Test Readiness Review

RAVEN

Rover and Air Visual Environment Navigation

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Customer: Nisar Ahmed

Advisor: Torin Clark

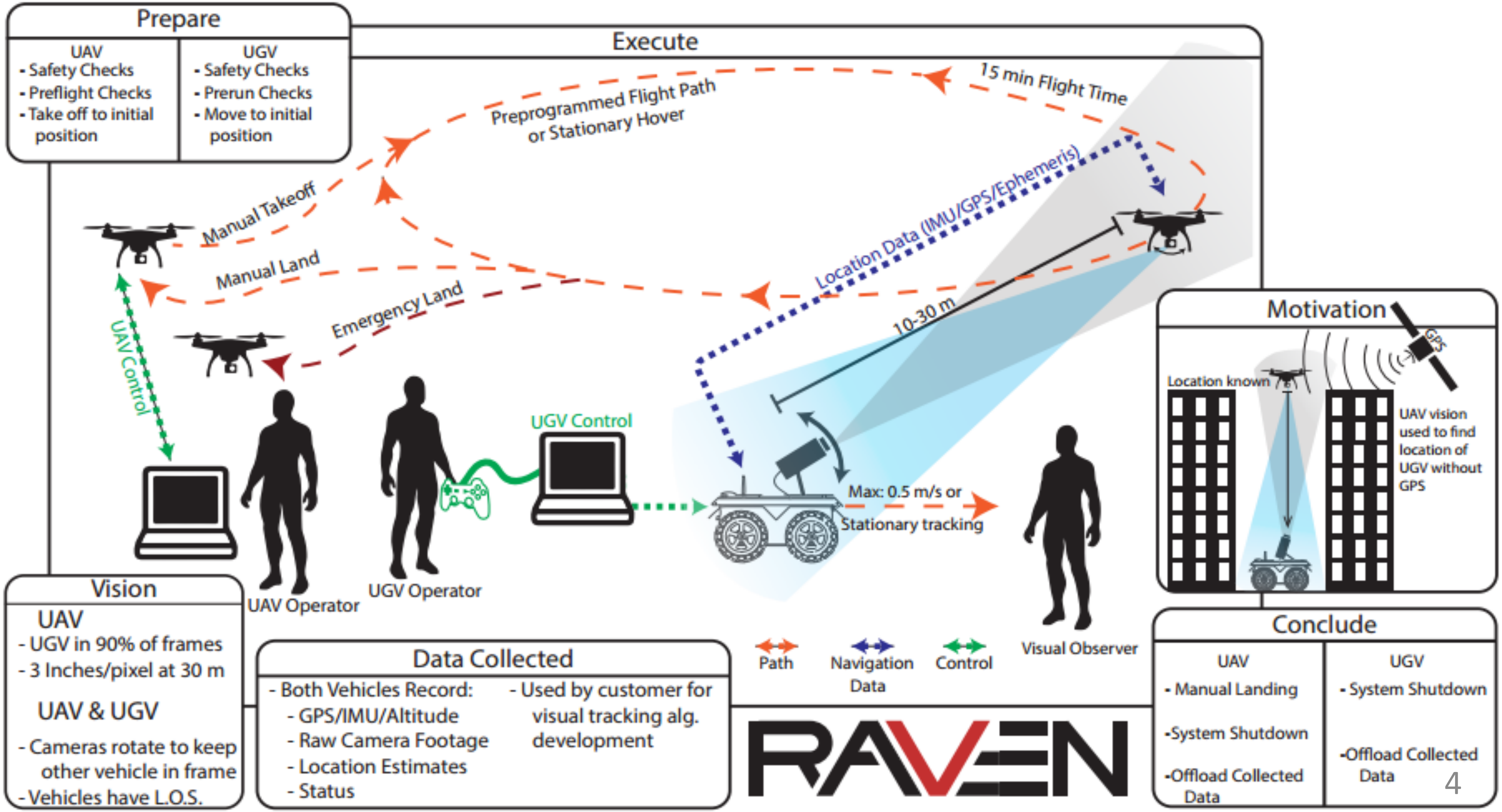
Agenda

Project Purpose and Objectives

Mission Statement: RAVEN will develop a testbed that will collect image, position, and sensor data to be used by the customer for the verification of customer developed cooperative localization algorithms.

- Provide the customer with an **UAV and UGV** pair **testbed**
- Record **image, position, and sensor** data
- **Deliver** recorded information, including **collected GPS data,** and UAV/UGV pair to customer

Concept of Operations



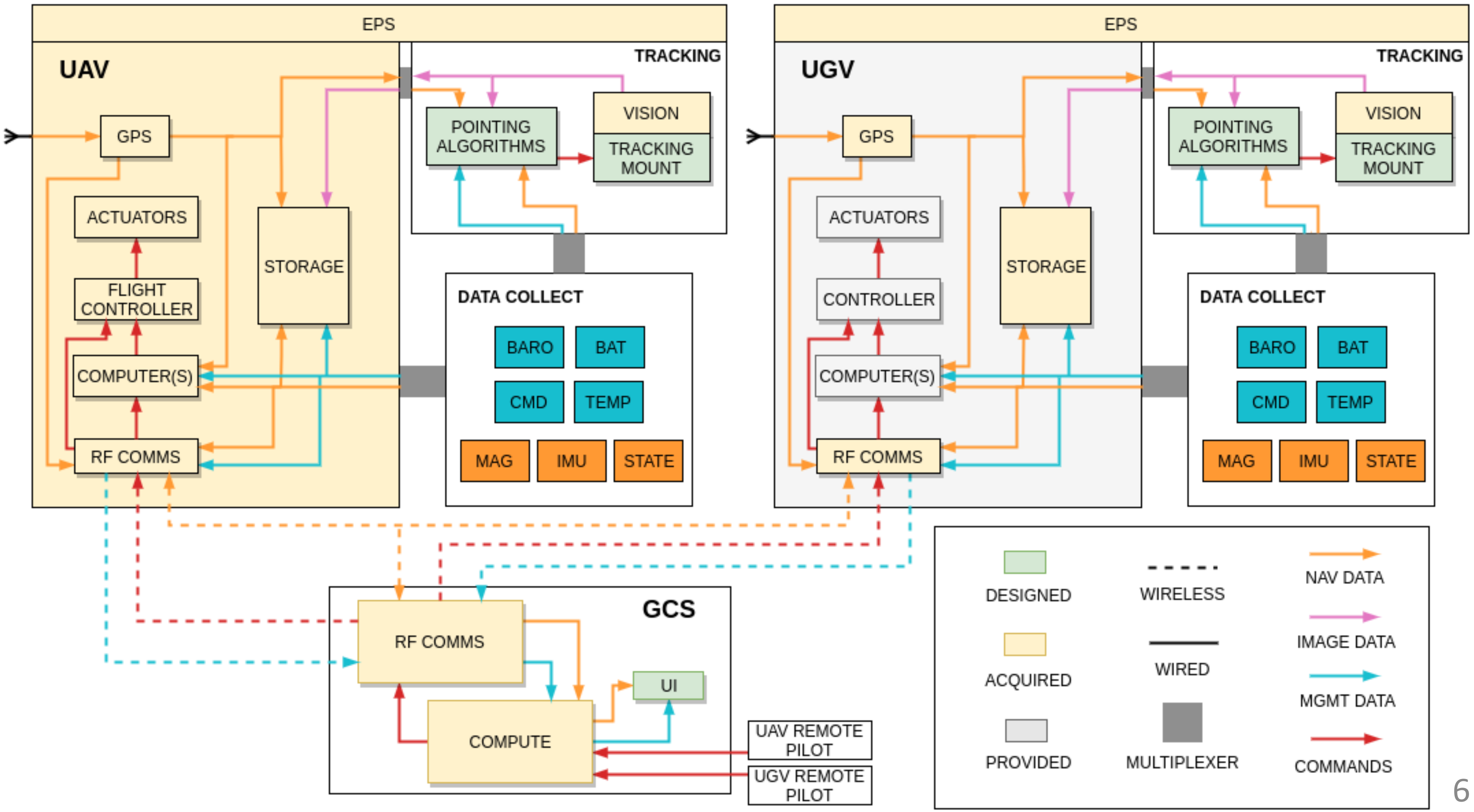
Specific Objectives

Significant Level 3 Objectives:

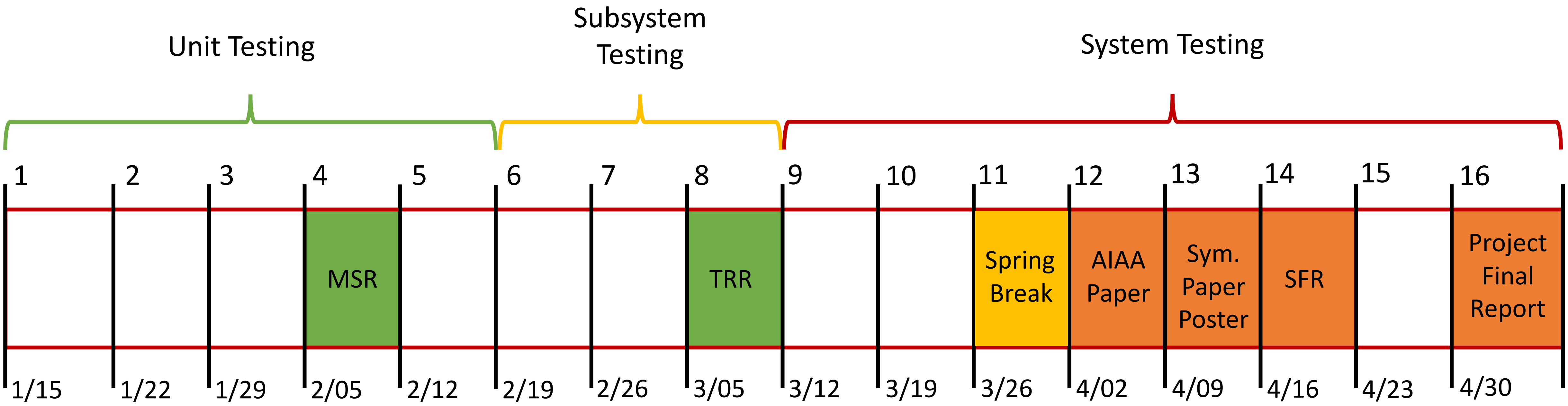
- Vision: A moving UAV shall track the UGV at 10-30 m and be **in 90 % of frames**. A stationary UGV shall track the UAV at 10-30 m and be in 90 % of frames. Acquire target **in less than 3 seconds**.
- Captured Data: Store battery life estimate, package temperature, control input data, GPS/ephemeris data, IMU data, magnetometer data, and barometer data all in **ROS bags** w/ 20 GB storage margin.
- Controls: UAV will have **emergency land** switch. Control station displays map overlay of UAV/UGV positions as well as battery status, flight timer, and storage capacity.
- Comms: Vehicles **shall share GPS data**, visual tracking, and state data with the control stations.
- Electronics/Software: Vehicles shall have **15 min tracking endurance**.
- Management: Project cost shall remain **under budget**.

Currently on track to achieve Level 3 Objectives.

System Level Functional Block Diagram

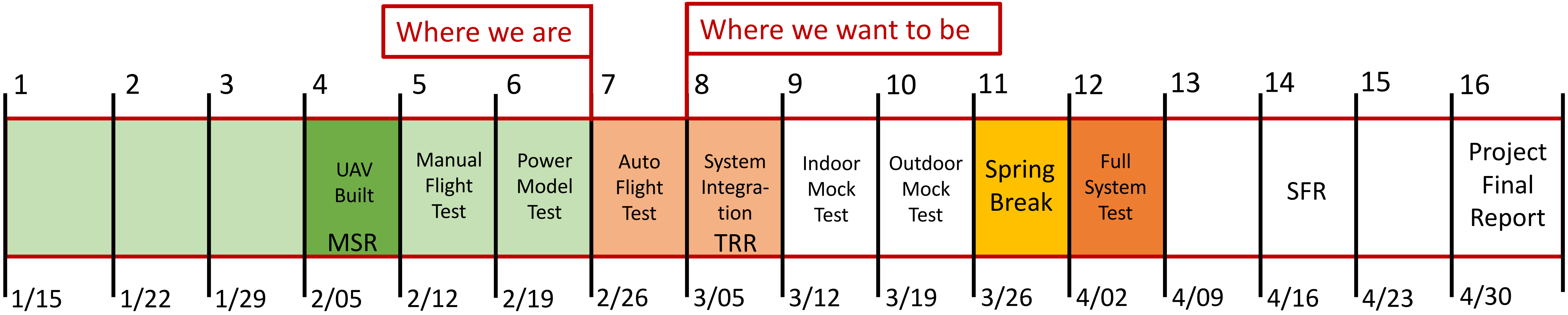


Schedule



Unit Testing
Subsystem Testing
System Testing
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
MSR
TRR
Spring Break
AIAA Paper
Sym. Paper Poster
SFR
Project Final Report
1/15
1/22
1/29
2/05
2/12
2/19
2/26
3/05
3/12
3/19
3/26
4/02
4/09
4/16
4/23
4/30

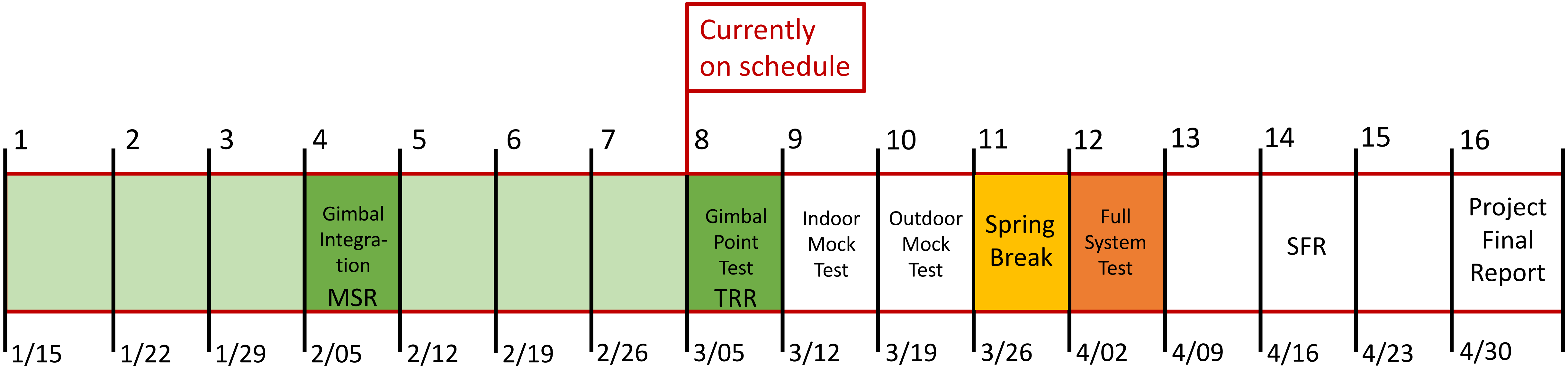
Schedule – UAV Critical Path



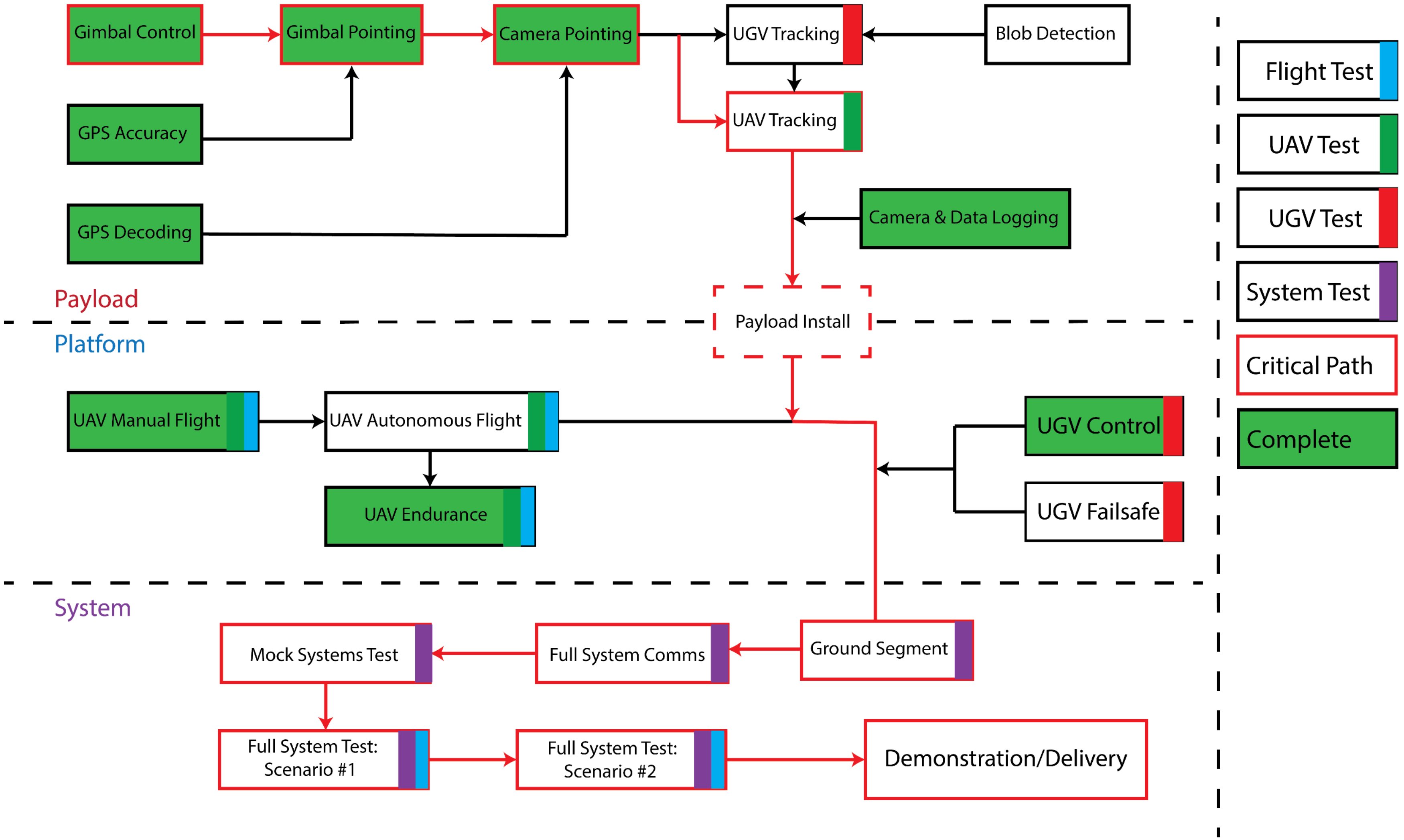
Behind schedule by 1 week

- Mitigate by crashing integration week

Schedule – Payload Systems Critical Path



Testing Flow Chart



Unit Testing

GPS Accuracy Verification

Reasoning: To determine the accuracy of the RTK GPS units. This will ensure that it will be sufficient enough for the tracking requirements and validate our model.

Testing Prerequisites:

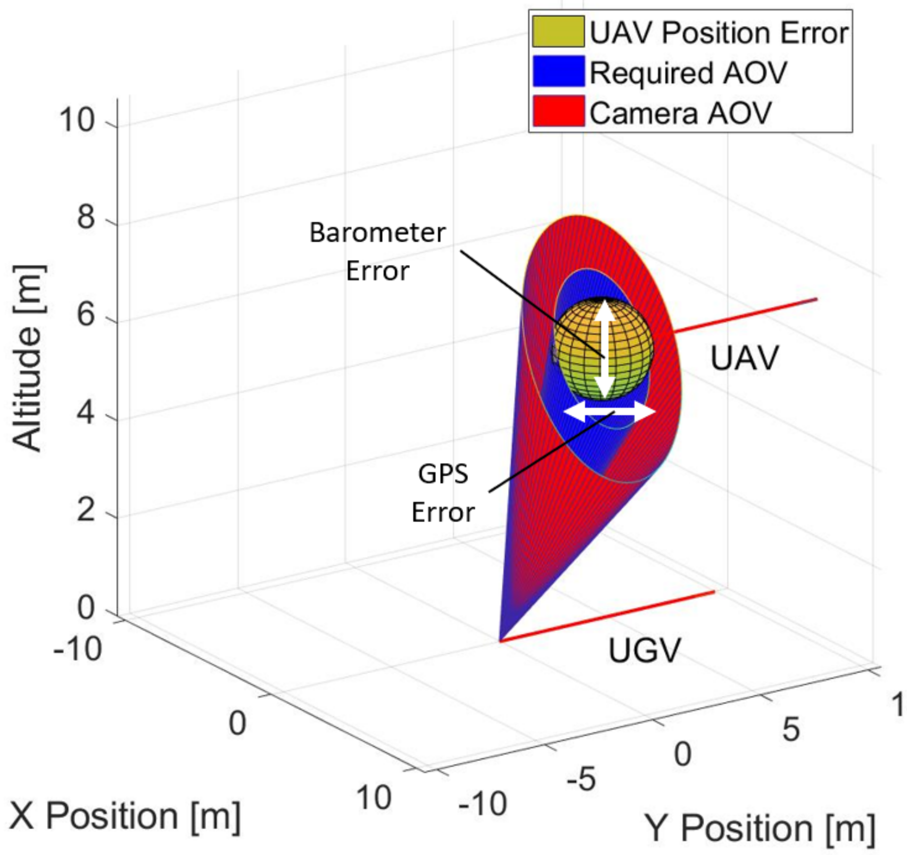
- MATLAB parsing tools developed.

Equipment and Facilities:

- C94-M8P GPS units w/Antennas
- 2 Laptops
- Business Field

Recorded Data:

- Position Data (Lat, Lon, Alt) [1 Hz]
- Velocity Data in NED Frame [1 Hz]
- Relative Position Vector from UGV to UAV [1 Hz]



Success Criteria:

- Standard Deviation < 0.973 m
- Handles data throughput of all necessary messages

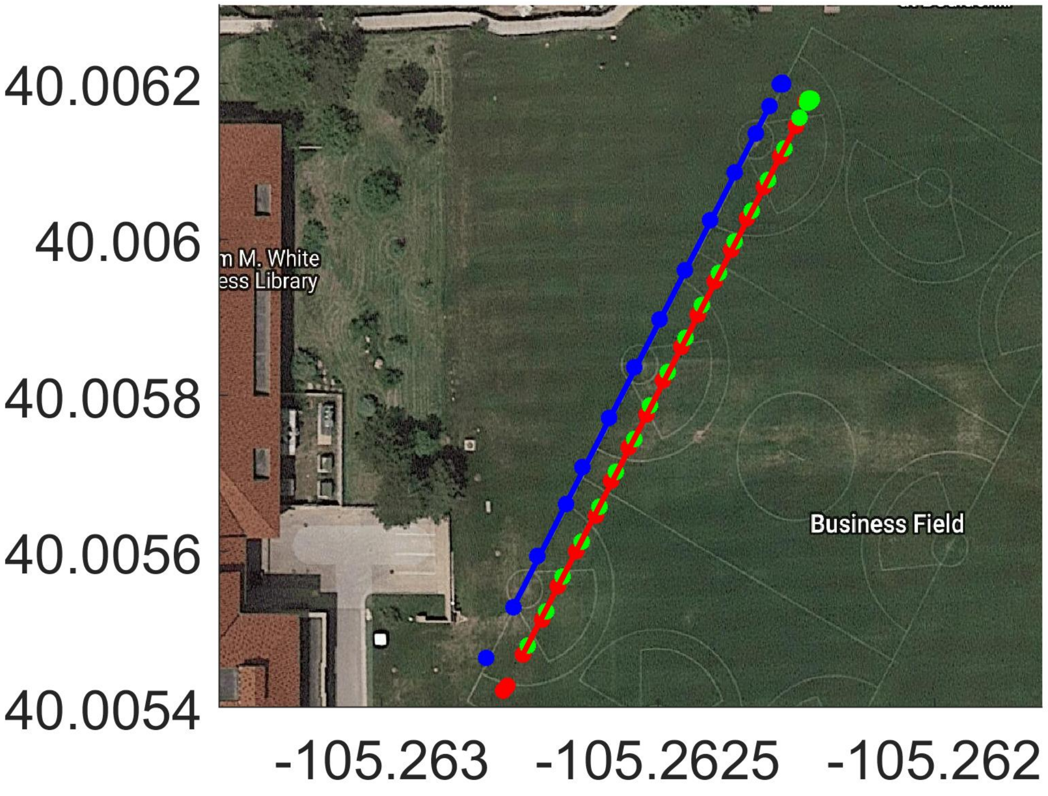
GPS Accuracy Verification - Results

Test Completed
- Dynamic test, where both units move along parallel lines was conducted.
  - Relative distance kept close to constant.

Accuracy
- UGV average deviation from line: 14 cm
  - Std Dev: 11 cm
- UAV average deviation from line: 11 cm
  - Std Dev: 8 cm

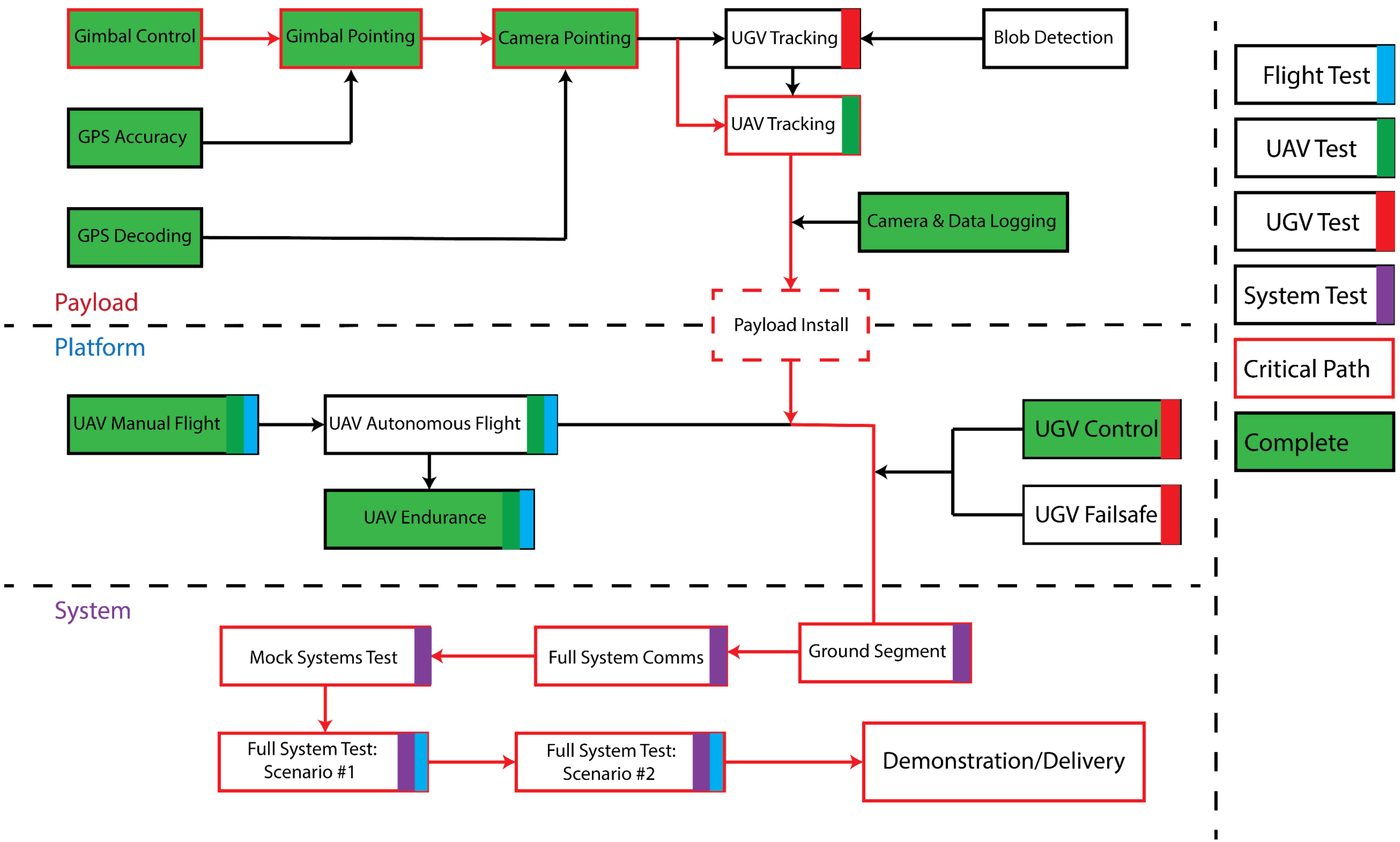
Issues:
- By collecting ephemeris data, message throughput was too high for 1 Hz update rate.

Solution:
- Have UGV collect ephemeris and UAV send relative position vector (1 Hz) to UGV for gimbal pointing.
  - **Second test planned**

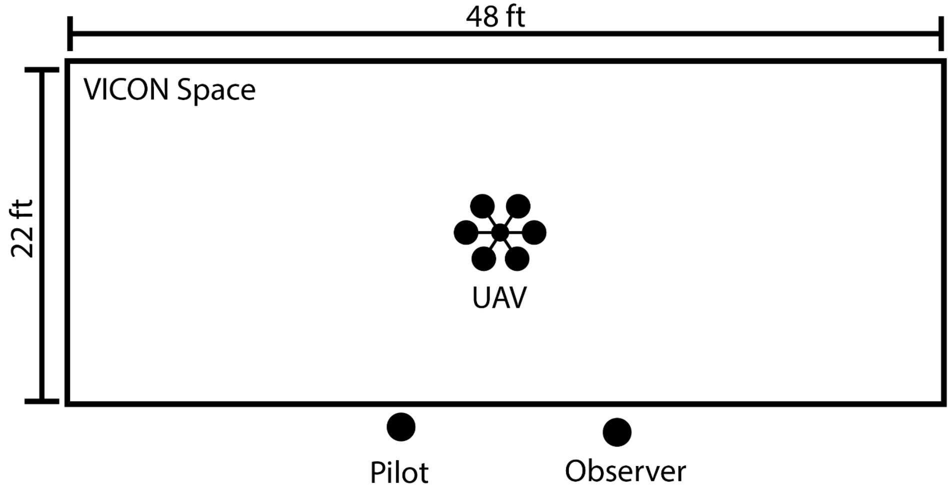


Success Criteria:
- Standard Deviation < 0.973 m: PASS
- Handles data throughput of all necessary messages: FAIL

Completed Subsystem Testing



Manual Flight



<u>Reasoning:</u> Determine flight characteristics of UAV platform. Ensure UAV is flyable and stable during manual flight operations using proxy masses for payload simulation.

<u>Testing Prerequisites:</u>
- UAV Built
- Proxy Masses
- Pixracer Unit Testing

<u>Equipment and Facilities:</u>
- VICON space (RECUV Fleming Lab)
- VICON markers
- UAV Transmitter
- Stopwatch

<u>Risks:</u>
- UAV crash/damage
- LiPo battery damage
- Damage to VICON space

<u>Recorded Data:</u>
- Flight Time
- VICON data

<u>Success Criteria:</u>
- UAV flight for >18.15 minutes
- UAV stable in flight

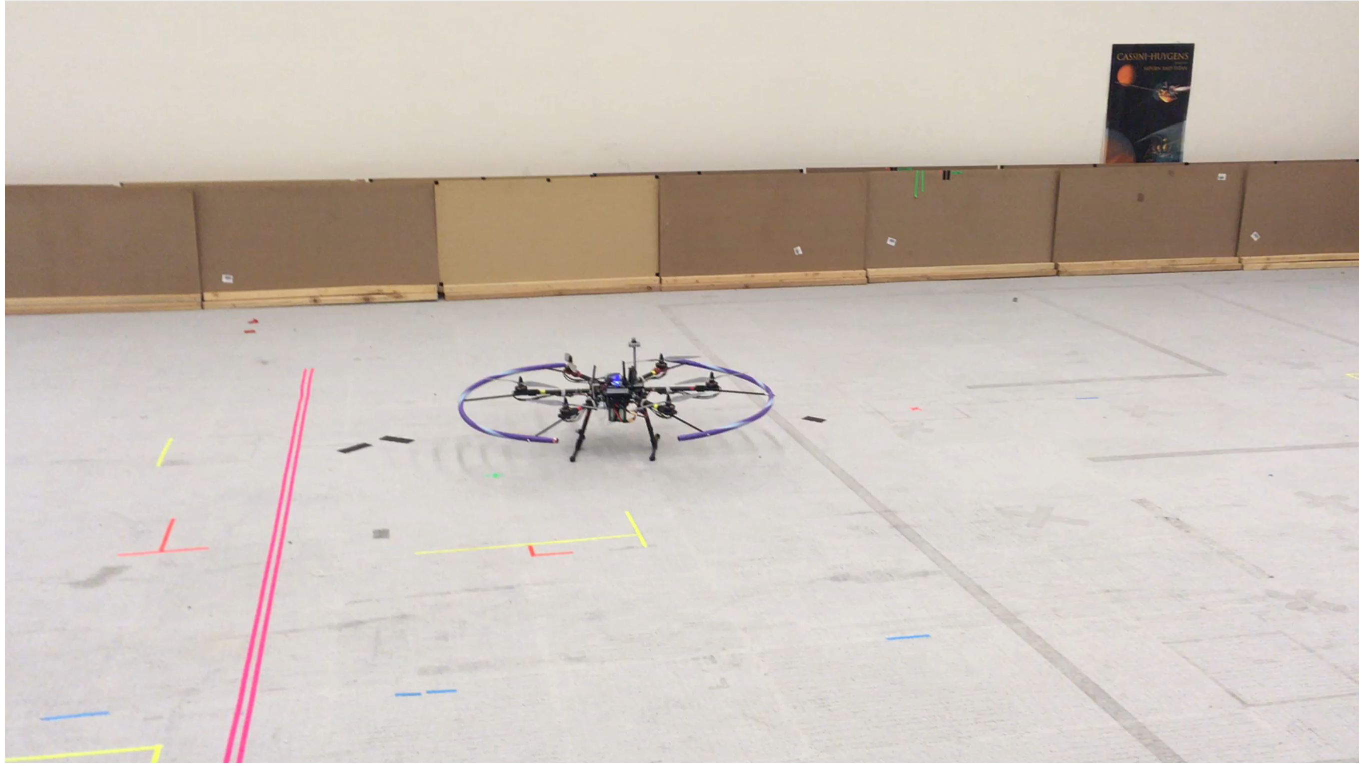
Manual Flight - Results

<u>Two tests completed:</u>

- Test 1
  - Flight Length: 15:03
  - VICON data collected
- Test 2
  - Flight Length: 18:36
  - VICON data collected

<u>Results:</u>

- No major damage to UAV
- Safety hoop needed to be refitted
- Testing concluded after impact
- Automatic landing successful



<u>Success Criteria:</u>

- UAV flight for >18.15 minutes: PASS
- UAV stable in flight: PASS

Power Model Verification

Reasoning: UAV flight to validate the accuracy of the power model developed in the previous semester. Two flights for each battery pack.

Testing Prerequisites:
- Manual Flight

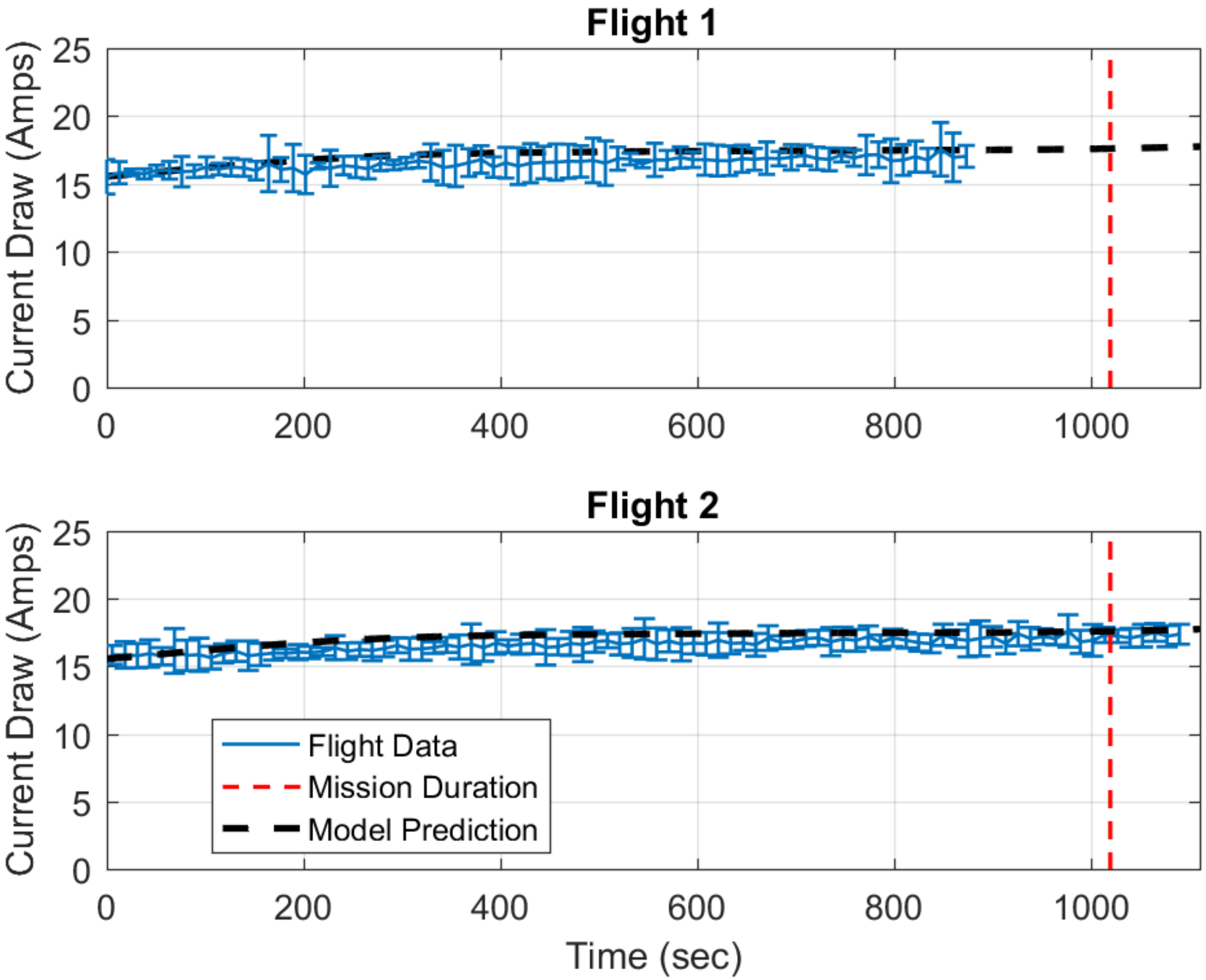
Equipment and Facilities:
- VICON space (RECUV Fleming Lab)
- VICON markers
- UAV Transmitter
- Stopwatch

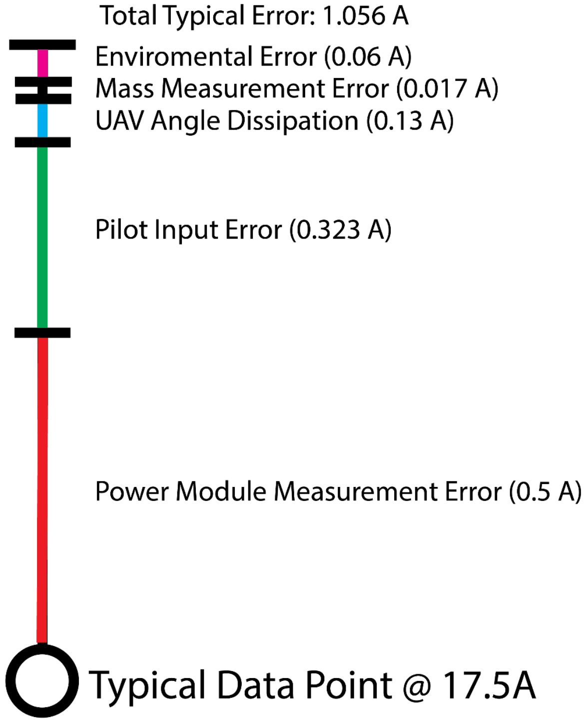
Risks:
- UAV crash/damage
- LiPo battery damage
- Damage to VICON space

Recorded Data:
- Amperage [100 Hz]
- Voltage [100 Hz]
- Throttle input [100 Hz]
- Flight time
- UAV flight mass 3.3 [kg]

Success Criteria:
- UAV flight for >18.15 minutes
- Data recorded for flight duration and offloaded between flights

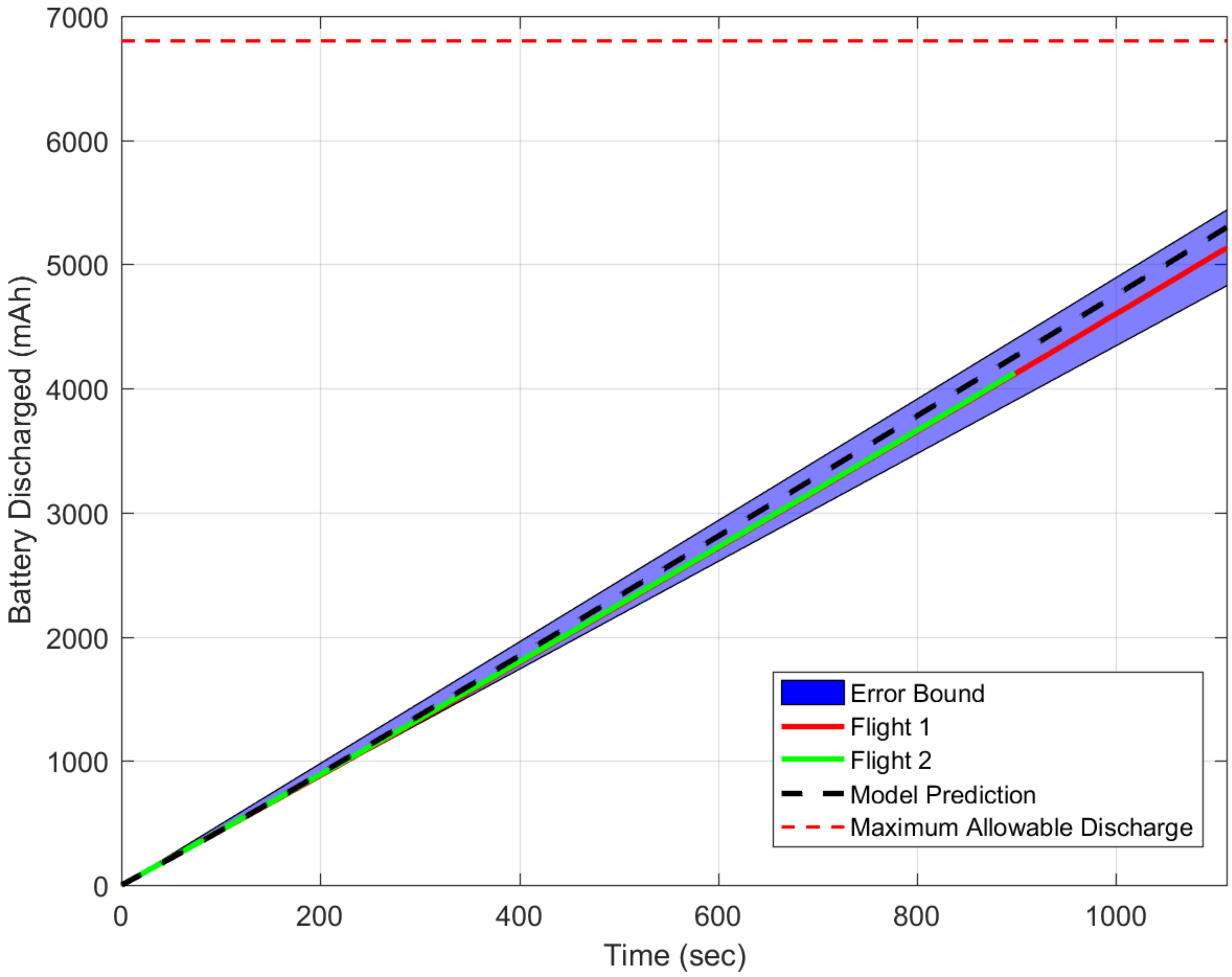
Power Model Verification - Results





Flight 1 σ: 0.83 A

Flight 2 σ: 1.02 A



1177 mAh reserve (17% of useable battery life)

5.56 A continuous payload draw allowable

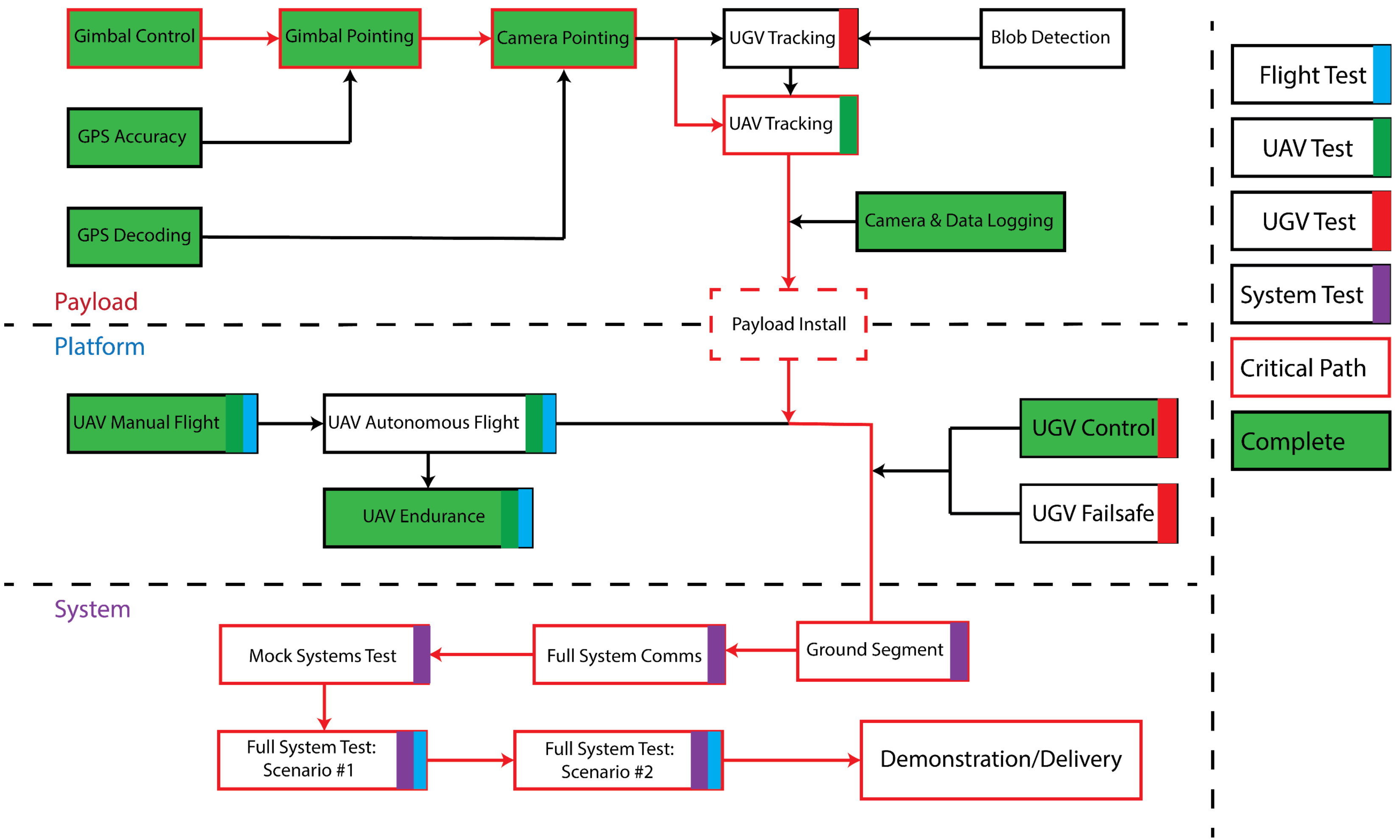
At 18.5 minutes: 1.03% deviation from model

1.75 A typical draw

Success Criteria:

- UAV flight for >18.15 minutes: PASS
- Data recorded for flight duration and offloaded between flights: PASS

Upcoming Tests



Automatic Flight

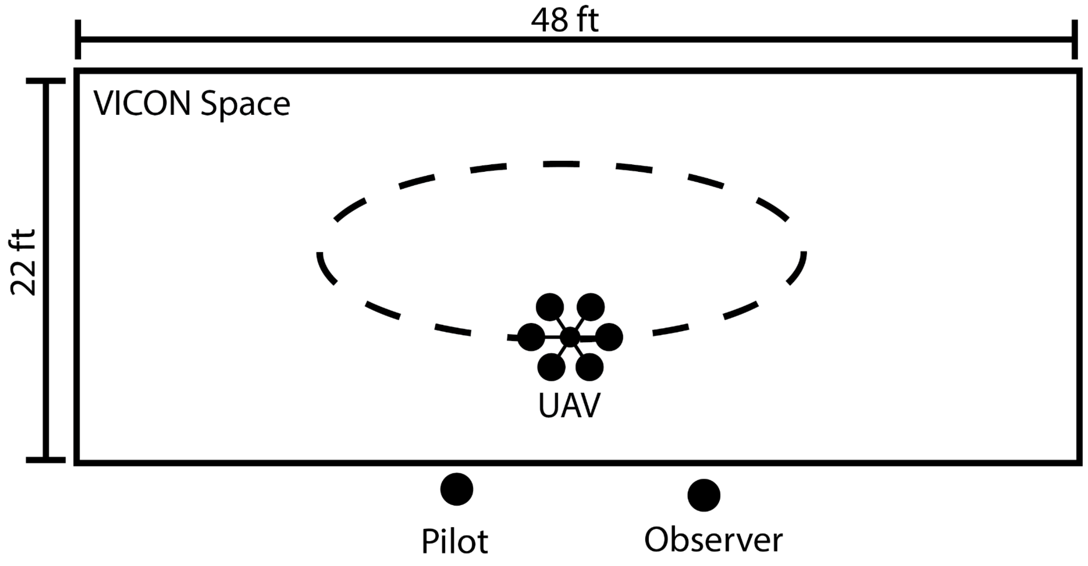
<u>Reasoning:</u> Verify operation of the pixracer's automatic flight system and waypoint positioning system.

<u>Testing Prerequisites:</u>

- Manual Flight
- Safety Systems

<u>Recorded Data:</u>

- Flight time
- VICON data
- Control Inputs



<u>Equipment and Facilities:</u>

- VICON space (RECUV Fleming Lab)
- VICON markers
- UAV Transmitter
- Stopwatch

<u>Risks:</u>

- UAV crash/damage
- LiPo battery damage
- Damage to VICON space

<u>Major Obstacles:</u>

- VICON data to fake GPS
- Publishing VICON data to onboard CPU
- Onboard CPU to flight controller comms.

<u>Success Criteria:</u>

- UAV flight for >18.15 minutes
- UAV stable in flight

Gimbal Pointing Test

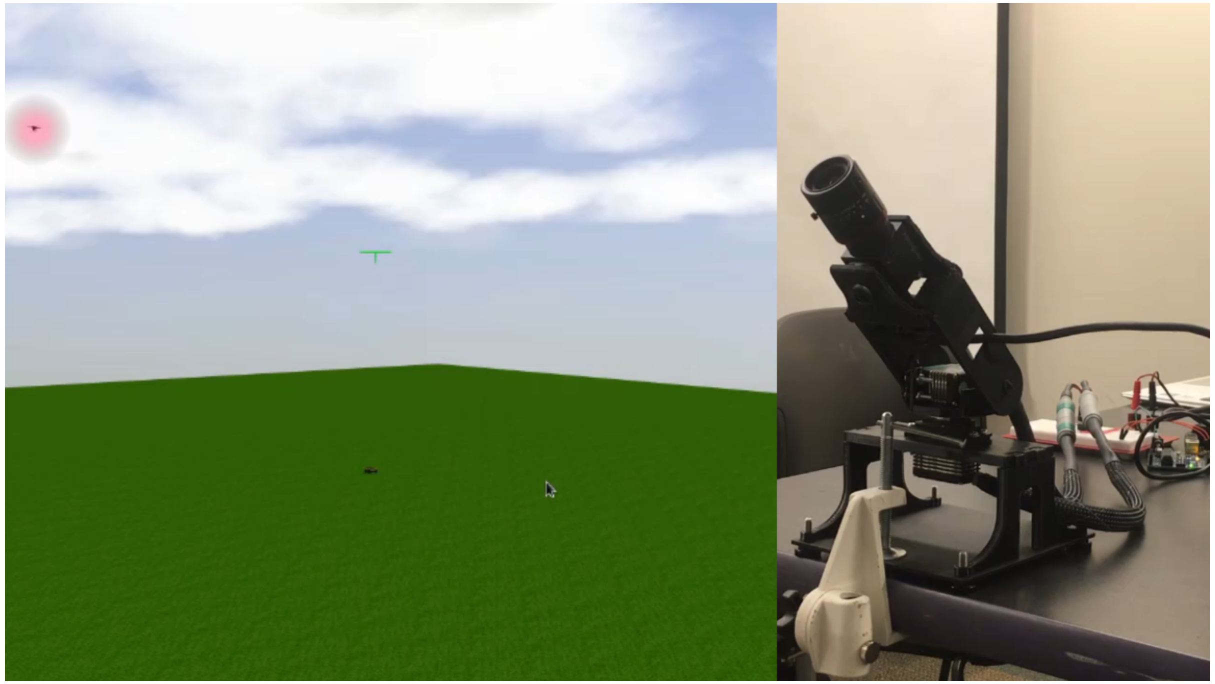
Reasoning: Verify that the gimbal pointing software and hardware works to desired specifications. Characterize pointing error in gimbal mechanism. Validate Gazebo models.

Testing Prerequisites:
- Gimbal unit test
- GPS unit test
- Odroid unit test
- Camera unit test

Equipment and Facilities:
- VICON space (RECUV Fleming Lab)
- UGV
- UAV

Risks:
- Damage to camera.
- Damage to gimbal
- Damage to GPS units

Recorded Data:
- Images [7 Hz]
- GPS [1 Hz]
- Pointing angles [1 Hz]

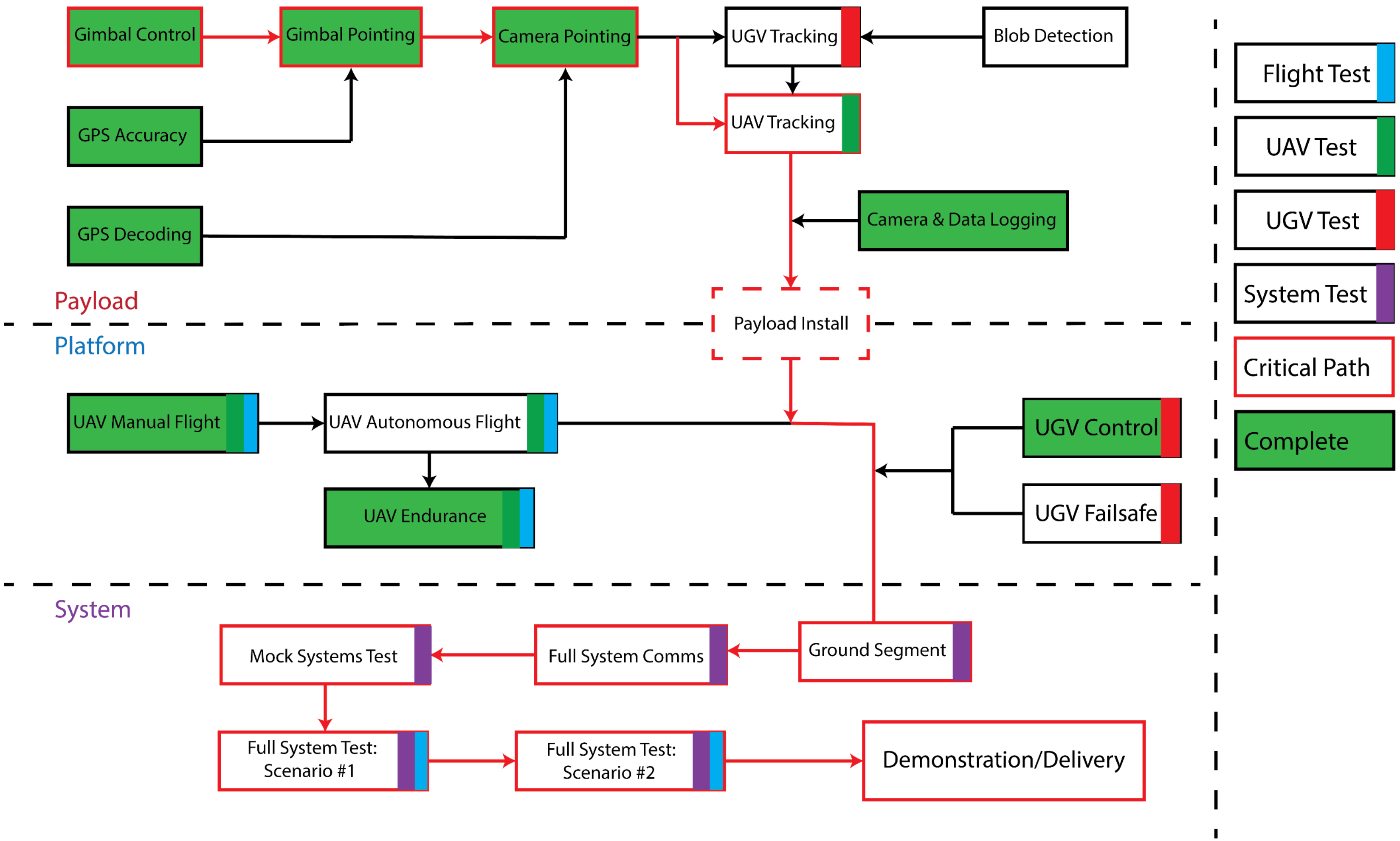


Major Obstacles:
- Servo Jitter
- Relative angle determination

Success Criteria:
- Gimbal keeps vehicle in 90% of frames

System Testing

Starting the week of 3/12



Indoor Mock System Test

Reasoning: Verify that the integrated system is ready to move on to final testing steps.

Testing Prerequisites:

- Automatic Flight
- Gimbal Pointing Test
- Integration
- Watchdogs

Equipment and Facilities:

- VICON space (RECUV Fleming Lab)
- Integrated UGV
- Integrated UAV
- GCS with UI

Risks:

- Schedule slippage
- Integration Failure
- Damage to VICON space

Recorded Data:

- RAW image data [7 Hz]
- Ephemeris data [1 Hz]
- Vehicle position and orientation [100 Hz]
- Gimbal state [1 Hz]
- Vehicle command [50 Hz]
- Housekeeping data [10 Hz]

Success Criteria:

- Mission duration > 18.15 minutes
- Data is saved in the correct format

Major Obstacles:

- UAV heading determination
- Camera integration

Outdoor Mock System Test

Reasoning: Verify GPS integration works in the full system.

Testing Prerequisites:
- Indoor Mock System Test

Equipment and Facilities:
- South Boulder Campus
- Integrated UGV
- Integrated UAV
- GCS
- Wifi router

Risks:
- Schedule slippage
- Integration Failure

Recorded Data:
- RAW image data [7 Hz]
- Ephemeris data [1 Hz]
- Vehicle position and orientation [1 Hz]
- Gimbal state [1 Hz]
- Vehicle command [50 Hz]
- Housekeeping data [10 Hz]

Success Criteria:
- Mission duration > 18.15 minutes
- Data is saved in the correct format

Major Obstacles:
- Switching to GPS from VICON data

Full System Test

Reasoning: Validate the completed RAVEN design.

Testing Prerequisites:

- Outdoor Mock System Test
- Detection Testing

Equipment and Facilities:

- South Boulder Campus
- Integrated UGV
- Integrated UAV
- GCS
- Wifi router

Recorded Data:

- RAW image data [7 Hz]
- Ephemeris data [1 Hz]
- Vehicle position and orientation [1 Hz]
- Gimbal state [1 Hz]
- Vehicle command [50 Hz]
- Housekeeping data [10 Hz]

Success Criteria:

- Mission duration > 18.15 minutes
- Data is saved in the correct
- All data is usable by the customer

Major Obstacles:

- Completion of mock systems testing
- Determination

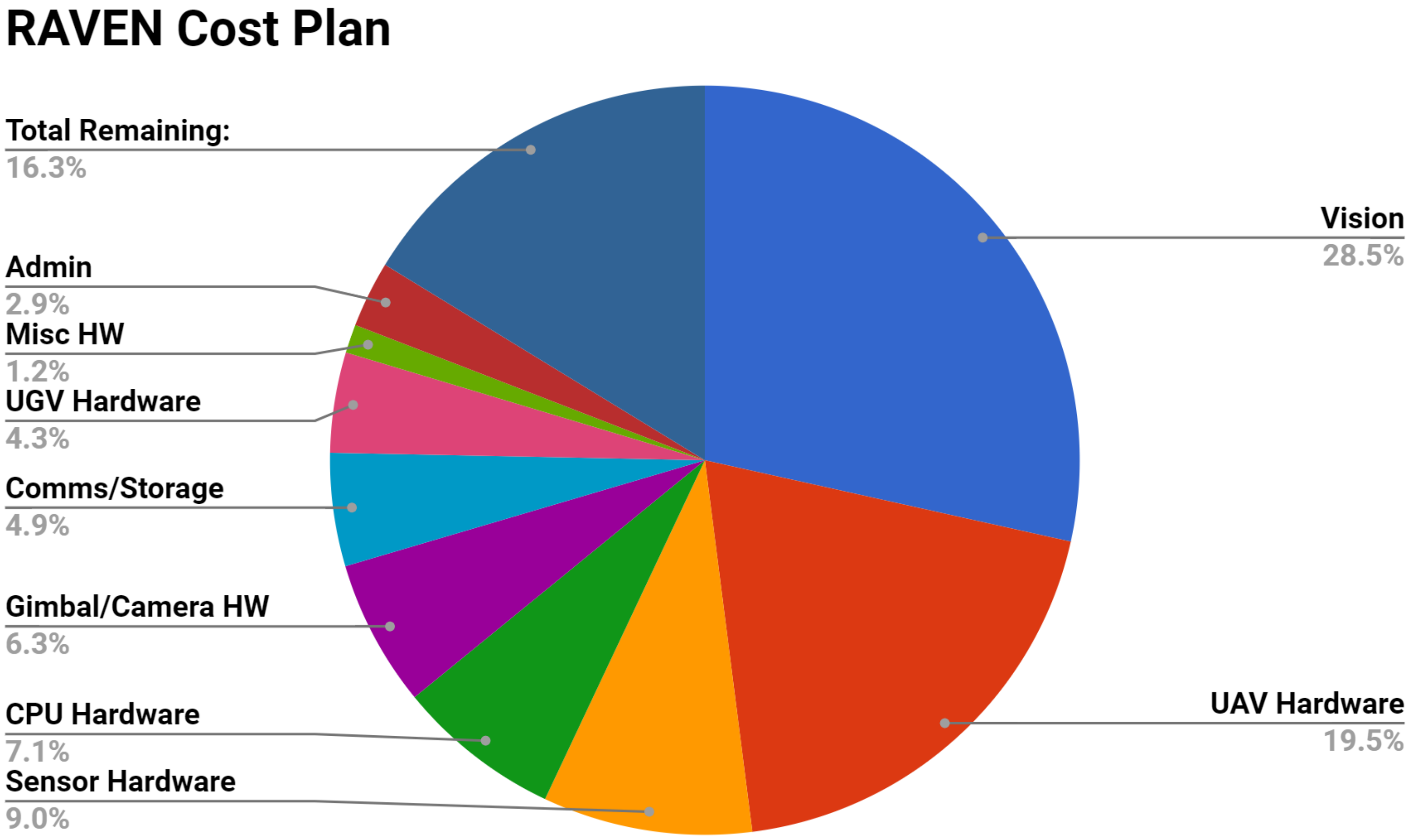
Procurement Update

Subsystem	Received	Purchased but not Received
Vision HW	Cameras, Lenses	
UAV HW	Frame, Motors, ESCs, Propellers, Batteries	
Sensor HW	GPS Receivers, GPS Antennas, Barometer	GPS Mount
CPU HW	ODROID (CPU, eMMCs, Power), Flight Controller, PWM Board, Voltage Regulators	
Gimbal HW	Gimbal, Feedback Servos, Mounting HW, Servo Brackets, Bracket Bearing	
Comms HW	Router, UAV Controller, micro SD cards, Telemetry Radios, Transceivers, Ethernet Cables, WiFi Module	
UGV HW	3030 Steel, Acrylic AR Mounts, Mounting HW	
Misc HW	Wires, Nuts, Bolts, Velcro, Cable Ties, Connectors, Mounting Tape, Battery Charger, Power Module	

Yet to be Purchased: Continuous Rotation Servos, Misc. HW**,** Administrative costs (Printing etc.)

Cost Plan

Subsystem	Cost
Vision HW	$ 1,994.00
UAV HW	$ 1,364.45
Sensor HW	$ 632.39
CPU HW	$ 496.21
Gimbal HW	$ 443.34
Comms HW	$ 342.03
UGV HW	$ 302.93
Misc HW	$ 86.30
Admin	$ 200.00
Money Spent	$ 5,861.55
Remaining Funds	**$ 1,138.45**
Total	**$ 7,000.00**



Uncertainties: Minor miscellaneous UAV/UGV Hardware.
Risks: UAV Crash, need money to replace.

Conclusion

- Behind schedule by one week
  - Mitigating delay by increasing testing time and crashing schedule
- Next large step is integration and mock system testing
- Have 1 week of buffer left for error during testing
- Under budget by $1,138.45


Questions?

Back up Slides

GPS Error (Backup)

Maximum allowable error:

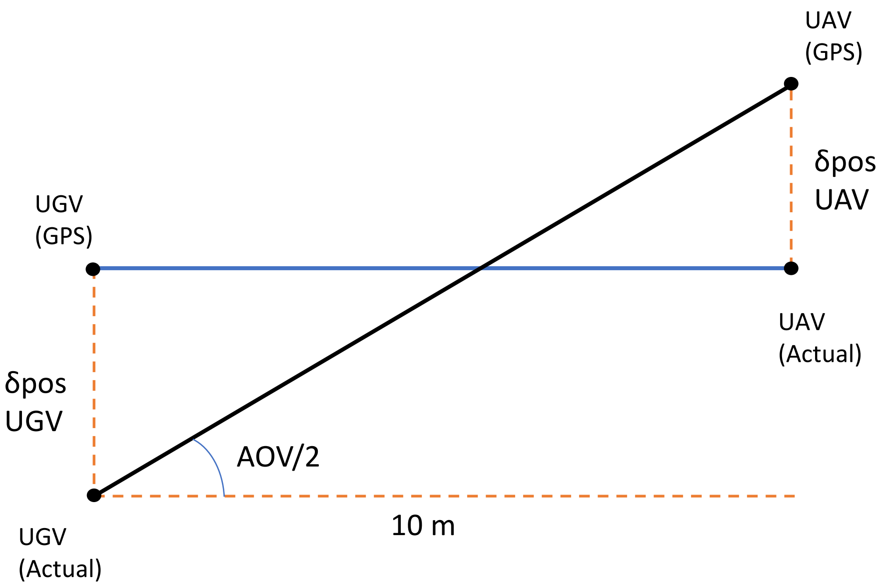
$$tan\left(\frac{AOV}{2}\right) = \frac{2\delta_{err}}{10m}$$

$$\delta_{err} = \frac{10m}{2} tan\left(\frac{28\deg}{2}\right) = 1.2466m$$

Z-score for 90% of frames is 1.281551.

$$\sigma = \frac{1.246640014m}{1.281551} = 0.9728m$$

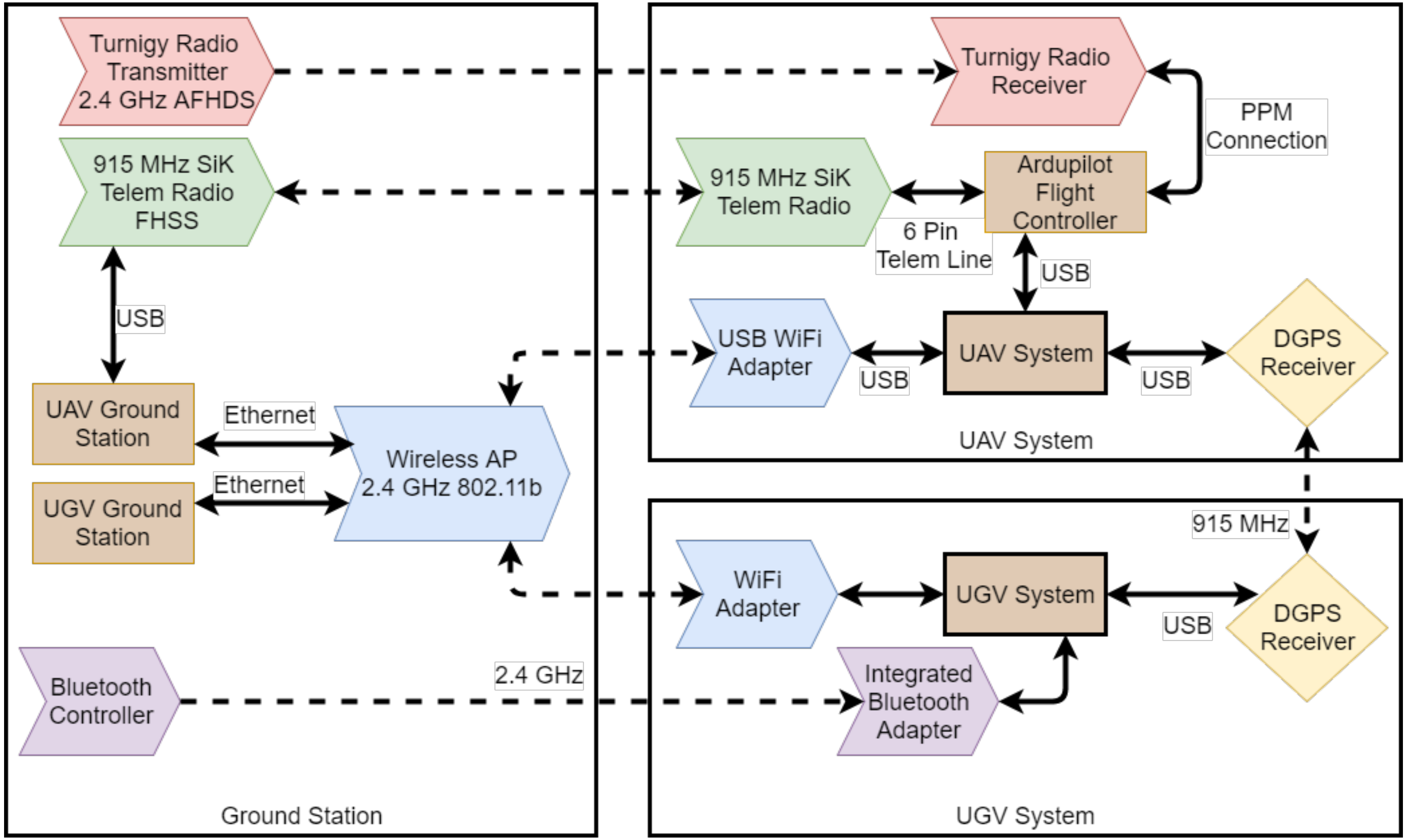
Therefore, the GPS error must have a standard of deviation less than or equal to 0.973 m in order to meet requirement.



Specific Objectives (All Level 3)

- **Vision: A moving UAV shall track the UGV at 10-30 m and be in 90 % of frames. A stationary UGV shall track the UAV at 10-30 m and be in 90 % of frames. Acquire target in less than 3 seconds.** Image resolution must be less than or equal to 3 in/pixel at 30 m.
- **Structure**: UAV < 50 lbs. UGV payload < 44 lbs. UAV and UGV are untethered. Batteries are field-accessible. Vision system shall be swappable and communicate over USB 3.0.
- **Captured Data**: Have at least 128 GB removable storage. **Store battery life estimate, package temperature, control input data, GPS/ephemeris data, IMU data, magnetometer data, and barometer data all in ROS bags w/ 20 GB storage margin.** Use lossless compression.
- **Controls**: **UAV will have emergency land switch.** Autonomous UAV tracking orbit with piloted takeoff and landing. UGV remotely piloted up to 0.5 m/s. Controls algorithms compatible with ROS. **Control station displays map overlay of UAV/UGV positions as well as battery status, flight timer, and storage capacity.**
- **Comms**: Vehicles shall communicate over ISM RF link. **Vehicles shall share GPS data, visual tracking, and state data with the control stations.**
- **Electronics/Software**: **Vehicles shall have 15 min tracking endurance.** GPS, IMU, Vision, magnetometer, and barometer shall be integrated. Shall be OpenCl 1.1 capable and have hardware floating point acceleration. Will be able to run cooperative localization algorithms on each vehicle with 50 % CPU overhead margin.
- **Management**: Adhere to UCB UAS FOM. Keep best safety practices. No DJI or prohibited components. **Project cost shall remain under budget.**

Communications Layout



UAV Gimbal Problem & Solution

- **Problem:** No way to tell where UAV gimbal was pointing.
- **Solution:** New 1D gimbal using feedback servo.

Old Gimbal	New Gimbal
167g	~75g
3-axis	1-axis
No feedback	Analog feedback

Proxy Masses

Proxy masses are needed for testing safety.

Part	Mass	Dimensions
Camera & Lens	116g	74 x 29 x 29mm
Gimbal	75g	45 x 39 x 32mm
ODroid XU4	65g	83 x 58 x 20mm
PixRacer	11g	36 x 36 x 20mm
GPS	35g	75 x 55 x 10mm
GPS Antenna	100g	30 x 30 x 100mm
Wiring	~150g	
Wireless Comms	~10g x3	10 x 10 x 10mm x3
Additional testing masses	10g x20	10 x 10 x 10mm x20

UAV Component Masses

Component	Measured Mass	Qty	Total
Frame	632g	1	632g
Propeller	24.5g	6	147g
Motor	88.2g	6	529.2g
Batt	954.5g	1	954.5g
Camera+lens	111g	1	111g
Telemetry Radio	16g	1	16g
Gimbal	76g	1	76g
Vibration Isolator	20g	1	20g
GPS System	123g	1	123g
Wifi Receiver	31g	1	31g
RC Receiver	15g	1	15g
ESC	31g	6	186g
Odroid + Arduino	120 g	1	120g
Wiring [estimate]	130g	1	130g
Total			3090g

Expected Mass: 2.9 kg

VICON motion capture

Overview: Motion capture system in RECUV indoor flight space. Allows for indoor vehicle flight tests. OTS ROS package solution: *vrpn_client_ros (virtual reality peripheral network)*

- VRPN:
  - **Inputs:** Data stream from VICON Tracker software [100Hz]
  - **Outputs:** Pose, linear and angular velocity, linear and angular acceleration of both vehicles [100Hz]
  - **Milestones:**
    - Attach motion capture markers and create VICON object for UAV and UGV [0/1]
    - Create launch file for *vrpn_client_ros* [0/1]
    - Integrate with UAV GPS collection process [0/5]

- "GPS" Handler
  - **Inputs:** Pose, linear and angular velocity, linear and angular acceleration of both vehicles
  - **Outputs:** Relative position and heading [1Hz]
  - **Milestones**:
    - Create handler [0/2]
    - Unit testing for integration [0/5]
    - Add noise to simulate sensor error [0/5]

Housekeeping Data

- UAV:
  - Pixracer outputs telemetry data when requested via mavROS message [50 Hz max]
  - Housekeeping process:
    - Create and send mavROS messages
    - Send data to SD storage and and package and send to GCS

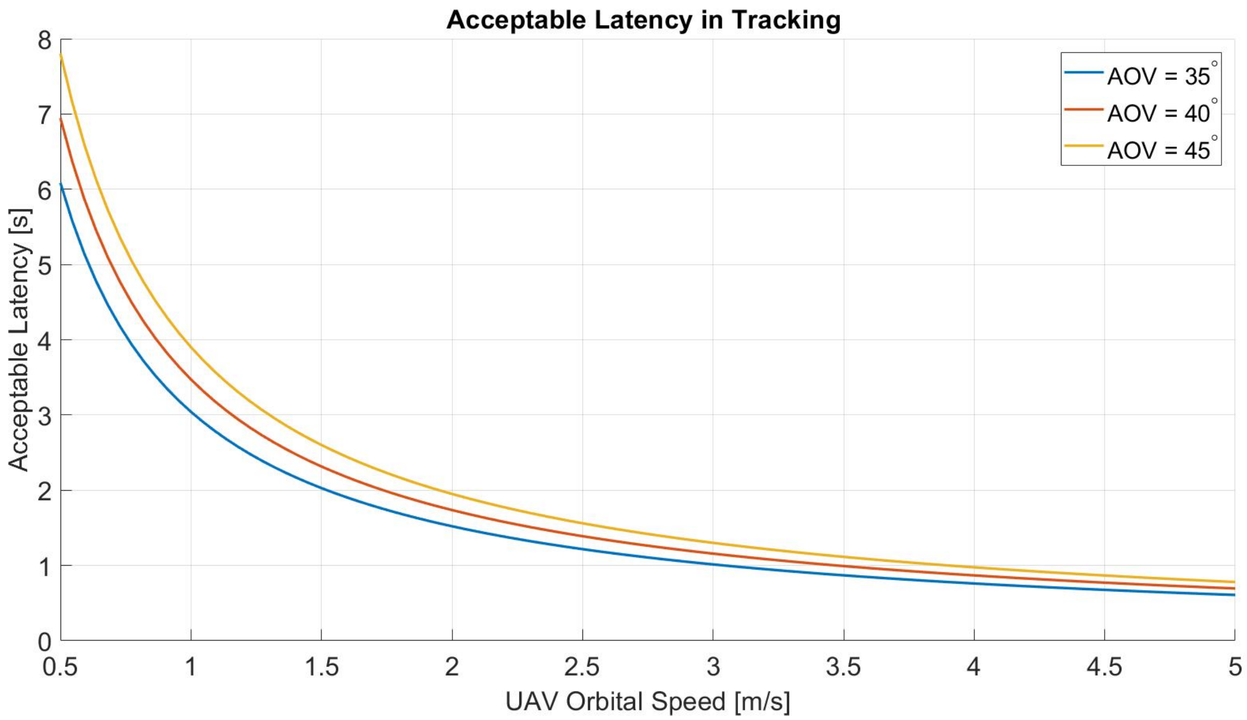
- Milestones:
  - Create and send mavROS messages [0/5]
  - Package data and send to GCS [0/2]
  - Send data to SD storage [0/2]

- ►UGV:
  - ►Jackal software makes temperature, battery information, command, and IMU data available out of the box [50 Hz]
  - ►Housekeeping process:
    - ►Grab data and send to SD storage and package and send to GCS

- ►Milestones:
  - ►Find all ROS topics with pertinent data [0/2]
  - ►Package data and send to GCS [0/2]
  - ►Send data to SD storage [0/2]

Latency Model

- Calculated Latency is time between pointing states
- Includes position transmission, processing, pointing commanding, and actuation



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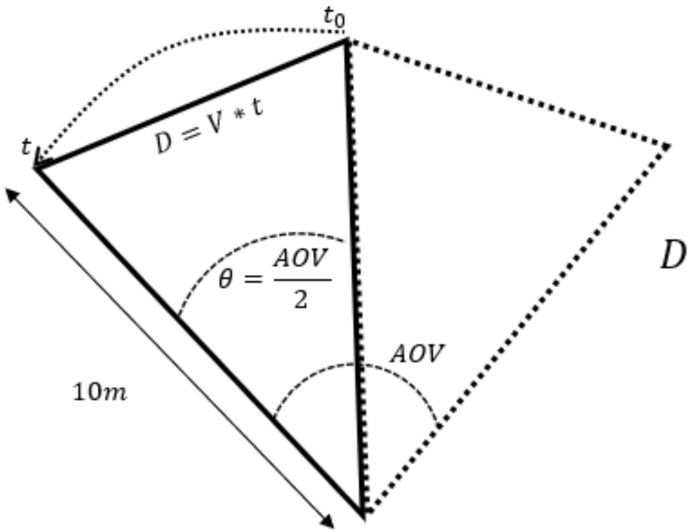
Latency Model



$$t - t_0 = t_{lat}$$
$$D = V * t_{lat}$$
$$D = 2 * 10m * \sin\left(\frac{\theta}{2}\right) = 2 * 10m * \sin\left(\frac{AOV/_2}{2}\right)$$
$$V * t_{lat} = 2 * 10m * \sin\left(\frac{AOV/_2}{2}\right)$$
$$\boldsymbol{t_{lat} = \frac{2}{V} * 10m * sin\left(\frac{AOV/_2}{2}\right)}$$

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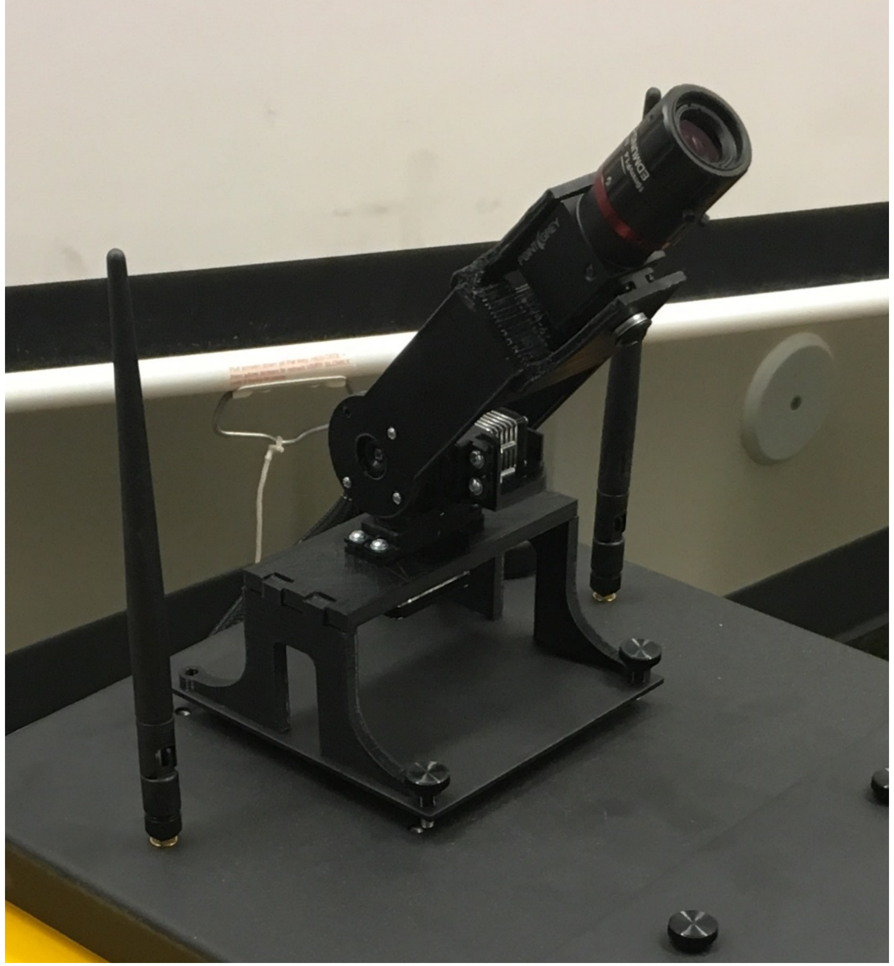
Mounting Rail

- Used to mount AR tag plates and gimbal
- 8020 – 3030
- M5 bolts for mounting onto UGV
- Weight not a concern

UGB Gimbal

- Prototyped from CDR
- 3D printed PLA
- Tolerances sufficient (no necessity for accuracy)
- M5 bolts
- 2 x analog feedback servos
- Servo bearing on other side of tilt arm for smooth movement

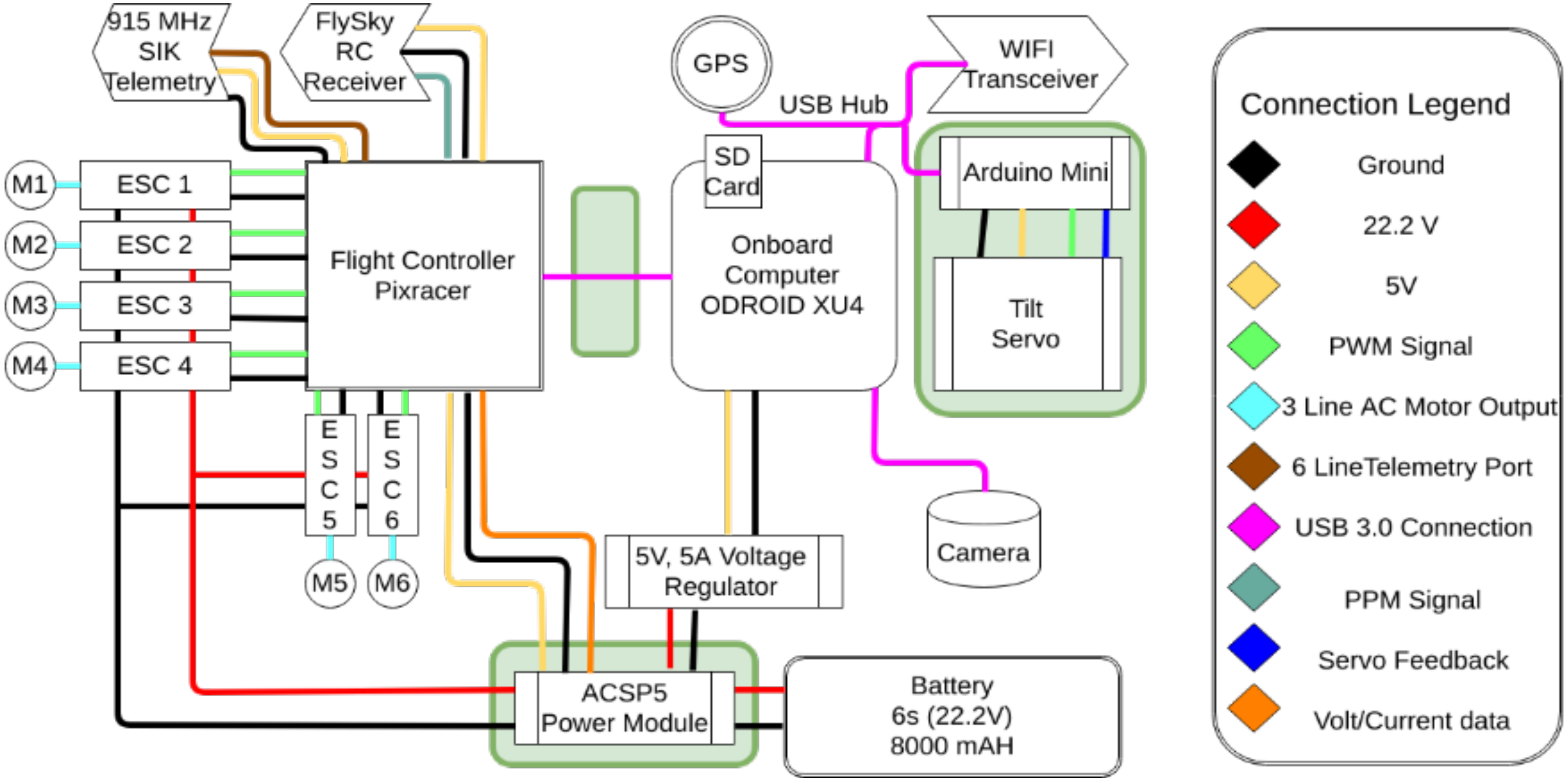


GPS Configuration

- RTK Moving Baseline Mode (MB)

- Requires RTCM Messages:
  - 1077 (GPS Observations), 1087 (GLONASS Observations), 1230 (GLONASS Code-phase Biases), 4072 (uBlox Proprietary MB Message).
- Base will send RTCM messages at 19200 Baud, and Rover will receive RTCM messages at 19200 Baud.
- Both the Base and the Rover will be configured with 1 Hz navigation rate.
- Users will receive:
  - NAV-DOP, NAV-HPPOSECEF, NAV-TIMEUTC, NAV-VELNED, NAV-RELPOSNED, RXM-RAWX (Observations), RXM-SFRBX (Navigation Subframe)
  - NMEA-RMC (Recommended minimum NMEA message)

Updated Electronics Connection Diagram



Electronics Integration Status

Tested Working Connection:

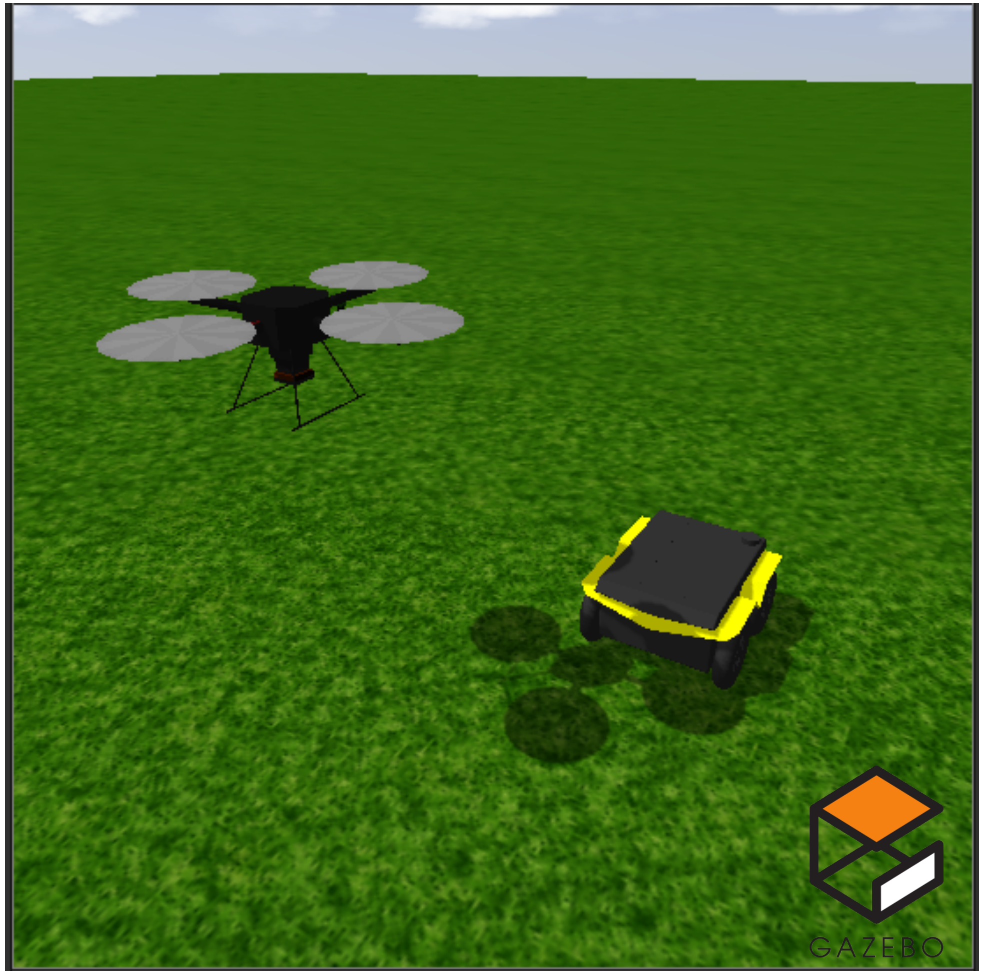
- Pixracer - Odroid Connection
- Pixracer - RC Controller
- Pixracer - Telemetry Radio
- UGV - Bluetooth
- Wifi router setup
- ODROID - Arduino – Servo

Untested Connection:

- Pixracer-ESC
- ODROID-Wifi
- ODROID-GPS
- ODROID-Camera
- UAV Power Distribution
- UGV Extra Sensors

Gazebo Overview

- ROS Simulation Tool
- Provides 3D visualization of systems
- Allows sensor emulation
- Simulates reasonable approximations of dynamics
- **Allows prototyping of RAVEN network**



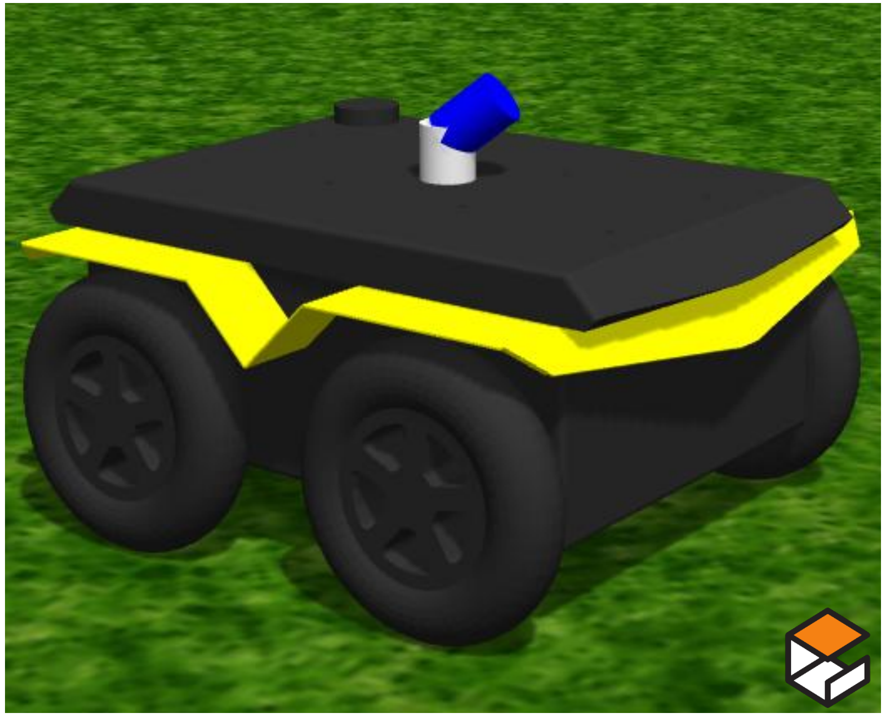
Gazebo Assumptions

- Sensors are emulated
  - Sensor traits are not yet configured
  - Sensor data source will change
- Physical characteristics
  - Magnitude of losses are unknown
  - Can change with environment

Project Purpose | Design Solution | CPEs | Design Reqs. | Project Risks | Validation | Project Planning

Simulated Camera and Mount

- Gazebo plugin for camera
  - Parameters
    - View distance
    - Resolution
    - Field of view
- Gazebo plugin for mount control
  - Modeled by two intersecting cylinders
  - Manually command pan and tilt joints to angles
  - Still to implement: mount tracks UAV by sharing GPS, more realistic model for camera and mount



Gazebo Playback

- A ROS Bag records ROS messages for topics that the bag is subscribed to, as well as a time record of the message.
- Using ROS playback, tools these messages can be played back in real time.
- Utilizing the Gazebo model, and replaying all ROS messages, the test conditions and results can be played back.
    - There are some limitations, based on the time difference between when a topic was published to, and when the value was processed.

UGV Gimbal Demonstration