REMOTE AUTONOMOUS MAPPING OF RADIO FREQUENCY OBSTRUCTION DEVICES

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Sponsor: Dennis Akos
Advisor: Jade Morton
## ACRONYM TABLE

<table>
<thead>
<tr>
<th>Acronym:</th>
<th>Meaning:</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGC</td>
<td>Automatic Gain Control</td>
</tr>
<tr>
<td>ET</td>
<td>Emerging Threat</td>
</tr>
<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>GNC</td>
<td>Guidance Navigation and Control</td>
</tr>
<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>IMU</td>
<td>Inertial Measurement Unit</td>
</tr>
<tr>
<td>INS</td>
<td>Inertial Navigation System</td>
</tr>
<tr>
<td>MCU</td>
<td>Microcontroller</td>
</tr>
<tr>
<td>PDOA</td>
<td>Power Difference of Arrival</td>
</tr>
<tr>
<td>PPD</td>
<td>Personal Privacy Device</td>
</tr>
<tr>
<td>RFI</td>
<td>Radio Frequency Interference</td>
</tr>
<tr>
<td>UAS</td>
<td>Unmanned Aerial System</td>
</tr>
</tbody>
</table>
AGENDA

1. Project Purpose and Objectives
2. Design Solution
3. Critical Project Elements
4. Design Requirements and Their Satisfaction
5. Risk Analysis
6. Verification and Validation
7. Project Summary
MISSION STATEMENT

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

- Personal Privacy Devices and Emerging Threats (spoofers) are interrupting civilian and military GNSS endeavors.

- Utilizing a UAS is the most efficient method for rapidly localizing these RFI sources.

- Flying a UAS in GPS-denied conditions is problematic due to most autopilots reliance on GNSS.

GPS Emerging Threat

Purpose & Objectives
Design Solution
CPE
Design Satisfaction
Risk Analysis
Verification & Validation
Project Summary
CONOPS

Step 1: Launch UAS with payload

Step 2: Start autonomous flight on pre-planned path

Step 3: Simulate GPS denied environment over designated area

Step 4: Collect data on signal strength

Step 5: Transmit signal strength and positioning measurements to ground

Step 6: Land UAS and localize signal source at ground station
DESIGN SOLUTION
UAS PLATFORM SOLUTION

Airframe
Name: X-UAV Talon
Wing Span: 1718 mm
Empty Weight: 1050 g
Configuration: V-tail
UAS PLATFORM SOLUTION

Power System
Name: Thunder Power TP700
Type: High Voltage LiPo
Capacity: 2x 3s 7000 mAh
Output: EC3/EC5
Mass: 423 g
Dimensions: 27 x 69 x 110 mm
UAS PLATFORM SOLUTION

Electronic Speed Control
Name: E-Flite Pro

Rating: 60-Amp – 13 AWG
Input: EC3/EC5
Output: 3.5mm Bullet

Mass: 75g
Dimensions: 73 x 33 x 15.5 mm
UAS PLATFORM SOLUTION

Motor
Name: E-Flite Power 25 BL
Rating: 1250 Kv, 14AWG
Input: 3.5mm Bullet
Mass: 221
Dimensions: 5 x 14 x 5 mm
Transmitter
Name: Spektrum DX6i
Range: 3 km
Channel: 6
UAS PLATFORM SOLUTION

Receiver
Name: Spektrum AR7700
Type: Serial Output (PixHawk)
Channel: 7
Mass: 8.9g
Dimensions: 29.2 x 34.3 x 11.4 mm
UAS PLATFORM SOLUTION

Auto-Pilot
Name: PixHawk

Mass: 39 g
Dimensions: 95 x 45 x 21 mm
UAS PLATFORM SOLUTION

Servos

Main
Name: HS-5065MG
Mass: 11.9g
Dimensions: 23.6 x 11.6 x 24 mm

Tail
Name: HS-5055MG
Mass: 9.5g
Dimensions: 22.8 x 11.6 x 24 mm
UAS PLATFORM SOLUTION

Other Systems:

**IMU**
Silicon Sensing DMU 11

**LIDAR**
Garmin LiDAR Lite

**GPS Module**
"Here" GPS Module

**Operational Payload**
Designed by RAMROD
INERTIAL NAVIGATION SYSTEM

Component outputs are fused and integrated with the onboard EKF

<table>
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<tr>
<th>Component</th>
<th>Contribution to EKF</th>
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</thead>
<tbody>
<tr>
<td>IMU</td>
<td>Angular rate: 3 axes</td>
</tr>
<tr>
<td></td>
<td>Acceleration: 3 axes</td>
</tr>
<tr>
<td>Optical Flow</td>
<td>Relative motion of UAS</td>
</tr>
<tr>
<td>Airspeed sensor</td>
<td>True airspeed</td>
</tr>
<tr>
<td>Magnetometer</td>
<td>Magnetic heading</td>
</tr>
<tr>
<td>Barometer</td>
<td>Altitude</td>
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Embedded: Magnetometer Barometer

IMU

Airspeed Sensor

Optical Flow Sensor

Purpose & Objectives

Design Solution

CPE

Design Satisfaction

Risk Analysis

Verification & Validation

Project Summary
IMU HARDWARE

DMU11 From Silicon Sensing

Features:
- Low cost
- High precision
- Low noise
- Internal temperature compensation
- 1000Hz sensor sample rate
- 200Hz data output
- Supporting evaluation kit and test software
OPERATIONAL PAYLOAD

- Pocket Port
- USB
- Battery
- MicroZed
- Power Splitting, LED Indicator & Interface PCB
- NT1065
- PixHawk
- Cell Modem
- GPS Antenna

Purpose & Objectives
Design Solution
CPE
Design Satisfaction
Risk Analysis
Verification & Validation
Project Summary
PAYLOAD STRUCTURE

3D printed from Nylon X
OPERATIONAL PAYLOAD
NT1065

Measures an RFI power source on multiple GPS bands

Board must be redesigned to have internal splitting
MicroZed

Stores data from NT1065 on USB drive

Interface with cellular modem, NT board, and PixHawk 2
OPERATIONAL PAYLOAD
BATTERY AND GPS ANTENNA

Battery
2200 mAh
5V, 1A, USB3
Lithium Ion Battery

GPS Antenna
Name: TW7872 Magnetic Mount Dual Band GNSS Antenna
Mass: 180 g
Dimensions: 69mm Diameter, 22mm height
OPERATIONAL PAYLOAD
LTE MODEM

LTE Modem:
Pantech UML290 Global
4G LTE Modem
Network: Verizon Wireless

Cellular Modem Bridge:
Proxicast PocketPORT2
Ethernet to USB converter
Operational Payload Interface Board

Interface Board – PCB Design

- Splits power between different components in payload
- Connection between MicroZed and PixHawk
- Indicators to show what’s connected
GROUND STATION

Machine Running Linux
• 2 GB RAM and 50 GB Storage
• Capable of running MATLAB
• Connected through a publicly accessible IP address
• Listening on an open port above 1024
# CRITICAL PROJECT ELEMENTS

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<th>Description</th>
<th>Reason</th>
<th>Purpose &amp; Objectives</th>
<th>Design Solution</th>
<th>CPE</th>
<th>Design Satisfaction</th>
<th>Risk Analysis</th>
<th>Verification &amp; Validation</th>
<th>Project Summary</th>
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<td>Payload</td>
<td>Self-powered <strong>sensor payload</strong> that can monitor, store and transmit RFI signal data while interfaced with the UAS platform</td>
<td>A self-contained payload is necessary to measure necessary data and feed into the autopilot, as well as downlink the data to a ground station.</td>
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<td>UAS</td>
<td>Develop a <strong>UAS platform</strong> capable of maintaining flight in a GPS denied environment while supporting all RFI measuring equipment</td>
<td>Measuring the RF profile over a large area will require an efficient means of surveying the area. A UAS capable of supporting the necessary sensors is the best means of covering this area.</td>
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<td>Algorithm</td>
<td>Maintain <strong>autonomous flight</strong> while in a simulated GPS denied environment for an extended period of time</td>
<td>A PPD or ET will cause GPS data to be inaccurate. Flying through the affected area will require an autonomous flight mode that is <strong>not reliant on GPS</strong></td>
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DESIGN REQUIREMENTS AND THEIR SATISFACTION
## FUNCTIONAL REQUIREMENTS

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<td>The payload shall have the ability to measure and localize an RFI source in GPS-denied environments.</td>
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Note: Pink point shown in the middle represents the CG location of the aircraft
UAS ASSEMBLY

- HD Camera and Mount
- Central Skid Plate and Launch Hook
- LiDAR
- RFI Power Monitoring Antenna
- Front Skid Plate
- Px4 Optical Flow Camera
- Control Servos (4 Locations)
- Tail Skid Plate

Purpose & Objectives
Design Solution
CPE
Design Satisfaction
Risk Analysis
Verification & Validation
Project Summary
UAS ASSEMBLY

Motor and Propeller
ESC
Two 7000mAh Batteries
Operational Payload
HD Camera and Mount
LiDAR
PixHawk Flight Controller
Px4 Optical Flow Camera

Note: Only large and critical components were modelled and shown; however, all components were considered for the CG calculation. The non-modelled components were assumed to be evenly distributed throughout the payload bay and thus their CG was located at the airframe CG.
### UAS REQUIREMENTS

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<td><strong>FR 4</strong>: The UAS shall support all flight hardware and instrumentation.</td>
<td>The UAS Payload Bay and inserts can support all hardware and instrumentation as shown in in the CAD model</td>
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<td><strong>FR 5</strong>: The UAS and its testing shall adhere to FAA and CU Boulder regulations.</td>
<td>The UAS complies with FAA weight and size requirements and testing will also comply with FAA regulations.</td>
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<td><strong>FR6</strong>: The UAS shall be capable of flying the operational payload.</td>
<td>The operational payload fits within the payload bay and is under the total weight requirement for the UAS</td>
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## UAS WEIGHT BREAKDOWN

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<tr>
<th>System</th>
<th>Weight [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight System (FS)</td>
<td>2398</td>
</tr>
<tr>
<td>Autopilot (AP)</td>
<td>242</td>
</tr>
<tr>
<td>Operational Payload (OP)</td>
<td>536</td>
</tr>
<tr>
<td>Miscellaneous (MS)</td>
<td>140</td>
</tr>
<tr>
<td>Structural Components (SC)</td>
<td>155</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>3471</strong></td>
</tr>
</tbody>
</table>

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<tr>
<td><strong>DR 5.1:</strong> The UAS shall weigh less than 25 kg</td>
<td>The UAS weighs 3.471 kg</td>
</tr>
<tr>
<td><strong>DR 6.2:</strong> The operational payload shall weigh less than 1 kg</td>
<td>The payload and additional connected antenna only weight 536 g</td>
</tr>
</tbody>
</table>
Maximum Speed
Achieved When Velocity Causes Power Required = 700 W

**Motor:** E-flite Power 25 BL

**700 W**

**Maximum Speed**

**Achieved When Velocity Causes Power Required = 700 W**

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<td><strong>FR 2:</strong> The UAS shall fly in winds of 30 km/h</td>
<td>The UAS has a max speed of 148 km/h</td>
</tr>
<tr>
<td><strong>DR 2.1:</strong> The UAS shall have a max speed of at least 45 km/h</td>
<td>The UAS has a max speed of 148 km/h</td>
</tr>
</tbody>
</table>

**Power Required**

\[
P_{\text{flight}} = \left( \frac{1}{2} \rho V^3 S C_{D,0} + \frac{W}{\frac{1}{2} \rho V_s (\frac{1}{\pi e A R})} \right) \frac{1}{\eta_{\text{overall}}} (1 + \text{crud})
\]

- **Power Required PR vs. Velocity V**
  - **700 W Motor Rating**
  - **39.5 m/s Max Speed**
### FLIGHT SYSTEM COMPONENT SELECTION

**Requirement** | **Satisfaction**
--- | ---
**DR 1.2:** The UAS propulsion System shall be electrically powered | The UAS runs on an electric motor
**DR 1.2.1:** The electric power source shall be a battery | The UAS power source is a battery

**Purpose & Objectives**

- **Design Solution**
- **CPE**
- **Design Satisfaction**
- **Risk Analysis**
- **Verification & Validation**
- **Project Summary**

\[ P_R \left( max \right) = 671 \text{ W} \]

E-flite Power 25 BL 1250 Kv – 700 W (Same as RECUV Talon)

E-flite 60-Amp ESC (recommended for motor)

2x Thunder Power RC 7000 mAh 3S LiPo batteries (Same as RECUV)
Time and Distance Covered in GPS-Denied Environment

Search Area

- Distance Covered in GPS-Denied Area = 4.5 km
- \( V_{\text{cruise}} = 14.4 \text{ m/s} \)
- Time Spent in GPS-Denied Area = 315 s
- Total Flight Path Length = 57.14 km
- Flight Time: 66.1 minutes

**Requirement**

**FR 1:** The UAS shall have a flight time of 60 minutes

**FR 3:** The UAS shall fly in a GPS-denied area for at least 2 km and 200 seconds

**Satisfaction**

- The UAS has a flight time of 66.1 minutes
- The UAS will spend 4.5 km and 315 s in GPS-denied area, with max single stretch of 69 s and 1 km
ENDURANCE

With cruise speed = 14.4 m/s, can the UAS fly for at least 66 minutes?

- Predicted Endurance @ 14.4 m/s and 14000 mAh LiPo Battery Capacity: 93 minutes
- Predicted power required during cruise: 78 W

\[
E = \frac{3.6Cv_bD_b\eta_{overall}}{\left[ \frac{1}{2} \rho V^3 SC_{D,0} + \frac{W^2}{1} \rho V S \left( \frac{1}{\pi e AR} \right) \right] (1 + \text{fudge})}
\]
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INERTIAL NAVIGATION SYSTEM

DMU11: Raw angular rate and linear acceleration

PX4FLOW: Ground speed

Digital airspeed sensor: True airspeed

Magnetometer: Constrains heading
Barometer: Constrains altitude

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</tr>
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<tr>
<td>FR 3: The UAS shall fly in a GPS denied environment for a linear distance of up to 2 km and a time of 200 seconds.</td>
<td>The DMU11 accumulates an error of &lt; 2° after 200 seconds of operation, and the additional sensors will enhance operation to allow for accurate flight.</td>
</tr>
<tr>
<td>FR 9: The UAS flight algorithm shall record and transmit data for all 6 degrees of freedom to assess flight performance.</td>
<td>The INS provides inertial data on all six degrees of freedom to be fused and recorded by the PixHawk.</td>
</tr>
</tbody>
</table>
DMU11 PERFORMANCE

Data courtesy of Stephen Clarke, Silicon Sensing Systems Ltd.
EXTENDED KALMAN FILTER

• A nonlinear state estimation system

• Incorporates noisy and/or slightly inaccurate sensor data with prior knowledge of the dynamics of the system to create an estimate of the system state

• Uses “innovations” for tuning and data rejection

• Innovation variance tests to check filter health
**EXTENDED KALMAN FILTER**

Reference Measurements

Airspeed, Optical Flow observations

Inertial Navigation System

Position, Velocity, Attitude Estimate

Extended Kalman Filter

Position, Velocity, Attitude Error Estimate

Estimated State

Purpose & Objectives

CPE

Design

Solution

Risk Analysis

Verification & Validation

Project Summary

Design Satisfaction
ARDUPILOT ESTIMATOR

• EKF2 Estimation System
• 24 state estimator
• Capable of processing data from multiple IMUs, increased chance of recovery from IMU fault
• Estimates error rotation vector, rather than quaternion orientation directly, resulting in faster and more efficient computations
• EK2_GPS_TYPE = 3
- GPS-enabled flight uses ArduPilot AUTO flight mode
- Take off, fly through each waypoint, land
- GPS 2D position and 3D velocity data used in EKF state estimation

**Requirement**

**Satisfaction**

DR 7.1: The UAS system shall be able to fly autonomously with access to GPS data.

The AUTO flight mode flies autonomously using GPS
MODIFIED ARDUPILOT
FLYING WITHOUT GPS – BLOCK DIAGRAM

- GPS-disabled flight will use FLY_BY_WIRE_B flight mode
- Using Extended Kalman Filter state estimation, autopilot will hold altitude, roll, and pitch
- GPS input into EKF disabled, but Optical Flow enabled

Requirement | Satisfaction
---|---
DR 7.2: The UAS flight system shall be able to fly autonomously without access to GPS data. | The modified FBW_B flight mode allows for autonomous flight without GPS
• Payload sends a binary input to PixHawk @3Hz
  • 0: GPS available
  • 1: No GPS available
• For testing purposes, AGC data replaced with simulated WiFi power data
• Flight software unchanged
• Flight mode switch will be written in existing function events.cpp (10Hz)

### Requirement | Satisfaction
---|---
**DR 8.1:** The UAS flight system shall integrate with RF sensors in order to monitor RF power levels in real time. | The NT1065/MicroZed sample AGC in real time, transmitting to the PixHawk
**DR 8.2:** The UAS flight system shall utilize an RF signal power threshold to trigger a switch in flight modes. | The modified autopilot switches between flight modes based on AGC power data
**Switch Time**

MicroZed/NT1065

- Sample GPS AGC at 3Hz
- Max time: 0.33s

Payload to PixHawk

PixHawk

- Sample Payload Input at 10Hz
- Max time: Negligible
- Switch Flight Modes at 10Hz
- Max time: 0.2s

Max total time: 0.73s

---

**Requirement**

**FR 8.0:** The system shall have the ability to switch between the GPS and GPS-denied flight modes within 1 second of RFI detection.

**Satisfaction**

The switch will happen with a maximum time of 0.73s
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<td>The payload components shall be fully functional in a self-contained structure.</td>
</tr>
<tr>
<td>FR12</td>
<td>The payload shall have the ability to measure and localize an RFI source in GPS-denied environments.</td>
</tr>
</tbody>
</table>
PAYLOAD STRUCTURE DESIGN

Purpose & Objectives
Design Solution
CPE
Design Satisfaction
Risk Analysis
Verification & Validation
Project Summary

Top View
**STRUCTURAL ANALYSIS**

Model name: Payload Box  
Study name: Static 2 (Default)  
Plot type: Factor of Safety  
Factor of safety distribution: Min FOS = 1.3e+003

<table>
<thead>
<tr>
<th>Structural Test</th>
<th>Yield Stress (N/m^2)</th>
<th>Factor of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static 1</td>
<td>6.00e7</td>
<td>3.562e3</td>
</tr>
<tr>
<td>Static 2</td>
<td>6.00e7</td>
<td>1.313e3</td>
</tr>
<tr>
<td>Static 3</td>
<td>6.00e7</td>
<td>2.751e3</td>
</tr>
<tr>
<td>4g Drop Test</td>
<td>6.00e7</td>
<td>N/A</td>
</tr>
</tbody>
</table>
### STRUCTURAL REQUIREMENTS SUMMARY

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR 6.1:</td>
<td>The operational payload must be small enough to fit within the UAS payload bay.</td>
</tr>
<tr>
<td>DR 6.1:</td>
<td>With dimensions of 3&quot;X3&quot;X5&quot; the payload easily fits in the Talon payload bay as shown in the UAS CAD Model</td>
</tr>
<tr>
<td>DR 11.2:</td>
<td>The operational payload structure shall have a mechanical interface to allow for attachment to a baseplate structure.</td>
</tr>
<tr>
<td>DR 11.2:</td>
<td>There are four clearance holes for #8-32 screws located on flanges that will be used to mount the structure inside the payload bay</td>
</tr>
<tr>
<td>DR 12.5:</td>
<td>The operational payload shall have an exterior interface for power and data post processing.</td>
</tr>
<tr>
<td>DR 12.5:</td>
<td>There are interfaces for a clip-in power switch, wires to the MicroZed, wires to the antenna, and wires to the LTE modem</td>
</tr>
<tr>
<td>DR 12.6:</td>
<td>The operational payload shall have an access panel on the exterior structure.</td>
</tr>
<tr>
<td>DR 12.6:</td>
<td>The lid of the structure can easily be removed by removing the four #4-40 screws located on the top</td>
</tr>
</tbody>
</table>
MODAL FREQUENCY

Model name: Payload Box
Study name: Frequency 1 (-Default-)
Plot type: Frequency Amplitude1
Mode Shape: 1 Value = 186.19 Hz
Deformation scale: 0.00105701

Requirements | Satisfaction
---|---
DR 11.1: Each structural component of the operational payload shall have a first modal frequency of above 100 Hz. | First modal frequency of the structure is 186 Hz.
OPERATIONAL PAYLOAD BATTERY

Capacity: 2200 mAh

Voltage Output: 5V

Payload draws at a maximum of 5W

Battery Discharge Duration:

\[
\text{Capacity} = 2200 \text{ mAh} \\
\text{Voltage Output} = 5 \text{ V} \\
\text{Payload draw} = 5 \text{ W} \\
\text{Battery Discharge Duration} = \frac{2200 \text{ mAh} \times 5 \text{ V}}{1000} = 11 \text{ Wh} \\
11 \text{ Wh} \div 5 \text{ W} = 2.2 \text{ hours}
\]

Requirement | Satisfaction
---|---
FR 12.2: The operational payload shall have its own power source | The battery selected will power the operational payload
FR 12.2.1: The operational payload shall operate for at least 1 hour | The payload should be able to operate for 2.2 hours
PAYLOAD WIRING DIAGRAM

Pocket Port

USB

MicroZed

NT1065

Battery

Power Splitting, LED Indicator & Interface PCB

PixHawk

Cell Modem

GPS Antenna

To Ground Station

USB

ETH

USB

Micro Headers

Micro USB

UART

CPE

Purpose & Objectives

Design Solution

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Project Summary

Design Satisfaction
FILE TRANSFER

SSH/SCP File Transfer Service

Cellular enabled Linux Machine

Cellular Network Access

Linux Machine with Public IP and open port
DATA TRANSFER

Intermediate Frequencies

AGC

Position

80 Mb 8-10s

Variable time to send all data

80 Mb 8-10s

Variable time

80 Mb 8-10s

Variable time

80 Mb 8-10s

Variable time

Send to Server

Done Sending

Send 2nd Set

Done Sending

Send Next Set

…

Send to Server

Done Sending

Send 2nd Set

Done Sending

Send Next Set

Purpose & Objectives

Design Solution

CPE

Design Satisfaction

Risk Analysis

Verification & Validation

Project Summary
## REQUIREMENTS & SATISFACTION

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DR 9.1</strong>: The UAS flight algorithm shall output GPS data which will be compared with the estimated flight generated by inertial sensors.</td>
<td>The PixHawk sends the position data from both the inertial sensor package (IMU) and the GPS data of the UAS.</td>
</tr>
<tr>
<td><strong>DR 10.1</strong>: The localization algorithm used with the operational payload shall function using payload hardware only.</td>
<td>The data is taken with the payload and sent to a ground station.</td>
</tr>
<tr>
<td><strong>DR 10.4</strong>: The localization algorithm shall interface with the flight algorithm during flight to receive positional data.</td>
<td>The connection between the PixHawk and the MicroZed sends the position data.</td>
</tr>
<tr>
<td><strong>DR 10.5</strong>: The algorithm shall store data for post-processing.</td>
<td>All of the data is saved to the USB drive connected to the MicroZed.</td>
</tr>
<tr>
<td><strong>DR 12.1</strong>: The operational payload shall have its own processing unit.</td>
<td>The MicroZed is the processing unit of the operational payload.</td>
</tr>
<tr>
<td><strong>DR 12.3</strong>: The operational payload shall have a board capable of measuring RFI power in the GPS band using AGC circuitry.</td>
<td>The NT1065 redesign and antenna.</td>
</tr>
<tr>
<td><strong>DR 12.4</strong>: The payload shall have a transmitter to relay the data, in real time, back to the ground station.</td>
<td>Transmission to ground station through LTE Modem and MicroZed.</td>
</tr>
</tbody>
</table>
# FUNCTIONAL REQUIREMENTS

<table>
<thead>
<tr>
<th>FR</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR1</td>
<td>The UAS shall have a flight time of 60 minutes.</td>
</tr>
<tr>
<td>FR2</td>
<td>The UAS shall fly in maximum winds of 30 km/hr.</td>
</tr>
<tr>
<td>FR3</td>
<td>The UAS shall fly in GPS denied environment for a linear distance of up to 2 km and a time of 200 seconds.</td>
</tr>
<tr>
<td>FR4</td>
<td>The UAS shall support all flight hardware and instrumentation.</td>
</tr>
<tr>
<td>FR5</td>
<td>The UAS and its testing shall adhere to FAA and CU Boulder regulations.</td>
</tr>
<tr>
<td>FR6</td>
<td>The UAS shall be capable of flying the operational payload.</td>
</tr>
<tr>
<td>FR7</td>
<td>The system shall fly autonomously given a pre-programmed flight plan.</td>
</tr>
<tr>
<td>FR8</td>
<td>The system shall have the ability to seamlessly switch between GPS and GPS-denied flight.</td>
</tr>
<tr>
<td>FR9</td>
<td>The UAS flight algorithm shall record and transmit data for all 6 degrees of freedom to assess flight performance.</td>
</tr>
<tr>
<td>FR10</td>
<td>The system shall create a profile of RF signal power.</td>
</tr>
<tr>
<td>FR11</td>
<td>The payload components shall be fully functional in a self-contained structure.</td>
</tr>
<tr>
<td>FR12</td>
<td>The payload shall have the ability to measure and localize an RFI source in GPS-denied environments.</td>
</tr>
</tbody>
</table>
RISK ANALYSIS
# RISK ANALYSIS - INTRODUCTION

## Likelihood

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
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</tr>
<tr>
<td>3</td>
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<tr>
<td>2</td>
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<tr>
<td>1</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

## Severity

<table>
<thead>
<tr>
<th></th>
<th>1 = 0-20%</th>
<th>1 = Insignificant</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 = 20-40%</td>
<td>2 = Minimal</td>
<td></td>
</tr>
<tr>
<td>3 = 40-60%</td>
<td>3 = Manageable but not ideal</td>
<td></td>
</tr>
<tr>
<td>4 = 60-80%</td>
<td>4 = Damage to physical components</td>
<td></td>
</tr>
<tr>
<td>5 = 80-100%</td>
<td>5 = Project cannot be completed</td>
<td></td>
</tr>
</tbody>
</table>
**RISK ANALYSIS - RISKS**

<table>
<thead>
<tr>
<th>R1</th>
<th>There is too much noise in the AGC data which leads to the UAS not knowing when to switch flight modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2</td>
<td>The time taken to switch between flight modes is over 1 second and it causes the UAS to crash</td>
</tr>
<tr>
<td>R3</td>
<td>There is structural damage to the airframe while taking off/landing</td>
</tr>
<tr>
<td>R4</td>
<td>Landing using the barometer data causes a small error in vertical location. The UAS does not land where it should or crashes</td>
</tr>
<tr>
<td>R5</td>
<td>Line of sight of the UAS is lost</td>
</tr>
<tr>
<td>R6</td>
<td>Operating conditions differ from simulated conditions causing a higher rate of error</td>
</tr>
<tr>
<td>R7</td>
<td>There is not enough bandwidth to downlink the AGC data</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Severity</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R7/R6</td>
</tr>
<tr>
<td>2</td>
<td>R1/R4</td>
</tr>
<tr>
<td>3</td>
<td>R3</td>
</tr>
<tr>
<td>4</td>
<td>R2/R5</td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Purpose &amp; Objectives</th>
<th>Design Solution</th>
<th>CPE</th>
<th>Design Satisfaction</th>
<th>Risk Analysis</th>
<th>Verification &amp; Validation</th>
<th>Project Summary</th>
</tr>
</thead>
</table>
RISK ANALYSIS - MITIGATION

R1: Coat payload structure in RFI paint to reduce noise in AGC data

R2: Ground tests will be done to ensure that flight mode switches in time. If it does not, improvements will be made to the algorithm.

R3: Skid plates have been added to the nose and underbelly of the UAS to ensure a more safe landing.

R4: LIDAR and Optical Flow devices were mounted on the UAS to improve accuracy.

R5: A “Return to Home” function will be set on the UAS that allows it to fly back to the takeoff location.

R6: Simulations have been run with data from real flights to ensure that the UAS can still achieve the necessary levels of success.

R7: Tests will be run during varying times of the day to ensure that the AGC downlink will be possible.

Likelihood

<table>
<thead>
<tr>
<th>Severity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td></td>
<td></td>
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<td>R2</td>
<td></td>
</tr>
<tr>
<td>R5</td>
<td></td>
<td></td>
<td></td>
<td>R2</td>
<td></td>
</tr>
<tr>
<td>R4</td>
<td>R4</td>
<td>R3</td>
<td>R1</td>
<td>R4</td>
<td></td>
</tr>
<tr>
<td>R7</td>
<td>R3</td>
<td>R6</td>
<td>R6/R7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R6</td>
<td>R3/R1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5</td>
<td></td>
<td></td>
<td></td>
<td>R5</td>
<td></td>
</tr>
</tbody>
</table>
RISK ANALYSIS - RISK 2

Severity: 5  Likelihood: 3  Total: 15

Description: Once the UAS realizes that it is in GPS denied flight, it needs to switch flight modes. If this process takes longer than 1 second, the UAS could crash.

Mitigation Options:
- Before the UAS flies, feed in simulated data on the ground to monitor time taken to switch flight modes.
- In the event of failure during flight testing, manual control will be taken over the UAS to fly back to the ground and troubleshoot.

Post Mitigation Risk Analysis

Severity: 5  Likelihood: 1  Total: 5
RISK ANALYSIS - RISK 4

Severity: 4  Likelihood: 4  Total: 16

Description: Trusting only the barometer data could lead to an inaccurate reading of altitude. This could cause the UAS to think that is above the ground and crash into it on landing.

Mitigation Options:
- LIDAR and Optical Flow have been added to the airframe so that the accuracy of positioning, especially closer to the ground, would be increased.

Post Mitigation Risk Analysis

Severity: 4  Likelihood: 1  Total: 4
VERIFICATION AND VALIDATION
TEST LOCATION: TABLE MOUNTAIN

- Full flight test will be performed at Table Mountain, CO
- CU RECUV can give access with two week notice
- Test environment is flat grassland free of large obstructions
# TEST PLAN

## Ground Level

<table>
<thead>
<tr>
<th>Test</th>
<th>Date (2018)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talon Hardware Calibration</td>
<td>February 9-12</td>
</tr>
<tr>
<td>Payload Functional Ground and Downlink Testing</td>
<td>February 17-24</td>
</tr>
<tr>
<td>GPS Denied Algorithm Ground Testing</td>
<td>February 20-24</td>
</tr>
<tr>
<td>System Integration</td>
<td>February 9-26</td>
</tr>
</tbody>
</table>

## Preliminary Flight Test

<table>
<thead>
<tr>
<th>Test</th>
<th>Date (2018)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talon EKF Calibration and Functionality Test</td>
<td>February 12-28</td>
</tr>
<tr>
<td>GPS Guided Flight Test, Endurance test</td>
<td>February 24-28</td>
</tr>
<tr>
<td>INS Guided Flight (Straight and Level)</td>
<td>March 1-17</td>
</tr>
<tr>
<td>Localization &amp; Power Profile</td>
<td>March 1-17</td>
</tr>
</tbody>
</table>

## Mission Level Test

<table>
<thead>
<tr>
<th>Test</th>
<th>Date (2018)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maneuvers in GPS Denied Environment</td>
<td>March 19-30</td>
</tr>
<tr>
<td>Mission Level Flight Test and Localization</td>
<td>March 19-30</td>
</tr>
<tr>
<td>Redundant Tests</td>
<td>March 20-30</td>
</tr>
</tbody>
</table>
## GROUND TESTING

<table>
<thead>
<tr>
<th>Test</th>
<th>Goals</th>
<th>Requirements Verified</th>
</tr>
</thead>
</table>
| Talon Hardware Calibration          | • Verify that Talon UAV hardware (servos, PixHawk) is ready for flight  
                                         • Tune EKF/Kalman filter                                               | • **FR 4**: UAS shall support all flight hardware and instrumentation              |
| Payload Functional Ground and Downlink Testing | • Verify data collection  
                                         • Thermal Analysis  
                                         • Verify downlink capability                                          | • **FR 11**: Payload shall be self contained  
                                         • **DR 11.5**: The temperature of the payload shall remain below the operating temperatures of all components  
                                         • **FR 9**: The UAS flight algorithm shall record and transmit data for all 6 degrees of freedom to assess flight performance. |
| GPS Denied Algorithm Testing       | • Verify navigation mode switch time  
                                         • Verify autopilot is ready for flight                                        | • **FR 8**: The UAS software shall seamlessly switch from GPS guided flight to inertial guided flight  
                                         • **DR 8.2**: UAS software shall utilize and RF power threshold in order to trigger a switch in flight modes |
| System Integration                | • Verify components interface                                          | • **All functional requirements**                                                  |
## PRELIMINARY FLIGHT TEST

<table>
<thead>
<tr>
<th>Test</th>
<th>Goals</th>
<th>Requirements Verified</th>
</tr>
</thead>
</table>
| Talon EKF Calibration and Functionality Test | • Tune EKF based on flight performance  
• Verify threshold drift during INS flight | • DR 3.2: The drift of the UAS in the Z direction (altitude) shall remain under 10 m  
• DR 3.3: The drift of the UAS in the x and y direction shall be less than 40m from 100 seconds of GPS denied flight. |
| GPS Guided Flight Test, Endurance test    | • Verify autonomous flight and successful flight plan  
• Verify basic flight capabilities | • FR 1: UAS shall have a flight time of 60 minutes  
• FR 2: UAS shall fly in maximum winds of 30 km/hr  
• DR 2.1: UAS shall fly at a maximum speed of 45km/hr  
• FR 7: UAS shall fly autonomously on a pre-programmed flight plan |
| INS Guided Flight (Straight and Level)     | • Verify INS flight for 2km linear distance | • FR 3: UAS shall fly in GPS denied conditions for a linear distance of 2km  
• DR 7.2.2: The UAS shall fly straight and level until GPS signal is regained. |
| Localization & Power Profile              | • Verify AGC & GPS data is obtained | • FR 12: Payload shall measure RF & localize and RF source  
• FR 10: The system shall create a profile of RF signal power. |
### MISSION LEVEL TEST

<table>
<thead>
<tr>
<th>Test</th>
<th>Goals</th>
<th>Requirements Verified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maneuvers in GPS Denied Environment</td>
<td>• Verify autopilot functions using INS data</td>
<td>• FR 8: The system shall have the ability to seamlessly switch between GPS and GPS-denied flight.</td>
</tr>
<tr>
<td></td>
<td>• Verify UAS executes flight plan in GPS denied area</td>
<td>• DR 8.2.1: The flight algorithm shall switch back to GPS flight when power level drops below power threshold.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• DR 8.2.2: The UAS flight algorithm shall correct path and recalibrate inertial sensors once access to GPS is regained.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• DR 7.1.2: The UAS flight system shall be able to withstand high winds as defined in FR2 while using a pre-programmed flight plan.</td>
</tr>
<tr>
<td>Mission Level Flight Test and Localization</td>
<td>• Verify autonomous flight and successful flight plan</td>
<td>• DR 10.2: System shall localize within a circular area with a 40 meter radius.</td>
</tr>
<tr>
<td></td>
<td>• Verify basic flight capabilities</td>
<td>• Ensuring requirements met for Preliminary flight test are met simultaneously</td>
</tr>
<tr>
<td>Redundant Tests</td>
<td>• Verify data collected is optimized and system error is minimal</td>
<td></td>
</tr>
</tbody>
</table>

### Design Solution

- Purpose & Objectives
- Design Solution
- CPE
- Design Satisfaction
- Risk Analysis
- Verification & Validation
- Project Summary
LOCALIZATION METHOD

Sphere of influence of a standard 2.4GHz Wi-Fi router mapped using Parrot Disco UAV:

• Supports autonomous flight
• Built-in Wi-Fi receiver
• Built-in GPS receiver

The power map will be used in conjunction with the Talon flight in order to perform localization that incorporates the position error generated by the IMU.
MODIFIED ARDUPILOT
SIMULATIONS – SOFTWARE IN THE LOOP

InertialNav
- Simulink/C model used to test state estimation
- Uses actual flight data to test EKF performance
- Useful for tuning EKF

  • EKF state estimation of test data without GPS for 200s
  • Height error ~500m
    • Will be improved with barometer + chosen IMU
  • Y-position error ~200m
    • Will be improved with chosen IMU
  • RAMROD flightpath is simpler than test data used

Flight path from test data
X-Plane
- Runs ArduPilot directly on PixHawk
- Interfaces with computer as a physics simulator
- Will be used as final verification of modified ArduPilot before flight/ground tests
EKF2 TUNING

• Default tune built around stock PixHawk sensors. A higher quality IMU, as well as a pitot tube, and optical flow sensor are to be added.

• Tuning for new IMU
  • Static baseline test
  • Utilize Mission Planner to analyze telemetry logs, view filter innovations
  • Update Parameters
  • Repeat

• Flight testing to follow static ground tests
  • Allow for pitot tube and optical flow tuning
EKF2 TUNING

Velocity Measurement Innovations

- Estimated Velocity, m/s
- Reference Velocity, m/s
- Velocity Innovation, m/s

North (m/s) vs. time (sec)

East (m/s) vs. time (sec)

Down (m/s) vs. time (sec)
PROJECT SUMMARY
ORGANIZATIONAL CHART

Dennis Akos
Customer

Selby Stout
Project Manager

Jorgen Baertsch
Financial Lead

Justin Williams
Systems Engineer

Mary Landis
Test Engineer

Kennedy Harrmann
Safety Officer

Jade Morton
Advisor

Technical Leads

Jake Ursetta
Electrical/Pilot

Ian Cooke
Manufacturing

Sarah Larson
Mechanical

Ethan Morgan
Software

Harrison Mast
Controls

Samantha Williams
Communications

Purpose & Objectives
Design Solution
CPE
Design Satisfaction
Risk Analysis
Verification & Validation
Project Summary
WORK BREAKDOWN STRUCTURE

Legend
- Green: Designed and Completed
- Yellow: Needs to be Completed

Integrated UAS Platform

Course Deliverables
- PDD
- CDD
- PDR
- CDR
- FFR
- MSR
- TSR
- AIAA
- SFR
- PFR
- PTS
- SPS

Project Management
- Schedule/ Gantt Chart
- Work Breakdown Structure

Financial
- PDR Budget
- Cost Plan
- Spring EEF Application
- Spring Financial Reports

Safety
- Risk Analysis
- Manufacturing Safety Plan
- Testing Safety Plan

Testing and Integration
- Payload Ground Testing
- Aircraft ground Testing
- Aircraft Calibration Flight Testing
- Algorithm Verification Flight Testing
- Full System Integration
- Full System Flight Testing

Purpose & Objectives
- Design Solution

CPE
- Design Satisfaction
- Risk Analysis
- Verification & Validation

Project Summary
WORK BREAKDOWN STRUCTURE

Manufacturing
- Payload Structure
  - UAS Airframe Modifications
    - Battery PCB
    - Manufacturing of Redesigned NT1065

Algorithm Development
- GPS Denied Flight Mode
  - Flight Mode Switching Protocol
  - PixHawk/MicroZed Communication Protocol
  - Upgraded IMU Integration

Payload Development
- Payload Structure Design
  - MicroZed Signal Processing Algorithm
  - Battery PCB Design
  - Redesigned NT1065 Signal Filter
  - Payload Integration

UAS Platform
- CG and Weight Balance
  - Propulsion System Design
  - Control System Design
  - Airframe ICD
  - Flight Time Estimations

Communication
- Telemetry Data Transfer Plan
  - Communication Timing Breakdown
  - Link Margin Analysis
  - MicroZed Data Downlinking Algorithm
  - LTE Modem and MicroZed Integration

Legend
- Designed and Completed
- Needs to be Completed
SPRING SCHEDULE
BUDGET BREAKDOWN

Cost Plan

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost (USD)</th>
<th>Margin (USD)</th>
<th>Surplus (USD)</th>
</tr>
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<tbody>
<tr>
<td>UAS</td>
<td>2209</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Payload</td>
<td>1315</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Misc. Electronics, Testing and Manufacturing</td>
<td>480$</td>
<td>250</td>
<td>230</td>
</tr>
<tr>
<td>Total</td>
<td>3754</td>
<td>496</td>
<td>750</td>
</tr>
</tbody>
</table>

Expenses (USD)

Purpose & Objectives
Design Solution
CPE
Design Satisfaction
Risk Analysis
Verification & Validation
Project Summary
ACKNOWLEDGEMENTS

Advisor: Jade Morton

Customer: Dennis Akos

PAB: Donna Gerren, Bobby Hodgkison, Trudy Schwartz, Matt Rhode, Jelliffe Jackson, Torin Clark, Zoltan Sternovsky, Francsico Lopez-Jimenez, Dale Lawrence

IRISS/RECUV: Daniel Liebert, Cory Dixon
QUESTIONS?
BACKUP SLIDES

Localization  
CAD Designs  
Power Model  
Time/Distance  
Weight Breakdown  
Flight Time  
UAS Model  
IMU Interface  
Flow Sensor/Pitot Tube  

Risk Analysis  
FAA  
EKF Tuning  
IMU Data Transmission  
GPS-Denied Time  
MicroZed Wiring  
Budget  
ArduPilot Testing  
Operation Payload  

Optical Flow  
IMU Hardware  
Data Transmission  
Timing Diagram  
Design Solutions  
Takeoff/Landing  
Operational Temperatures
LOCALIZATION MODEL

UAS Path (109 samples) (Error: 29.74 m)
The distance to the receiver can be estimated using nonlinear least-squares curve fitting. If we assume an unknown transmitter location at position \((x,y)\) on a finite search grid, we can use the free space loss principle from the previous slide. The space loss coefficient \(\alpha\) is determined by obstructions and ground reflections in the environment.

The objective function \(Q\) measures the difference between the actual measured power between two grid points and the predicted power difference between two grid points.

\[
P_{12} = P_1 - P_2 = 10\alpha \log_{10} \left( \frac{d_2}{d_1} \right)
\]

\[
P_{12} = 5\alpha \log_{10} \left[ \frac{(x-x_2)^2 + (y-y_2)^2}{(x-x_1)^2 + (y-y_1)^2} \right]
\]

\[
Q(x,y) = \sum_{k<l} \left( \tilde{P}_{kl} - 5\alpha \log_{10} \left[ \frac{(x-x_l)^2 + (y-y_l)^2}{(x-x_k)^2 + (y-y_k)^2} \right] \right)^2
\]

The \((x,y)\) grid point where the objective function \(Q\) is minimized is the estimated transmitter location.
SIGNAL ATTENUATION IN FREE SPACE

• The path-loss for a given environment can be approximated by:

\[ D^{-\alpha} \]

Where \( \alpha \) is the path-loss exponent.

• Ideally, signal intensity decreases proportional to the inverse square of distance between transmitter and receiver in three-dimensional space. (\( \alpha = -2 \))

• Factors such as noise interference, ground reflection, obstacles, and imperfect antenna gains can increase signal attenuation.

\[ \frac{P_r}{P_t} = G_tG_r \frac{\lambda^2}{(4\pi)^2D^{-\alpha}L} \]

\( \alpha \) can be determined by measuring actual signal attenuation in the test environment with known transmitter/receiver locations and known transmitter signal power.
PAYLOAD STRUCTURE BOX
DIMENSIONS

Left View

Right View
PAYLOAD STRUCTURE BOX
DIMENSIONS

Front View
PAYLOAD STRUCTURE TOP
DIMENSIONS
BATTERY BRACKET DIMENSIONS
TAIL SKID DIMENSIONS
HD CAMERA MOUNT DIMENSIONS
MAXIMUM POWER REQUIRED

12° Pitch Climbout
\( a = 0.75 \, \text{m/s}^2 \)

\( FoS = 1.46 \)

\( \rho = 1.047 \, \text{kg/m}^3 \) \( V_f = 14.4 \, \text{m/s} \) \( S = 0.545 \, \text{ft}^2 \) \( m = 3.467 \, \text{kg} \)

\( AR = 5.42 \) \( C_{D,0} = 0.027 \) \( crud = 0.29 \) \( e = 0.8 \) \( \eta_{overall} = 85 \% \)

\( PR_{max} = 671 \, \text{W} \)
TIME AND DISTANCE COVERED IN GPS-DENIED ENVIRONMENT

Radius of GPS-Denied Area

Sensor Range

Ratio

Length of Side of Search Area

Total flight Path Length:

Distance Covered in GPS-Denied (D):

Even Terms of \( \frac{R}{r} \):

Odd Terms of \( \frac{R}{r} \):

Sensor Radius Derivation

\[ D \left( \frac{R}{r} \right) \approx 787.7 \frac{R}{r} - 264.2 = 4.5 \text{ km} \]

With \( S = 57.14 \text{ km}, \frac{R}{r} = 6.2, \text{ and desired } FT \text{ of } 63 + \text{ minutes,} \]

\[ V_{\text{cruise}} = 14.4 \text{ m/s}, FT = 66.13 \text{ min} \]
# UAS WEIGHT BREAKDOWN

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Weight [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor w/ Prop</td>
<td>1</td>
<td>221</td>
</tr>
<tr>
<td>Battery</td>
<td>2</td>
<td>423</td>
</tr>
<tr>
<td>Pixhawk Power Module</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>ESC</td>
<td>1</td>
<td>133</td>
</tr>
<tr>
<td>Receiver</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>Aileron Servo</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>Ruddervator Servo</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Wet Noodle</td>
<td>3 ft</td>
<td>16 g/ft*3 ft = 48</td>
</tr>
<tr>
<td>Airframe</td>
<td>1</td>
<td>1050</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>2398</strong></td>
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</tbody>
</table>
## UAS WEIGHT BREAKDOWN

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Weight [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixhawk 2</td>
<td>1</td>
<td>74</td>
</tr>
<tr>
<td>IMU</td>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>Telemetry Antenna</td>
<td>1</td>
<td>45</td>
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<tr>
<td>GPS Module</td>
<td>1</td>
<td>47</td>
</tr>
<tr>
<td>Airspeed Sensor/Pitot Tube</td>
<td>1</td>
<td>9/3</td>
</tr>
<tr>
<td>LiDAR</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>Optical Flow</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>242</strong></td>
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</table>
# UAS WEIGHT BREAKDOWN

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Weight [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Structure</td>
<td>1</td>
<td>135</td>
</tr>
<tr>
<td>Top Structure</td>
<td>1</td>
<td>26</td>
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<tr>
<td>Battery bracket</td>
<td>1</td>
<td>5.2</td>
</tr>
<tr>
<td>Hardware</td>
<td>1</td>
<td>2.9</td>
</tr>
<tr>
<td>Battery</td>
<td>1</td>
<td>73</td>
</tr>
<tr>
<td>Wires</td>
<td>1</td>
<td>30</td>
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<tr>
<td>Battery PCB</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>MicroZed</td>
<td>1</td>
<td>43.6</td>
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<tr>
<td>NT1065 V. RAMROD</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>Power Monitoring Antenna</td>
<td>1</td>
<td>180</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>536.1</strong></td>
</tr>
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</table>
# UAS WEIGHT BREAKDOWN

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Weight [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wires</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Connectors</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>HD Camera</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>140</strong></td>
</tr>
</tbody>
</table>
## UAS WEIGHT BREAKDOWN

### Structural Components (SC)

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Weight [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward Mounting Plate</td>
<td>1</td>
<td>68</td>
</tr>
<tr>
<td>Aft Mounting Plate</td>
<td>1</td>
<td>55</td>
</tr>
<tr>
<td>Forward Skidplate</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Rear Skidplate</td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>155</strong></td>
</tr>
</tbody>
</table>
# FLIGHT TIME

## General
- **Model Weight:** 3500 g (incl. Drive: 123.5 oz)
- **# of Motors:** 1 (on same Battery)
- **Wing Area:** 54.5 dm²
- **Drag:** coefficient \( \text{Cd} = 0.027 \) dm²
- **Cross Section:** 125.6 dm²
- **Field Elevation:** 1609 m ASL
- **Air Temperature:** 21 °C
- **Pressure (QNH):** 900 hPa

## Battery Cell
- **Type (Cont. / max. C) - charge state:** LiPo 1400mAh - 30/45C
- **Configuration:** 3 S 1 P
- **Cell Capacity:** max. discharge 1400 mAh total
- **Voltage:** 3.7 V
- **C-Rate:** 30 C cont. 45 C max
- **Resistance:** 0.001 Ohm
- **Weight:** 644 g
- **Weight:** 29.8 oz

## Controller
- **Type:** CC Phoenix Edge HV 80
- **Current:** 80 A cont.
- **Resistance:** 0.001 Ohm
- **Weight:** 125 g
- **Wire extension battery:** AWG10 = 5.27 mm²
- **Length:** 0 mm
- **Wire extension motor:** AWG10 = 5.27 mm²
- **Length:** 0 mm

## Motor
- **Manufacturer - Type (Kv) - Cooling:** E-flite Power 26B (1250)
- **KV (w/o torque):** 1250 rpm/V
- **no-load Current:** 2 A @ 10 V
- **Limit (up to 15s):** 58 A
- **Resistance:** 0.02 Ohm
- **Case Length:** 54 mm
- **# mag. Poles:** 14
- **Weight:** 183 g
- **Weight:** 6.5 oz

## Propeller
- **Type - yoke twist:** APC Electric E
- **Diameter:** 10 inch 254 mm
- **Pitch:** 6 inch 152.4 mm
- **# Blades:** 2
- **PConst / TConst:** 1.08 / 1.0
- **Gear Ratio:** 0:1
- **Flight Speed:** 0 km/h

##Load: 2.77
##Min: 20.9
##Current: 38.8
##Est. Temperature: 40
##Thrust-Weight: 0.54
##Pitch Speed: 111

<--- Back
FLIGHT TIME

Motor Characteristic at Full Throttle

- el. Power [in W]
- Efficiency [%]
- max. Revolutions [in 100 rpm]
- waste Power [in W]
- Motor Case Temp. [°C]
- Motor Case Temp. overlimit [°C]

(e) by eCalc V2.05
UAS MODEL

Foundational Questions
1. Can the selected UAS platform achieve a 60-minute flight time? Which airframes can/can't?
2. What is the upper limit of endurance for our UAS platform?
3. How can we optimize for minimum power consumption onboard the UAS?
4. How much will the UAS weigh given airframe and electronics? How heavy does the battery need to be? How much power is required?

Assumptions
- E = 63 min (inc. 5% buffer)
- Worst-case headwind is 10 m/s
- Steady, level flight throughout
- Battery discharge depth is 85%
- Overall system efficiency is 85%
### UAS MODEL

<table>
<thead>
<tr>
<th>Equations</th>
<th>Quantity [Units]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_b = \frac{C_b}{\sigma}$</td>
<td>Battery Mass [kg]</td>
</tr>
<tr>
<td>$W = g(m_e + m_{elec} + m_{fp} + m_b)$</td>
<td>Total Weight [N]</td>
</tr>
<tr>
<td>$C_{D,0} = \sum_{i=1}^{N} k_i c_{f,i} S_{wet,i} / S_{ref}$</td>
<td>Parasite Drag Coefficient [none]</td>
</tr>
<tr>
<td>$P_{flight} = \frac{1}{2} \rho V^3 S C_{D,0} + \frac{W^2}{2 \rho V} \left( \frac{1}{\pi e b^2} \right)$</td>
<td>Power Required For Steady, Level Flight [W]</td>
</tr>
<tr>
<td>$P_{true} = \frac{P_{flight}}{\eta_{overall}}$</td>
<td>Propulsion System Power Required for Steady, Level Flight [W]</td>
</tr>
<tr>
<td>$E = 3600 \eta_{overall} \frac{V_b D_b C_b}{P_{flight}}$</td>
<td>Endurance [s]</td>
</tr>
</tbody>
</table>
# UAS MODEL

<table>
<thead>
<tr>
<th>Name</th>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>( \rho ) [kg/m(^3)]</td>
<td>1.047</td>
</tr>
<tr>
<td>Wing Area</td>
<td>( S ) [m(^2)]</td>
<td>0.545</td>
</tr>
<tr>
<td>Wingspan</td>
<td>( b ) [m]</td>
<td>1.718</td>
</tr>
<tr>
<td>Efficiency Factor</td>
<td>( e ) [%]</td>
<td>80</td>
</tr>
<tr>
<td>Propulsive Efficiency</td>
<td>( \eta_{\text{overall}} ) [%]</td>
<td>85</td>
</tr>
<tr>
<td>Battery Discharge Depth</td>
<td>( D_b ) [%]</td>
<td>85</td>
</tr>
<tr>
<td>Endurance</td>
<td>( E ) [min]</td>
<td>63</td>
</tr>
<tr>
<td>Capacity Density</td>
<td>( \sigma ) [mAh/kg]</td>
<td>16600</td>
</tr>
<tr>
<td>Battery Voltage</td>
<td>( V_b ) [V]</td>
<td>11.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>( V ) [m/s]</td>
</tr>
<tr>
<td>True Power Req’d</td>
<td>( P_{\text{true}} ) [W]</td>
</tr>
<tr>
<td>Parasite Drag Coeff.</td>
<td>( C_{D,0} ) [none]</td>
</tr>
<tr>
<td>Battery Weight</td>
<td>( W_b ) [N]</td>
</tr>
<tr>
<td>Total Weight</td>
<td>( W ) [N]</td>
</tr>
<tr>
<td>Total Drag</td>
<td>( D ) [N]</td>
</tr>
</tbody>
</table>
\[ P_{flight} = TV = DV \]

\[ P_{flight} = V \left( \frac{1}{2} \rho V^2 S \left( C_{D,0} + \frac{C_I^2}{\pi e AR} \right) \right) \]

\[ C_L = \frac{W}{\frac{1}{2} \rho V^2 S} \]

\[ P_{flight} = \frac{1}{2} \rho V^3 S \left( C_{D,0} + \frac{W^2}{\left( \frac{1}{2} \rho V^2 S \right)^2} \left( \frac{1}{\pi e AR} \right) \right) \]

\[ P_{flight} = \frac{1}{2} \rho V^3 S C_{D,0} + \frac{W^2}{\frac{1}{2} \rho V S} \left( \frac{1}{\pi e AR} \right) \]

\[ P_{flight} = \frac{1}{2} \rho V^3 S C_{D,0} + \frac{W^2}{\frac{1}{2} \rho V} \left( \frac{1}{\pi e b^2} \right) \]

\[ P_{true} = \frac{P_{flight}}{\eta_{overall}} \]

Can find \( V_{\text{min,PR}} \) by setting \( \frac{\partial P_{flight}}{\partial V} = 0 \)

\[ \frac{\partial P_{flight}}{\partial V} = 0 = \frac{3}{2} \rho V^2 S C_{D,0} - \frac{W^2}{\frac{1}{2} \rho V^2} \left( \frac{1}{\pi e AR} \right) \]

\[ V_{\text{min,PR}} = \left[ \frac{4}{3} \left( \frac{W}{S} \right)^2 \left( \frac{1}{\rho^2 C_{D,0}} \right) \left( \frac{1}{\pi e AR} \right) \right]^{\frac{1}{3}} \]
UAS MODEL

Parameters

Well-Known Parameters
• S - Wing Area (given by manufacturer, easy to measure)
• AR - Wing Aspect Ratio (easy to measure b (wing span) and then calculate)
• W - Total Weight (easy to measure on a scale)
• E - Endurance (easy to measure with a timer)

Unknown Parameters, Fairly Easy to Measure
• \( \rho \) - Air Density (Take temp + pres measurements)
• V - Airspeed (use total + static pressure from pitot tube measurement)

Unknown Parameters, Difficult to Measure
• CD,0 - Parasitic Drag Coefficient (difficult to estimate and measure)
• e - wing efficiency factor (difficult to measure/estimate)
Most Impactful Parameters

**Which** parameters will have the largest impact upon the Power Required (and hence endurance?)

- $V \rightarrow V^3$ in first term, $1/V$ in second term (Which terms will dominate for given airframes? How much effect does a given velocity increase have on required power?)
- $W \rightarrow W^2$ in second term (how much of a power increase is required for a given weight increase?)
- $b \rightarrow 1/b^2$ in second term (does increasing wingspan (also increases weight) produce an appreciable decrease in required power?)
- $\eta$ - Overall efficiency of the propulsion system could be extremely low

Less important parameters

- $C_{D,0}$ - wide range of values, could significantly impact power required
UAS MODEL

Drag Buildup

\[ C_{D,0} = \sum_{i=1}^{N} k_i c_{f_i} S_{wet_i} / S_{ref} \]

- \( k \) is form factor
- \( c_{f_i} \) is skin friction coefficient
- \( S_{wet} \) is wetted area
- \( N = 3 \) (wing, fuselage, tail)
- \( S_{ref} = S_{wing} \)

\[ c_f = \frac{0.455}{(\log_{10}(Re_L))^{2.58}} \]

\[ Re_L = \frac{\rho V L}{\mu} \]

\[ k = 1 + 2(t/c) + 60(t/c)^4 \] Wing and Tail

\[ k = 1 + 1.5(d/l)^{1.5} + 7(d/l)^3 \] Fuselage

\[ S_{wet} = 2(1 + 0.2(t/c))S_{ref} \] Wing and Tail

\[ S_{wet} = 2\pi(d/2)^2 + \pi dl \] Fuselage

\[ C_{D,0} = C_{D,0,wing} + C_{D,0,fuselage} + C_{D,0,tail} \]
• RECUV operates XUAV Talon in long-endurance configuration with suite of sensors and antennas

• Serves as excellent point of reference for RAMROD Talon-based UAS. 60 min+ Flight time is feasible on this airframe

### RECUV Talon Drive System

<table>
<thead>
<tr>
<th>Component</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor</td>
<td>E-Flite Power 25BL (1250 Kv)</td>
</tr>
<tr>
<td>Battery</td>
<td>Thunder Power RC TP7000-3SH (14000 mAh)</td>
</tr>
<tr>
<td>ESC</td>
<td>Phoenix Edge HV 80A</td>
</tr>
<tr>
<td>Propeller</td>
<td>APC 9x7 10x7</td>
</tr>
</tbody>
</table>

### RECUV Talon Overview

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Weight [g]</td>
<td>422 (x2)</td>
</tr>
<tr>
<td>Total Weight [g]</td>
<td>3343</td>
</tr>
<tr>
<td>Motor Power Rating [W]</td>
<td>700 (1250 Kv)</td>
</tr>
<tr>
<td>Motor Power Rating [W]</td>
<td>700 (1250 Kv)</td>
</tr>
<tr>
<td>Battery Capacity [mAh]</td>
<td>7000 3S 11.4 V (x2)</td>
</tr>
<tr>
<td>Optimal Cruise Speed [m/s]</td>
<td>14-17</td>
</tr>
<tr>
<td>Endurance [min]</td>
<td>60-90</td>
</tr>
</tbody>
</table>
DMU11 INTERFACE

PIN GUIDE: PixHawk
PixHawk 2.0:
- 5V Out = 5V supply to sensor
- Tx = UART transmit output
- Rx = UART receive input
- GND = Ground

PIN GUIDE: MAX490
MAX490:
- A = Non-inverting receiver input
- B = Inverting receiver input
- Y = Non-inverting driver output
- Z = Inverting driver output
- DI = Driver input
- RO = Receiver output
- Vcc = Supply voltage
- GND = Ground

PIN GUIDE: DMU11
DMU11:
- RxLo = Negative receive
- RxHi = Positive receive connection
- TxLo = Negative transmit connect
- TxHi = Positive transmit connection
- Vcc = Supply voltage
- GND = Ground
- RT = Termination resistor (120Ω)
DMU11 INTERFACE
PX4FLOW / PITOT TUBE INTERFACE

PIN GUIDE
- SCL = Clock connection
- SDA = Data connection
Example data transmission, switching between the flow sensor and airspeed sensor through the I2C splitter

No color: Sent by PixHawk
- Green: Sent by flow sensor
- Blue: Sent by airspeed sensor
RISK ANALYSIS - RISK 1

Severity: 4  Likelihood: 3  Total: 12

Description: The noise in the downlink of the AGC data makes the UAS appear as if it has not yet entered the sphere of influence of the PPD and it will continue to trust it’s GPS even if it shouldn’t. It will also tell the UAS not to trust its GPS if it can

Mitigation Options:
• Downlink the data during different times of the day to try and find the time of day that downlinking the data is the most difficult to ensure that the UAS can downlink in the worst case scenario

Post Mitigation Risk Analysis
Severity: 2  Likelihood: 2  Total: 4
RISK ANALYSIS - RISK 3

Severity: 4    Likelihood: 2    Total: 8
Description: The UAS could have structural damage when it lands. This damage could be severe enough to force the team to buy a replacement part.

Mitigation Options:
• Skid plates have been added to the bottom of the UAS so when the UAS lands, the fuselage will not hit the ground
• Structural analysis of the airframe has been conducted to ensure that the structure can handle a significant load

Post Mitigation Risk Analysis
Severity: 2    Likelihood: 2    Total: 4
RISK ANALYSIS - RISK 5

Severity: 5  Likelihood: 2  Total: 10

Description: While testing the UAS, it flies out the line of sight and the team is unsure about where it is

Mitigation Options:
- A “Return Home” function will be implemented so that this problem doesn’t happen
- An HD camera has been added to the front of the UAS and the pilot of the UAS will be able to see what the UAS sees if they take manual control

Post Mitigation Risk Analysis
Severity: 1  Likelihood: 2  Total: 2
RISK ANALYSIS - RISK 6

Severity: 3  Likelihood: 3  Total: 9

Description: The simulations the team uses with simulated data don’t behave the same as real life and some of the items the team bought will no longer be adequate for the project.

Mitigation Options:

• Simulations have been run using data from real flights to show that the parts selected should be adequate.
• Margins have been built into the budget along with duplicate parts being ordered in order to avoid this. The biggest concern is if the IMU gets destroyed.

Post Mitigation Risk Analysis

Severity: 2  Likelihood: 1  Total: 2
RISK ANALYSIS - RISK 7

Severity: 3  Likelihood: 3  Total: 9

Description: If the AGC can’t downlink then a power profile of the signal source will not be able to be replicated at the ground station and the localization will not be possible.

Mitigation Options:
• Test during different times of the day with varying bandwidth traffic to ensure that our downlink will work during the busiest time of the day
• Ensure that the AGC data and positional data get sent down before the IF data in order to generate the power profile

Post Mitigation Risk Analysis
Severity: 3  Likelihood: 1  Total: 3
FAA POLICY

1. Pilot must have eyes on the UAS at all times.
2. Manual controls must be ready and available at all times.
3. Flight paths may not be within a 5 mile radius of an airport unless the airport has been notified and has approved of the flight path.
4. Flight must be under 400 ft. altitude.
5. The Aircraft must remain under 55 lbs.
EKF2 TUNING

• Pitot Tube
  • EK2_EAS_NOISE
  • EK2_EAS_GATE

• Optical Flow
  • EK2_MAX_FLOW
  • EK2_FLOW_NOISE
  • EK2_FLOW_GATE
  • EK2_FLOW_DELAY

• IMU
  • EK2_GYRO_PNOISE
  • EK2_ACC_PNOISE
  • EK2_GBIAS_PNOISE
  • EK2_GSCL_PNOISE
  • EK2_ABIAS_PNOISE
EKF2 STATES

- Attitude (Quaternions)
- Velocity (North, East, Down)
- Position (North, East, Down)
- Gyro bias offsets (X,Y,Z)
- Gyro bias factors (X,Y,Z)
- Z acceleration bias
- Earth magnetic field (X,Y,Z)
- Body magnetic field (X,Y,Z)
- Wind velocity (North, East)
DMU11 DATA TRANSMISSION

Message Contents

<table>
<thead>
<tr>
<th>Word</th>
<th>Data Item</th>
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<tbody>
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<td>Z-Axis Acceleration</td>
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<td>14-15</td>
<td>Reserved</td>
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<td>16-17</td>
<td>Average IMU Temperature</td>
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<td>18</td>
<td>System Start-up BIT Flags</td>
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<td>19</td>
<td>System Operation BIT Flags</td>
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<td>Reserved</td>
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<td>21</td>
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Maximum Time in GPS Denied Conditions

3 km

100 sec
1 km

3 km
MICROZED WIRING AND CONNECTIONS

Rx (Pmod-D1)
Tx (Pmod-D2)
# BUDGET BREAKDOWN

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Cost per Unit (USD)</th>
<th>Total Cost (USD)</th>
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<td><strong>UAS Components</strong></td>
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<td>E-Flight 60-Amp Pro Switch-Mode</td>
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<td>Eagle Tree Prandtl Pitot Tube Kit</td>
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<td>Pixhawk Digital Airspeed Sensor</td>
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<td>Mobius HD ActionCam</td>
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<td>Here GPS Reciever</td>
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<td>HS-5065MG Wing Servos</td>
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# BUDGET BREAKDOWN

<table>
<thead>
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<th>Total Cost (USD)</th>
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<td><strong>Payload Components</strong></td>
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<td>MicroZed</td>
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<td>NI1065</td>
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<td>2200mAh USB Battery Pack</td>
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<td>TW7872 GPS Antenna</td>
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<tr>
<td>Nylonx Carbon Fiber Filament</td>
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<tr>
<td><strong>Payload Total</strong></td>
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<td>Misc. Electronics</td>
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<tr>
<td><strong>Margin</strong></td>
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</table>
ARDUPILOT - AUTO
MODIFIED ARDUPILOT
SIMULATIONS – SOFTWARE IN THE LOOP

MavProxy
- Runs autopilot code in real time natively on Windows/Linux
- Sensor data estimated based on predictive modeling
- Useful to test/debug code changes
- Access to full range of C++ debuggers
- Can test physical sensors using serial connections

Replay
- Use DataFlash to simulate flight using actual flight data, with changed parameters
- Useful for testing flight-mode switch with actual data
- EKF tuning
BACK UP - OPERATIONAL PAYLOAD INTERFACE BOARD

Interface Board – PCB Design

Splits power between different systems in payload

Connection between MicroZed and PixHawk

LED Indicators to verify connections

Programming access to MicroZed
BACK UP – INTERFACE BOARD CONNECTIONS

Interface Board – PCB Design

Splits power between different systems in payload

Connection between MicroZed and Pixhawk

LED Indicators to verify connections

Programming access to MicroZed
OPTICAL FLOW CALCULATIONS

Pixel Size $p = 6.0 \times 6.0 \, \mu m$
Focal length $f = 16 \, mm$
Resolution $= 480 \times 752$ pixels

$w = (480 \, \text{pixels})(6.0 \, \mu m) = 2.88 \, mm$
$h = (752 \, \text{pixels})(6.0 \, \mu m) = 4.512 \, mm$

$AFOV_h = 2 \tan^{-1} \left( \frac{w}{2f} \right) = 10.26^\circ$

$AFOV_v = 2 \tan^{-1} \left( \frac{h}{2f} \right) = 16.05^\circ$

$x = 2(60 \, m) \tan \left( \frac{AFOV_h}{2} \right) = 10.8 \, m$

$y = 2(60 \, m) \tan \left( \frac{AFOV_v}{2} \right) = 16.9 \, m$

$x_{res} = y_{res} = \frac{x}{w} = \frac{y}{h} = 0.0225 \, m/\text{pixel}$

Resolution

Horizontal distance seen

Vertical distance seen
IMU HARDWARE

DMU11 From Silicon Sensing

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

Stages of Data Transfer testing
- Computer to Computer with Wifi (sine wave)
- Computer to Computer with 64 bit counter
- MicroZed to Computer
- MicroZed to Server to Computer via cell network

Cell Modem → LTE Network → Web Server
TIMING DIAGRAM

TX - Telem 1 Pin 3
Pixhawk System
Start Bit
Data Bits - Location Data
Stop Bit
Rx - Pmod(D1)
Microzed Board
Rx - Pmod(D1)

RX - Telem 1 Pin 2
Stop Bit
Data Bits - GPS switch (1/0)
Start Bit
Tx - Pmod(D2)
### DESIGN SOLUTION

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Takeoff Weight</td>
<td>3471 g</td>
</tr>
<tr>
<td>Wing Span</td>
<td>1.718 m</td>
</tr>
<tr>
<td>Battery Capacity</td>
<td>14000 mAh</td>
</tr>
<tr>
<td>Maximum Flight Endurance</td>
<td>92 min</td>
</tr>
<tr>
<td>RFI Sampling Rate</td>
<td>3 Hz</td>
</tr>
<tr>
<td>GPS Sample Rate (location)</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Max Data Transfer Rate to Ground</td>
<td>10 Mbps</td>
</tr>
<tr>
<td>Cruise Speed</td>
<td>14.4 m/s</td>
</tr>
<tr>
<td>Cruise Altitude</td>
<td>60 m</td>
</tr>
</tbody>
</table>
**TAKE OFF & LANDING**

**Take Off**
- **Manual**
  - Initial testing
  - Hand launch w/ transmitter
- **Autonomous**
  - Deliverable
  - Bungee or hand launch

**Landing**
- **Manual**
  - Testing/Emergency
  - Controlled using transmitter
- **Autonomous**
  - Deliverable
  - Controlled using PixHawk
# OPERATIONAL TEMPERATURES

<table>
<thead>
<tr>
<th>Component</th>
<th>Minimum Temperature (°C)</th>
<th>Maximum Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MicroZed</td>
<td>-40</td>
<td>80</td>
</tr>
<tr>
<td>NT1065</td>
<td>-40</td>
<td>85</td>
</tr>
<tr>
<td>Battery</td>
<td>-20</td>
<td>60</td>
</tr>
</tbody>
</table>

The openings in the box will allow for heat dissipation and keep the components within the operating temperatures.

**Requirements** | **Satisfaction**
--- | ---
DR 11.3: The temperature inside the operational payload shall stay within the operating temperature of all electronic components contained | The operational temperatures of the components will not go outside their operating temperature.