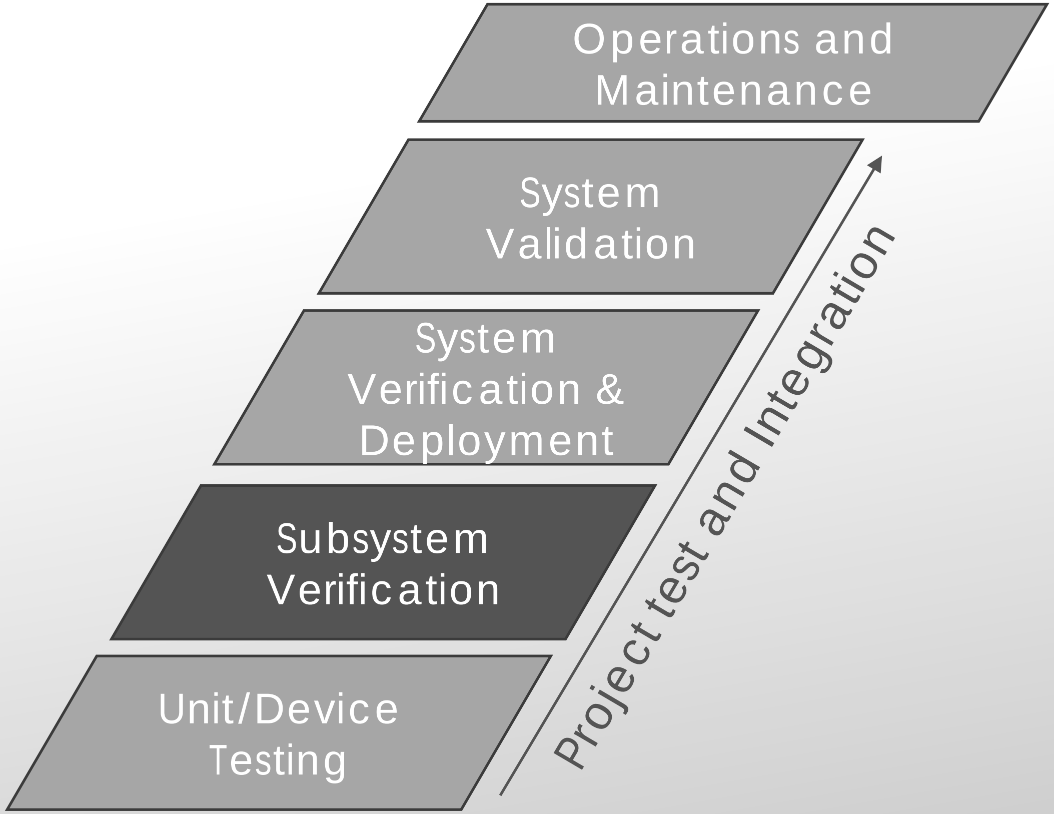


SUBSYSTEM VERIFICATION

UAS Verification
- Airframe assembly
- Calibration flight

Payload Verification
- Downlink testing
- Power test

Autopilot Verification
- Ran software and hardware tests
- Used ArduPilot testing to verify software



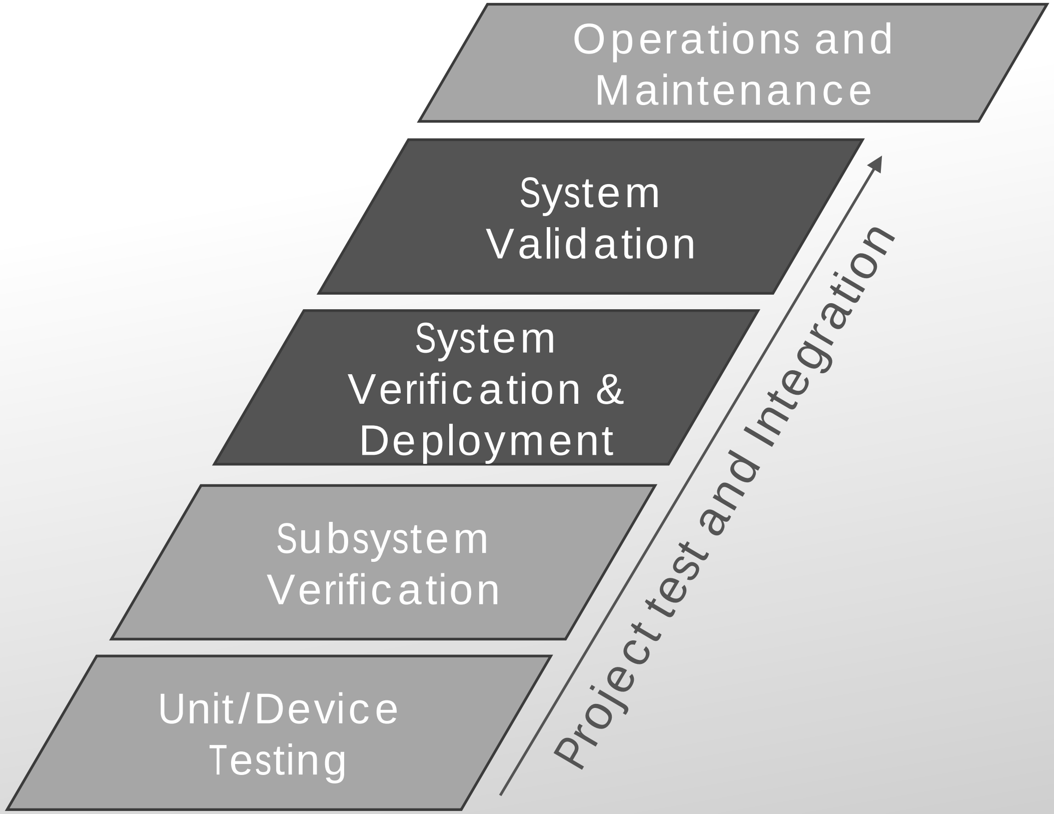
SYSTEM VALIDATION

GPS Denied Flight:

- Goals
  - Fly in GPS denied conditions for 2 km
  - Perform maneuvers in GPS denied
  - Tune the Kalman Filter for our aircraft
- Result
  - Incomplete

Localization:

- Goals
  - Localize signal source within 40 meters
- Result
  - Partially Validated



CDR LEVEL RISK

R1	Too much noise in the AGC data
R2	Time taken to switch flight modes is over 1 second
R3	Structural damage to airframe during take off/landing
R4	Plane lands in wrong location during autonomous landings
R5	Line of sight of the UAS is lost
R6	Higher rate of error due to simulations being incorrect
R7	There is not enough bandwidth to downlink the AGC data

Did not occur	Occurred, no major impact	Occurred, major impact

ISSUES AND CHALLENGES

Risks that were not thought of during design:

Weather

- Numerous tests were postponed due to weather (wind, snow, rain, etc.)

Availability

- Testing at CU South Boulder required two days notification
- Not able to test at Table Mountain
- Never heard back from Boulder Model Airfield

Faulty parts from manufacturer

- Design change of battery during project
- Flight controller board stopped working
- Electronic speed controller did not work

LESSONS LEARNED

- Importance of subsystem testing
- Engineering design process
- Contingency planning
- Expect the little things to happen
- Murphy's Law

PROJECT MANAGEMENT

MANAGEMENT PROCESS

- Team communication is key to success
  - Weekly full team meetings 1-2 times per week
  - Communication via Slack
  - Weekly meetings with customer
- Each subsystem has a lead to ensure each subsystem meets all requirements
- All major changes and issues are reviewed by entire team
  - Minor changes only needed subsystem approval
- Dead lines set on a weekly basis during team meetings

MANAGEMENT SUCCESSES/DIFFICULTIES

Successes	Difficulties
Process worked very well for design portion of the project	Team communication degraded over time
Weekly meeting ensured everyone was aware of the current project status	Lack of accountability for deadlines and tasks
	Could not sustain so many delays during manufacturing and testing

Lessons Learned

- There must be a way to hold team members accountable for tasks
- Must actively ensure that all required subsystem communication occurs
- Things will rarely get done when they are supposed to

CDR BUDGET VS CURRENT BUDGET

Subgroup	Final Expense	Expense at CDR	Difference
UAS	2602	2184	- $418
Payload	1240	1315	+ $75
Misc. Hardware	490	230	- $260
Bungee Launcher	95	25	-$70
Margin	0	750	+$750
Total	4427	4504	+ $77

Unexpected Expenses

- Hardware replacements from crashes
- Additional Batteries
- LTE server

$573 Under Budget!

ESTIMATED TOTAL COST

Cost	Amount
First Semester Hours: 2263	$ 70,718
Spring Semester Hours: 1913	$ 59,782
Total Hours: 4176	$130,500
Material Cost	$ 4,427
Subtotal	$134,927
200% Overhead	$ 261,000
Estimated Total	$ 395,927

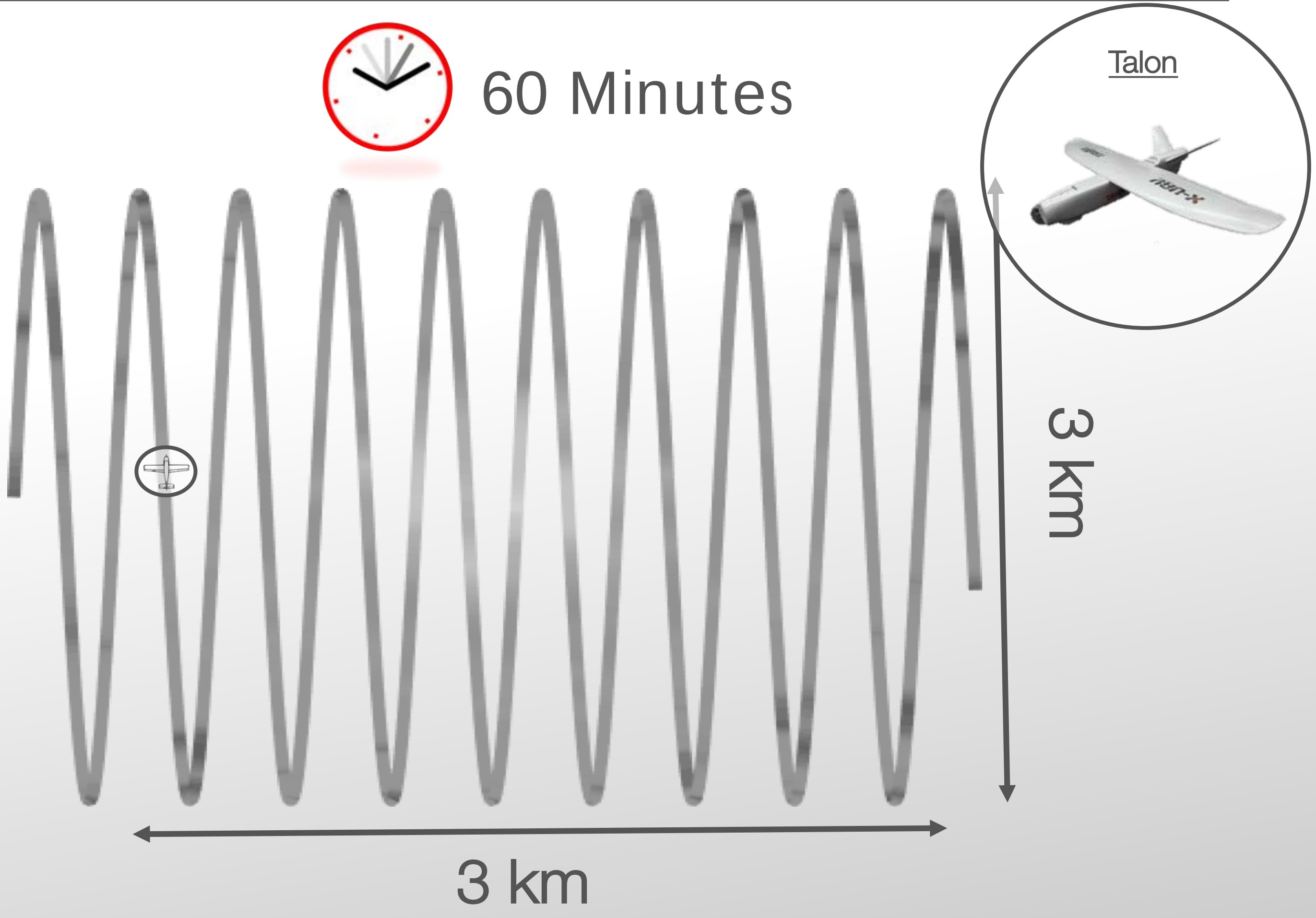
QUESTIONS

BACKUP SLIDES

FULL SCALE SEARCH AREA

Objectives:

1. Extend RAMROD search area to 3km x 3km search area
2. Ensure UAS is capable of 60 minute autonomous flight time
3. Verify autonomous landing capabilities
4. Achieve level 2 success and verify FR 3



TRUE GPS DENIED STRAIGHT AND LEVEL

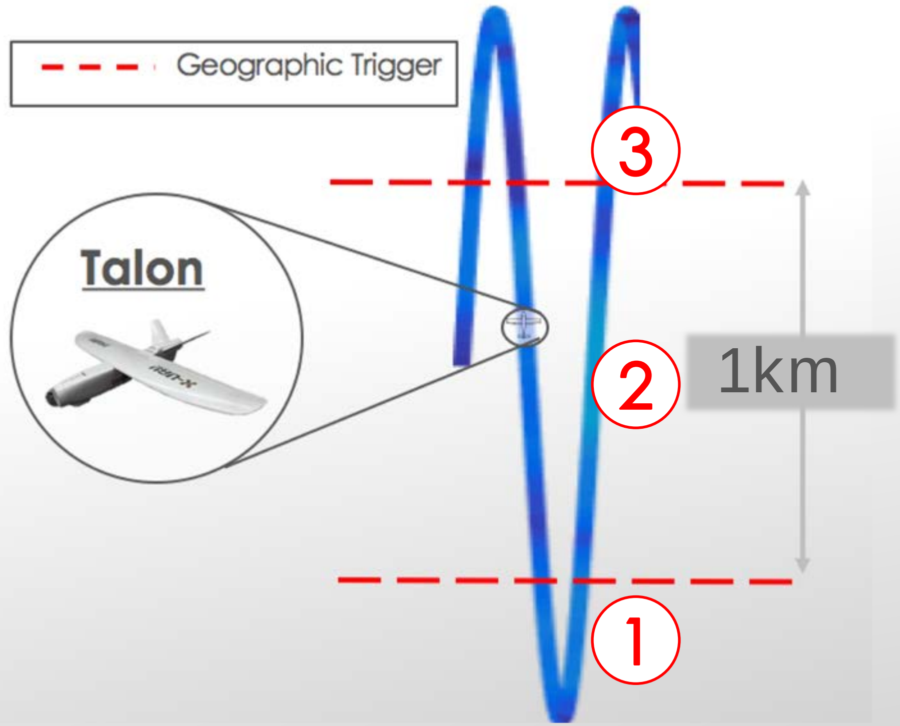
Objectives:

1. Continue tuning EKF
2. Verify that UAS can sustain flight in GPS denied state
3. Achieve level 2 success

1 Geographic Location triggers switch to GPS Denied flight mode

2 Talon flies straight for 200 meters with inertial navigation

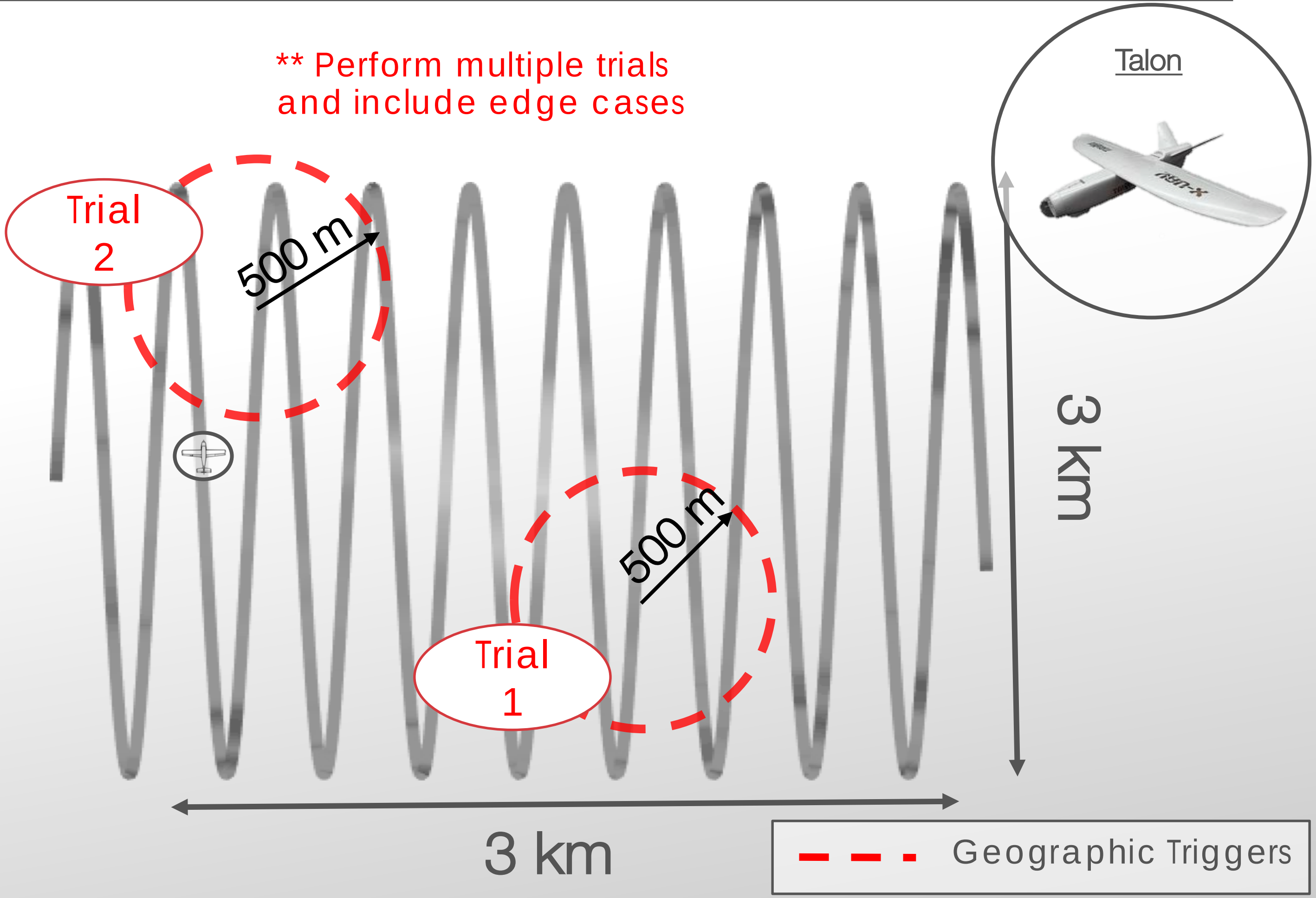
3 Autopilot switched back to GPS enabled state and completes flight plan guided with GPS



MANEUVERS IN GPS DENIED

Objectives:

1. Ensure UAS can maneuver around waypoints in GPS denied state
2. Include multiple trials for performance analysis
3. Full system integration
4. Achieve level 3 success



REFERENCE SLIDES

- Not included in presentation, used for reference for requirement verification
- Use these as a reference for our requirements verification and data collection!

FR 1: THE UAS SHALL SUSTAIN FLIGHT FOR 60 MINUTES

Test:

1. Fly at 40% throttle with max weight
2. Ensure UAS capable of 60 minute flight

Verification

1. Use Pixhawk data to verify 60 minute flight
2. Extrapolate data to analyze flight time capabilities
3. Compare to Power Model from PDR

FR 2: UAS SHALL BE CAPABLE OF FLYING IN 30KM/HR WINDS

Test:

1. Fly at 80% throttle with max weight
2. Ensure UAS capable of 30km/hr flight speed for 60 minutes

Verification

1. Use pixhawk data to analyze max speed and average speed
2. Analyze throttle needed to achieve 30km/hr sustained 60 minute flight
3. Extrapolate data and analyze performance
   - Show throttle vs speed data
   - Compare to flight model

FR 3: THE SYSTEM SHALL FLY AND NAVIGATE IN GPS DENIED REGION FOR LINEAR DISTANCE OF 1KM

Test:

1. TRR Plan: Initial GPS denied flight

Verification

1. Quantify position error
2. Ensure inertial drift is below 40m
3. Perform 5-10 redundant tests and analyze error
4. Compare to static IMU model

FR: 4 UAS SHALL FLY WITH ALL NECESSARY HW AND INSTRUMENTATION

Test:

1. Fly at 40% throttle with max weight
2. Ensure UAS capable of 60 minute flight

Verification

1. Use Pixhawk data to verify 60 minute flight
2. Extrapolate data to analyze flight time capabilities
3. Compare to Power Model from PDR

FR 5: THE UAS SHALL ADHERE TO ALL FAA & CU REGULATIONS

Verification

1. Inspection

FR 6: UAS SHALL BE CAPABLE OF FLYING THE PAYLOAD

Test:

1. How does battery life depend on UAS weight?
2. What is max flight time with full payload weight?
3. What is max speed with full payload weight (for 60 minute flight)

Verification

1. Inspection: show that payload fits inside UAS
2. Show UAS is capable of 60 minute flight at current weight (with payload)
3. Compare to Power Model from PDR

FR 7: THE PAYLOAD SHALL BE CAPABLE OF FULL AUTONOMOUS FLIGHT

Test:

1. Show parameters for autonomous flight (including launch, landing, and flight path)
2. Fly autonomously around a series of set waypoints to analyze the accuracy of the UAS on the flight path

Verification

1. Present the average distance to a waypoint that the UAS achieves during autonomous flight
2. Analyze error

FR 8: THE RAMROD SYSTEM SHALL SEAMLESSLY SWITCH FROM GPS GUIDED FLIGHT TO INERTIAL GUIDED FLIGHT WITHIN ONE SECOND

Test:

1. Ground test: test switch time and switch capabilities
2. Ground test: flight mode switch using actual AGC data? (data from Akos?)
3. Flight test: test the flight mode switch during flight

Verification

1. Present ground test results -> verify ground test capabilities
2. Present flight test results
3. Verify switch time results
4. Analyze error
   - Average switch time?
   - Number of failed switches?
   - SD of data sets

FR 9: THE RAMROD SYSTEM SHALL DOWNLINK THREE DEGREES OF FREEDOM ,AGC AND I.F. DATA

Test:

1. Downlink data and ensure that downlink speed matches 4G LTE network capability

Verification

1. Present downlink speed and capability
2. Number of dropped packets?

FR 10: THE RAMROD SYSTEM SHALL GENERATE A POWER PROFILE OF THE SEARCH AREA

Test:

1. Gather ACG data using Parrot disco
2. Gather position data using Talon
3. Generate power profile

Verification

1. Present power profile
2. Analyze error in true position and estimate position in power profile

FR 11: THE PAYLOAD SHALL FIT INSIDE THE UAS

Test:

1. Is this one even necessary?

FR 12: THE RAMROD SYSTEM SHALL MEASURE AND LOCALIZE AN RF SOURCE

Test:

1. Collect AGC data using payload
2. Gather inertial drift data from static tests, ground test, and flight test.
3. Localize source using Disco/Talon

Verification

1. Show that data is accurate AGC data linked with a geographic position
2. Present localization accuracy
3. Analyze error
4. Compare to PDOA model

PAYLOAD DOWNLINKING TESTS

Downlinking: Upload AGC data received to a web server and download onto a ground computer

Purpose: To understand possible data rates and access collected AGC data during a live test, To verify requirements FR?, FR?, and FR?.

- 5 *speedtest.net* tests at various positions at testing location to determine data rates
- Dowlinking test to ensure proper data transfer MZ -> server -> ground computer

Components

- GPS Antenna and Signal Filter
- Microcontroller and USB Drive
- Battery Pack
- 4G LTE Modem
- Ground Computer

PIXHAWK/MICROZED INTERFACE TESTS

Receives:
Time [s],
Reliability on
GPS L1 L2

```
66.0,0,0
66.2,0,0
66.4,0,0
66.6,0,0
66.8,1,0
67.0,1,1
67.2,0,0
67.4,0,1
67.6,1,1
67.8,0,1
68.0,1,0
68.2,1,1
68.4,1,1
68.6,1,1
68.8,1,1
69.0,1,1
```

to microcontroller →

Simulated GPS Switch

← to flight controller

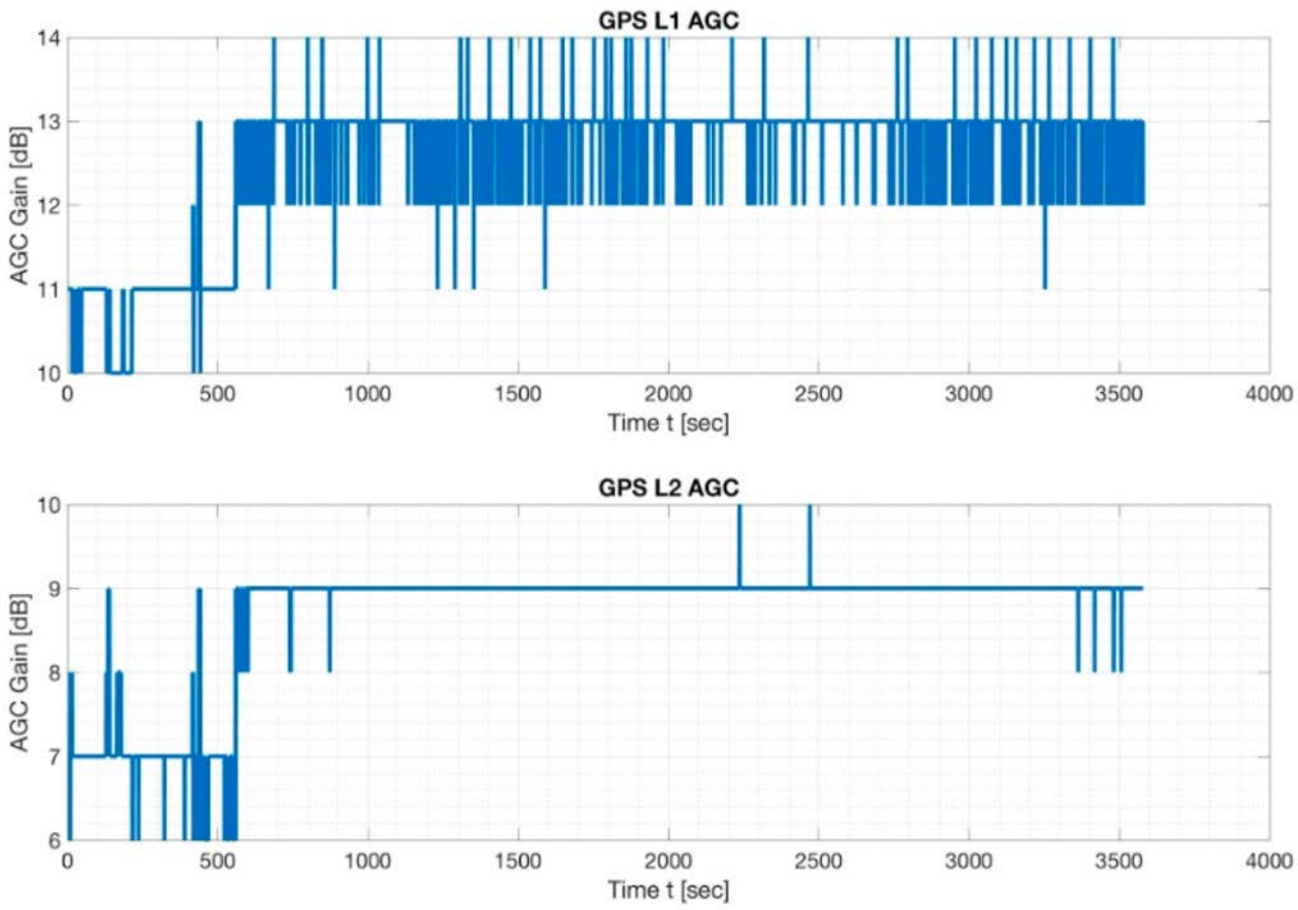
Successfully able to
send/receive correct data

```
77501,400051171,-1052629791,1642660
79842,400051162,-1052629813,1642370
82242,400051168,-1052629816,1642520
84442,400051160,-1052629819,1642560
86642,400051154,-1052629824,1642320
89042,400051140,-1052629839,1642600
91243,400051128,-1052629843,1642300
93242,400051118,-1052629846,1642600
95281,400051113,-1052629854,1642790
95843,400051111,-1052629856,1642260
96443,400051111,-1052629859,1642560
96921,400051110,-1052629861,1642440
97462,400051110,-1052629861,1642480
98101,400051110,-1052629863,1642740
98721,400051108,-1052629864,1642700
99242,400051108,-1052629864,1642400
100043,400051106,-1052629864,1642130
```

Receives:
Time [ms],
Lat [deg],
Lon [deg],
Alt [mm]
(from USB
log file)

PAYLOAD AGC CHARACTERIZATION TESTS

60-minute Test



GPS data collected for 60 minutes:

- Test run at the Lockheed Martin Conference table
- Can log data for 60 minutes

Purpose:

- Characterize GPS data
- Ensure data can be logged for 60 minutes.

INERTIAL SENSOR INTEGRATION TEST

Objective

- Verify IMU is capable of interfacing with PixHawk in Autopilot

Description

- 10 minute autonomous flight at CU South Boulder
- Triangular pattern over 300 m area.

Measurements

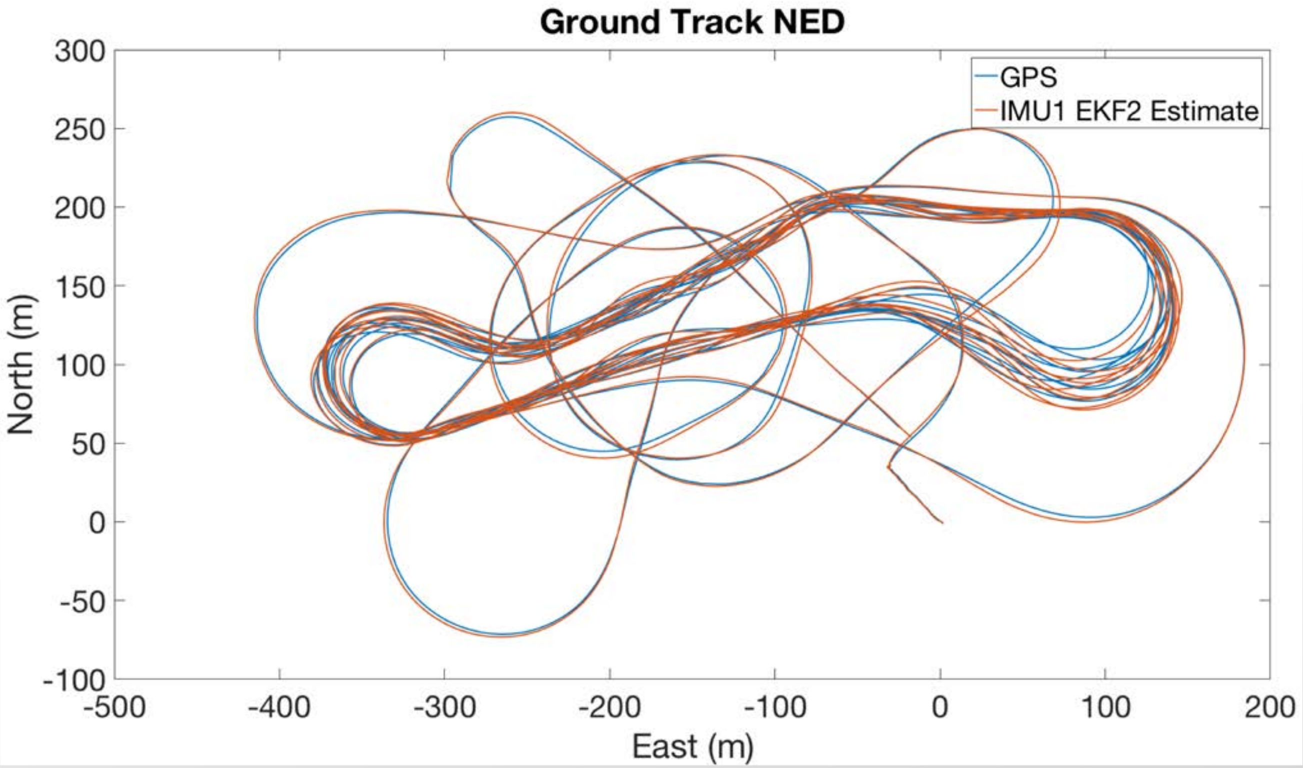
- GPS position and estimated position data recorded onboard PixHawk flight controller
- NED coordinates directly from GPS
- NED coordinate estimated from Kalman Filter with new IMU input

DMU 11

INERTIAL SENSOR INTEGRATION TEST

Result

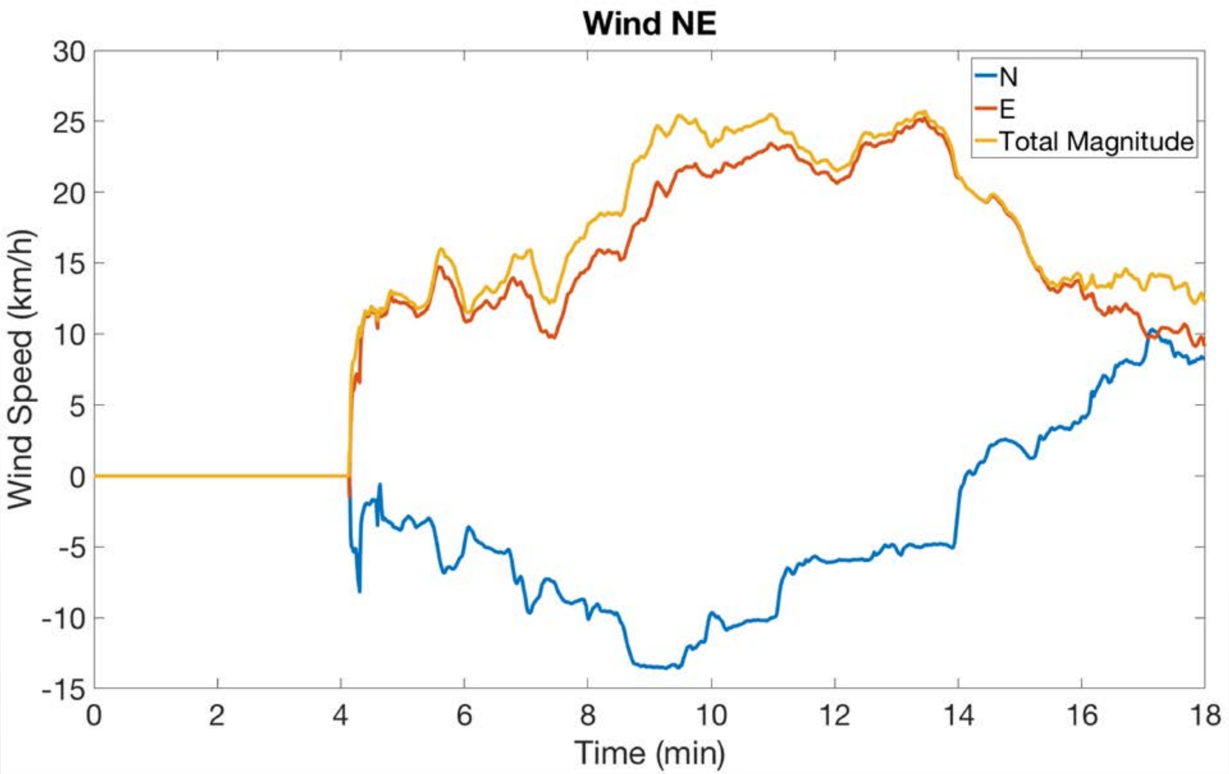
- Ground track estimated by EKF (given inertial sensor measurements) aligns with GPS ground track



FR 2: THE UAS SHALL BE CAPABLE OF FLYING IN 30 KPH WINDS

Description

- 14 minute flight conducted in winds averaging 18.2 kph
- Maximum wind of 25.7 kph
- UAS performed fine in the air, though had difficulties with landing



Functional Requirement Validation	
FR 2: The UAS shall be capable of flying in 30 kph winds	Partially Verified

INERTIAL SENSOR INTEGRATION TEST

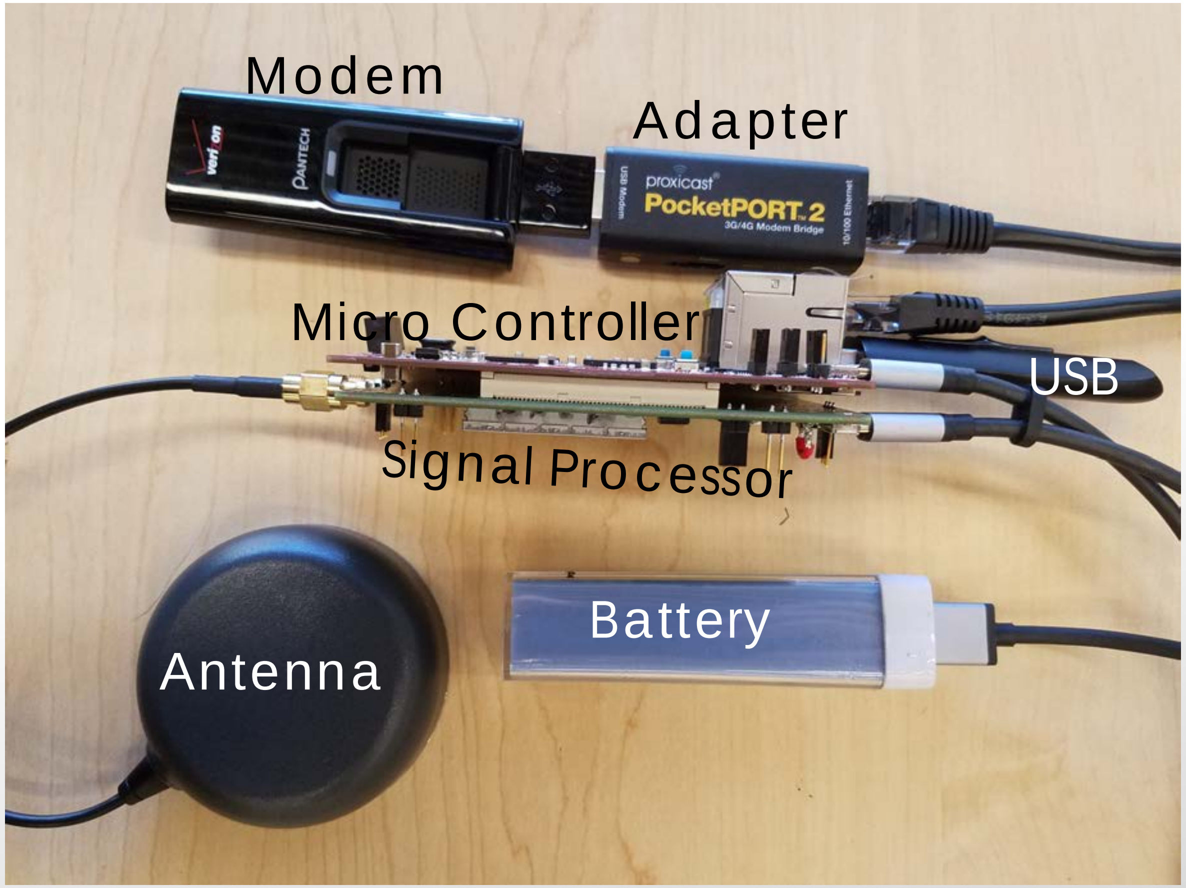
Verification - Almost

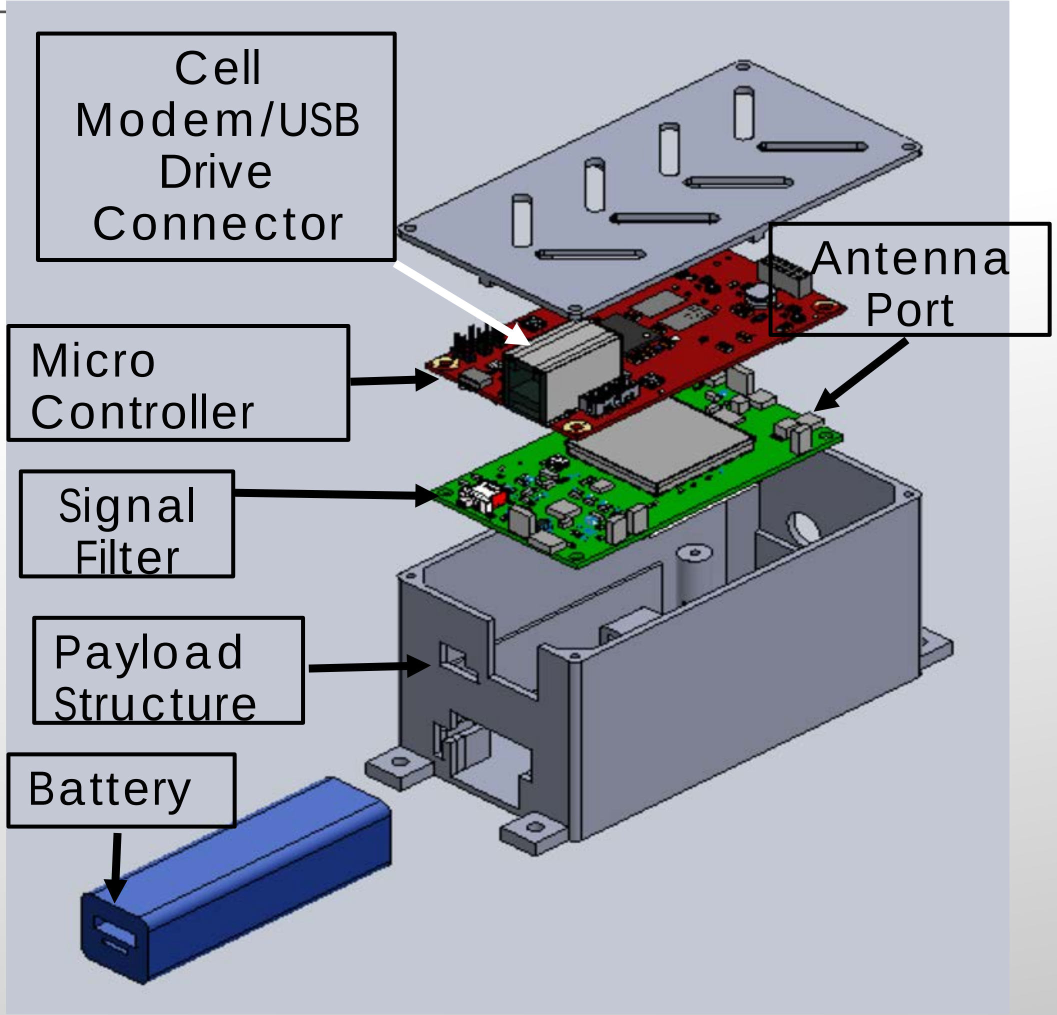
- FR 3: The system shall fly and navigate in GPS denied region for a linear distance of 1 km
  - Confirm inertial drift is under 40 m

Confidence

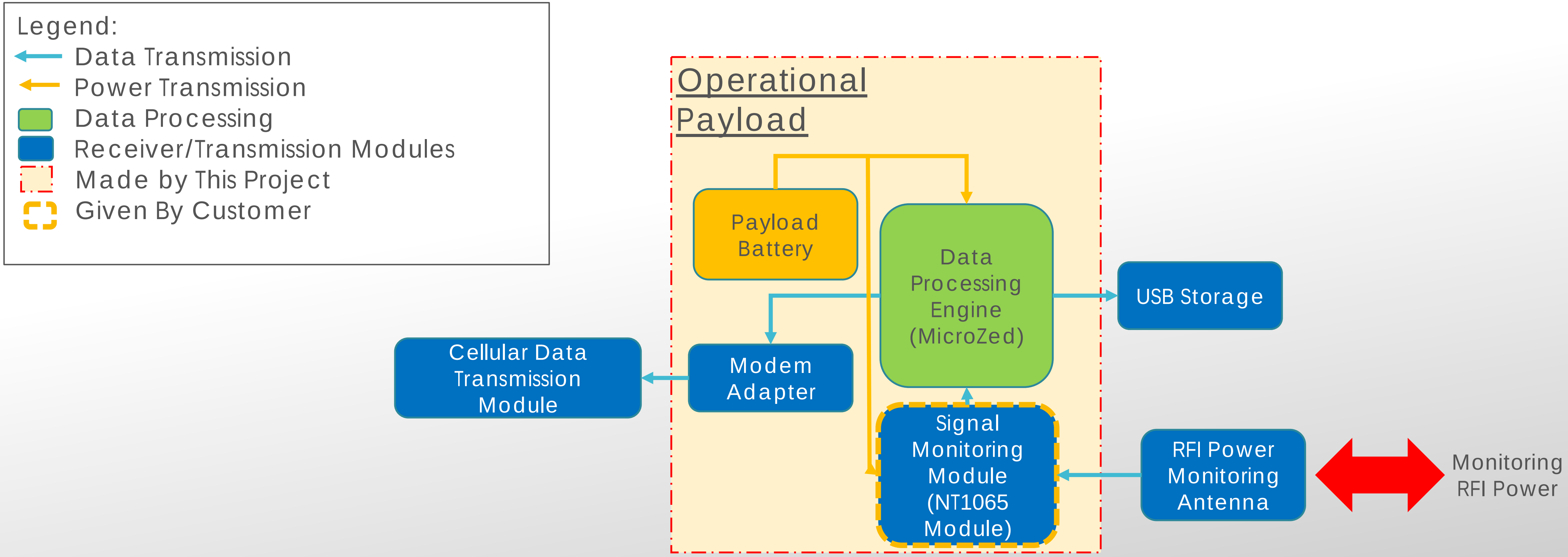
- Flight controller can interface with 3rd part inertial sensor
- Capable of remaining under inertial drift requirement while GPS denied

PAYLOAD INTEGRATION DIAGRAM





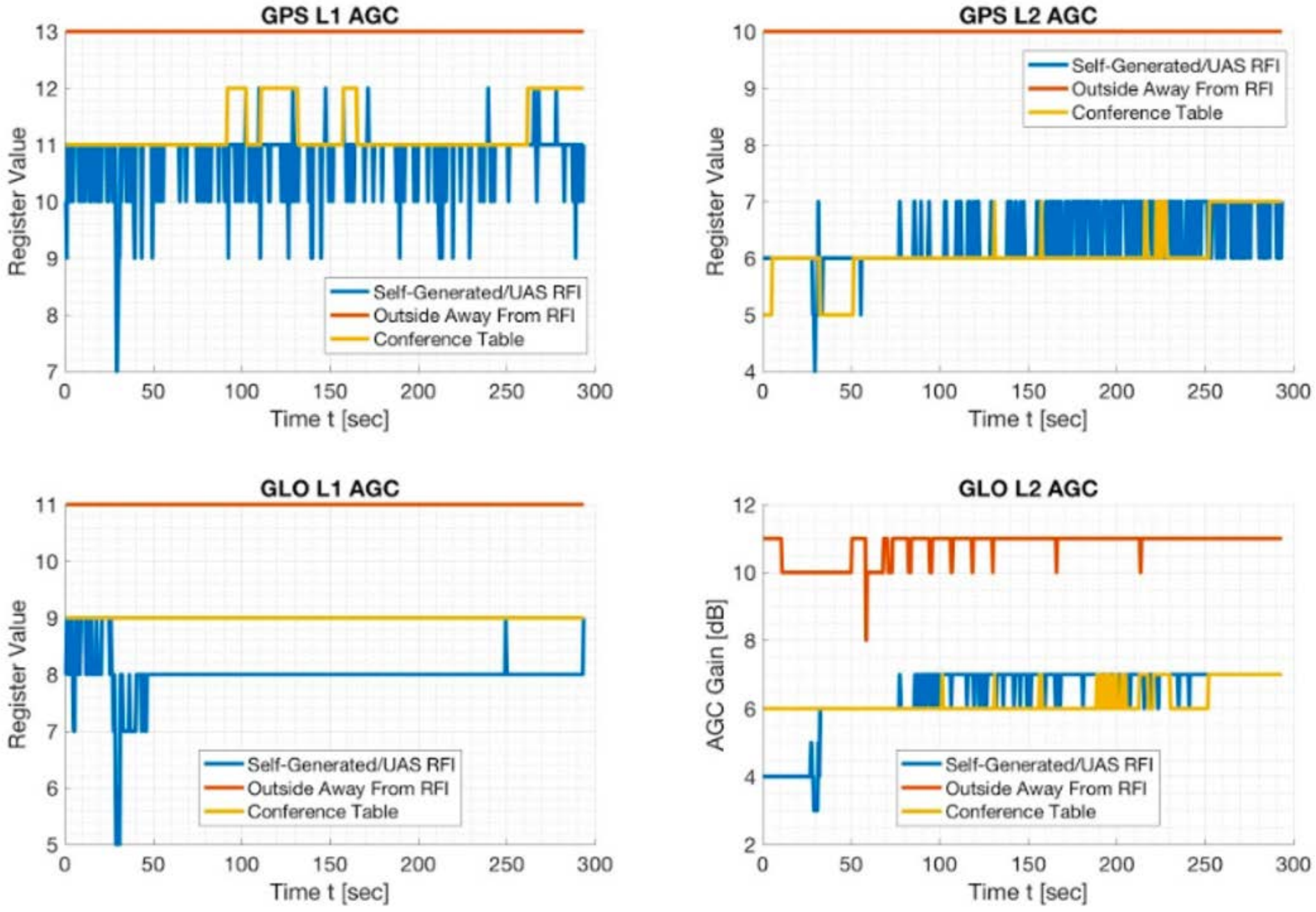
PAYLOAD FBD



Legend:
Data Transmission
Power Transmission
Data Processing
Receiver/Transmission Modules
Made by This Project
Given By Customer
Operational Payload
Payload Battery
Data Processing Engine (MicroZed)
USB Storage
Cellular Data Transmission Module
Modem Adapter
Signal Monitoring Module (NT1065 Module)
RFI Power Monitoring Antenna
Monitoring RFI Power

PAYLOAD: AGC CHARACTERIZATION TESTS

5-minute Tests in Various Locations



GPS data collected for three scenarios:

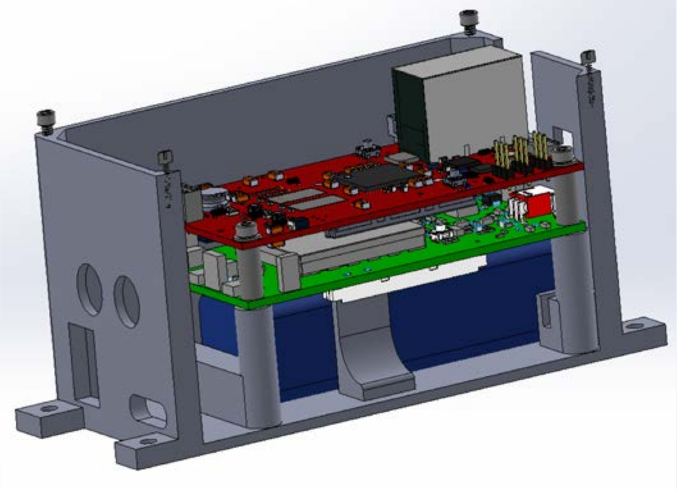
- Lockheed Martin Conference table
- Open area away from RFI
- UAS generated RFI

Purpose:

- Characterize AGC data
- Ensure data can be logged.
- Success is defining when GPS data cannot be trusted

PROJECT DELIVERABLES

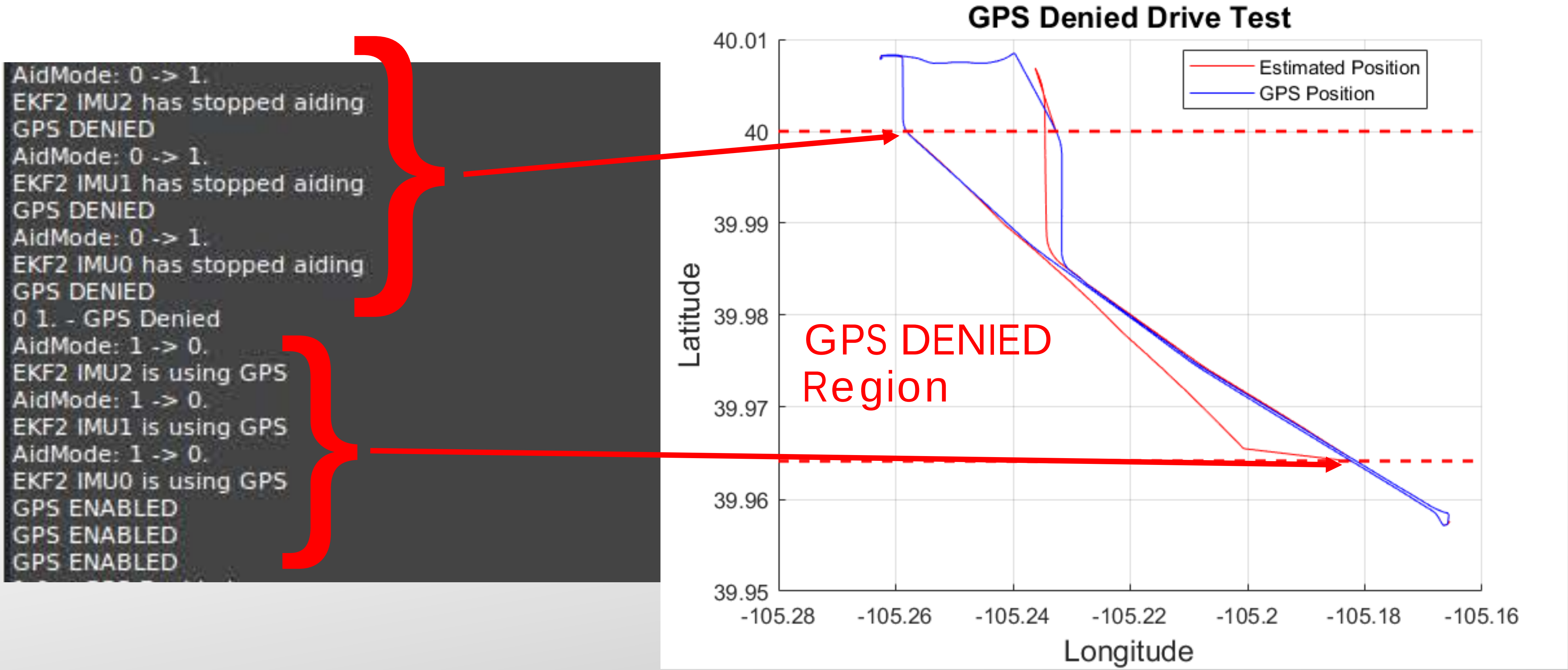
- Self-integrated payload containing customer provided microprocessor and signal filter



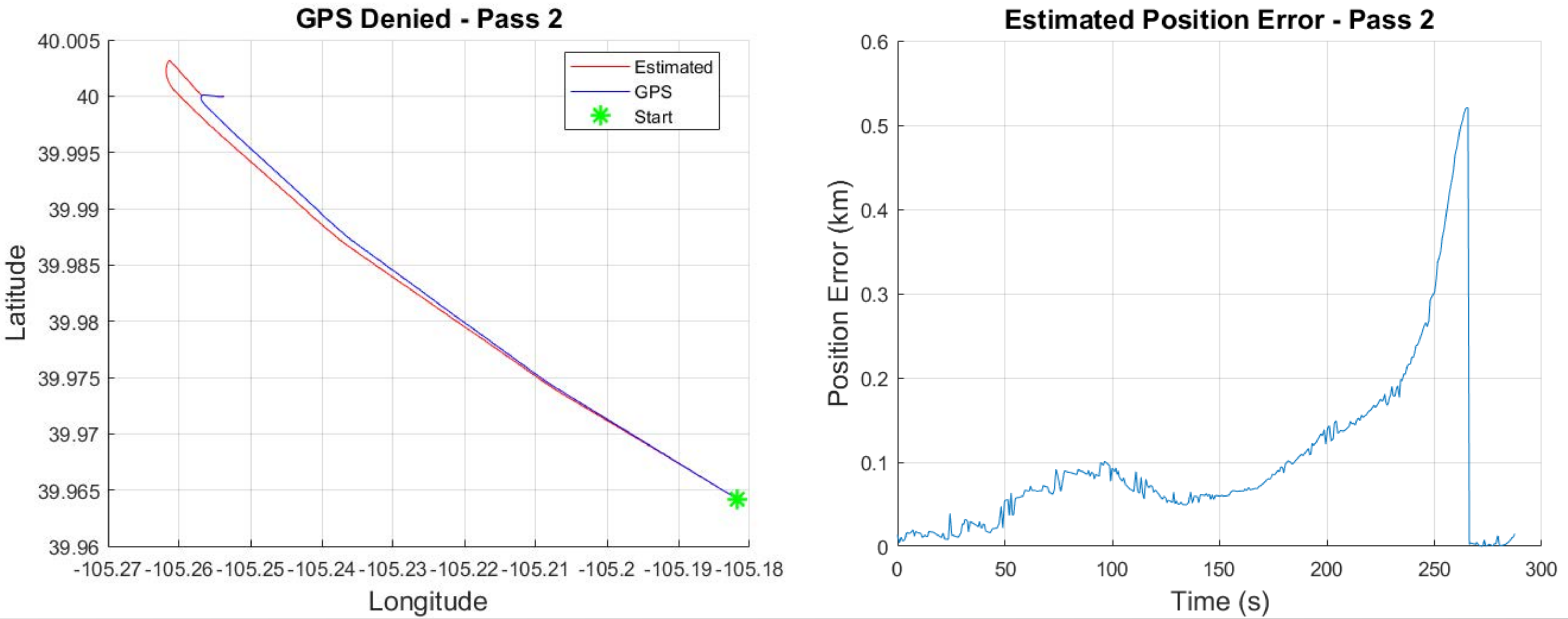
- Modified Flight Software allowing for GPS denied flight

- Fully Integrated UAS with payload and flight software

SOFTWARE: GEOGRAPHIC FLIGHT MODE SWITCH



GPS DENIED PERFORMANCE– DRIVING TEST

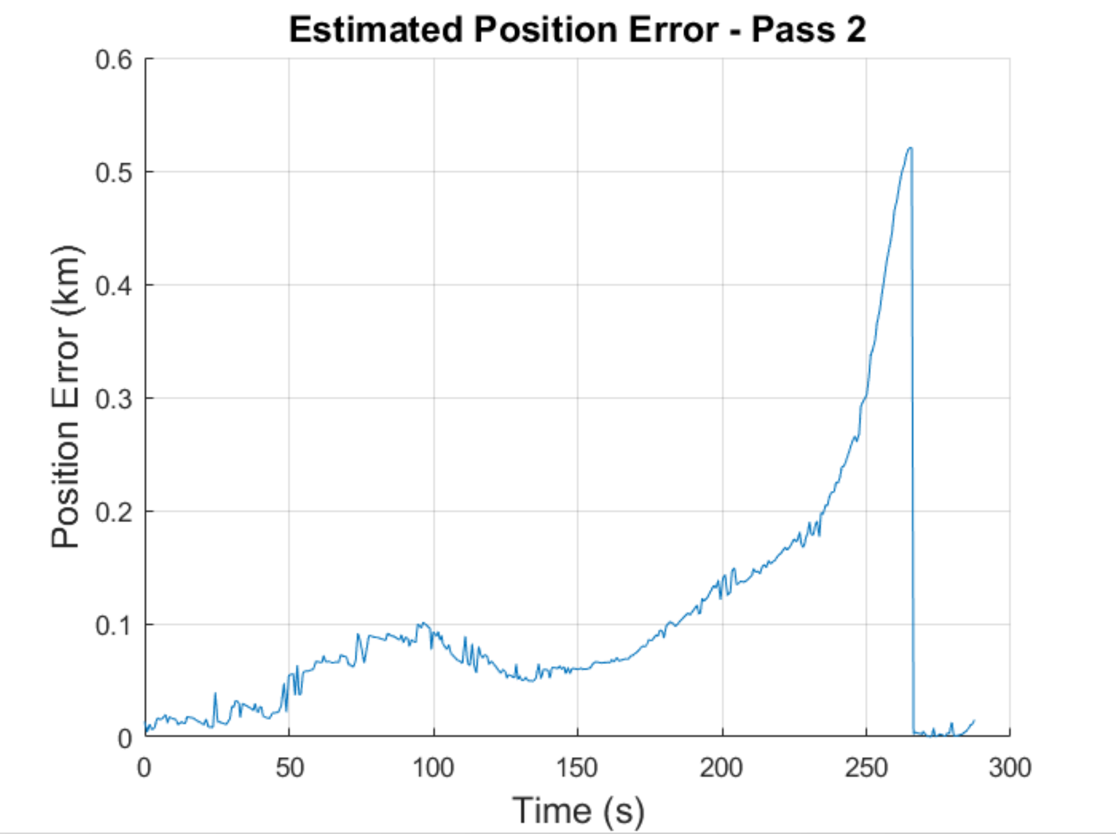


SOFTWARE: GPS DENIED FIX

Driving test performed in 2 ways to verify GPS denial:

1. Physically removing GPS module
2. Software geofence

GPS denial tested for ~200 seconds

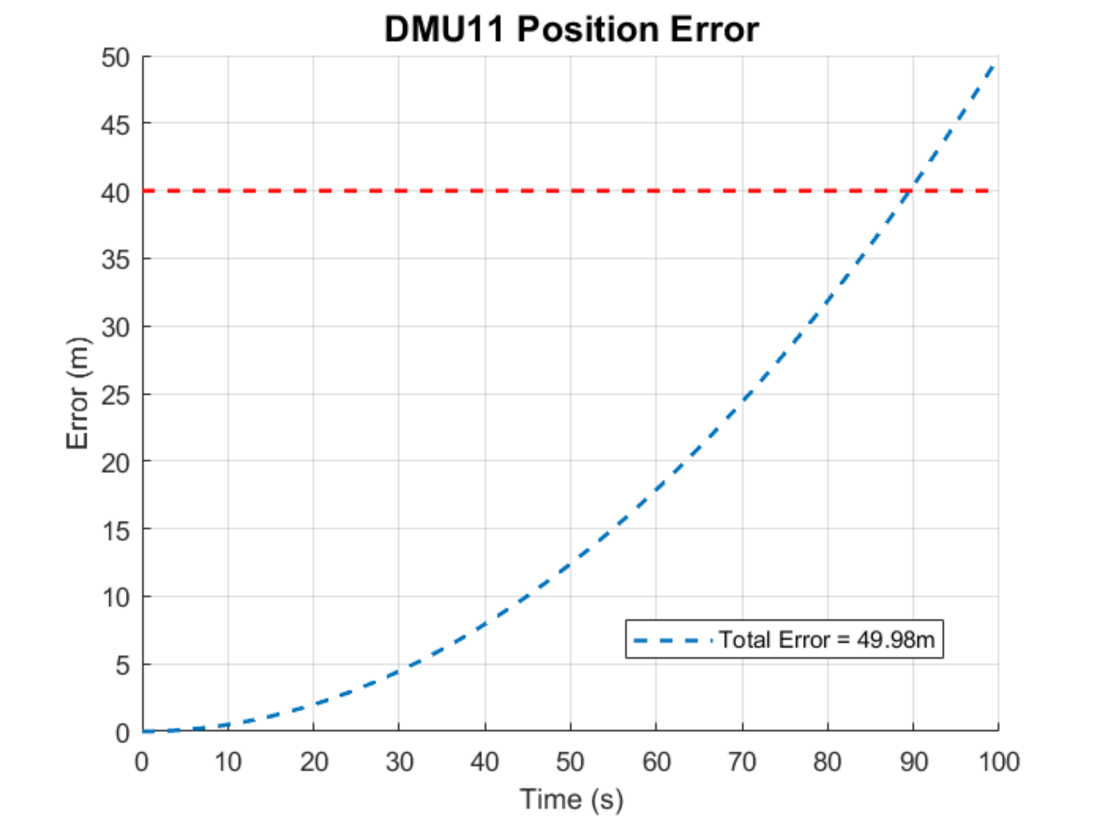


Results:

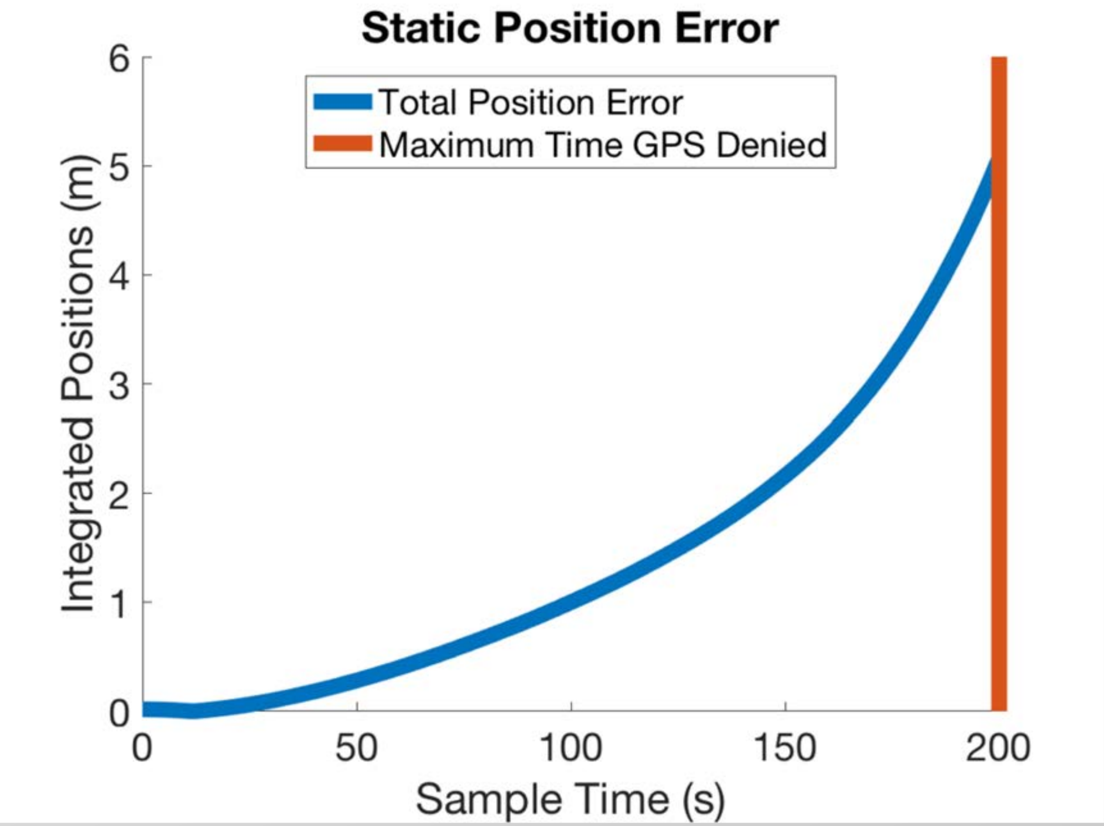
- Similar error for both tests
  - 150 meters NE error
- Consistent with expected t^2 error

GPS DENIED PERFORMANCE

MODEL ESTIMATION



INTEGRATED STATIC DATA



PIXHAWK/MICROZED INTERFACE TESTS

Interfacing: 2-way serial communication between flight/micro controllers

Purpose: To provide flight controller with AGC data to enable flight mode switching, to receive and log position data, To verify requirements FR3, FR6, FR8, and FR9.

- Send GPS data reliability value to flight controller
- Receive and log position data from microcontroller

Components

- GPS Antenna and Signal Filter
- Microcontroller and USB Drive
- Flight Controller

PIXHAWK/MICROZED INTERFACE TESTS

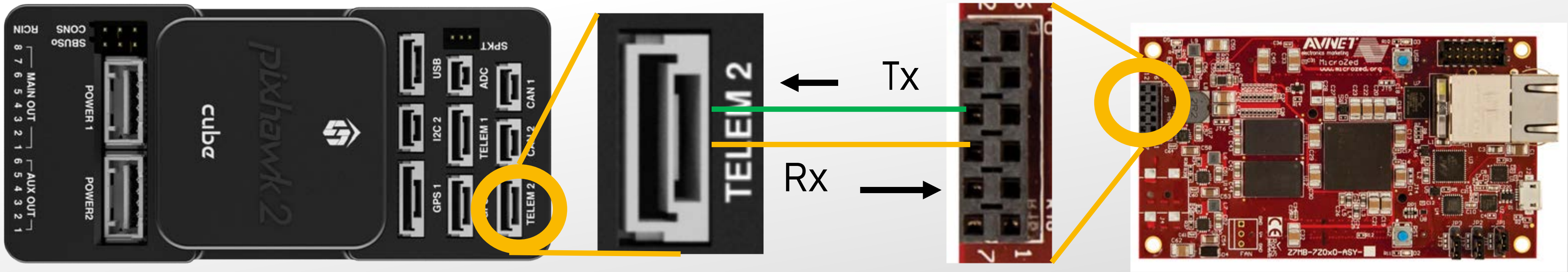
Goal: Have flight and microcontrollers communicate via a serial interface

Test Setup

UART, Baud 115200, 8-N-1

Receives: GPS Reliability

Receives: Time, lat/long, altitude



Pixhawk Flight Controller

Telem 2 Port

Serial Port

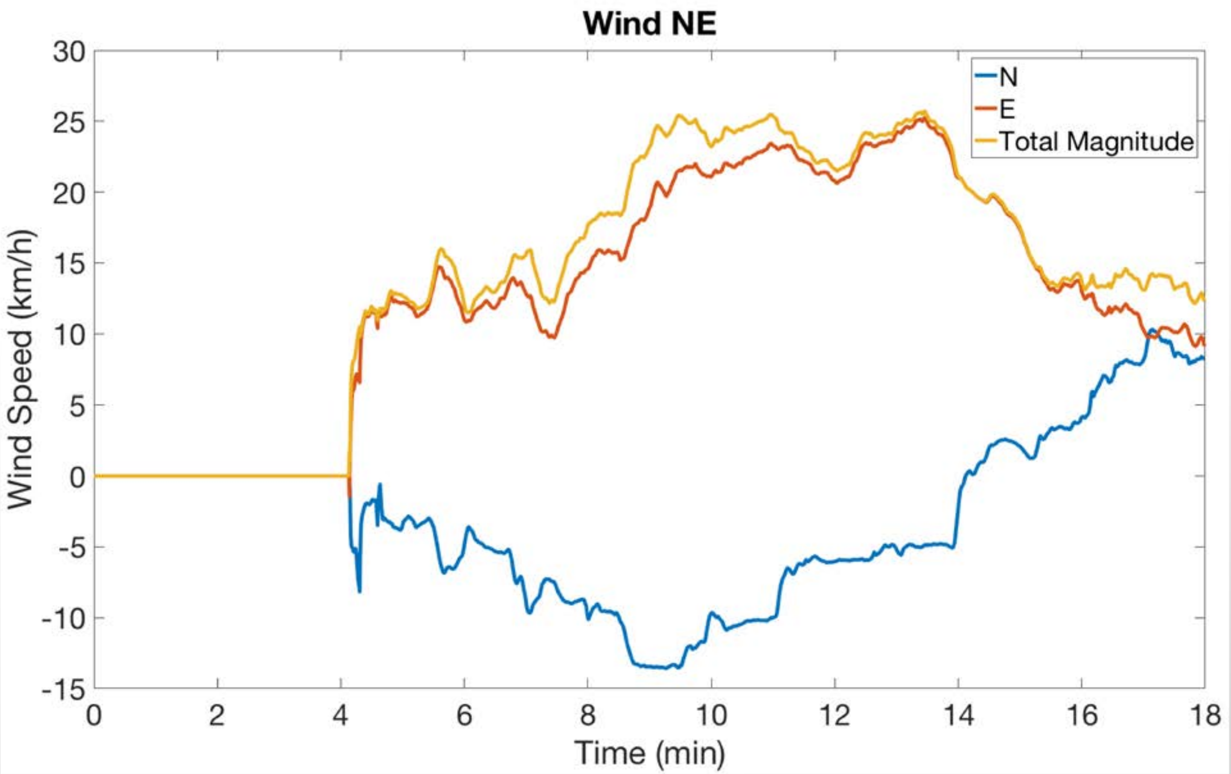
MicroZed Microcontroller

Result: Successfully transmitted and received data on both devices

UAS WIND PERFORMANCE

Description

- 14 minute flight conducted in winds averaging 18.2 kph
- Maximum wind of 25.7 kph
- UAS performed fine in the air, though had difficulties with landing



Functional Requirement Validation	
FR 2: The UAS shall be capable of flying in 30 kph winds	Partially Verified