Agenda

- Project Overview
  - Master Test Plan
- Subsystem breakdown
  - Design Description
  - Test Overviews
  - Test Results
- Systems Engineering Perspective
- Project Management
Project Overview
Overview

Field of Application

- GPS Navigation

Problem Addressed

- detect GPS RFI and locate the source
  - Enable user to locate and deactivate a device which may impede GPS navigation for other vehicles

Potential Impact

- Airport Security
- Academic RFI research

3 km max
During entire mission telemetry is relayed back to ground station.

RFI Zone of influence is detected, vehicle stores last known trusted position and switches to inertial sensor based flight.

As vehicle travels inside of RFI influenced area, it uses its inertial sensors to maintain a constant heading and travel through the area of influence.

Once 3 trusted locations are stored, the vehicle will return home.

Expected mapping duration: 5 min.
## LOS Overview

| Levels of Success |  
|-------------------|---
| **Level 1:**      | a) Autonomous navigation with GPS  
b) RFI detection  
c) Extended range with larger battery  
| **Level 2:**      | a) Long range communication via cell modem  
b) Transmit video via cell modem  
c) Identify red target with video  
d) Integration of electronics with PCB  
e) Integration of electronics, battery, and cell modem with custom hull  
| **Level 3:**      | a) Return home with inertial navigation  
b) Map RFI zone and find source  

# Test Overview

<table>
<thead>
<tr>
<th>Test #</th>
<th>Test Description</th>
<th>Verifies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Flight Test:</strong> Autonomous Waypoint Navigation</td>
<td>1a</td>
</tr>
<tr>
<td>2</td>
<td><strong>Ground Test:</strong> RFI Detection test</td>
<td>1b</td>
</tr>
<tr>
<td>3</td>
<td><strong>Flight Test:</strong> Battery’s extended range</td>
<td>1c</td>
</tr>
<tr>
<td>4</td>
<td><strong>Ground Test:</strong> Command and Communicate via cell modem 3km away</td>
<td>2a</td>
</tr>
<tr>
<td>5</td>
<td><strong>Ground Test:</strong> Video transmission from drone to GCS via cell modems</td>
<td>2b</td>
</tr>
<tr>
<td>6</td>
<td><strong>Ground Test:</strong> Identify red target with video feed on GCS</td>
<td>2c</td>
</tr>
<tr>
<td>7</td>
<td>PCB integration and functionality <strong>check</strong></td>
<td>2d</td>
</tr>
<tr>
<td>8</td>
<td>Manufacturing <strong>check</strong> of custom hull</td>
<td>2e</td>
</tr>
<tr>
<td>9</td>
<td><strong>Flight Test:</strong> Return Home Inertially</td>
<td>3a</td>
</tr>
<tr>
<td>10</td>
<td><strong>Ground Test:</strong> Mapping RFI zone</td>
<td>3b</td>
</tr>
</tbody>
</table>
## Test Matrix

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>TESTS</th>
<th>RFI</th>
<th>Mapping</th>
<th>Mechanical</th>
<th>Waypoint Flight</th>
<th>Paparazzi Waypoint</th>
<th>Video</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waypoint Navigation</td>
<td>1.QUADFR.1</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
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<tr>
<td>Monitor GPS Integrity</td>
<td>1.QUADFR.2</td>
<td>✔️</td>
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<tr>
<td>Locate RFI Device</td>
<td>1.QUADFR.3</td>
<td>✔️</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>View Target</td>
<td>1.QUADFR.5</td>
<td>✔️</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✔️</td>
</tr>
<tr>
<td>Operational Conditions</td>
<td>1.QUADFR.7</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long Range Communication</td>
<td>1.QUADFR.8</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6km Mission</td>
<td>1.QUADFR.9</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inertial Navigation</td>
<td>1.GRNFR.1</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>Waypoint GUI</td>
<td>1.GRNFR.1</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCS Data Processing</td>
<td>1.GRNFR.2</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
GPS RFI Detection
- Automatic Gain Control

Automatic Gain Control (AGC) is an adaptive circuit which dynamically adjusts incoming signal gains to match the level requirement of downstream electronics.

- AGC is low complexity and is intrinsic in all multi-bit GPS receivers.

- AGC is not part of NMEA message but some civilian GPS receivers include it in the digital output.

- GPS RFI can be detected by monitoring the output of the AGC circuitry:
  - A boosted GPS signal causes the AGC to drop.
Analysis

• ΔAGC = 2 is when GPS signal is compromised, which corresponds for -108dB of RFI signal*

• AGC resolution = 1.6 dB/step

Outcome

• The amount of power received (which caused a signal jam) is used to calculate the power output of the Wi-Fi simulation device using the Friis transmission equation

\[ P_{t_{\text{WiFi}}} = \left( \frac{4 \pi f_{\text{WiFi}} d}{c} \right)^2 \left( \frac{P_r}{G_t G_r} \right) \]

*More tests must be run to fine tune this value through use of smaller attenuation steps
Functional Requirement 2: SIVAQ shall monitor GPS information integrity and detect radio frequency interference. Signal shall be considered compromised if AGC value ventures outside $3\sigma$ from its nominal value.

Test: Attempt to detect simulated RFI zone

• Location: Kittridge Fields

• Note: Drone was taped to stick to remove blocking effects from hand and power levels were manually retrieved from the drone on the ground station.

Test Goal: Verify that the AR.Drone has the capability to detect power levels
Test Procedure RFI Detection

1. Set up Wi-Fi router in middle of field
2. Attached drone to a wooden stick to remove conductive effects from holding it
3. Started outside Wi-Fi zone, walked towards router
4. Started at router, walked out of Wi-Fi zone
5. Recorded signal strength values every 5 ft
Flight toward router
- Expected RFI threshold distance was **179.5 ft**
- Actual RFI threshold distance was **119.0 ft** when vehicle tipped away from the router
- Error obtained from resolution tests
  - Resolution tests took multiple signal readings at various distances
  - Conducted at 164, 100 and 40 ft

±3 dBm error
Flight away from router
- Expected RFI threshold distance was **179.5 ft**
- Actual RFI threshold distance was **164.0 ft** when facing the router

±1 dBm error
• Wi-Fi chip has a resolution of ±1 dBm
• Flying away from RFI source has only the resolution error
• Hardware adds a ±2 dBm error
• To minimize the error, the Wi-Fi antenna needs to be relocated so that the hardware is not adding interference
Mapping RFI Zone
1. Pre-Zone
- Check for AGC
RESULT: First GPS position
ACTION: Turn off GPS and fly into zone

2. First Leg
- Maintain heading and speed
- Check for AGC
RESULT: Second GPS position
ACTION: Fly back into zone

3. Second Leg
Part 1
- Maintain heading and speed
- Check for estimated position
ACTION: Stop and turn 90°

4. Second Leg
Part 2
- Maintain heading and speed
- Check for AGC
RESULT: Third GPS position
ACTION: Calculate center transition to next case
Mapping Model

Requirement
Vehicle will be capable of locating RFI source within 7 meters of true location

Assumptions
• Circle radii: 50m
• Vehicles flight speed is $4.4 \frac{m}{s}$
• Omnidirectional source antenna
• Area is free of antenna interference

Constraints
• All points gathered must be at least 10 meters apart

Results
• In order to achieve consistent 90% success rate, vehicles trusted GPS locations must be within 5m on either side of threshold
• Vehicle must be able to sample AGC at least 1.5 times per second

$P_{ec} = $ Estimated RFI source location
$P_{ac} = $ Actual RFI source location
Functional Requirement 3: SIVAQ attempt to locate circle of influence and approximate location (within 7 meters) of location of RFI Device

Test: Walk Through Mapping Test

• Location: Kittredge Fields

• Note: Drone was taped to stick for test and power levels were manually quarried from the drone using the ground station.

Test Goal: Validate that the mapping procedure will find a source point within the error boundaries.
Test Results Mapping

- Placed three points 50 meters from Wi-Fi source (-80 dBm) and carried the drone through the mapping procedure.
- Once threshold was reached the GPS position was acquired through a handheld receiver.
## Test Results Mapping

### Distances between expected and measured points

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Test 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point 1</td>
<td>8.9 m</td>
<td>13 m</td>
<td>2.8 m</td>
<td>2.8 m</td>
</tr>
<tr>
<td>Point 2</td>
<td>2.4 m</td>
<td>1.2 m</td>
<td>10.0 m</td>
<td>2.2 m</td>
</tr>
<tr>
<td>Point 3</td>
<td>9.6 m</td>
<td>5.6 m</td>
<td>1.1 m</td>
<td>7.7 m</td>
</tr>
<tr>
<td>Source</td>
<td>6.2 m</td>
<td>21.4 m</td>
<td>16.0 m</td>
<td>8.5 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Error Source</th>
<th>Error Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS Position</td>
<td>+/- 3 m</td>
</tr>
<tr>
<td>RFI Threshold</td>
<td>+/- 9.2 m</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>+/- 12.2 m</td>
</tr>
</tbody>
</table>

Note: Model predicted error needs to be within 5 meters for 90% success rate

Could not completely fulfill requirement 1.QUADFR.3
Model Success Rates

<table>
<thead>
<tr>
<th>GPS/Wi-Fi Error [m]</th>
<th>Radius of Circle [m]</th>
<th>Requirement [m]</th>
<th>Success Rate [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>50</td>
<td>7</td>
<td>24.1*</td>
</tr>
<tr>
<td>9**</td>
<td>50</td>
<td>7</td>
<td>48.0</td>
</tr>
<tr>
<td>12</td>
<td>50</td>
<td>10</td>
<td>53.2</td>
</tr>
<tr>
<td>9</td>
<td>50</td>
<td>10</td>
<td>76.4</td>
</tr>
</tbody>
</table>

*Success rate from testing was 25%.

**9m error attainable by ensuring all points are captured while moving away from source
Test Conclusions

*Vehicle can detect a source of RFI within 7m of source

**Can map to find source but not within requirement

<table>
<thead>
<tr>
<th>Levels of Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1:</td>
</tr>
<tr>
<td>a) Autonomous navigation with GPS</td>
</tr>
<tr>
<td>b) <strong>Vehicle can detect RFI</strong></td>
</tr>
<tr>
<td>c) Extended range with larger battery</td>
</tr>
<tr>
<td>Level 2:</td>
</tr>
<tr>
<td>a) Long range communication via cell modem</td>
</tr>
<tr>
<td>b) Transmit video via cell modem</td>
</tr>
<tr>
<td>c) Identify red target with video</td>
</tr>
<tr>
<td>d) Integration of electronics with PCB</td>
</tr>
<tr>
<td>e) Integration of electronics, battery, and cell modem with custom hull</td>
</tr>
<tr>
<td>Level 3:</td>
</tr>
<tr>
<td>a) Return home with inertial navigation</td>
</tr>
<tr>
<td>b) <strong>Map RFI zone and find source</strong></td>
</tr>
</tbody>
</table>
Electronics Package
Electronics Package

**Function:**

1. Communicate with GPS Satellites to obtain position solution, pass solution to additional microprocessor
2. Convert NMEA message to SiRF IV message
3. Convert UART data from Arduino Pro Mini into USB 2.0 format, send data to AR. Drone 2.0
4. Read SiRF IV message and interprets AGC Value

---

**Example:**

$GPGGA,092750.000,5321.6802,N,00630.3372,W,1,8,1.03,61.7,M,55.2,M,,*76$

$GPMTKAGC,05,0F,02721,07155,07509,02885*38$

---

**Key:**

- **Data**
- **Interface**

---

**Diagram:**

1. **GPS receiver**
2. **Additional microprocessor**
3. **USB to UART**
4. **Vehicle**

- **Serial Interface:** UART TTL
- **Header:** 6 Pin Header
- **Standard:** USB 2.0

---

**Data Interface Key:**

Example:

- **Message type**
- **Arrival Time**
- **Position**
- **Altitude**
- **NMEA**
- **AGC message**
PCB Integration

- Unfortunately due to miscommunication with manufacturer regarding the GPS unit’s datasheet, PCB that was designed was done so incorrectly
- This prevented GPS from being able to gather fix from satellite data
Successful Results

Figure 1: Newly designed circuit

NMEA GPS log file exert:

$GPGGA,000123.096,,,,,0,0,,M,,M,,*47
$GPGSA,A,1,,,,,,,,,,,*1E
$GPGSV,1,1,03,11,,,20,08,,,13,07,,,13*77

GPS receiver correctly communicates with satellites using new setup
Successful Results

- GPS receiver
- Microprocessor
- UART to USB
- Vehicle

Logic Analyzer

Lab Computer

AGC Value

Actual AGC Message

Modified SiRF Message

Arduino is correctly converting NMEA message to SiRF with AGC included
**Requirement** : The vehicle must navigate via GPS based flight, be capable of monitoring GPS signal integrity, and must integrate with the stock AR. Drone 2.0

**Test Result Analysis:**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Test</th>
<th>Result</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implement GPS receiver capable of monitoring RFI</td>
<td>Lab and open field signal quality testing</td>
<td>Partial Success</td>
<td>Original PCB design was incorrect, however correct schematic was able to receive position data as well as AGC values</td>
</tr>
<tr>
<td>Alter standard NMEA message to SiRF message</td>
<td>Logic Analyzer lab test</td>
<td>Partial Success</td>
<td>Logic Analyzer showed AGC values coming from GPS receiver as well as correct AGC addition and conversion of message to SiRF</td>
</tr>
<tr>
<td>Design Requirement 9.1</td>
<td>Incorporation of components</td>
<td>Success</td>
<td>PCB, Additional microprocessor, and UART to USB adapter integrated fully with stock AR. Drone 2.0</td>
</tr>
<tr>
<td>Hull Design Requirement 9.1.1</td>
<td>Weighing system after incorporating all required components</td>
<td>Fail</td>
<td>PCB mass was larger than the expected value due to the addition of resistors and capacitors to remove noise as well as the need for a backup battery</td>
</tr>
</tbody>
</table>
### Test Conclusions

*PCB design discrepancy, but mitigation meets functional requirements*

<table>
<thead>
<tr>
<th>Levels of Success</th>
</tr>
</thead>
</table>
| **Level 1:** | a) Autonomous navigation with GPS  
|             | b) **Vehicle can detect RFI**  
|             | c) Extended range with larger battery |
| **Level 2:** | a) Long range communication via cell modem  
|             | b) Transmit video via cell modem  
|             | c) Identify red target with video  
|             | d) **Integration of electronics with PCB**  
|             | e) Integration of electronics, battery, and cell modem with custom hull |
| **Level 3:** | a) Return home with inertial navigation  
|             | b) **Map RFI zone and find source** |

**Key**

- Success
- Partial Success
- Unsuccessful
Mechanical
AR.Drone 2.0 Hardware

Motor (x4)
- Brushless
- 14.5 Watts
- 28,500 RPM
- Microball
- Berings
- Nylatron Gears

Motor Controller (x4)

Memory
- DDR2 RAM
- 200 MHz clock

Microprocessor
- 32 bit ARM Cortex A8
- 1 GHz clock

Wi-Fi
- Atheros AR61036 chipset
- 2.4 GHz Tx frequency

Downward facing camera
- QVGA
- 64° diagonal lens
- 60 fps recording speed

Forward facing camera
- 93° wide angle lens
- 720p
- 30fps recording speed

Battery
- Lithium Polymer
- 1000 mAh capacity

USB port
- 400 Mb/s

Navboard

Microprocessor
- 16 bit PIC
- 40 MHz clock

Altimeter
- Barometric pressure sensor
- ± 10 Pa precision

Ultrasound
- 6 m precision

Accelerometer
- 3 axis
- ± 50 mg precision

Magnetometer
- 3 axis
- 6° precision

IMU
- Invensense IMU-3000
- Contains 3 axis gyro and input for 3-axis accelerometer

Motherboard

Project Purpose and Overview
Design Description
Test Results
Systems Engineering
Project Management
Stock AR.Drone

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor Hull</td>
<td>32</td>
</tr>
<tr>
<td>1000 mAh Battery</td>
<td>101</td>
</tr>
<tr>
<td>Stickers</td>
<td>10</td>
</tr>
<tr>
<td>USB Port</td>
<td>1.18</td>
</tr>
<tr>
<td>Navigation Boards</td>
<td>61.1</td>
</tr>
<tr>
<td>Battery Housing</td>
<td>33.25</td>
</tr>
<tr>
<td>Structure/Frame</td>
<td>56.25</td>
</tr>
<tr>
<td>Cross Strut</td>
<td>140</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>424.6</strong></td>
</tr>
</tbody>
</table>
**Functional Requirement:** SIVAQ must fly 6 km.

**Stock AR.Drone 2.0 Capabilities:** 3.6 km max range

### Estimating Current Draw

**STEP 1:** Find current during hover

\[ \text{Amps}_{\text{hover}} \]

**STEP 2:** Find flight angle at designated speed

\[ \text{Amps}_{\text{flight}} = \frac{\text{Amps}_{\text{hover}}}{\cos(\text{Angle})} \]

\[ \text{Amps}_{\text{flight}} = 4800 \text{ mA} \]

- **Battery Size**
  - Current Draw from motors over 6km:
    \[ 4800 \text{ mA} \times \left( \frac{24}{60} \right) \text{ hr} = 1920 \text{ mAh} \]
  - Current Draw from additional sensors:
    \[ 800 \text{ mA} \times \left( \frac{24}{60} \right) \text{ hr} = 320 \text{ mAh} \]

- **Battery Choice**
  - LiPo 11.1 V 30 C 3200mAh*
    - Mass: 240 g
    - Dimensions (LxWxH): 135x43x22mm
    - *LiPo 80% rule

- **Attainable Flight**
  \[ \left( \frac{3200 \text{ mAh}}{5600 \text{ mAh}} \right) \times 80\% = 27 \text{ minutes} \]
  \[ 4.4 \text{ m/s} \times (27 \times 60) \text{ s} = 7.1 \text{ km} \]

- **Speed with Sivaq mass 510 g**

### Design Requirement 1:
- Reconfigure hull to incorporate larger battery, stock sensors, and any additional electronics

### Hull Design Requirement 1.1:
- Reconfigured hull shall not alter stability (SIVAQ shall not be more than 130% of stock AR.Drone 2.0 mass)
Mechanical Design

Design Requirement 1: Reconfigure hull to incorporate larger battery, stock sensors, and any additional electronics

Stock AR.Drone 2.0 Mass: 424 g
Mass Removed: 239 g
Mass Added: 324 g
SIVAQ Mass: 510 g
New Mass: 120% of Stock

Custom Hull
Dimensions(LxWxH): 140x58x44 mm
Thickness: 4 mm
Mass: 48 g
## Custom Hull Mass

<table>
<thead>
<tr>
<th>Component</th>
<th>Estimated Mass [g]</th>
<th>Actual Mass [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Custom Hull</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>3200 mAh Battery</td>
<td>225</td>
<td>250</td>
</tr>
<tr>
<td>Cross Strut</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Navigation Boards</td>
<td>61</td>
<td>61</td>
</tr>
<tr>
<td>GPS receiver</td>
<td>2.5</td>
<td>4</td>
</tr>
<tr>
<td>Microprocessor / USB-UART</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>PCB</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Cell Modem</td>
<td>21</td>
<td>23</td>
</tr>
</tbody>
</table>

**TOTAL**  
510  
543*  

*Difference in estimated mass and actual mass is due to a combination of underrepresented mass of components and underestimated adhesive material.

Experimentally Determined Max Take-off Mass: 530g
Function Requirement 9: SIVAQ shall be able to fly to a target location within a 3km radius area, then return home.

Test: Validate Range Model (at 510 g)

• Location: Balch Fieldhouse

• Note: Partial SIVAQ system, not including electronic package (PCB, USB-UART, Microprocessor) or cell modem, tested using cell phone application.
### Test Results Mechanical

<table>
<thead>
<tr>
<th>Test</th>
<th>Flight Distance [km]</th>
<th>Flight Duration [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.15</td>
<td>28.4</td>
</tr>
<tr>
<td>2</td>
<td>6.21</td>
<td>27.9</td>
</tr>
<tr>
<td>3</td>
<td>6.12</td>
<td>28.7</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>6.16</strong></td>
<td><strong>28.3</strong></td>
</tr>
<tr>
<td><strong>Model Prediction</strong></td>
<td><strong>7.10</strong></td>
<td><strong>27</strong></td>
</tr>
<tr>
<td><strong>Adjusted Model</strong></td>
<td><strong>6.14</strong></td>
<td><strong>27</strong></td>
</tr>
</tbody>
</table>

Estimated Average Speed: 4.4 m/s

Actual Average Speed: 3.8 m/s
Test Results Mechanical

**Function Requirement 9**: SIVAQ shall be able to fly to a target location within a 3km radius area, then return home.

**Design Requirement 9.1**: Reconfigure hull to incorporate larger battery, stock sensors, and any additional electronics

**Hull Design Requirement 9.1.1**: Reconfigured hull shall not alter stability (SIVAQ shall not be more than 130% of stock AR.Drone 2.0 mass)

**Test Result Analysis:**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Test</th>
<th>Result</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional Requirement 9</td>
<td>Flight Range Model Validation</td>
<td>Partial Success</td>
<td>Test conducted at 510 grams. Several components removed to allow for flight.</td>
</tr>
<tr>
<td>Design Requirement 9.1</td>
<td>Incorporation of components</td>
<td>Success</td>
<td>Addition of battery to PCB prevented the inclusion of PCB lid as initially designed, however, use of adhesive material allowed successful incorporation</td>
</tr>
<tr>
<td>Hull Design Requirement 9.1.1</td>
<td>Weighing system after incorporating all required components</td>
<td>Fail</td>
<td>Difference in estimated mass and actual mass is due to a combination of underrepresented mass of components, components not initially incorporated in SIVAQ design, and underestimated adhesive material</td>
</tr>
</tbody>
</table>
Test Conclusions

*Vehicle can fly to an extended range of 6km without additional electronics
**Additional electronics integrate mechanically as expected

<table>
<thead>
<tr>
<th>Levels of Success</th>
</tr>
</thead>
</table>
| **Level 1:** | a) Autonomous navigation with GPS  
b) Vehicle can detect RFI  
c) Extended range with larger battery |
| **Level 2:** | a) Long range communication via cell modem  
b) Transmit video via cell modem  
c) Identify red target with video  
d) Integration of electronics with PCB  
e) Integration of electronics, battery, and cell modem with custom hull |
| **Level 3:** | a) Return home with inertial navigation  
b) Map RFI zone and find source |

Key
- Success
- Partial Success
- Unsuccessful
Flight Software
Software

Drone Motherboard (Linux OS)

Flight Software

\dot{\theta} \quad \dot{\phi} \quad \dot{\psi} \quad \Delta \vec{V}

User

Kernel

Sensor Inputs

Sensors

Sensor Log File

Drone Stability Algorithms

Δ\text{Speed}

Motors

Digital

Hardware

Software

Firmware

Digital

Hardware

44
Software

User Space

Flight Software

Custom Modules

- Dead Reckoning
- RFI Simulation
- RFI Behavior

Sensor data

- Current Location (update every 10s)
- AGC

Cellular

- Current Location + AGC

GPS

- Current Location

Auto Navigation

- \( \dot{\theta} \)
- \( \dot{\phi} \)
- \( \dot{\psi} \)
- \( \Delta \vec{V} \) (200-2000 mm/s)

User Flight Plan

- (up to 254 waypoints)

Modify Preset Waypoints

Destination

Current Location

- (200-2000 mm/s)
- (-0.7 to 6.1 rad/s)

45
**Waypoint Navigation Test**

**Requirement:** SIVAQ shall travel autonomously via predetermined waypoints while maintaining pseudo range accuracy of 7.8 meters

**Test:** Designate waypoints on the ground control station and launch vehicle tethered to fishing pole

**Location:** Kittredge Fields

**Test Goal:** Verify the drone’s capability of navigating through waypoints

**Challenges**
- 3 weeks
- 5 attempts
- 3-4 members for 3-4 hours on a weekday
- Coordinate with James Mack
## Waypoint Navigation

<table>
<thead>
<tr>
<th>Attempt</th>
<th>Configuration</th>
<th>Result</th>
<th>Note</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flight Software + Custom GPS</td>
<td>Fail</td>
<td>Flight Software thought drone had taken off at full throttle when nothing was moving</td>
<td>Changed setting to display read data instead of command</td>
</tr>
<tr>
<td>2</td>
<td>Flight Software + Custom GPS</td>
<td>Fail</td>
<td>Custom GPS did not attain fix</td>
<td>Confirmed Custom GPS was receiving correct power with multi-meter. Try a different GPS unit.</td>
</tr>
<tr>
<td>3</td>
<td>Flight Software + Recreational GPS #1</td>
<td>Fail</td>
<td>Recreational GPS not receiving power when plugged into drone or GCS</td>
<td>Try a different GPS unit.</td>
</tr>
<tr>
<td>4</td>
<td>Flight Software + Recreational GPS #2</td>
<td>Fail</td>
<td>Acquired fix. Initiated flight. Drifted around “Home” waypoint and couldn’t raise elevation. Battery level unsteady</td>
<td>Weak or unreliable battery. Replace with fully-charged battery.</td>
</tr>
<tr>
<td>5</td>
<td>Flight Software + Recreational GPS #2</td>
<td>Fail</td>
<td>Initiated flight. Unpredictable response to commands and steady path in wrong direction. “Kill” command given.</td>
<td>Potential problem with flight software navigation calculations, but could be hardware-related due to vehicle damage</td>
</tr>
<tr>
<td>6</td>
<td>Flight Software #2 + Recreational GPS #2</td>
<td>Partial Success</td>
<td>Vehicle navigated to within 5m of desired waypoints, meeting requirement</td>
<td>Not the flight software or GPS we’ve designed for.</td>
</tr>
</tbody>
</table>
Flight Software Debugging

- Flight Software
  - Common Autonomous Navigation Programs (~500,000 lines of code)
  - 16 configuration files specific to this vehicle (~10,000 lines of code)

  *GPS into flight software is correct

  *calculated Lat/Long/Alt starts correct but jumps to 0ºN, 180ºW, 0m elevation
  *Heading is constant at 0º, even though drone is turning

Suspected error location: GPS.c
Test Conclusions

Vehicle can navigate autonomously from a list of waypoints, but flight software issues must be debugged.

Levels of Success

| Level 1: | a) Autonomous navigation with GPS  
b) Vehicle can detect RFI  
c) Extended range with larger battery |
| Level 2: | a) Long range communication via cell modem  
b) Transmit video via cell modem  
c) Identify red target with video  
d) Integration of electronics with PCB  
e) Integration of electronics, battery, and cell modem with custom hull |
| Level 3: | a) Return home with inertial navigation  
b) Map RFI zone and find source |
<table>
<thead>
<tr>
<th>Lat</th>
<th>Lon</th>
<th>Alt</th>
<th>Velocity</th>
<th>Heading</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>69.82278</td>
<td>-183.7181</td>
<td>100.2569</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>69.82278</td>
<td>-183.7181</td>
<td>100.2569</td>
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<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
</tbody>
</table>

Data Corruption Event:
- Correct (raw data)
- Incorrect
- Correct (raw data)

Error remains
Long Range (Cell) Communication
Long Range Cell Connection

Drone communicates to controller and back using UDP Packets across direct Wifi connection.

<table>
<thead>
<tr>
<th>UDP = Universal Data Protocol</th>
<th>TCP = Transmission Data Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>can send many packets of data quickly</td>
<td>3 packet “handshake”, then data</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source → PACKET+PACKET+...+PACKET → Destination</th>
<th>Source → “knock knock” → Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination → “Yes? I’m listening” → Source</td>
<td>Source → PACKET → Destination</td>
</tr>
</tbody>
</table>

From Proxy’s perspective, it sees GCS and Drone.

TCP Ping time 2-3s
GCS → Proxy → GCS

*UDP Packets dropped Proxy → Drone, so GCS commands don’t reach drone
*Communication will work with TCP packets, but put this aside to refocus on level 1 success

TCP Ping time 4-6s
GCS → Proxy → Drone

12-18s for 3 packet handshake
command delay

50-80m traveled during command delay flying at 4.4 m/s
**Test Conclusions**

*Suspect TCP would allow for cell communication with large (but acceptable) latency*

<table>
<thead>
<tr>
<th>Levels of Success</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1:</strong> a) Autonomous navigation with GPS b) Vehicle can detect RFI c) Extended range with larger battery</td>
</tr>
<tr>
<td><strong>Level 2:</strong> a) Long range communication via cell modem b) Transmit video via cell modem c) Identify red target with video d) Integration of electronics with PCB e) Integration of electronics, battery, and cell modem with custom hull</td>
</tr>
<tr>
<td><strong>Level 3:</strong> a) Return home with inertial navigation b) Map RFI zone and find source</td>
</tr>
</tbody>
</table>

**Key**

- **Success**
- **Partial Success**
- **Unsuccessful**
## Test Matrix

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>TESTS</th>
<th>RFI</th>
<th>Mapping</th>
<th>Mechanical</th>
<th>Waypoint Flight</th>
<th>Paparazzi Waypoint</th>
<th>Video</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waypoint Navigation</td>
<td>1.QUADFR.1</td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Monitor GPS Integrity</td>
<td>1.QUADFR.2</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locate RFI Device</td>
<td>1.QUADFR.3</td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>View Target</td>
<td>1.QUADFR.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Operational Conditions</td>
<td>1.QUADFR.7</td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long Range Communication</td>
<td>1.QUADFR.8</td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6km Mission</td>
<td>1.QUADFR.9</td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inertial Navigation</td>
<td>1.QUADFR.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Waypoint GUI</td>
<td>1.GRNFR.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCS Data Processing</td>
<td>1.GRNFR.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>
Systems Engineering
• Chose flight software for ability to add modules for custom behavior
  • Alternative was to modify base code
    • Lack of team skills
  • Best design choice given constraint
• Design changes resulted from integrating components
  • Add battery to PCB
  • Custom hull to accommodate final PCB design
  • Inconsistencies between advertised and actual mass
• Had to redefine Levels of Success
**Levels of Success**

| Level 1: | a) Autonomous navigation with GPS  
b) Vehicle can detect RFI  
c) Extended range with larger battery |
|---|---|
| Level 2: | a) Long range communication via cell modem  
b) Transmit video via cell modem  
c) Identify red target with video  
d) Integration of electronics with PCB (From 3 to 2)  
e) Integration of electronics, battery, and cell modem with custom hull (From 3 to 2) |
| Level 3: | a) Return home with inertial navigation (From 1 to 3)  
b) Map RFI zone and find source (From 2 to 3) |

*Made changes post-TRR to reflect better understanding of project complexity*
Project Management
**Project Management Approach**

- Itemized Schedule
  - Weekly updates on individual responsibilities
  - 3-4 weekly team meetings
  - Weekend assignments

- Restructured Levels of Success to reflect complexity

- Assigned test “leads”
  - Create the test plan
  - Enlist help from appropriate members
  - Coordinate dry run
  - Coordinate time, location, and observers for test
  - Report on results

---

**Project Cost**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Hours</td>
<td>3197</td>
</tr>
<tr>
<td>Cost Per Hour</td>
<td>$31.25</td>
</tr>
<tr>
<td>Cost of Man-hours</td>
<td>$99906.25</td>
</tr>
<tr>
<td>Cost of Overhead</td>
<td>$199812.50</td>
</tr>
<tr>
<td>Total</td>
<td>$299718.75</td>
</tr>
</tbody>
</table>

**Successes**

- Weekly coordination/communication improved
- Major improvement from MSR to TRR
- Task oriented responsibilities
- Full scale schedule made individual roles easier

**Difficulties**

- Reorganization of PM role in spring semester
- Big picture communication between subgroups
- Too task oriented = lack of innovation and motivation
- Explaining big picture to PAB every assignment

---

**Biggest Lesson Learned:** Scope of project was very large for time and team skills**
Project Management

Major Changes

- Decreased need for cell data plan
- No need for additional hardware upgrades
- Only 1 medical qualification for Table Mountain testing

PLANNED BUDGET

ACTUAL BUDGET

<table>
<thead>
<tr>
<th>Category</th>
<th>Planned Budget</th>
<th>Actual Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navigation Electronics</td>
<td>23%</td>
<td>20%</td>
</tr>
<tr>
<td>Hardware Upgrades</td>
<td>6%</td>
<td>1%</td>
</tr>
<tr>
<td>Vehicles</td>
<td>10%</td>
<td>33%</td>
</tr>
<tr>
<td>Fuselage+PCB</td>
<td>8%</td>
<td>5%</td>
</tr>
<tr>
<td>Power</td>
<td>8%</td>
<td>3%</td>
</tr>
<tr>
<td>Communication</td>
<td>6%</td>
<td>9%</td>
</tr>
<tr>
<td>Project Admin</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Margin</td>
<td>10%</td>
<td>6%</td>
</tr>
</tbody>
</table>
Lessons Learned

1. More adequately understand limitations of selected vehicle
2. Start software work as soon as possible
3. Don’t trust documentation or data sheets until proven yourself
4. Identify regulatory restrictions
5. Identify off ramps as soon as possible
BACK UP
**Requirement:** SIVAQ shall loiter for at least 1 minute while capturing overhead images of specified area. Video data should allow users to identify a red target 1 m$^2$ in a 3600 m$^2$ field.

**Test:** View video stream of drone’s down-facing camera from the third story of a building and identify a red shirt

**Location:** Parking garage of Engineering Center

**Test Goal:** Identify the red target on the video stream.
## Levels of Success

| Level 1: | a) Autonomous navigation with GPS  
b) Vehicle can detect RFI  
c) Extended range with larger battery |
| Level 2: | a) Long range communication via cell modem  
b) Transmit video via cell modem  
c) Identify red target with video  
d) Integration of electronics with PCB  
e) Integration of electronics, battery, and cell modem with custom hull |
| Level 3: | a) Return home with inertial navigation  
b) Map RFI zone and find source |

*Can identify 1 m² red target using down-facing video stream*
CONOPS – Scenario 1

Transfer list of all GPS waypoints (lat, long, alt) via FTP

Begin mission by initiation via ground station

Vehicle reads file and creates appropriate flight plan

During entire mission telemetry is relayed back to ground station

3 km

Vehicle continuously monitors AGC value received from installed GPS receiver

If signal is determined to be trusted, nominal mission plan is followed

Expected Mission Duration: 30 min
CONOPS – Scenario 2

During entire mission telemetry is relayed back to ground station.

RFI Zone of influence is detected, vehicle stores last known trusted position and switches to inertial sensor based flight.

As vehicle travels inside of RFI influenced area, it uses its inertial sensors to maintain a constant heading and travel through the area of influence.

Once 3 trusted locations are stored, the vehicle will return home.

Expected mapping duration: 5 min.
Flight away from router
• Expected RFI threshold distance was **179.5 ft**
• Actual RFI threshold distance was **164 ft** when vehicle tipped toward the router
Equipment

- Spectrum Analyzer
- Variable Attenuator
- Laptop
- GPS Evaluation Board
- Rooftop Antenna
- DC Block
- Signal Merger
- GPS RFI Device
- 12v Power Supply
RFI Detection Design

- Illegal to transmit RFI L1 signals
- Using Wi-Fi to emulate an RFI zone
- Wi-Fi is at 2.4 GHz, RFI is at 1.575 GHz
- Had to correlate power levels to obtain same gradient
- Resulted in a -80 dBm Wi-Fi threshold

\[ P_t = \left( \frac{4\pi df}{c} \right)^2 P_r \]
**Requirement:** Vehicle will be capable of locating RFI source within 7 meters of true location

**Solution:** Use triangular circumscribed circle to define radii and center point

**Assumptions**
- RFI source antenna is omnidirectional
- Antenna broadcast is free of interference

**Relevant Equations**

\[ P_1 = \begin{bmatrix} x_1 \\ y_1 \end{bmatrix}, P_2 = \begin{bmatrix} x_2 \\ y_2 \end{bmatrix}, P_3 = \begin{bmatrix} x_3 \\ y_3 \end{bmatrix} \]

\[ r = \frac{|P_1 - P_2||P_2 - P_3||P_3 - P_1|}{2|(P_1 - P_2) \times (P_2 - P_3)|} \]

\[ P_c = \alpha P_1 + \beta P_2 + \gamma P_3 \]

\[ \alpha = \frac{|P_2 - P_3|^2(P_1 - P_2) \cdot (P_1 - P_3)}{2|(P_1 - P_2) \times (P_2 - P_3)|^2} \]

\[ \beta = \frac{|P_1 - P_3|^2(P_2 - P_1) \cdot (P_2 - P_3)}{2|(P_1 - P_2) \times (P_2 - P_3)|^2} \]

\[ \gamma = \frac{|P_1 - P_2|^2(P_3 - P_1) \cdot (P_3 - P_2)}{2|(P_1 - P_2) \times (P_2 - P_3)|^2} \]
Start

Enter RFI Zone

Record Last Trusted GPS Location

Maintain Heading and Speed

Measure AGC Level

AGC Level Acceptable?

Yes

Calculate Midpoint

Yes

End

No

Turn 90° Towards Center and Fly

Maintain Heading and Speed

Measure AGC Level

AGC Level Acceptable?

Yes

Start

No

Re-acquire GPS

Turn 180° and Re-enter Zone

Maintain Heading and Speed

Check if at Midpoint

Yes

End

No

GPS is Trustworthy

Decision

GPS is Compromised

Legend
• Leaving RFI zone is more accurate
  • Results in ±1 dBm error

• Entering RFI zone blocks Wi-Fi chip with hardware
  • Results in ±3 dBm error
Spectrum Analyzer

- Used to measure router transmit power
- $P_{\text{transmit}} = -10.19$ dBm
- With 5 dBi antenna gain gives $P_{\text{transmit}} = -5.19$ dBm
**Wi-Fi Simulation Module**

**Atheros Wi-Fi Chip**
Outputs a Wi-Fi power in dBm
- iwlist ath0 scan

**Mediatek GPS Chip**
Outputs a AGC value

---

**Wi-Fi Simulation**

- Compare Wi-Fi power to expected RFI threshold of -78 dBm
- Outputs AGC

---

- **Wi-Fi Power > -78 dBm**
  - Modify AGC

- **Wi-Fi Power < -78 dBm**
  - Leave AGC alone
**Wi-Fi Simulation Test**

**Requirement:**
Vehicle must be able to detect RFI threshold from a proxy signal within 8m

**Test:**
1. Measure zone with spectrum analyzer and mark zone with cones.
2. Carry drone into RFI zone

**Verification:**
LEDs will start to blink red when the drone senses the zone.
RFI Sphere of Influence

\[ AGC = \max(f(P_{Sat} + P_{L1\,Trans}), f(P_{WiFi})) \]

\[ P_{WiFi} = 0 \]

L1 Transmitter (1575 MHz)
Wi-Fi Sphere of Influence

\[ AGC = \max(f(P_{Sat} + P_{L1\, Trans}), f(P_{WiFi})) \]

\[ P_{L1\, Trans} = 0 \]

Wi-Fi Access Point (2.4 GHz)
Test Results RFI Detection

- First mapping point will be the most inaccurate, yet the following two has minimal error
- The Athero Wi-Fi chip on the AR.Drone is on the bottom of the vehicle
- Causes the large error while flying into the RFI zone as all the AR.Drone’s components disrupt the signal strength
- Flying away from the RFI source results in the more accurate data as the Wi-Fi chip is in direct sight with the source
Resolution Test Data

Power distribution of router at 164 ft

Pointing away from router

Pointing at the router
Resolution Test Data

Power distribution of router at 100 ft

Pointing away from router

Pointing at the router
Resolution Test Data

Power distribution of router at 40 ft

Pointing away from router

Pointing at the router
Requirement:
The vehicle must navigate via GPS based flight, be capable of monitoring GPS signal integrity, and must integrate with the stock AR. Drone 2.0

SIVAQ will add...
- Global Top MediaTek 3339 GPS receiver
- Arduino Pro Mini Microprocessor
- Silicon Labs CP2102 UART to USB converter

Total Additional Mass = 20g
Electronics Package Verification

Key

- Data
- Interface

Additional microprocessor

GPS receiver 1

USB to UART

6 Pin Header

USB 2.0

AR. Drone 2.0

Position log file 1

To Move File:
1. Telnet
2. File Transfer Protocol (FTP)

Ground Station

Position log file 2

GPS receiver 2

Both log files contain lists of GPS position (lat, lon, alt)

Compare both to verify functionality of extra electronics

Storage Location:
/data/gps.0.nav.csv
Discovering the problem

- GPS outputs matched what was expected before a fix was obtained.
- Evaluation board designated with same GPS chip was able to obtain fix
- Noticed advertisement from manufacturer for new GPS module released in March 2014
- This was the chip we actually had, not the one we thought
Datasheet issues

Figure 1: Pad layout according to datasheet

<table>
<thead>
<tr>
<th>Pin</th>
<th>Name</th>
<th>I/O</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VCC</td>
<td>P/I</td>
<td>Main DC power input</td>
</tr>
<tr>
<td>2</td>
<td>NC</td>
<td>—</td>
<td>Not connected</td>
</tr>
<tr>
<td>3</td>
<td>GND</td>
<td>P</td>
<td>Ground</td>
</tr>
<tr>
<td>4</td>
<td>VBACKUP</td>
<td>P</td>
<td>Backup power input</td>
</tr>
<tr>
<td>5</td>
<td>3D-FIX</td>
<td>O</td>
<td>3D-fix indicator</td>
</tr>
<tr>
<td>6</td>
<td>IPPS</td>
<td>O</td>
<td>IPPS Time Mark Output 2.8V CMOS Level</td>
</tr>
<tr>
<td>7</td>
<td>NC</td>
<td>—</td>
<td>Not connected</td>
</tr>
<tr>
<td>8</td>
<td>GND</td>
<td>P</td>
<td>Ground</td>
</tr>
<tr>
<td>9</td>
<td>TX</td>
<td>O</td>
<td>Serial data output of NMEA</td>
</tr>
<tr>
<td>10</td>
<td>RX</td>
<td>I</td>
<td>Serial data input for firmware update</td>
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<td>11</td>
<td>GND</td>
<td>P</td>
<td>Ground</td>
</tr>
<tr>
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<td>GND</td>
<td>P</td>
<td>Ground</td>
</tr>
<tr>
<td>13</td>
<td>GND</td>
<td>P</td>
<td>Ground</td>
</tr>
</tbody>
</table>

Figure 2: GPS module as received

Figure 3: GlobalTop response to discrepancy

Regards

GlobalTop Inc.
No.15, Nan-ke 9th Rd., Science-based Industrial Park, Tainan 741, Taiwan
TEL: 886-6-5051268 #3104
FAX: 886-6-5053381
http://www.gtop-tech.com
ISO9001 / TL9000
CAGE Code: SNT15
Remediating the problem

- The correct pin configuration was able to be prototyped to produce the following results
Custom Modules

Flight Software Library (Pertinent Functions and Variables)

- **Electrical**
  - Charge Consumed

- **Navigation**
  - Move Waypoint
  - Coordinate Conversion
  - Home/Destination

- **GPS**
  - Current Position

**Shared Module Variables**
- RFI Simulation
- AGC
- Safepoints
- Dead Reckoning
- Telemetry

**RFI Behavior**

---

**Project Purpose and Overview**

**Design Description**

**Test Results**

**Systems Engineering**

**Project Management**

---
Waypoint Navigation Test

30m 231°SW

±2m

40.00142° N 105.26044° W

±5m

40.00131° N 105.26072° W

±2m

Enter waypoints into flight software “flight plan” file

Mark desired flight path with cones

After handheld GPS has a fix (~10min), mark error zone of each waypoint with cones

Attach tether

Check for suitable wind conditions

Initiate Flight
Waypoint Navigation

1st attempt = Flight Software + Custom GPS
Problem: Flight software on GCS and drone both thought engines had taken off at full throttle but in fact were not moving
Trouble Shoot: Attempt to change setting to display commands instead of reading response of engines

2nd attempt = Flight Software + Custom GPS
Problem: Custom GPS would not attain fix after 30min
Trouble Shoot: Checked that GPS was receiving correct power with multimeter. Conclude that custom GPS may be encountering RFI from other vehicle electronics preventing it from acquiring fix

3rd attempt = Flight Software + Recreational GPS
Problem: Brand new recreational GPS sold with vehicle would not acquire fix. Was not receiving power when plugged into drone or GCS.
Trouble Shoot: Broken circuitry in the recreational GPS we did not have access to.

4th attempt = Flight Software + Recreational GPS #2
Problem: Upon initiating flight, drone drifts around "Home" waypoint, struggles to get more than 1ft elevation, battery indicator on GCS bouncing between 20% - 30%
on operational capacity
Trouble Shoot: Drained or unsteady battery

5th attempt = Flight Software + Recreational GPS #2
Problem: Unsteady flight, seemed to struggle to reach and maintain proper elevation, unpredictable response to commands from GCS
Trouble Shoot: Flight software may be miscalculating autonomous navigation between waypoints

6th attempt = Flight Software + Recreational GPS #2
Problem: Not the flight software or GPS designed for project
Trouble Shoot: Proves that navigation issues are software related, but hardware is fully functional

Project Purpose and Overview
Design Description
Test Results
Systems Engineering
Project Management
From Proxy’s perspective, it sees GCS and Drone

GCS Loop-back Port Chosen by OS

Publicly Accessible CU Proxy Network

Drone Loop-back Port 5555

Port Chosen by OS

Port 5555

Port assigned to Paparazzi

Port 5554

Connect to port 4242

Port assigned to Paparazzi

SOCKS4 Proxy

Cell Connection Layout
Inertial Navigation

• Sensors: accelerometer, magnetometer, downward facing camera

• Design: dead reckoning
  • Estimate current location by keeping track of heading, speed and time since last position
Inertial Navigation

- Calculate speed...
- Sensors:
  - X axis accelerometer, 50 mg precision
  - Downward facing camera
Inertial Navigation

- Calculate heading...
  - Sensor:
    - Magnetometer, 6° precision

- Calculate Current Position...

\[
\begin{align*}
  d &= Vt \\
  a &= \frac{d}{R} \\
  \Delta \varphi &= a \cos H \\
  \varphi_2 &= \varphi_1 + \Delta \varphi \\
  \varphi' &= \ln \left( \frac{\tan \left( \frac{\pi}{4} + \frac{\varphi_2}{2} \right)}{\tan \left( \frac{\pi}{4} + \frac{\varphi_1}{2} \right)} \right) \\
  q &= \cos \varphi_1 \\
  \text{if } \Delta \varphi' = 0, \\
  \text{else } q &= \frac{\Delta \varphi'}{\Delta \varphi} \\
  \Delta \lambda &= \frac{a \sin H}{q} \\
  \lambda_2 &= (\lambda_1 + \Delta \lambda + \pi) \% 2\pi - \pi
\end{align*}
\]
Inertial Navigation

• Correction frequency requirement
  • At >5 Hz, random heading and speed error do not significantly effect vehicle’s navigation ability
    • +/- 6° heading error
    • +/- 1 m/s speed error

• Bias requirement
  • Bias must be eliminated to within ~2° heading, ~0.133 m/s speed
• Dead reckoning Paparazzi module
# Test Results

<table>
<thead>
<tr>
<th>RFI Test</th>
<th>Mapping Test</th>
<th>Mechanical Test</th>
<th>Flight Waypoint Test</th>
<th>Paparazzi Waypoint Test</th>
<th>Video Test</th>
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<td>X</td>
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<td>X</td>
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<td>1.GRNFR.2</td>
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<td></td>
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<td>X</td>
<td></td>
</tr>
</tbody>
</table>
RFI Behavior

Start

- Home/Destination
- Current Position
  - AGC
  - Battery

Low Battery?

Yes

- Set Destination to Home
- Change Destination Waypoint

No

Is Leg Pre-Zone?

No

- Set destination to the middle of safepoints 1 and 2

Yes

- Set Leg to 2
- Save Safepoint

Is Leg 1?

No

In Zone (AGC)?

No

- Set Leg to 1
- Save Safepoint

Yes

Is Leg 2?

No

- Set destination to be 10m ahead

Yes

- Close enough to middle?

No

- Set Leg to 3
- Turn 90°

Yes

Set Leg to 3

End

Convert points from LLA to ENU using home as a reference point

Is Leg 3?

No

- Convert points from ENU to LLA

Yes

- Save Safepoint

- Set Leg to 2

- Set destination to be 10m ahead

- Convert points from ENU to LLA

- Save Safepoint

- Set Leg to 3

- Turn 90°
RFI Behavior Module

Pre-Zone
- Check for AGC
RESULT: First safepoint
ACTION: Turn off GPS and fly into zone

First Leg
- Maintain heading and speed
- Check for AGC
RESULT: Second safepoint
ACTION: Fly back into zone

Second Leg
- Maintain heading and speed
- Check for estimated position
ACTION: Stop and turn 90°

Third Leg
- Maintain heading and speed
- Check for AGC
RESULT: Third GPS position
ACTION: Calculate center and return home

Start
- Conversion from LLA to ENU using home as a reference point
- Home/Destination
- Current Position
- AGC
- Battery
- Low Battery?
  - Yes
  - Set destination to Home
  - Save Safepoint
  - Change Destination Waypoint from ENU to LLA
  - End
- No
- Close enough (AGC below threshold)?
  - Yes
  - Set Leg to 3
  - Set destination to the middle of safepoints 1 and 2
  - Save Safepoint
  - Convert points from ENU to LLA
  - End
  - No
  - Is Leg 2?
  - No
  - Set Leg to 2
  - Save Safepoint
  - Convert points from ENU to LLA
  - End
  - Yes
  - Is Leg 1?
  - No
  - Set Leg to 1
  - Save Safepoint
  - No
  - In Zone (AGC below threshold)?
    - Yes
    - Set destination to be 10m ahead
    - Convert points from ENU to LLA
    - End
    - No
    - In Zone (AGC below threshold)?
      - Yes
      - Is Leg Pre-Zone?
        - Yes
        - Convert points from LLA to ENU using home as a reference point
        - End
        - No
      - No
      - Change Destination Waypoint
      - End
      - Low Battery?
        - Yes
        - Set destination to Home
        - Save Safepoint
        - Change Destination Waypoint from ENU to LLA
        - End
        - No
      - First Leg – Maintain heading and speed – Check for AGC – Result: First safepoint – Action: Turn off GPS and fly into zone
      - Second Leg – Maintain heading and speed – Check for estimated position – Action: Stop and turn 90°
      - Third Leg – Maintain heading and speed – Check for AGC – Result: Third GPS position – Action: Calculate center and return home

End
Functional Requirement: SIVAQ must fly 6 km.
Stock AR.Drone 2.0 Capabilities: 3.6 km max range

Design Description Mechanical

**Functional Requirement:** SIVAQ must fly 6 km.

**Stock AR.Drone 2.0 Capabilities:** 3.6 km max range

**Design Description Mechanical**

**Estimated Current Draw**

- **STEP 1:** Find current during hover
- **STEP 2:** Find flight angle at designated speed

\[
Amps_{flight} = \frac{Amps_{hover}}{\cos(\text{Angle})}
\]

- **Amps_{hover}**
- **Velocity**
- **Thrust**
- **Weight**
- **Angle**

**Battery Size**

- Current Draw from motors over 6 km: 
  \[
  4800 \text{ mA} \times 24 = 1920 \text{ mAh}
  \]
- Current Draw from additional sensors: 
  \[
  800 \text{ mA} \times 24 = 320 \text{ mAh}
  \]

**Battery Choice**

- **LiPo 11.1 V 30 C 3200mAh**
  - Mass: 240 g
  - Dimensions (LxWxH): 135x43x22mm
  - *LiPo 80% rule

**Attainable Flight**

\[
\left(\frac{3200 \text{ mAh}}{5600 \text{ mA}}\right) \times 80\% = 27 \text{ minutes}
\]

- **4.4 m/s \times (27\times60) s = 7.1 km**

**Extra minute from ‘search’ period of nominal conops**

- **Current Draw from motors over 6 km:**
  \[
  4800 \text{ mA} \times 24 = 1920 \text{ mAh}
  \]
- **Current Draw from additional sensors:**
  \[
  800 \text{ mA} \times 24 = 320 \text{ mAh}
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\]

- **4.4 m/s \times (27\times60) s = 7.1 km**

- **Design Requirement 1:** Reconfigure hull to incorporate larger battery, stock sensors, and any additional electronics
- **Hull Design Requirement 1.1:** Reconfigured hull shall not alter stability (SIVAQ shall not be more than 130% of stock AR.Drone 2.0 mass)
Max Flight Mass (Backup)

- Hull Design Requirement 1.1: Reconfigured hull shall not alter performance (No more than 130% of stock AR.Drone Mass)

**Stability Testing**

Stability defined as the amount of ‘rocking’ in the drone when a force is applied

**Stock Ar.Drone Response:**
- Magnitude: 4.5 in.
- Time: 6.5 sec.

**SIVAQ Response:**
- Magnitude: 4.3 in.
- Time: 6.3 sec.

Max Takeoff Mass: 530 g

\[ F = 5 \text{ N} \]
\[ \text{Range} = V_{\text{flight}} \frac{C_{\text{battery}} - (I_{\text{electronics}})(t_{\text{search}} + 2t_{\text{hover}}) - I_{\text{flight}}t_{\text{search}} - I_{\text{hover}}2t_{\text{recover}}}{I_{\text{flight}} + I_{\text{electronics}}} - \text{Distance}_{\text{map}} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>4.4 m/s</td>
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</tr>
<tr>
<td>3200 mAh</td>
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</tr>
<tr>
<td>5.478 A</td>
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<tr>
<td>4.744 A</td>
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<tr>
<td>0.785 A</td>
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<tr>
<td>60 s</td>
<td></td>
</tr>
<tr>
<td>3-30 s</td>
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</tr>
<tr>
<td>0.521 m</td>
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<table>
<thead>
<tr>
<th>Electronics</th>
<th>Value</th>
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<td>0.075 A</td>
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<td>0.05 A</td>
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<tr>
<td>0.25 A</td>
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<tr>
<td>0.16 A</td>
<td></td>
</tr>
<tr>
<td>0.25 A</td>
<td></td>
</tr>
<tr>
<td>0.785 A</td>
<td></td>
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</table>

6.385 km
# Master Test Plan

<table>
<thead>
<tr>
<th>Date</th>
<th>Test to be done</th>
<th>Test #</th>
<th>Type</th>
<th>Level of Success</th>
<th>Test Lead</th>
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<tbody>
<tr>
<td>20-Mar</td>
<td>Autonomous GPS flight verification</td>
<td>2</td>
<td>Flight</td>
<td>1a</td>
<td>Erin</td>
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<td></td>
<td>Dynamic altering of waypoints in flight</td>
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<td>Flight</td>
<td>supports 1c, 2c</td>
<td>Erin</td>
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<tr>
<td></td>
<td>Communicate and command drone with cell connection in flight (may move to 25 MAR)</td>
<td>1</td>
<td>Ground</td>
<td>2a, 2b?</td>
<td>Sean</td>
</tr>
<tr>
<td></td>
<td>Impact of wind of vehicle in flight</td>
<td>4</td>
<td>Flight</td>
<td></td>
<td>Steve</td>
</tr>
<tr>
<td>25-Mar</td>
<td>Comms and video via cell modem @ 3km range</td>
<td>5</td>
<td>Ground</td>
<td>2a</td>
<td>Sean</td>
</tr>
<tr>
<td>31-Mar</td>
<td>Manufacturing check of custom hull with vehicle and all electronics</td>
<td>6</td>
<td>Manufacturing</td>
<td>2e</td>
<td>Geoff</td>
</tr>
<tr>
<td>1-Apr</td>
<td>Find red target from with video from top of parking garage</td>
<td>7</td>
<td>Ground</td>
<td>2c</td>
<td>Matt</td>
</tr>
<tr>
<td>3-Apr</td>
<td>PCB integration test to verify that drone is properly receiving GPS and AGC messages from PCB</td>
<td>8</td>
<td>Manufacturing/ground</td>
<td>2d</td>
<td>Ross</td>
</tr>
<tr>
<td></td>
<td>Return home inertially</td>
<td>9</td>
<td>Flight</td>
<td>3a</td>
<td>Nick</td>
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<tr>
<td>4-Apr</td>
<td>RFI detection test - verify that vehicle responds to wifi zone by observing LED</td>
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<td>Ground</td>
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<td>Shane</td>
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<td>10-Apr</td>
<td>Flight test to verify exactly what our extended range is with bigger battery</td>
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<td>Mapping Spoof Zone</td>
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<td>15-Apr</td>
<td>Contingency testing date OR final Spoof Zone CONOPS Demo</td>
<td>13</td>
<td>Flight</td>
<td></td>
<td>Brett</td>
</tr>
</tbody>
</table>
Backup Slides

FLIGHT TEST 2: GPS Waypoint Navigation

Test Date (Location): 3/20 (Table Mountain)
Dry Run Date: 3/19
Test Lead: Erin Overcash
Test Assistants: Sean Rivera, Shane Maleke, Steve Gentile

Purpose: In order to ensure that the vehicle has the ability to fly autonomously, a GPS will be attached to the vehicle through a microprocessor. The microprocessor will be used to convert the GPS NMEA message into SRF IV, a GPS language that can be understood by the vehicle. With this set-up, a list of GPS waypoints will be loaded onto the vehicle. The vehicle will begin to fly with observers at each waypoint to ensure the accuracy of 7.6 meters is met. This data will be compared to flight data from the observers.

Procedure:

- Determine wind direction with flag. Select appropriate location on Table Mountain with this in mind. Choose starting point with greatest width and wind blowing from behind the vehicle, propelling it forward.
- Place GCS at starting location
- Startup GCS
- Startup Handheld GPS units so they have a few minutes to warm up
- Plug a battery into the drone so its GPS has a few minutes to warm up and get a fix. Tape down loose pieces with electrical tape so they don’t get caught up in rotors.
- Steak flag into ground
- Tether vehicle
- Measure direction of wind with flag and compass
  - Velocity variation (min/max) [m/s]
  - Variation in heading (min/max) [deg]
  - Is the flight GO / NO GO (circle one)?
- Place 1st observer 30m downwind of GCS and 5m to the right. Mark this location with a 6m diameter ring of cones. Record the GPS fix of this location with the handheld Garmin GPS device once it has warmed up and its error is within ±3m.

  - GPS Coordinate (ddd.dddddd*)

- Place 2nd observer 60m downwind of GCS and 5m to the right. Mark this location with a 6m diameter ring of cones. Record the GPS fix of this location with the handheld Garmin GPS device once it has warmed up and its error is within ±3m.
  - GPS Coordinate (ddd.dddddd*)

- Work through Drone and GCS Startup Procedures worksheet
- In Paparazzi GUI, make sure it says ardrone2_raw next to the red dot on top of screen
  - Click on that ardrone2_raw
  - Select center A/C to center GUI on vehicle’s home location
- Measure strength and direction of wind (for verification of previous measurement, in case wind changes right before flight)
  - Velocity variation (min/max) [m/s]
  - Variation in heading (min/max) [deg]
  - Is the flight GO / NO GO (circle one)?

- Initialize flight with someone constantly monitoring ground station and James Mack at the controls
- During entire flight, one observer at GCS should be recording wind speed and direction every 10s form anemometer and flag respectively. This data will be collected for entire duration of flight and stored for future reference with the wind model. See Wind Recorder Worksheet
- When vehicle begins flight, observer at ground station will raise arm, indicating each observer needs to start their timers. Observers will stop their timers when the drone changes direction above them (indicating the time at which the drone reached the defined waypoint).
  - Time to reach 1st waypoint [s]
  - Was vehicle within 6 m zone of GPS accuracy? Y / N (circle one)
  - Time to reach 2nd waypoint [s]
  - Was vehicle within 6 m zone of GPS accuracy? Y / N (circle one)

- Kill command used on vehicle if it begins to fly off course
- Land at the second waypoint near the 2nd observer (may be thrown off in strong wind)
- Store GPS data and sensor data from the vehicle to the GCS in the format Data_Type/Flight_Number/Date/Attempt_Number
- Post-process the GPS data to ensure GPS navigation matches (within GPS error) the GPS locations of the observers
**Software Critical path**

<table>
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<tr>
<th>Task Name</th>
<th>Feb 23</th>
<th>Mar 2</th>
<th>Mar 9</th>
<th>Mar 16</th>
<th>Mar 23</th>
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<td>find exact commands to dynamically alter waypoint</td>
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<td>Verify cell/internet connection between modems over CU Proxy</td>
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<td>65% Unit test of DR module</td>
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<tr>
<td>Design Driver modification so Auto Nav separates AGC from and of SIRP message</td>
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<td>Convert RFI behavior module to C</td>
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<tr>
<td>50% Unit test of RFI behavior module</td>
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<td>Ground test to verify data transfer and comm with vehicle 3 km away</td>
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<td>50% unit test of wifi module</td>
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<tr>
<td>Flight test to command drone with GPS waypoint (fly from a list of user waypoints)</td>
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<td>test to verify drone responds to WiFi/RFI zone and enters mapping mode</td>
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<td>50% Unit test of RFI behavior module</td>
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<tr>
<td>Full software system integration testing on drone</td>
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<td>Flight test to verify drone can dynamically alter waypoints in flight</td>
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<td>Test to verify drone’s Auto Nav software can switch from reading true GPS to reading Dead Reckoning calculated waypoint</td>
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<td>Full flight test of spoof zone CONOPS</td>
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Flight test to verify telemetry and communication with Drone

Flight test to command drone with GPS waypoints

Full software system integration testing

Flight test to verify Drone can dynamically alter waypoints from RFI behavior module

Test to verify Drone’s Auto Navigation software can switch from true GPS to dead reckoning calculated position

FLIGHT TEST OF SPOOF ZONE CONOPS