## CRITICAL DESIGN REVIEW

# INFERNO

**INtegrated Flight-Enabled Rover For Natural disaster Observation**

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# PRESENTATION OUTLINE

- Project Purpose and Objectives
- Design Solution
- Critical Project Elements
- Design Requirements and Satisfaction
- Verification and Validation
- Project Risk Assessment
- Project Planning

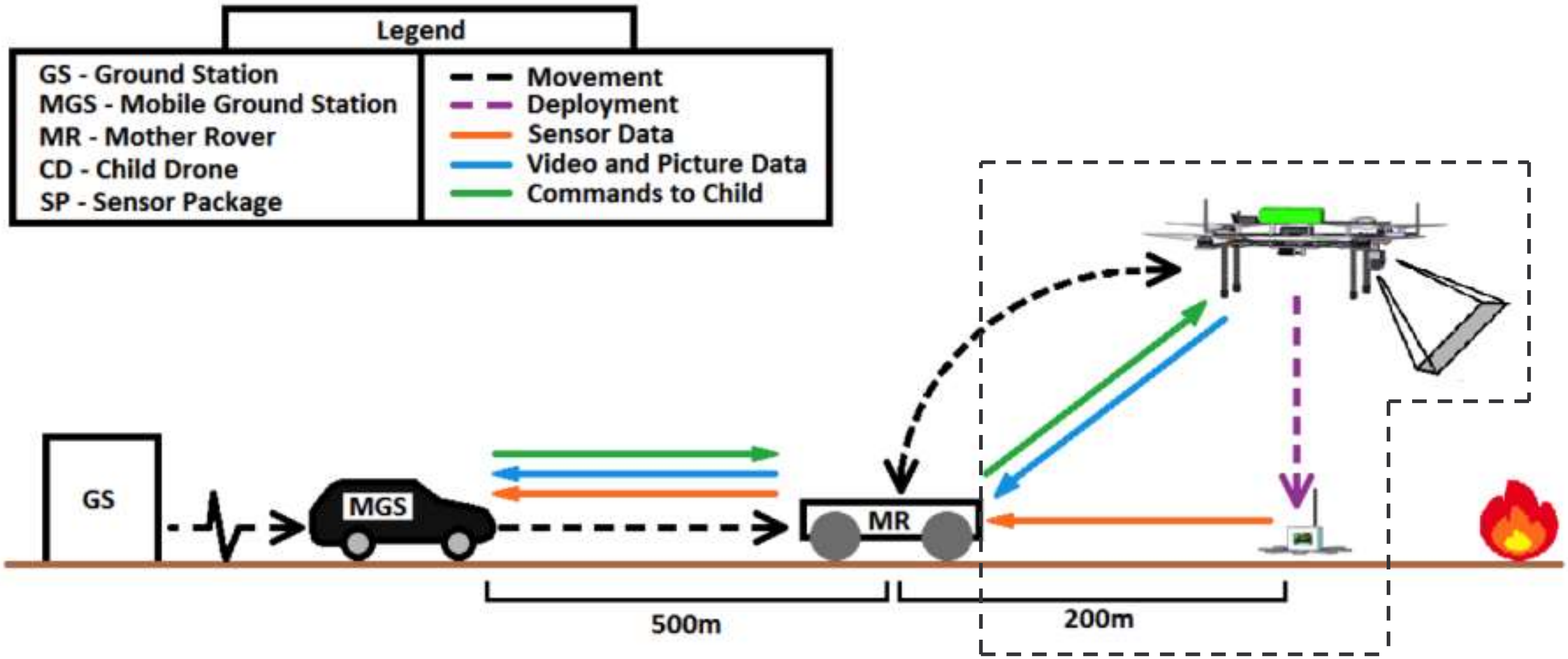
# PROJECT PURPOSE AND OVERVIEW

# INFERNO MISSION STATEMENT

*Design and create an **aerial sensor package delivery system** for future integration with a natural disaster observation system.*

Project Context | Design Solution | Critical Elements | Requirements | V&V Plans | Project Risk | Project Planning

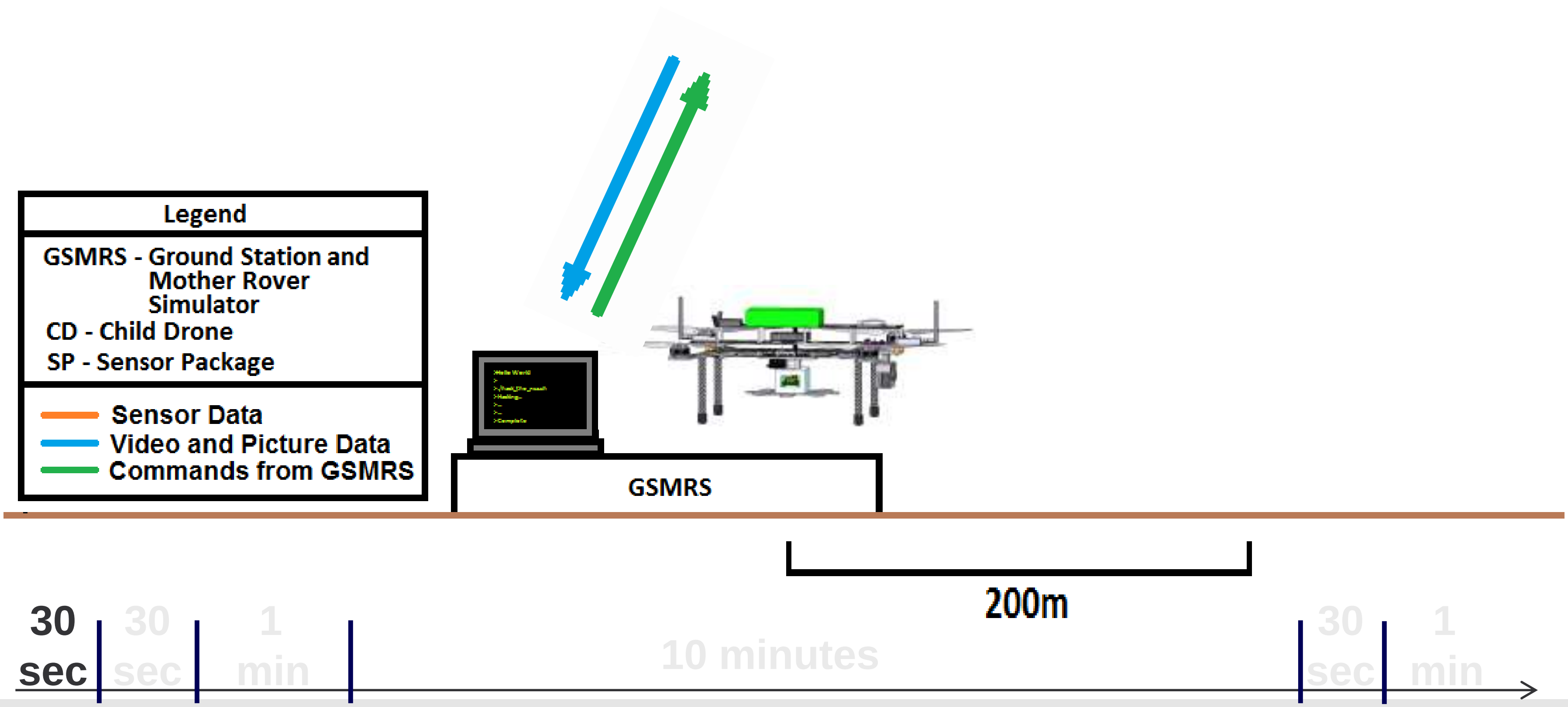
# FIRE TRACKER SYSTEM




Project Context | Design Solution | Critical Elements | Requirements | V&V Plans | Project Risk | Project Planning

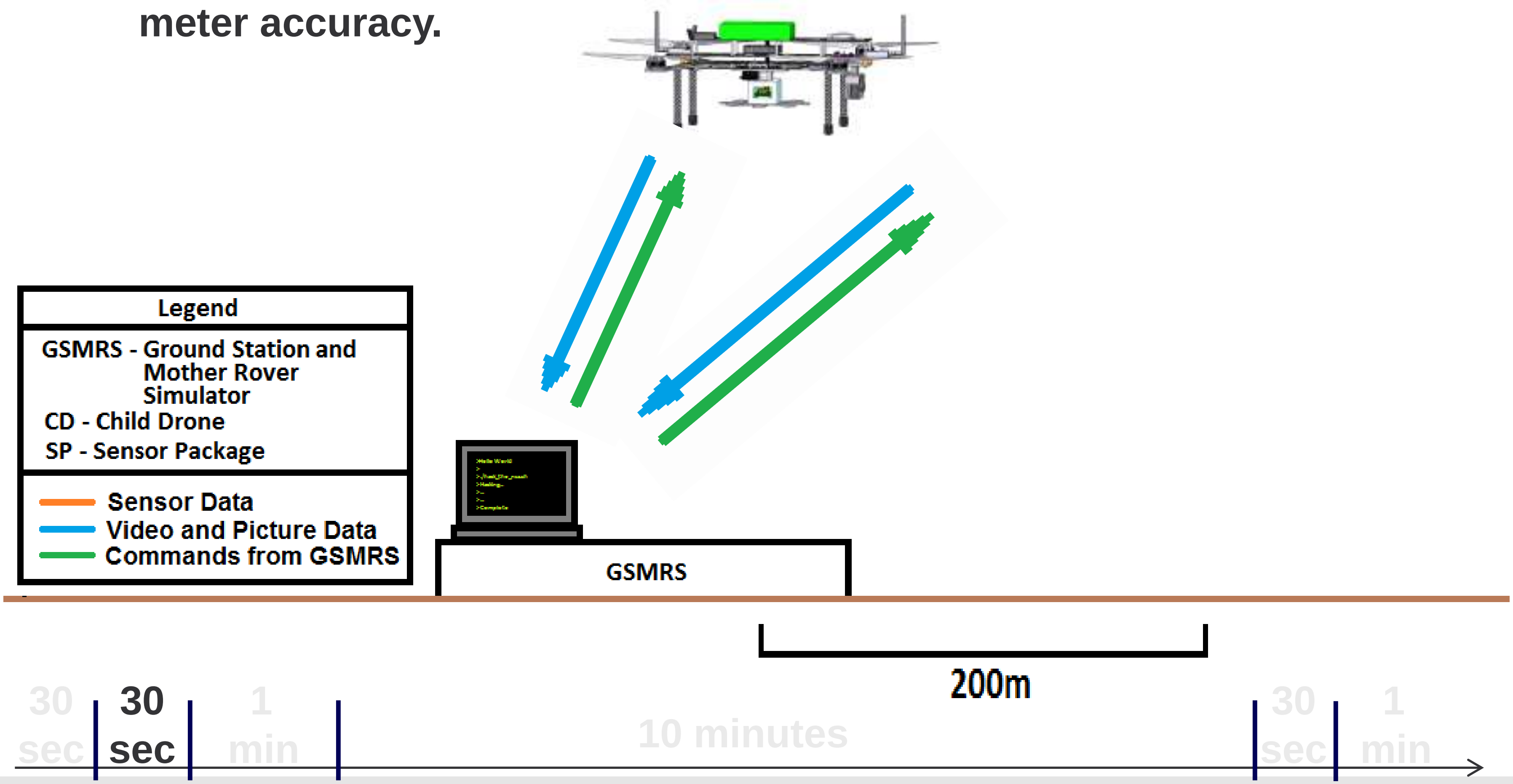
# INFERNO SCOPE: CONCEPT OF OPERATIONS

**The CD takes off from the GSMRS using autopilot.**



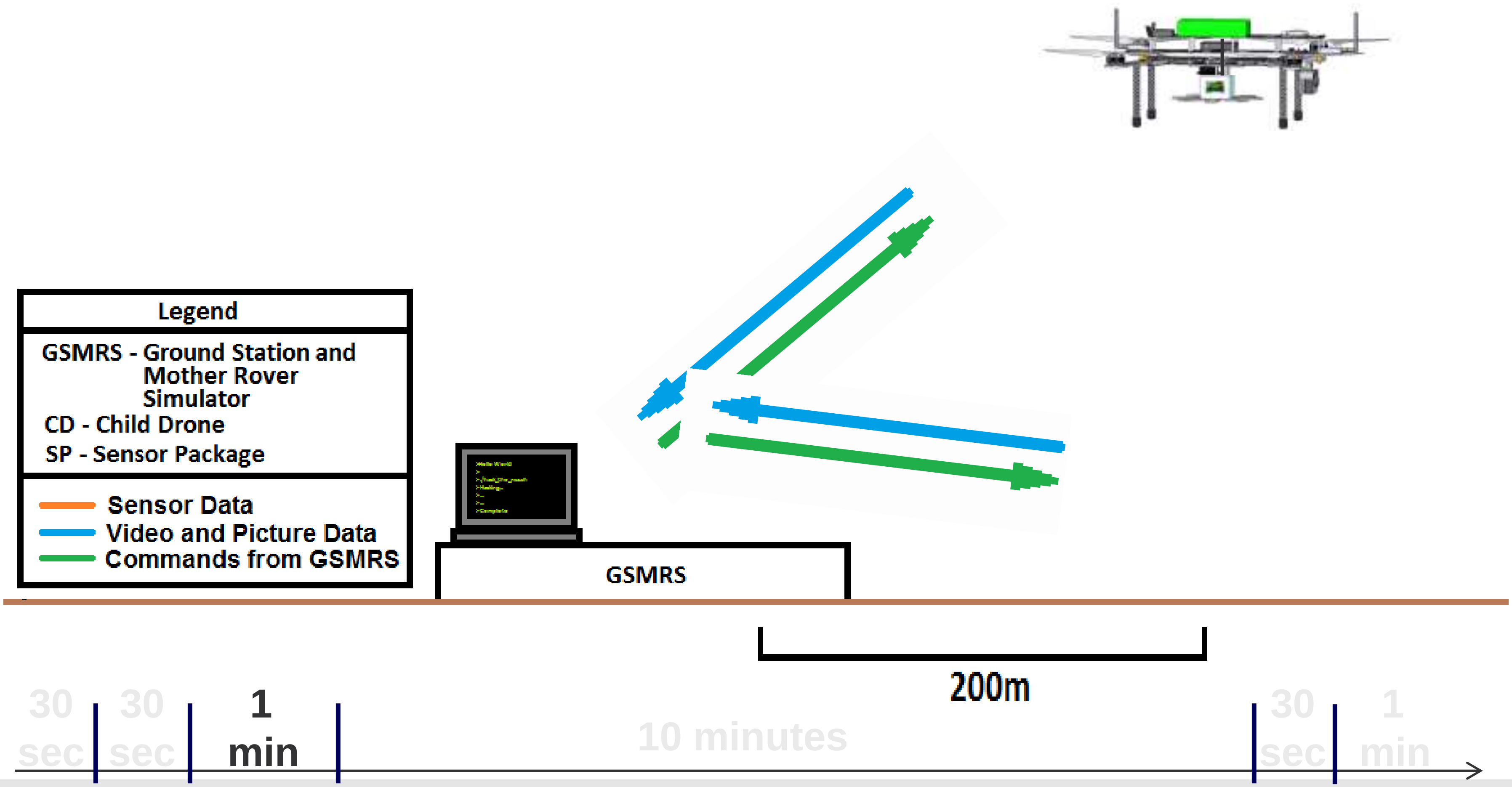
# INFERNO SCOPE: CONCEPT OF OPERATIONS

**The CD flies to a GPS waypoint up to 200 meters away using autopilot. The CD then maintains its commanded position to 5 meter accuracy.**



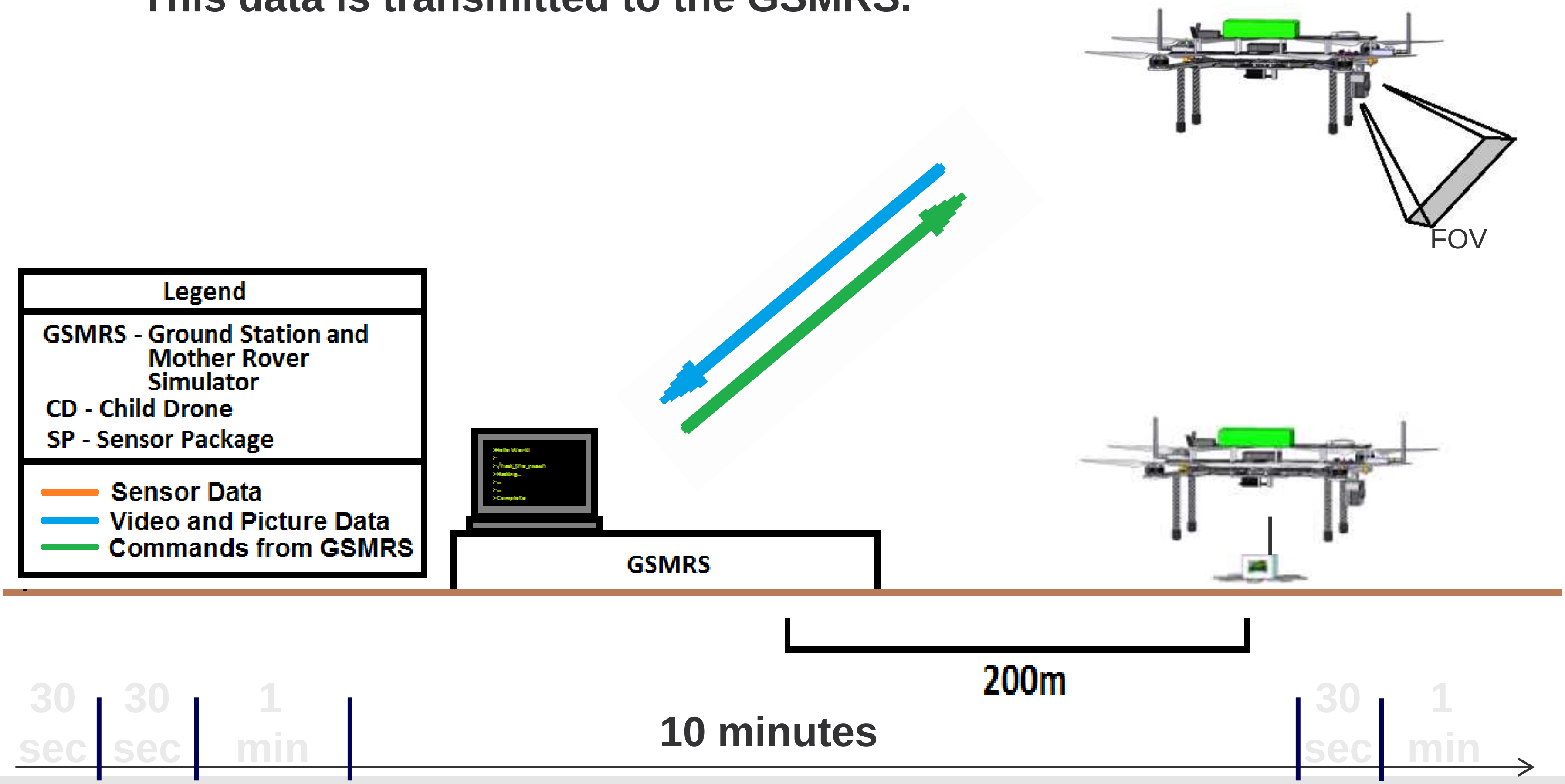
# INFERNO SCOPE: CONCEPT OF OPERATIONS

**Using autopilot, the CD lands and deploys the SP which begins collecting and storing 1 hour of data.**



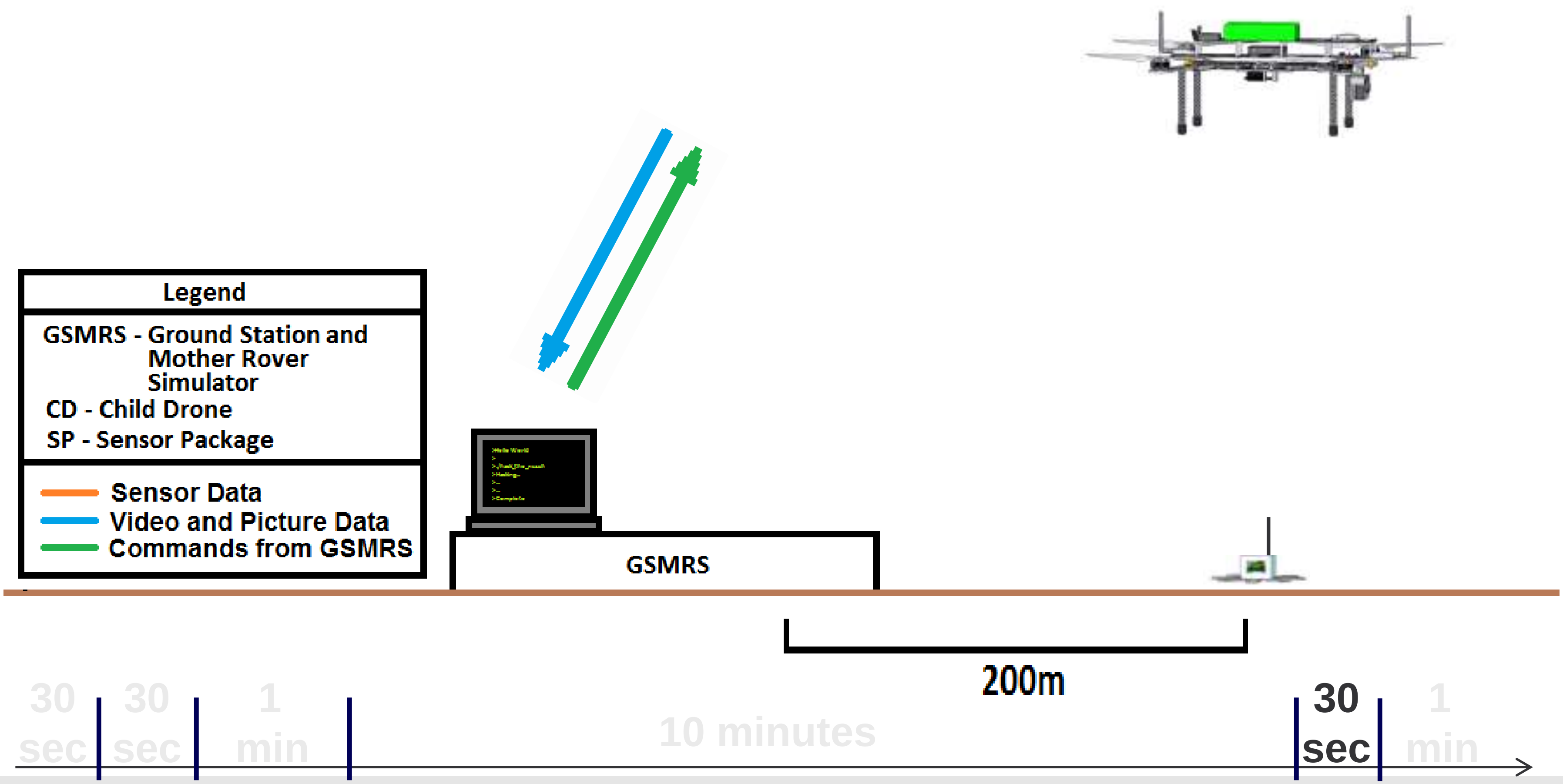
# INFERNO SCOPE: CONCEPT OF OPERATIONS

**The CD returns to hover using autopilot. It may be commanded to capture video and/or still images at any time. This data is transmitted to the GSMRS.**



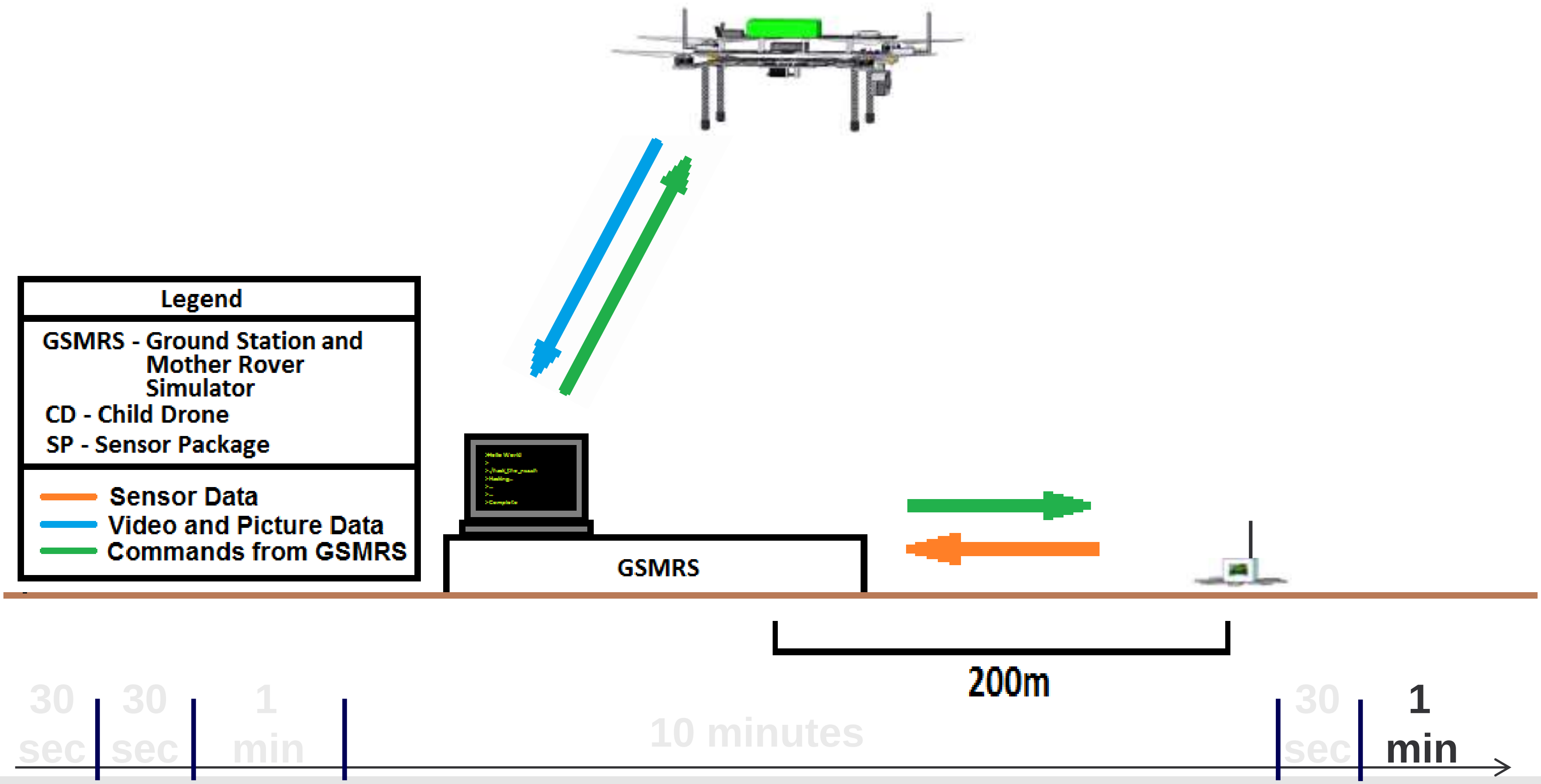
# INFERNO SCOPE: CONCEPT OF OPERATIONS

**The CD returns to the GSMRS after a 15 minute maximum flight duration using autopilot.**



# INFERNO SCOPE: CONCEPT OF OPERATIONS

**The CD lands on the GSMRS under pilot control and the SP begins transmitting to the GSMRS.**



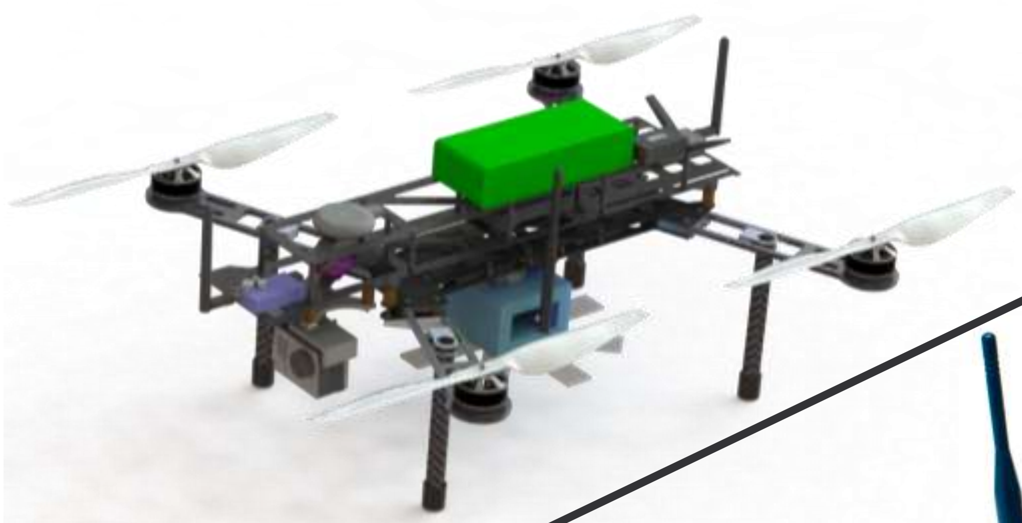
# SYSTEM FUNCTIONAL REQUIREMENTS

| Functional Requirement | Description |
|---|---|
| **FR 1.0** | The system shall collect 1 Hz ambient temperature data at ground level for 60 minutes at the LOI. |
| **FR 2.0** | The system shall collect 1080p aerial video at 30 FPS with TBD quality for 15 minutes. |
| **FR 3.0** | The system shall collect 8 MP aerial pictures. |
| **FR 4.0** | The system shall wirelessly receive commands at a minimum horizontal range of 200 meters. |
| **FR 5.0** | The system shall wirelessly transmit data at a minimum horizontal range of 200 meters. |
| **FR 6.0** | The system shall have a maximum footprint of 0.545 $m^2$ . |

# DESIGN SOLUTION

# SYSTEM DESIGN

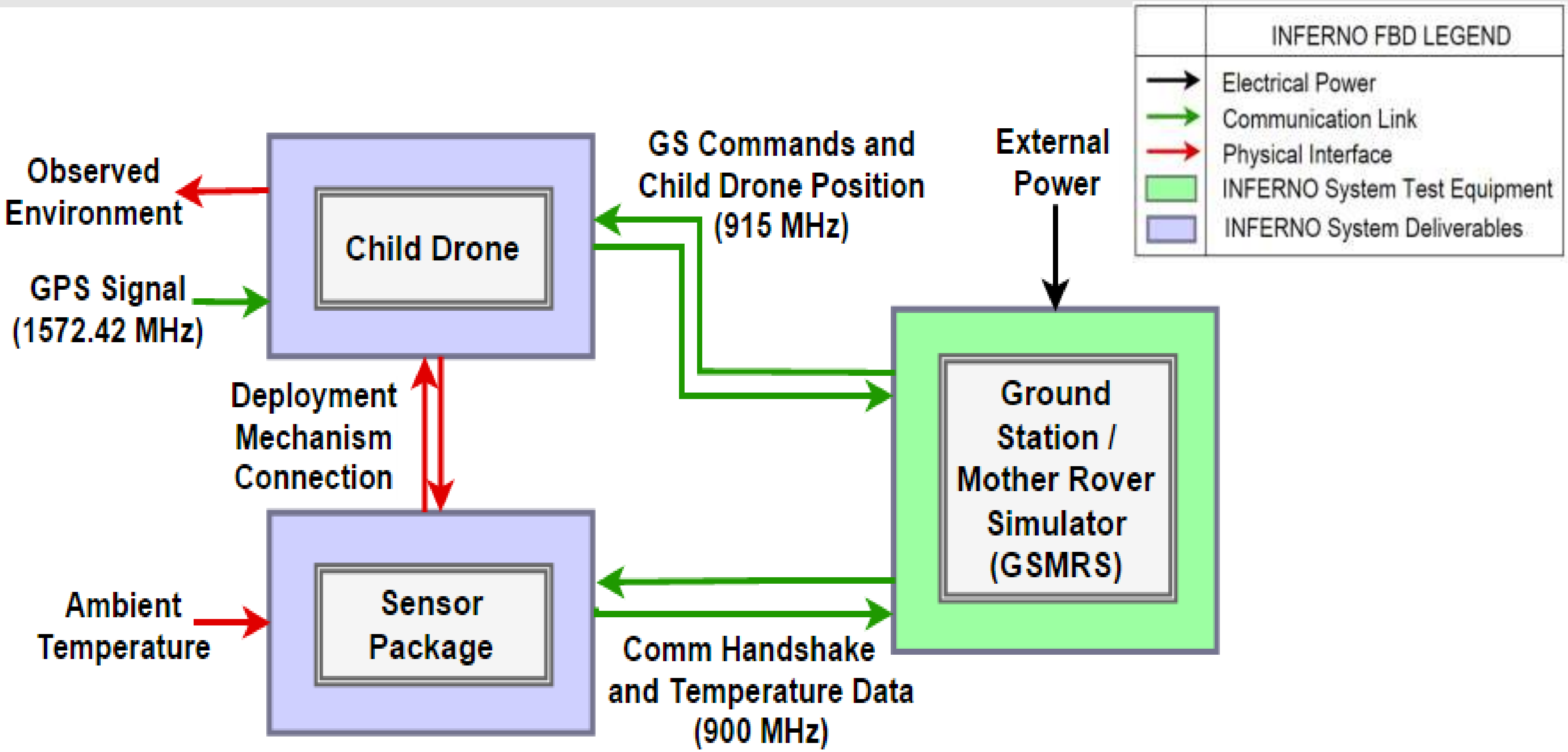
## Integrated INFERNO System



## GSMRS

Project Context | **Design Solution** | Critical Elements | Requirements | Project Risk | V&V Plans | Project Planning

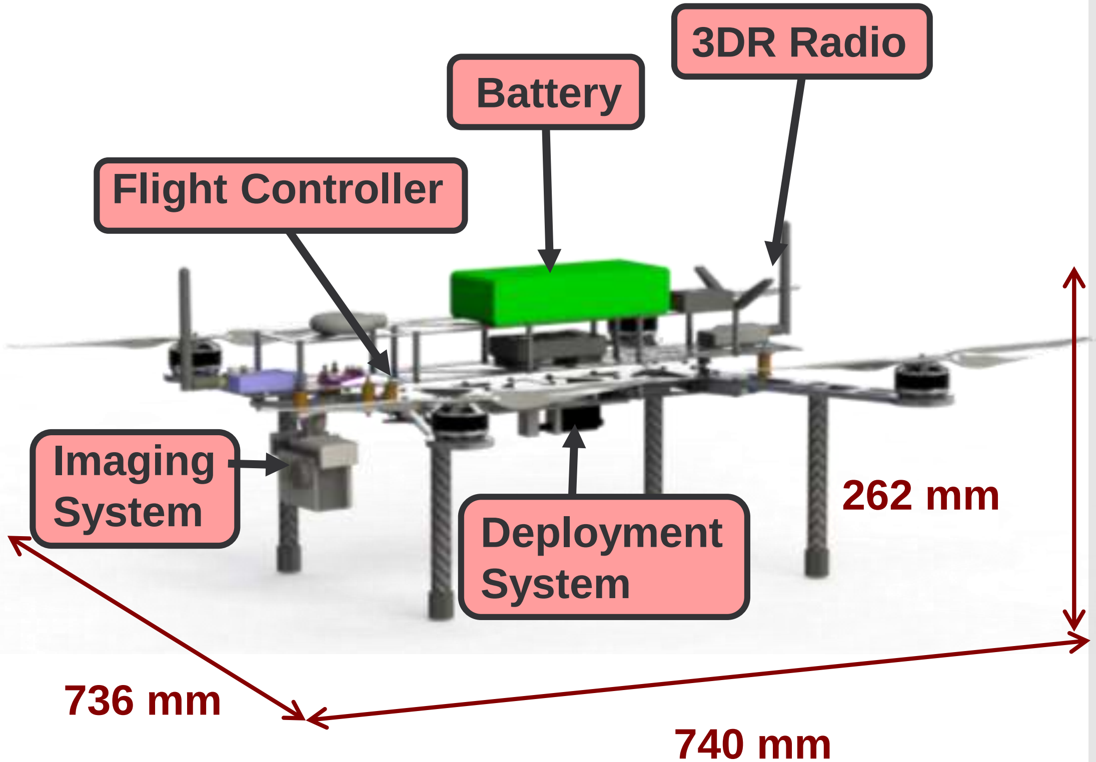
# SYSTEM FUNCTIONAL BLOCK DIAGRAM



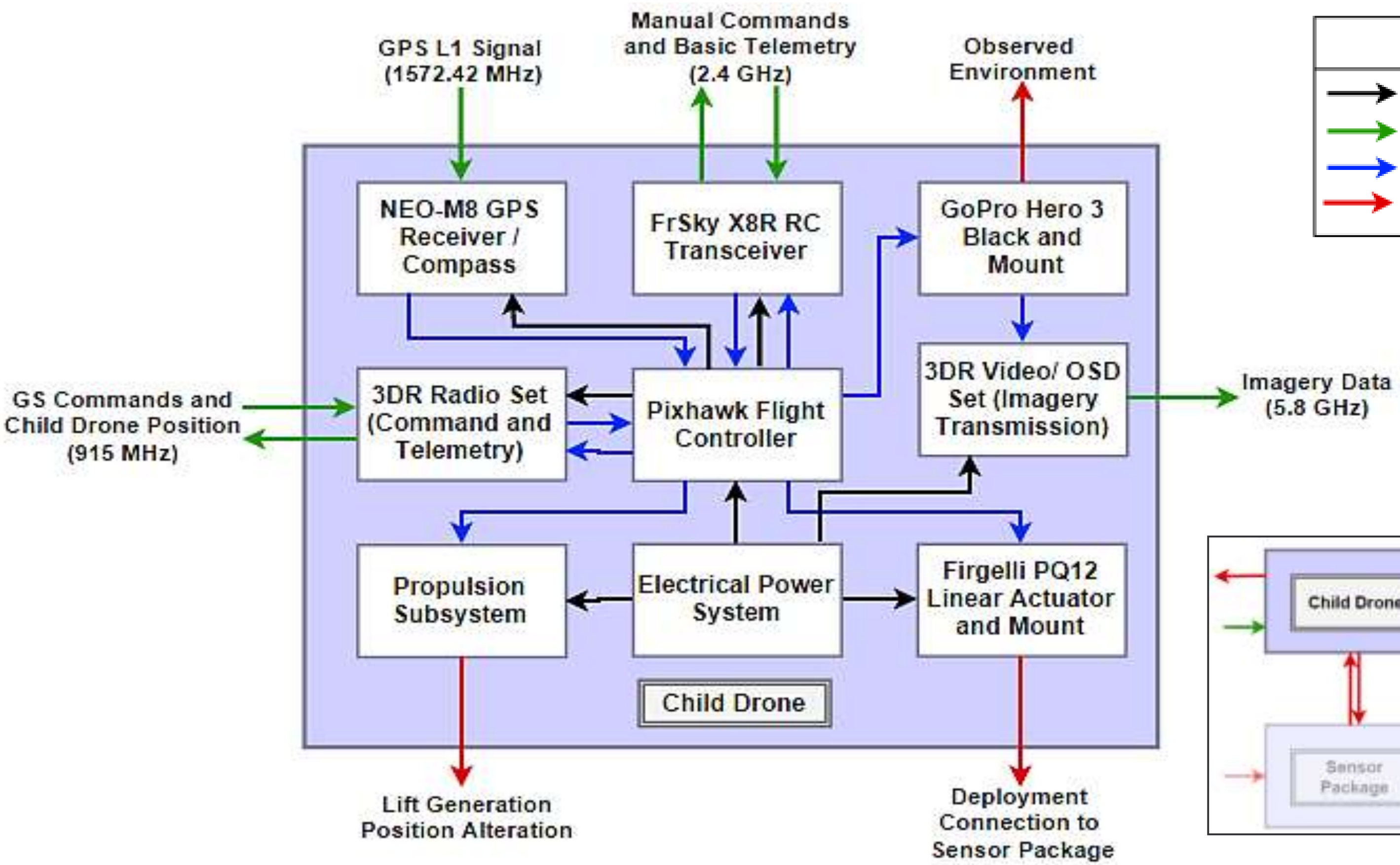

Project Context | **Design Solution** | Critical Elements | Requirements | V&V Plans | Project Risk | Project Planning

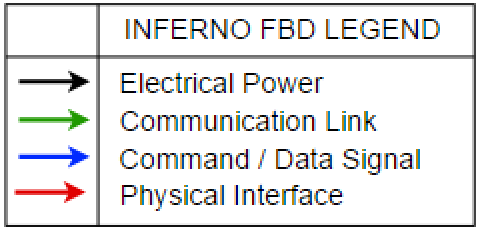
# CHILD DRONE

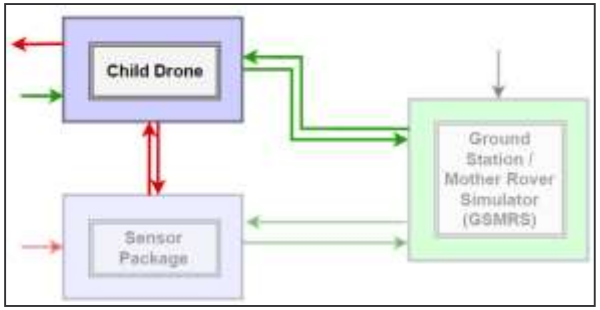
| Child Drone Specifications | |
|---|---|
| Airframe | Lumenier QAV500 V2 |
| Battery | 10,000 mAh 14.8V LiPo |
| Flight Controller | 3DR Pixhawk |
| Telemetry Transceiver | 3DR Radio V2 900 MHz |
| RC Transceiver | Taranis X8R 2.4 GHz |
| Video Transmitter | 3DR Video Kit 5.8 GHz |
| Drone Mass | 2321 g |
| Cost | $1322 |



# FUNCTIONAL BLOCK DIAGRAM: CHILD DRONE



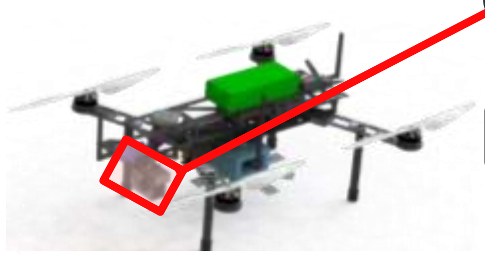



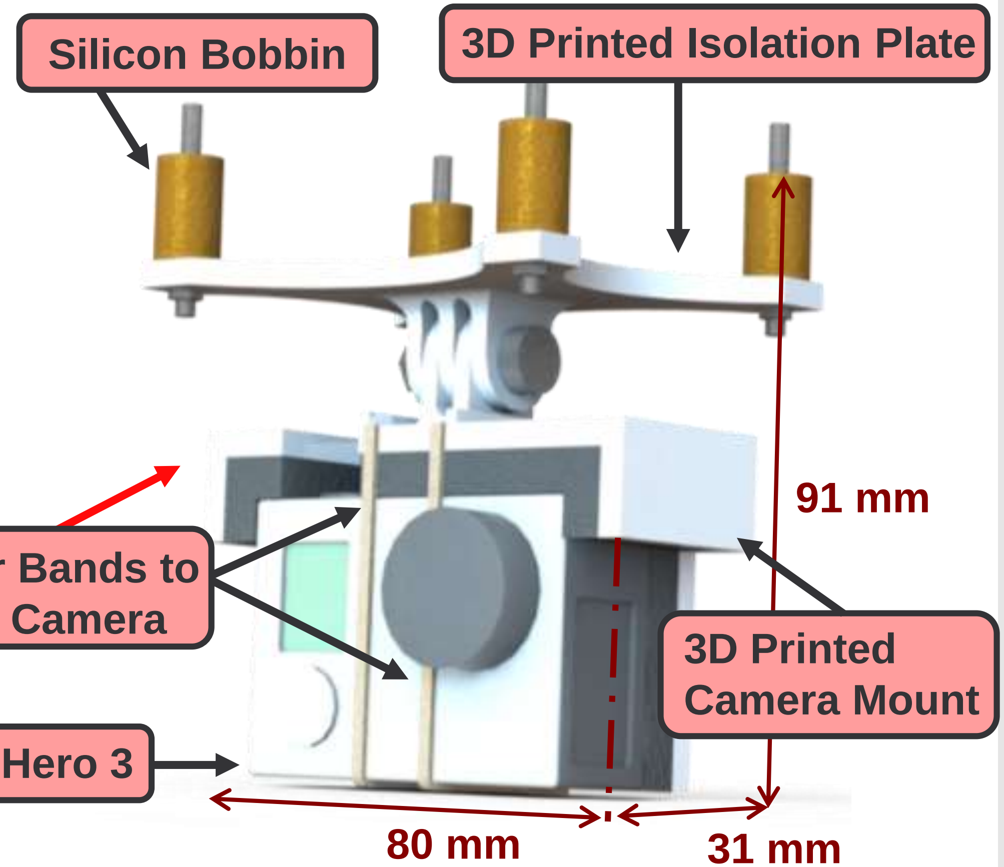

Project Context | **Design Solution** | Critical Elements | Requirements | V&V Plans | Project Risk | Project Planning

# IMAGING SYSTEM

| | GoPro Hero3 Black | Mounting System |
|---|---|---|
| Weight | 78 g | 81 g |
| Cost | Faculty Donation | $25 |
| Material | COTS | ABS P430 |

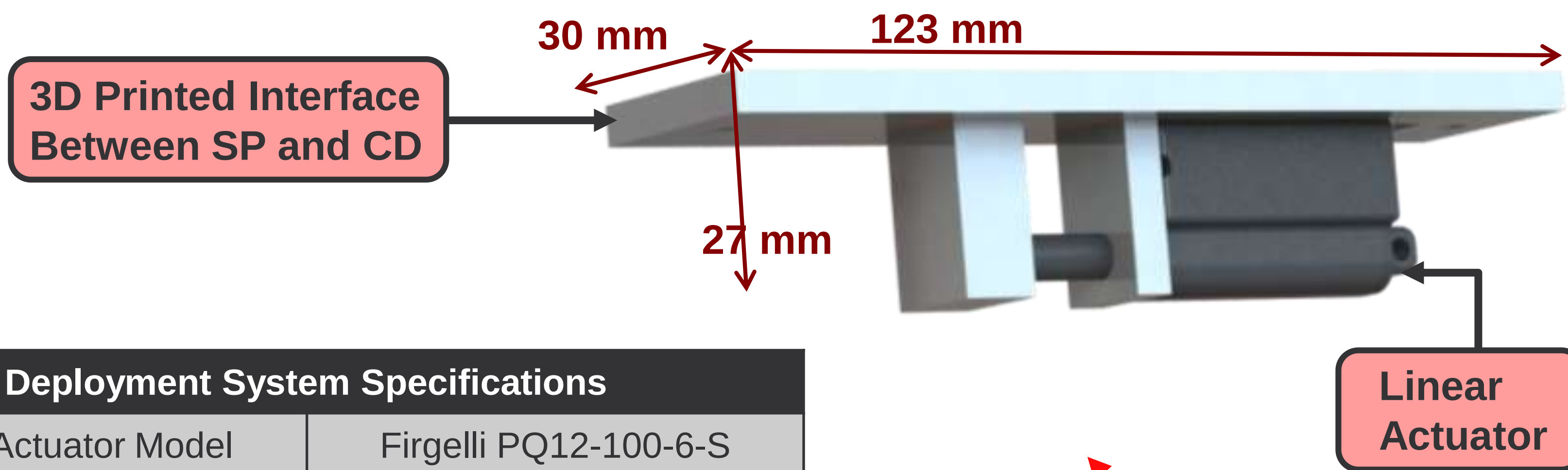
| | |
|---|---|
| **Total Weight** | 159 g |
| **Total Cost** | $25 |



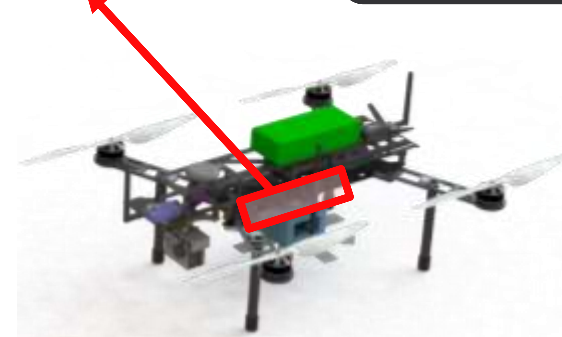



Project Context | **Design Solution** | Critical Elements | Requirements | Project Risk | V&V Plans | Project Planning

# DEPLOYMENT SYSTEM

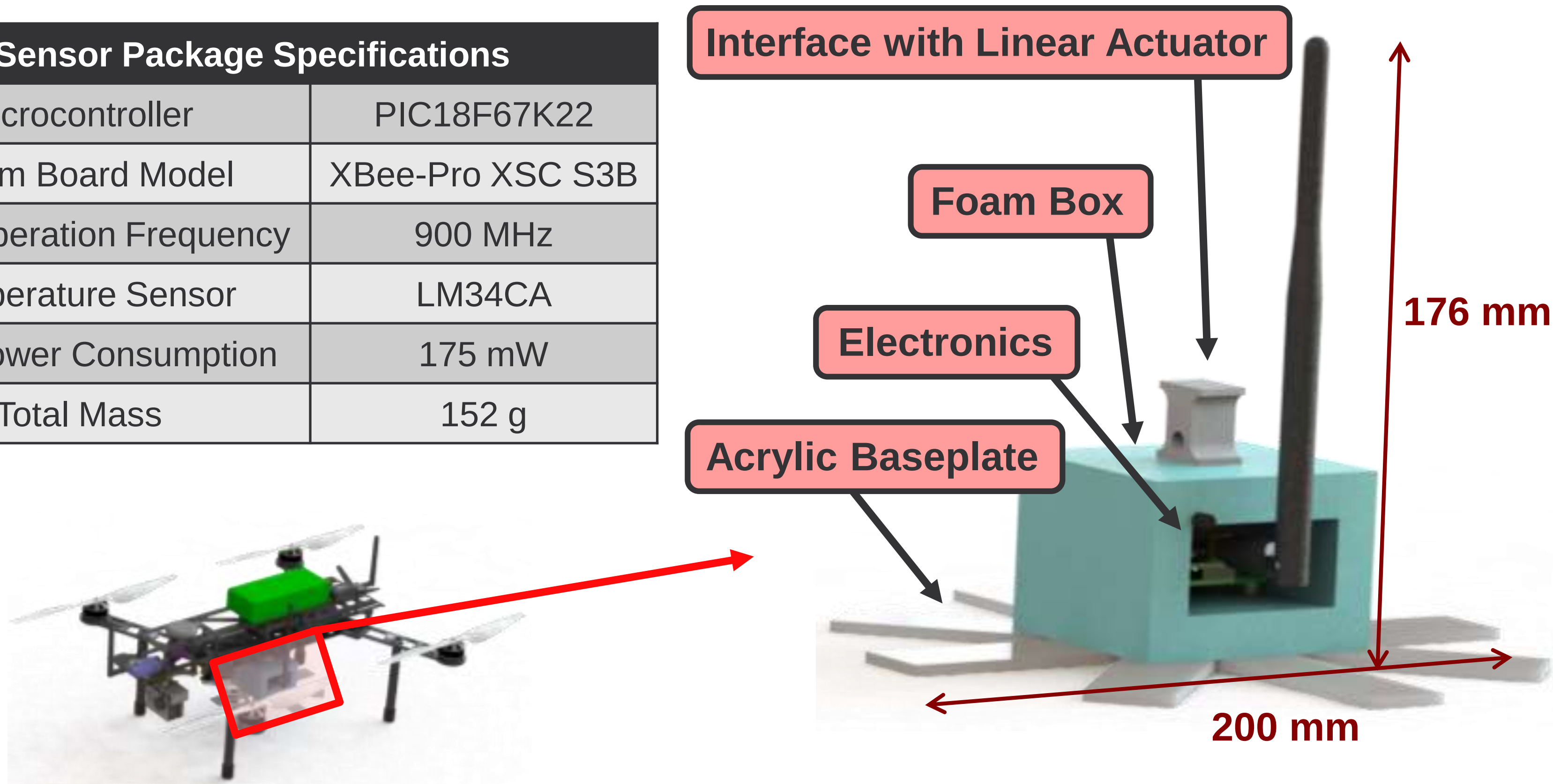



| Deployment System Specifications | |
|---|---|
| Linear Actuator Model | Firgelli PQ12-100-6-S |
| Deployment Time | 4.2 seconds |
| Total Mass | 39 g |
| Voltage Required | 5 V |
| Current Draw | 0.11 A |
| Attachment Material | 3D Printed ABS P430 |
| Attachment Cost | $10 |

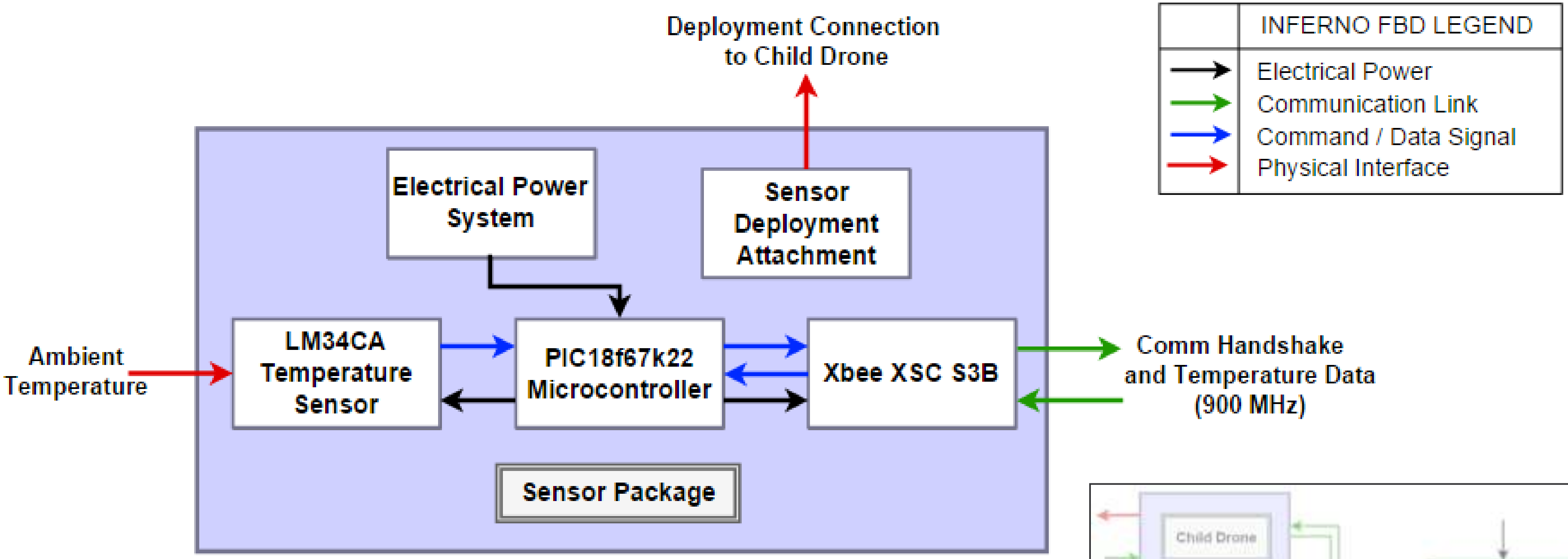


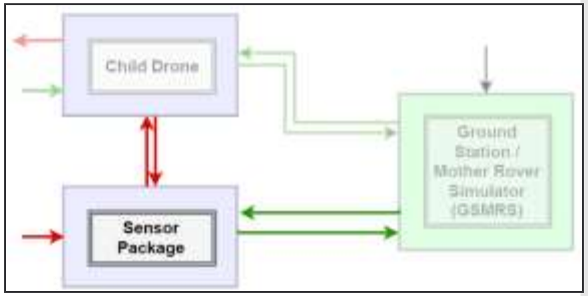
# SENSOR PACKAGE

| Sensor Package Specifications | |
|---|---|
| Microcontroller | PIC18F67K22 |
| Comm Board Model | XBee-Pro XSC S3B |
| XBee Operation Frequency | 900 MHz |
| Temperature Sensor | LM34CA |
| Total Power Consumption | 175 mW |
| Total Mass | 152 g |



# FUNCTIONAL BLOCK DIAGRAM: SENSOR PACKAGE



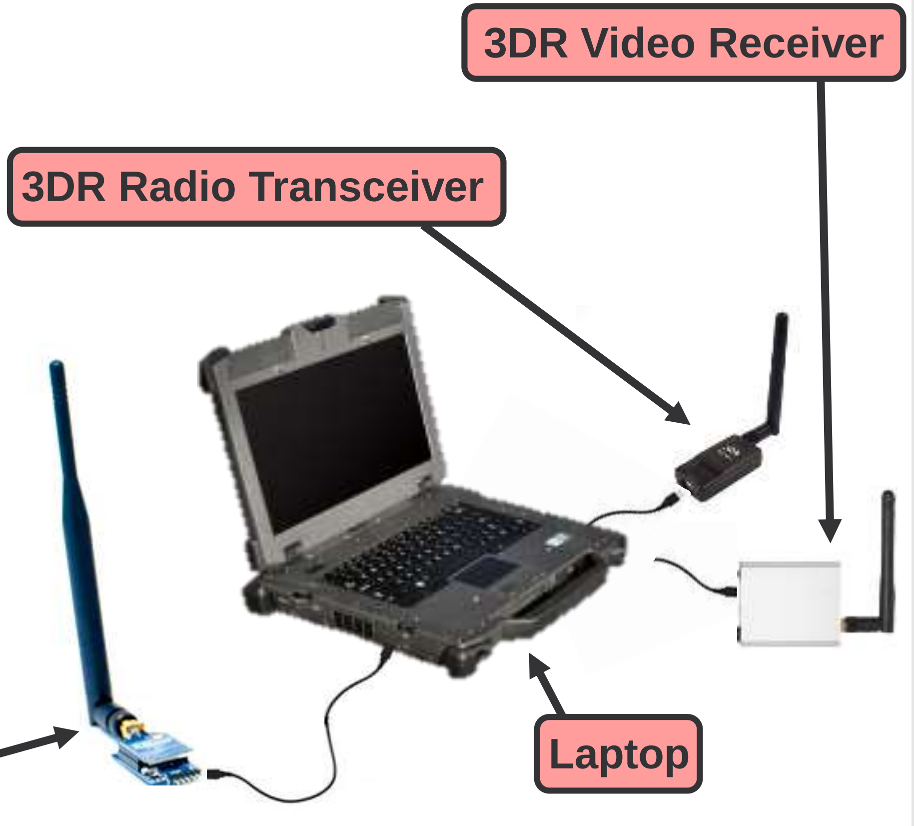

Project Context | Design Solution | Critical Elements | Requirements | V&V Plans | Project Risk | Project Planning

# GROUND STATION MOTHER ROVER SIMULATOR (GSMRS)

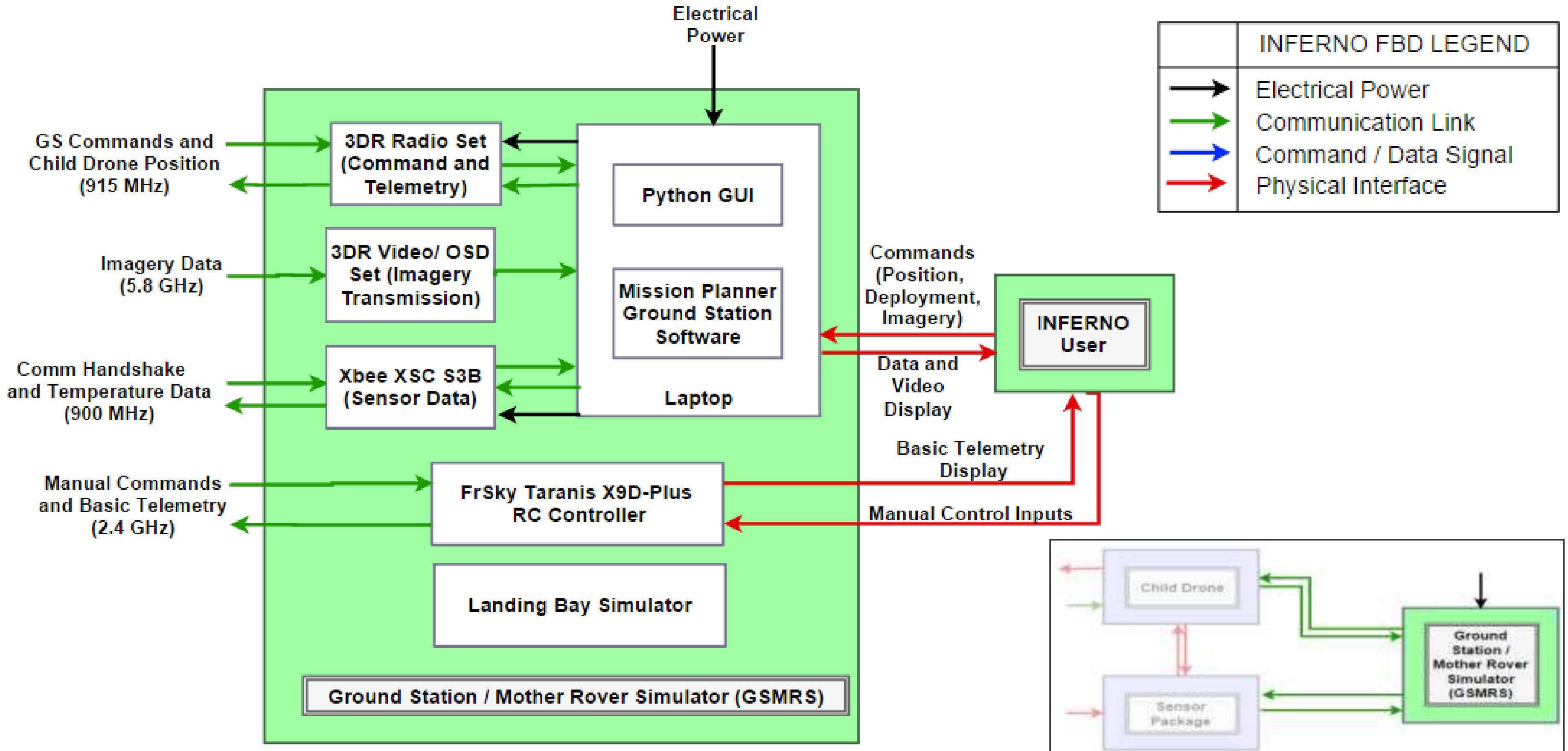
| Xbee Specifications | |
|---|---|
| Model | Pro XSC X3B |
| Frequency | 900 MHz |
| Cost | $42 each |
| Software | Custom Python Gui |

| 3DR Radio Set Specifications | |
|---|---|
| Frequency | 915 MHz |
| Cost | $100 |
| Software | Mission Planner |

| 3DR Video Set Specifications | |
|---|---|
| Frequency | 5.8 GHz |
| Cost | $190 |
| Software | Mission Planner |



# FUNCTIONAL BLOCK DIAGRAM: GSMRS




Project Context | **Design Solution** | Critical Elements | Requirements | V&V Plans | Project Risk | Project Planning

# CRITICAL PROJECT ELEMENTS

# CRITICAL PROJECT ELEMENTS

| Critical Element | Mission Influence |
|---|---|
| Communications | Subsystems must be able to send and receive commands and data to ensure mission success and safety |
| Software Integration | Responsible for command and execution of all systems |
| Subsystem Integration | Full mission success is unachievable without compatible integration |
| Power Limitations | Subsystems must be able to function for mission duration on limited power supplies |
| FAA Certificate of Authorization (COA) | Required for full-scale system integration testing |

Project Context | Design Solution | **Critical Elements** | Requirements | Project Risk | V&V Plans | Project Planning

# DESIGN REQUIREMENTS AND SATISFACTION

# CHILD DRONE

# CHILD DRONE STRUCTURE REQUIREMENTS

| Requirement | Description |
|---|---|
| **DR 1.2.2** | The system shall contain a drone with a minimum airspeed of 10 meters per second. |
| **DR 2.2** | The drone shall have a minimum flight endurance of 15 minutes |
| **FR 6.0** | The system shall have a maximum footprint of 0.545 $m^2$ |
| **DR 6.1** | The drone shall have a maximum footprint of 0.545 $m^2$ with the imaging system and sensor package attached |

# CHILD DRONE - STRUCTURE

| QAV500 V2 Specifications | |
|---|---|
| COTS Kit Assembled by Team | |
| Modification Friendly for Easy Integration | |
| Airframe Mass | 600 g |
| Airframe Dimensions | 456 mm x 519 mm |
| Ground Clearance with Landing Gear | 150 mm |

42 mm

330 mm

| Tiger MN3508 Motors Specifications With 330 mm Propellers | |
|---|---|
| Total Motor/Prop Mass | 400 g |
| Total Thrust ( 70% ) | 3677 g |
| Maximum Thrust ( 100% ) | 5253 g |
| Total Footprint with Props | 740 mm x 736 mm |
| Total Footprint Area with Props | 0.545 $m^2$ |

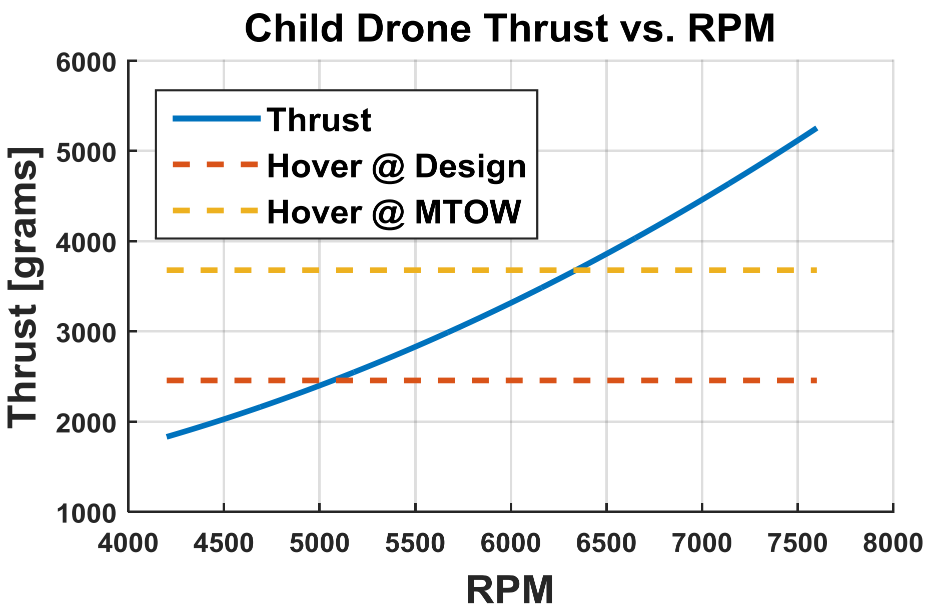
Conclusion:
- FR 6.0 satisfied by Total Footprint Area
- 3677 g Structure-Imposed Max Takeoff Mass

# CHILD DRONE – MASS BUDGET

- CD must carry payload and imaging

| Component | Mass [g] |
|---|---|
| Airframe/Propulsion/Battery | 1927 |
| Flight Electronics | 197 |
| Imaging System | 158 |
| Deployment System | 39 |
| Sensor Package | 134 |

| | |
|---|---|
| **Total Mass** | **2455** |
| **Max Takeoff Weight** | **3677** |
| **Margin vs. MTOW** | **1222** |
| **Margin vs. Max Thrust** | **2798** |




Conclusion:

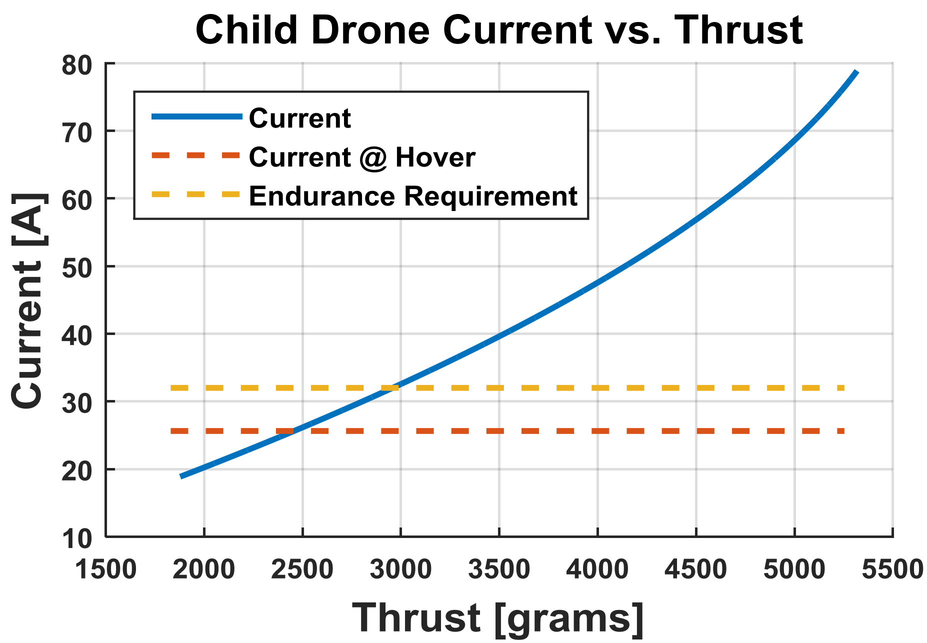
- 33% thrust margin from MTOW
- 50% thrust margin from max thrust
- DRs 1.2, 2.1, and 3.1 satisfied

# CHILD DRONE – POWER BUDGET

- 10,000 mAh, 14.8V, 10C battery
  - 8,000 mAh usable
- 15 minute endurance

| Component | Current [A] | Charge Used [mAh] |
|---|---|---|
| Propulsion @ Hover | 24.8 | 6,190 |
| Pixhawk/Radios | 0.2 | 45 |
| Video Transmitter | 0.7 | 175 |
| Deployment System | 0.1 | ~0 |

| | | |
|---|---|---|
| **Total** | **25.8** | **6,410** |
| **Endurance** | **32.0** | **8,000** |




Conclusion:
- 20% charge margin @ 15 minute hover
- DR 2.2 satisfied

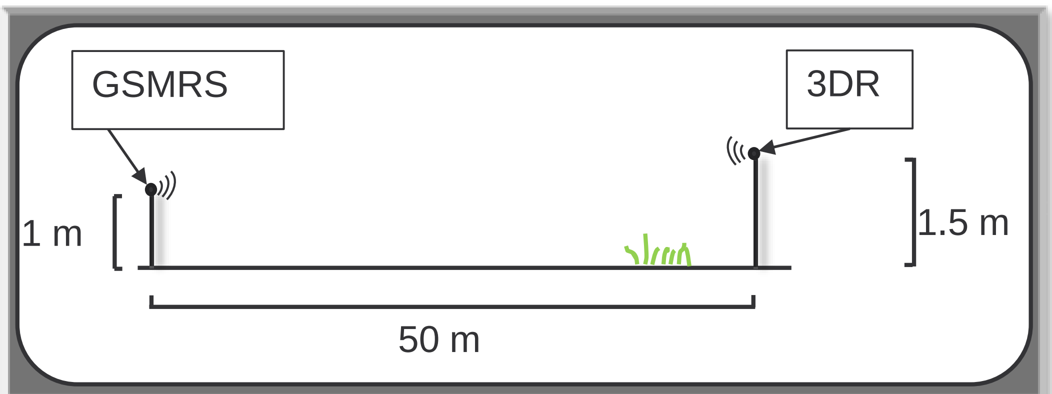
Project Context | Design Solution | Critical Elements | **Requirements** | V&V Plans | Project Risk | Project Planning

# CHILD DRONE COMMUNICATIONS REQUIREMENTS

| Requirement | Description |
|---|---|
| **DR 4.1** | The drone shall possess a communication system capable of receiving commands at a minimum horizontal range of 200 meters. |
| **FR 5.0** | The system shall wirelessly transmit data at a minimum horizontal range of 200 meters. |
| **DR 5.1** | The drone shall possess a communication system capable of transmitting position data at a minimum horizontal range of 200 meters. |
| **DR 5.2** | The drone shall possess a communication system capable of transmitting TBD quality video data at a minimum horizontal range of 200 meters. |
| **DR 5.3** | The sensor package shall possess a communication system capable of transmitting data at a minimum horizontal range of 200 meters. |

# CHILD DRONE - COMMUNICATIONS

| | 3DR Radio Set | 3DR Video Set |
|---|---|---|
| Predicted Link Margin | ~ 50 dB | ~ 35 dB |
| RSSI from Testing | ~ -65 dBm | • Unable to test without video set |
| 3DR Sensitivity | ~ -117 dBm | |
| Actual Margin | ~ -65 dBm – (-117 dBm) = 52 dB | |




<u>Conclusion:</u>

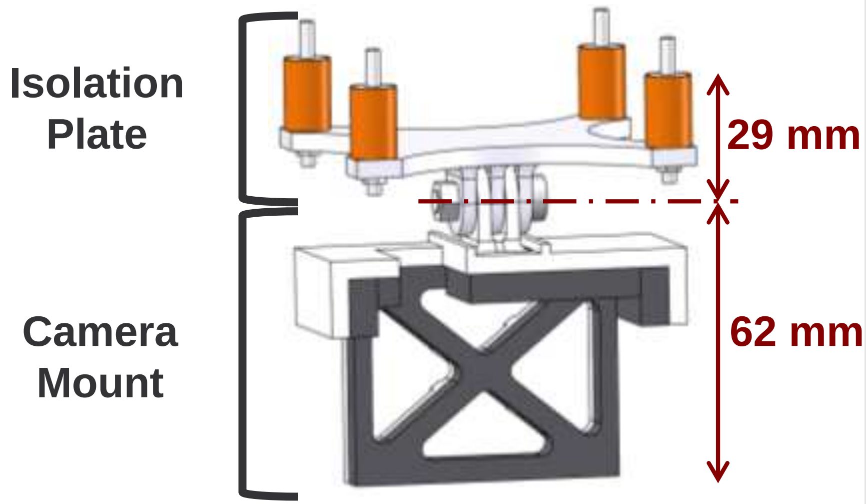
- Testing results matched well with model
- DR 4.1, 5.1, and 5.2 satisfied

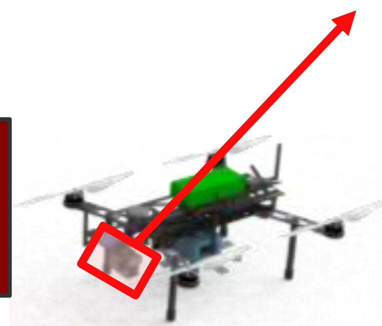
# IMAGING SYSTEM REQUIREMENTS

| Derived Requirement | Description |
|---|---|
| **DR 2.1** | The camera shall collect 1080p aerial video at 30 FPS with TBD quality for 15 minutes. |
| **DR 2.1.1** | The imaging system shall have a minimum FOV of 90˚. |
| **DR 2.1.2** | The imaging system shall have a maximum mass of 200 g. |
| **DR 2.1.3 & 3.1.1** | The imaging system shall have a minimum storage capacity of 1.35 GB. |
| **DR 3.1** | The drone shall carry an imaging system capable of capturing 8MP pictures. |

# IMAGING SYSTEM

| Imaging Specifications | |
|---|---|
| Total Mass (Camera & Mount) | 159 g |
| Video Specs | 1440p @ 48 FPS |
| FOV | 122.6º H & 94.4º V |
| Photo Resolution | 12 MP |
| Battery Life | 1 hr |
| Storage Capacity | 2.25 hr (32 GB) |

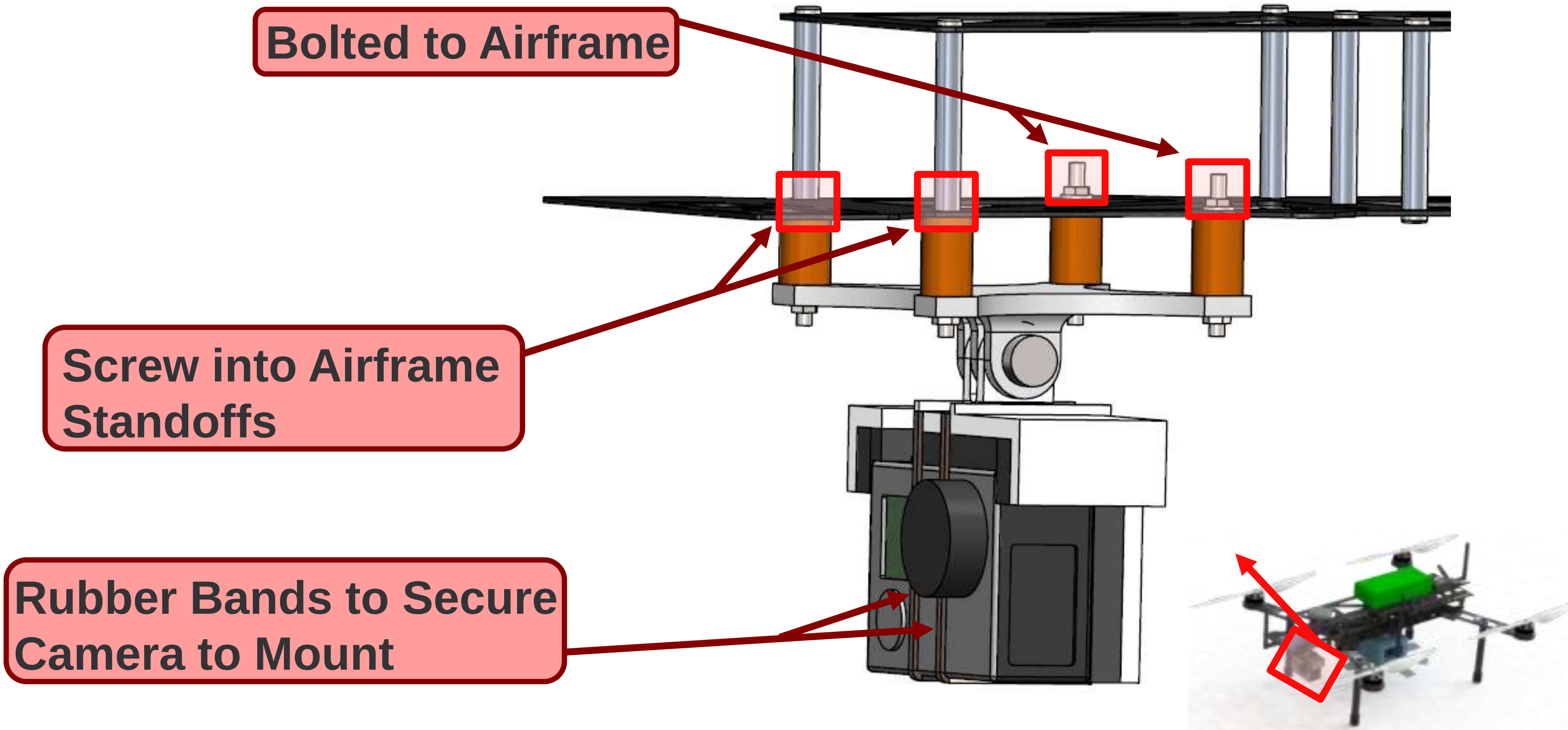



<u>Conclusion:</u>

- Satisfies DR 2.1, 2.1.1, 2.1.2, 2.1.3 & 3.1.1, 3.1

# IMAGING SYSTEM INTEGRATION

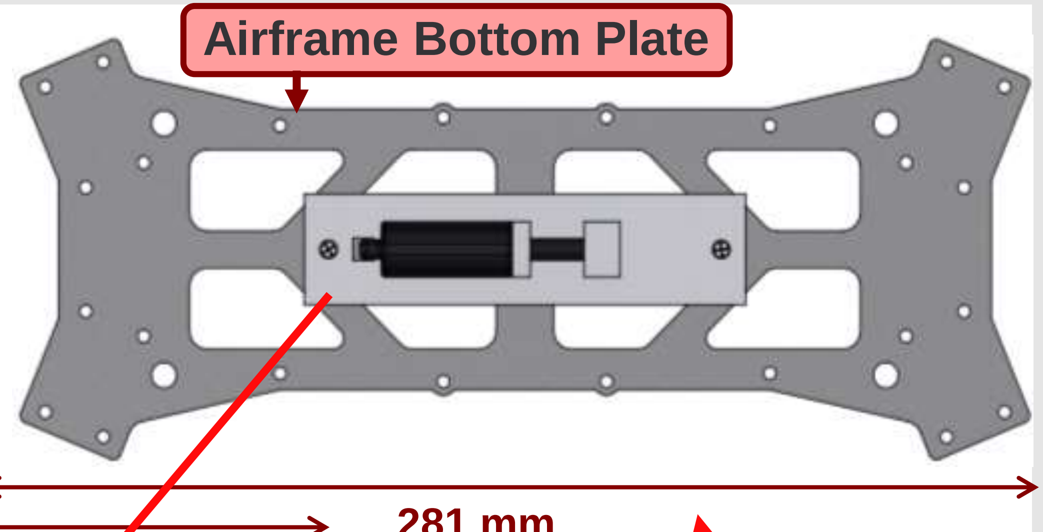


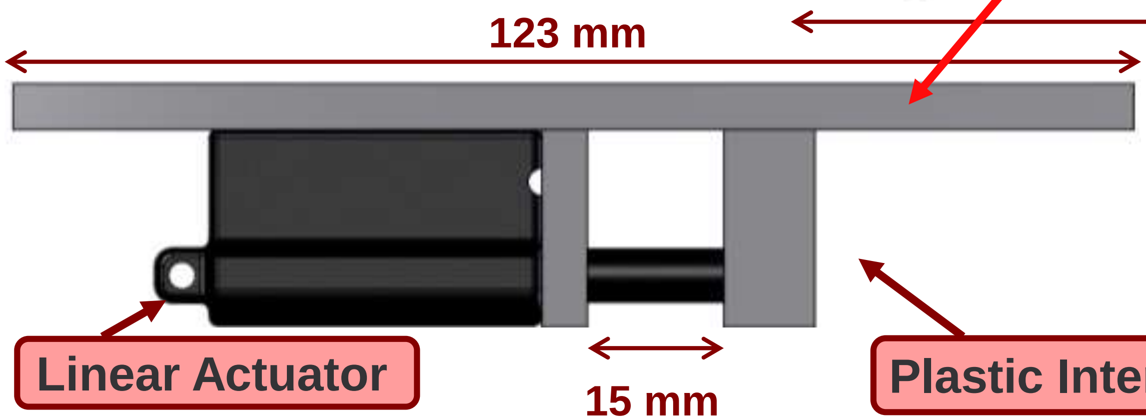
# DEPLOYMENT SYSTEM REQUIREMENTS

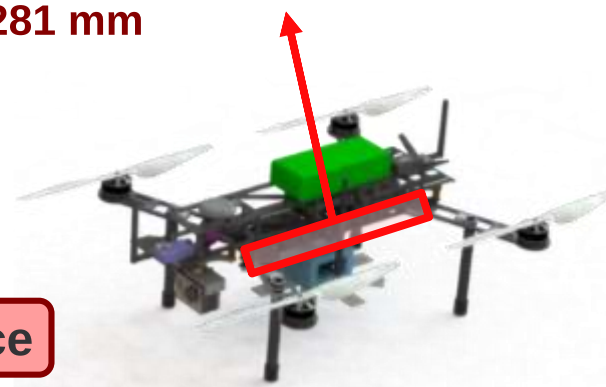
| Derived Requirement | Description |
|---|---|
| **DR 1.2** | The system shall be capable of carrying a disposable sensor package a minimum horizontal range of 200 meters to the LOI. |
| **DR 1.3** | The system shall deploy a disposable sensor package at the LOI maximum error of 5 horizontal meters. |
| **DR 1.3.2** | The drone shall possess a deployment system capable of deploying the sensor package to the LOI with a maximum horizontal error of 5 meters. |

# DEPLOYMENT MECHANISM - STRUCTURE

| Deployment Interface Structural Overview Assuming 1 g Acceleration | |
|---|---|
| **ABS Tensile Strength** | **31 MPa** |
| Maximum Tensile Load | 4 KPa |
| **ABS Flexure Strength** | **35 MPa** |
| Horizontal Flexure Load | 6 KPa |
| Vertical Flexure Load | 10 KPa |

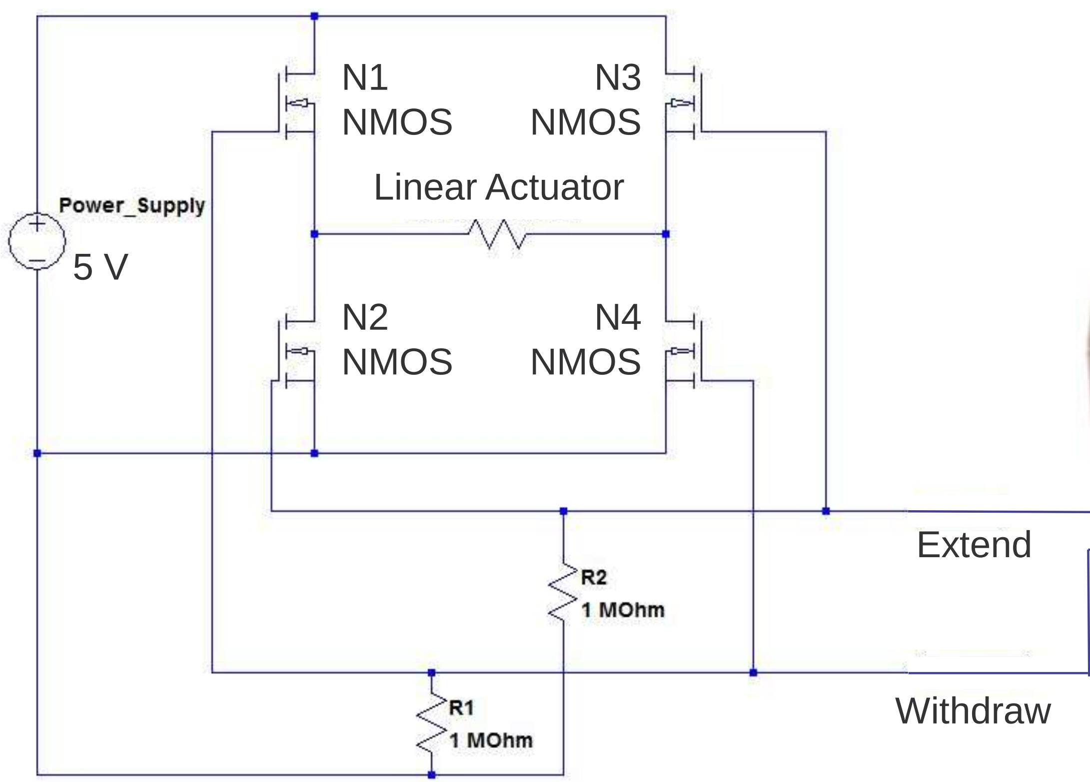


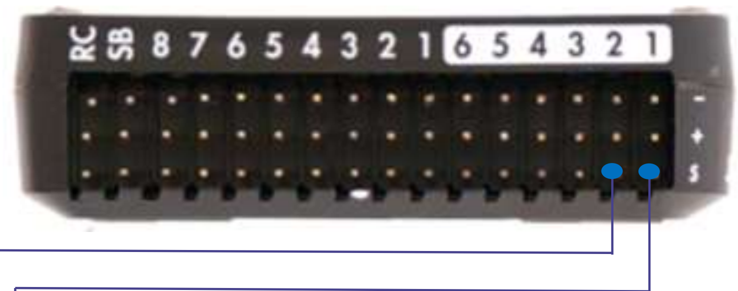



# CHILD DRONE SUBSYSTEM INTEGRATION

# DEPLOYMENT MECHANISM - ELECTRICAL




| Device | Power Draw |
| --- | --- |
| Linear Actuator | 112mA 5V for 4.2 sec |
| MOSFETs | ~1mA 5V for 4.2 sec |




Conclusion:

- Total power draw of 565 mW for 4.2 seconds
- DR 1.3 satisfied

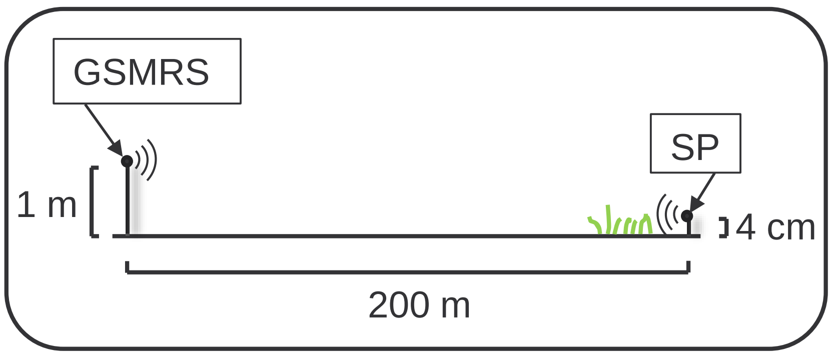
# SENSOR PACKAGE

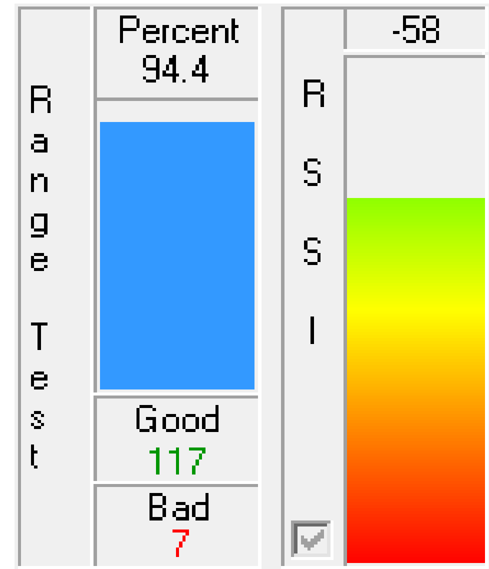
# SENSOR PACKAGE – DESIGN REQUIREMENTS

| Requirement | Description |
|---|---|
| **FR 1.0** | The system shall collect 1 Hz ambient temperature data at ground level for 60 minutes at the LOI. |
| **DR 1.1** | The system shall contain a disposable sensor package capable of collecting 1 Hz ambient temperature data for 60 minutes. |
| **DR 1.1.2** | The sensor package shall be capable of operating continuously for a minimum of 60 minutes. |
| **DR 1.1.3** | The sensor package shall contain a CDH system capable of sampling the temperature sensor at a minimum frequency of 1 Hz. |
| **FR 5.0** | The system shall wirelessly transmit data at a minimum horizontal range of 200 meters. |
| **DR 5.3** | The sensor package shall possess a communication system capable of transmitting data at a minimum horizontal range of 200 meters. |

# VALIDATION OF COMMUNICATIONS

| XBee-Pro XSC S3B | |
|---|---|
| Predicted Link Margin | ~ 50 dB |
| RSSI from Testing | ~ -60 dBm |
| XBee Sensitivity | ~ -110 dBm |
| Actual Margin | ~ -60 dBm – (-110 dBm) = 50 dB |




**Conclusion:**

- Testing results matched well with model
- DR 5.3 satisfied

# SENSOR PACKAGE - ELECTRICAL

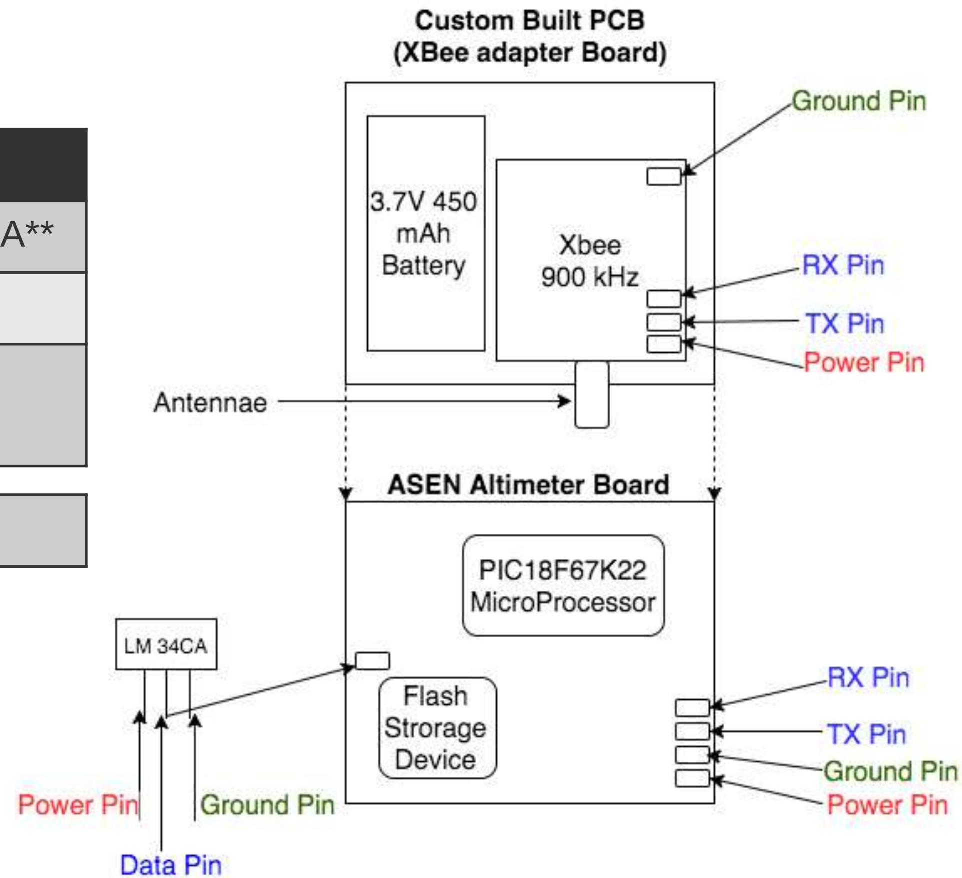
- 3.7 V, 450 mAh battery

| Component | Voltage | Current |
|---|---|---|
| Xbee-Pro | 3.3 V | 265 mA/45µA** |
| ASEN Altimeter Board | 3.7 V | 12 mA |
| LM34CA Temperature Sensor | 5 V | 75 µA |

| Total Power | 278 mW |
|---|---|

** Assuming transmitting 0.25% of the time

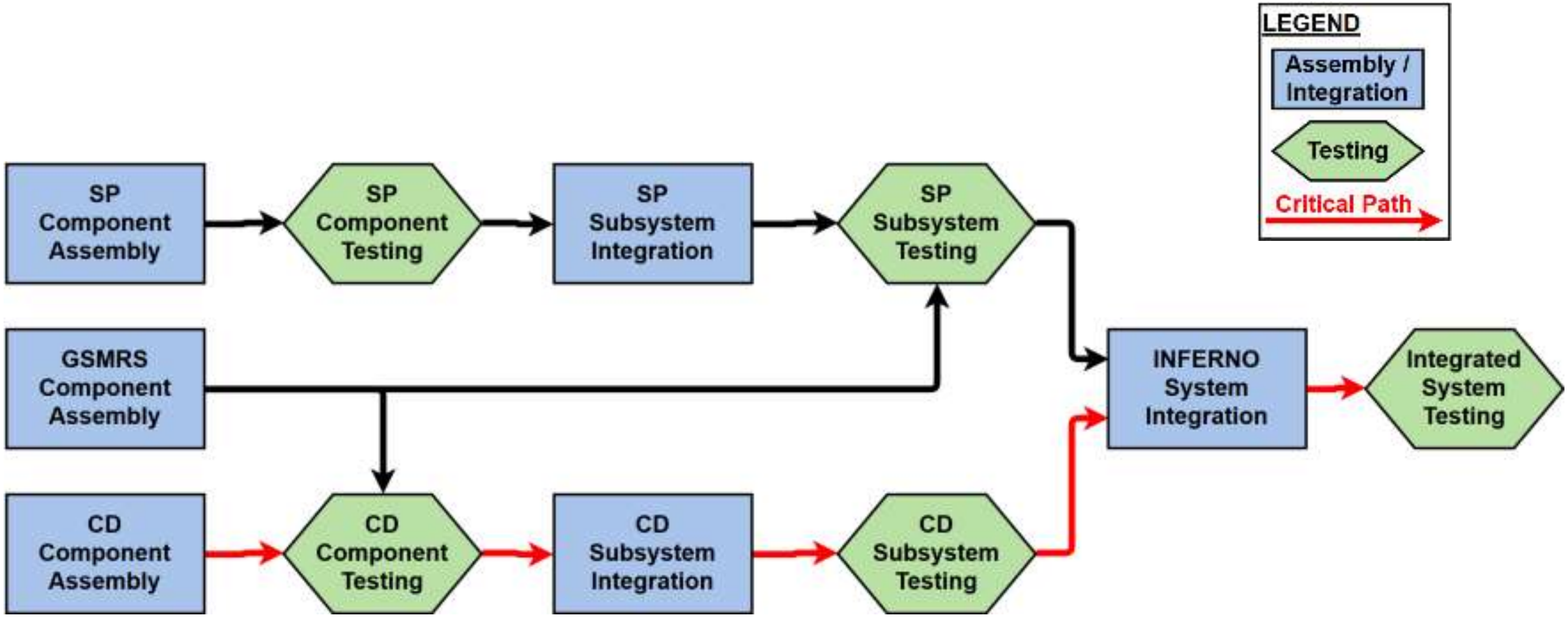
Conclusion:
- Enough power for 6 hours
- DR 1.0 satisfied




Project Context | Design Solution | Critical Elements | **Requirements** | V&V Plans | Project Risk | Project Planning

# VERIFICATION AND VALIDATION

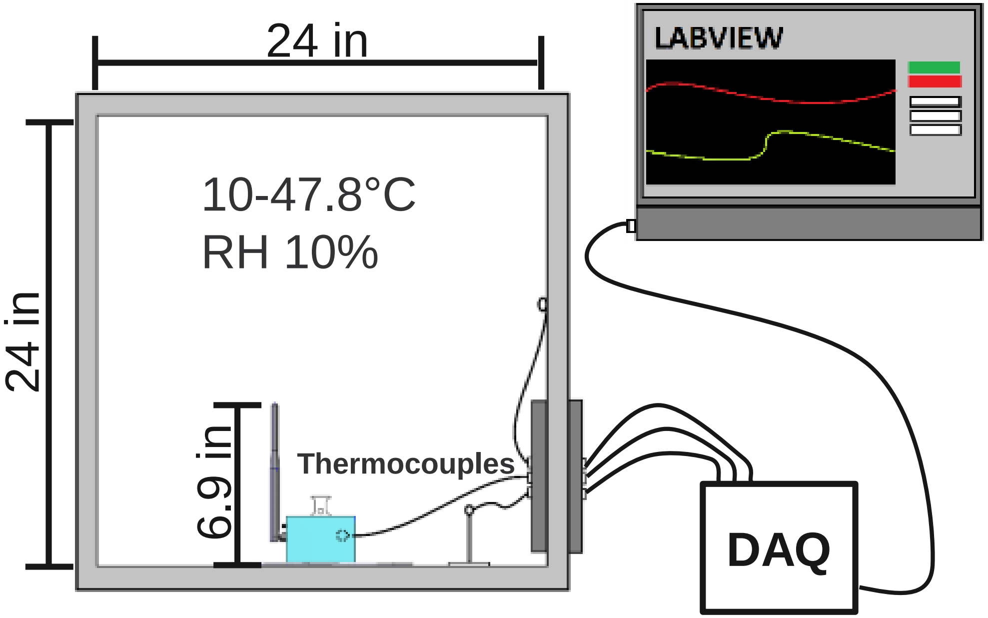
# ASSEMBLY, INTEGRATION & TEST (AI&T) FLOW



# V&V – SENSOR PACKAGE THERMAL TEST

- Executed at Dr. Nabity's climate chamber
- Verify sample rate, accuracy, precision, and storage of temperature sensor/software
  - ***DRs 1.1, 1.1.1***
- Verify SP thermal model
- Requires electrical/structural integration

- Overview:
  - Chamber temperature 10-47.8°C
  - Integrated SP subsystem collects/stores/transmits data for 1 hour
  - Thermocouples measure chamber and sensor temperature
  - Computer records temperature data
  - Key errors include temperature control calibration, and line losses



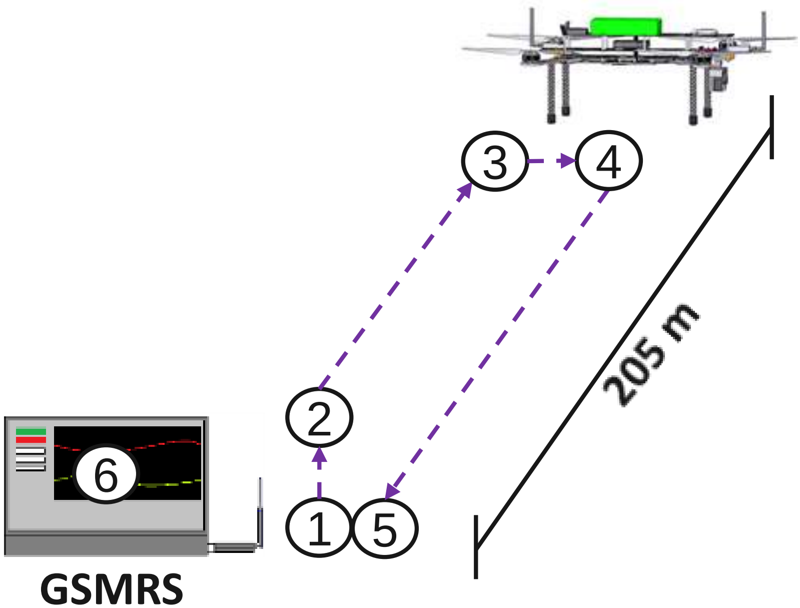

**Conclusions:**
- Testing facilities available
- Can be off-ramped

Project Context | Design Solution | Critical Elements | Requirements | V&V Plans | Project Risk | Project Planning

# V&V – CHILD DRONE FLIGHT TEST

- Executed at Table Mountain
- Verify CD flight/telemetry/command communications range
  - ***DRs 4.1, 5.1***
- Verify CD command/telemetry link budget model
- Assess and refine flight dynamics prior to addition of payload/imaging

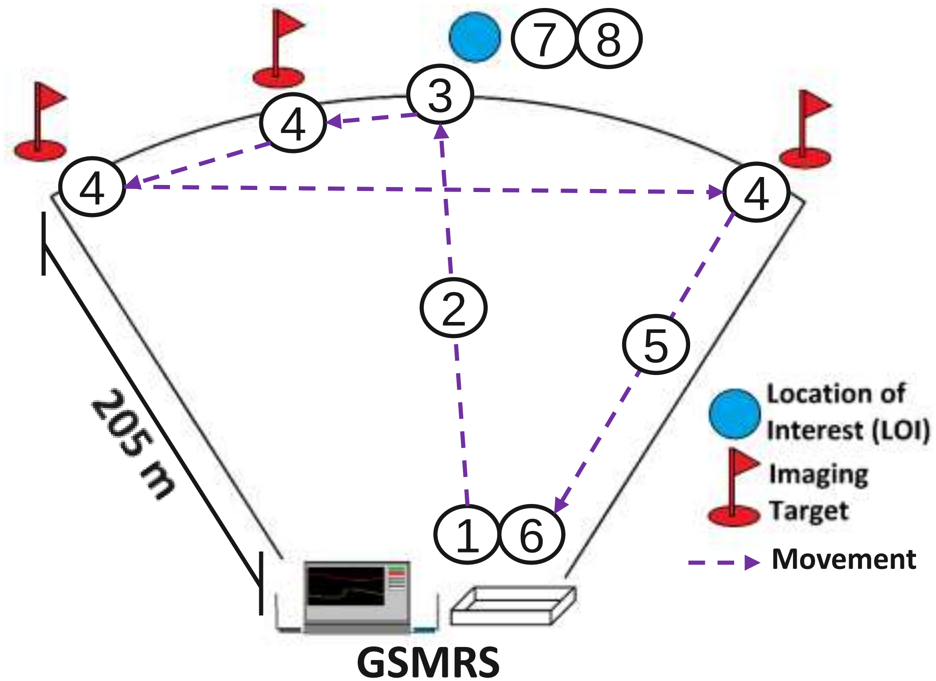
- Overview:
  1. CD commanded to takeoff
  2. Pilot flies maneuvers w/ manual control
  3. CD commanded to fly to GPS waypoint >205m from GSMRS
  4. Pilot flies maneuvers w/ manual control
  5. CD commanded to return to GSMRS and land
  6. RSSI and position assessed by telemetry logs (10 Hz sample rate)




Conclusions:
- Assess CD flightworthiness
- Verifies CD command/telemetry range

# V&V – SYSTEM VALIDATION TEST

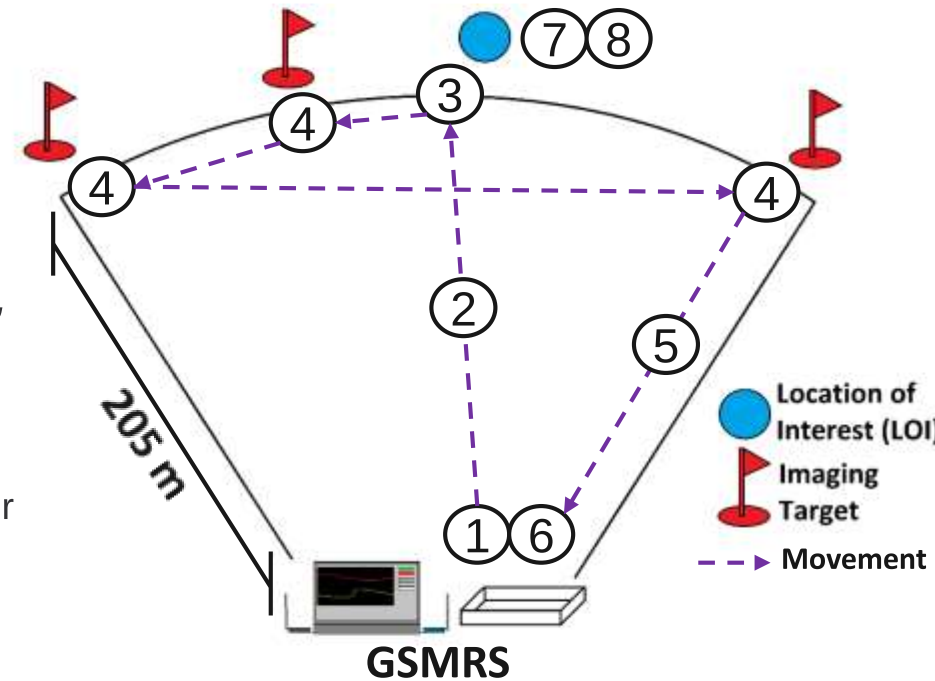
- Executed at Table Mountain
- Location of Interest (LOI) and Imaging Targets
  - All >205m from GSMRS
  - Placed along a single 90° arc
- Integrated CD/SP system is validated against system functions through baseline mission profile




Project Context | Design Solution | Critical Elements | Requirements | **V&V Plans** | Project Risk | Project Planning

# V&V – SYSTEM VALIDATION TEST

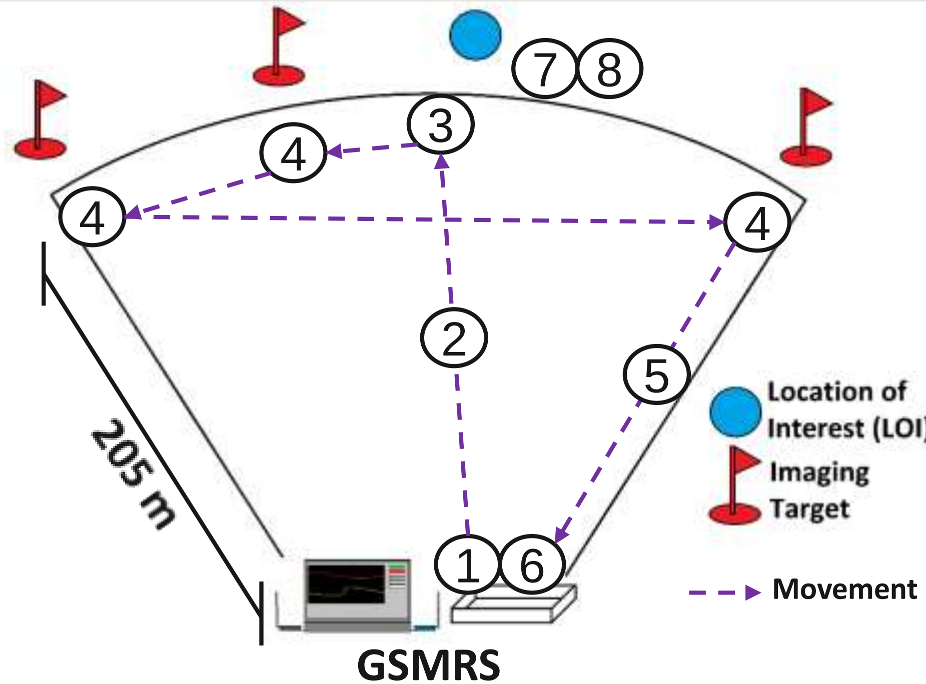
- Procedure Outline:
  1. T+0:00 Takeoff from GSMRS ***(FR 6.0)***
  2. T+0:30 Flight to LOI
  3. T+1:00 Deployment of SP ***(FR 1.0)***
  4. T+2:00 Visual Reconnaissance ***(FRs 2.0, 3.0)***
  5. T+12:00 Return to GSMRS
  6. T+15:00 Land on GSMRS ***(FRs 2.0, 6.0)***
  7. T+15:00 Verify GSMRS Receiving Sensor Data ***(FR 1.0)***
  8. T+75:00 Verify GSMRS Still Receiving Sensor Data ***(FR 1.0)***
- Data post-processed to ensure within acceptable limits




Project Context | Design Solution | Critical Elements | Requirements | V&V Plans | Project Risk | Project Planning

# V&V – SYSTEM VALIDATION TEST

- All targets >205 m from GSMRS
  - Positions measured by GPS and marked
  - Sample for 1 hr @ 1 Hz
  - Evaluate means, standard deviations
- 90° arc evaluated by compass
  - ±1° error
- SP must land within 5 m of LOI
  - Evaluated by tape measure
- Times measured by stopwatch
  - Initiated upon takeoff command
  - Human-error dependent
- Video must be recorded for entire mission profile
- Photos and video must capture all 8 numbered signs of each Imaging Target




Conclusions:
- Verifies and validates system
- Test site available
- Procedure in progress

# V&V – OFF-RAMPS

| Problem | Requirements Off-Ramped | Solution |
|---|---|---|
| SP Software Integration | ***DRs 1.1.1, 1.1.2, 1.1.2.1, 1.1.2.2, 1.1.3, 5.3*** | Individual testing of SP comm, microcontroller, temperature sensor, power system. |
| GSMRS Data Interpretation Software | ***DR 5.3*** | SP comm assessed by RSSI testing. |
| GSMRS Mission Planner Software Integration | ***DRs 1.3, 1.3.1, 1.3.2, 5.1, 5.2*** | Test MAVProxy, APM Planner, and/or DroneKit. Utilize manual control and alternate video receiver. |
| Unstable CD Flight Control | ***DRs 1.2.1, 1.2.2, 1.3.2, 2.1, 3.1, 4.1, 5.1, 5.2*** | Static testing of CD comms, deployment, and power. CFD analysis to verify airspeed. |
| CD Imagery Integration | ***DRs 1.2, 1.2.1, 1.2.2, 1.3, 1.3.1, 1.3.2, 2.1, 2.1.1, 2.1.2, 2.1.3, 2.2, 3.1, 3.1.1, 5.2, 6.1*** | Static testing of image quality/transmission. Verify CD performance with mass simulator. Verify CD footprint with CAD analysis. |
| CD Payload Integration | ***DRs 1.2, 1.2.1, 1.2.2, 1.3, 1.3.1, 1.3.2, 2.2, 6.1*** | Static testing of deployment system. Verify CD performance with mass simulator. Verify CD footprint with CAD analysis. |

# V&V – OFF-RAMPS

| Problem | Requirements Off-Ramped | Solution |
| --- | --- | --- |
| Environmental Chamber | ***DR 1.1.1*** | Test SP precision/accuracy/sample rate under ambient indoor/outdoor conditions only. |
| Video Vibration and/or Latency | ***FR 2.0***<br>***DRs 5.2*** | Test alternative vibration isolation materials. Utilize CCD camera for video transmission. |
| Outdoor Flight | ***FRs 1.0, 2.0, 3.0, 4.0, 5.0***<br>***DRs 1.2, 1.2.1, 1.2.2, 1.3, 1.3.1, 1.3.2, 2.1, 2.2, 3.1, 4.1, 5.1, 5.2*** | Tethered flight testing of CD position-hold, imaging, and deployment. Endurance verified by hovering flight. |

Conclusions:

- Off-ramps available for high-risk contingency scenarios
- Flexible test flow allows maximum in parallel with the critical path

# PROJECT RISKS

# ORIGINAL RISK MATRIX

| Risk Management Matrix | | | | Acceptable | Tolerable | Intolerable |
|---|---|---|---|---|---|---|
| RISK | Severe | | | (3) | | |
| | Significant | | (4) | | (2)(5)(6) | (1) |
| | Moderate | | | | | |
| | Minor | | | | | |
| | Negligible | | | | | |
| | | Very Unlikely | Unlikely | Possible | Likely | Very Likely |
| | | Likelihood | | | | |

| Legend | | |
|---|---|---|
| (1) Software development delay | (2) Crashing Child Drone | (3) Failure to obtain COA |
| (4) Camera Mount Structural Failure | (5) Improper Sensor Package Orientation | (6) Airframe Integration Issues |

# RISK MITIGATION

| Mitigation | | |
|---|---|---|
| (1) Software version control and internal code reviews. Large schedule uncertainty allocated. | (2) Using experienced pilots for flying. Having spare parts on hand. | (3) Early Application. Working with RECUV. |
| (4) Manufacture multiple versions. Proper testing. | (5) Design sensor package structure for stability. Land child drone to deploy sensor package. | (6) Clear design with RECUV before purchase. Work with faculty during the assembly process. |

| Legend | | |
|---|---|---|
| (1) Software development delay | (2) Crashing Child Drone | (3) Failure to obtain COA |
| (4) Camera Mount Structural Failure | (5) Improper Sensor Package Orientation | (6) Airframe Integration Issues |

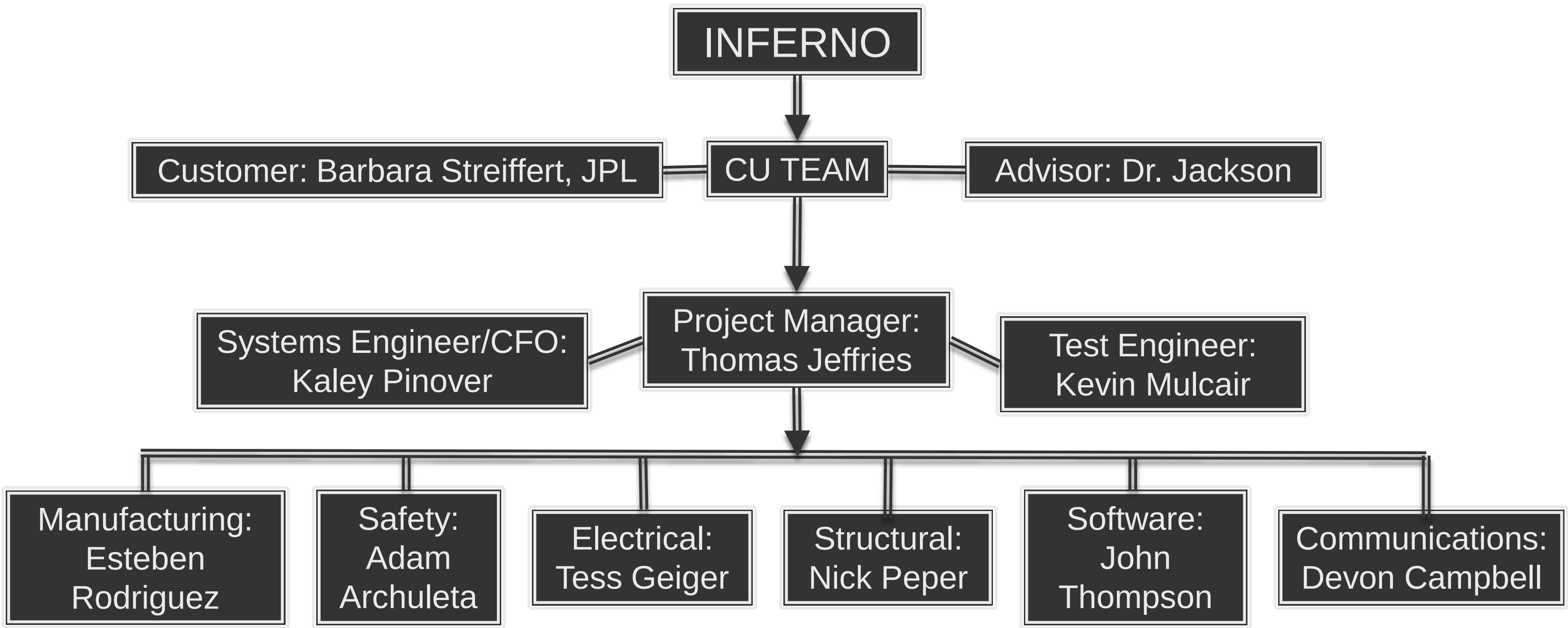
# UPDATED RISK MATRIX

| Risk Management Matrix | | | | Acceptable | Tolerable | Intolerable |
|---|---|---|---|---|---|---|
| RISK | Severe | (3) | | | | |
| | Significant | | (5) | (1) (6) | | |
| | Moderate | (4) | | (2) | | |
| | Minor | | | | | |
| | Negligible | | | | | |
| | | Very Unlikely | Unlikely | Possible | Likely | Very Likely |
| | | Likelihood | | | | |

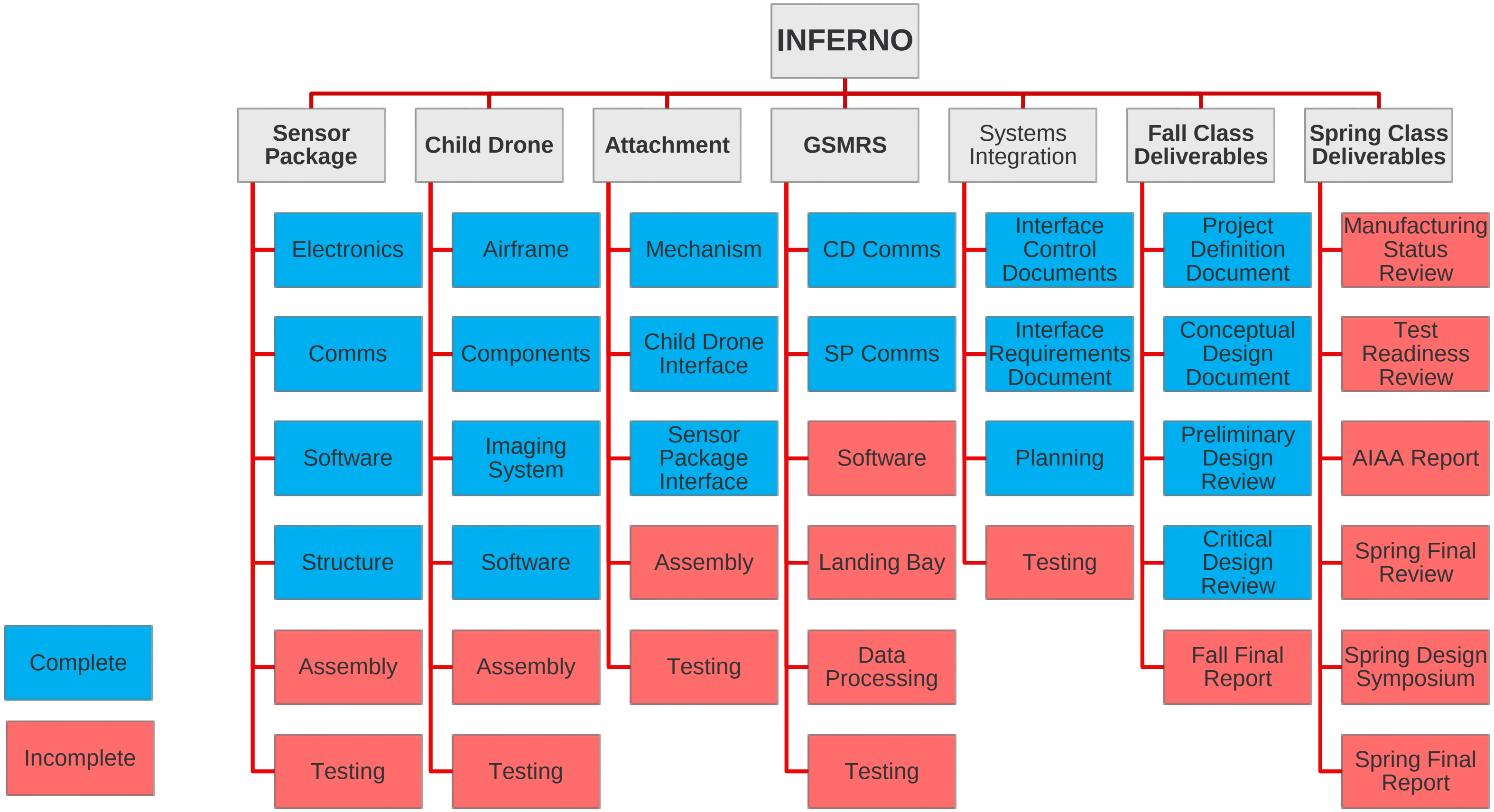
| Legend | | |
|---|---|---|
| (1) Software development delay | (2) Crashing Child Drone | (3) Failure to obtain COA |
| (4) Camera Mount Structural Failure | (5) Improper Sensor Package Orientation | (6) Airframe Integration Issues |

# PROJECT PLANNING

# ORGANIZATIONAL CHART

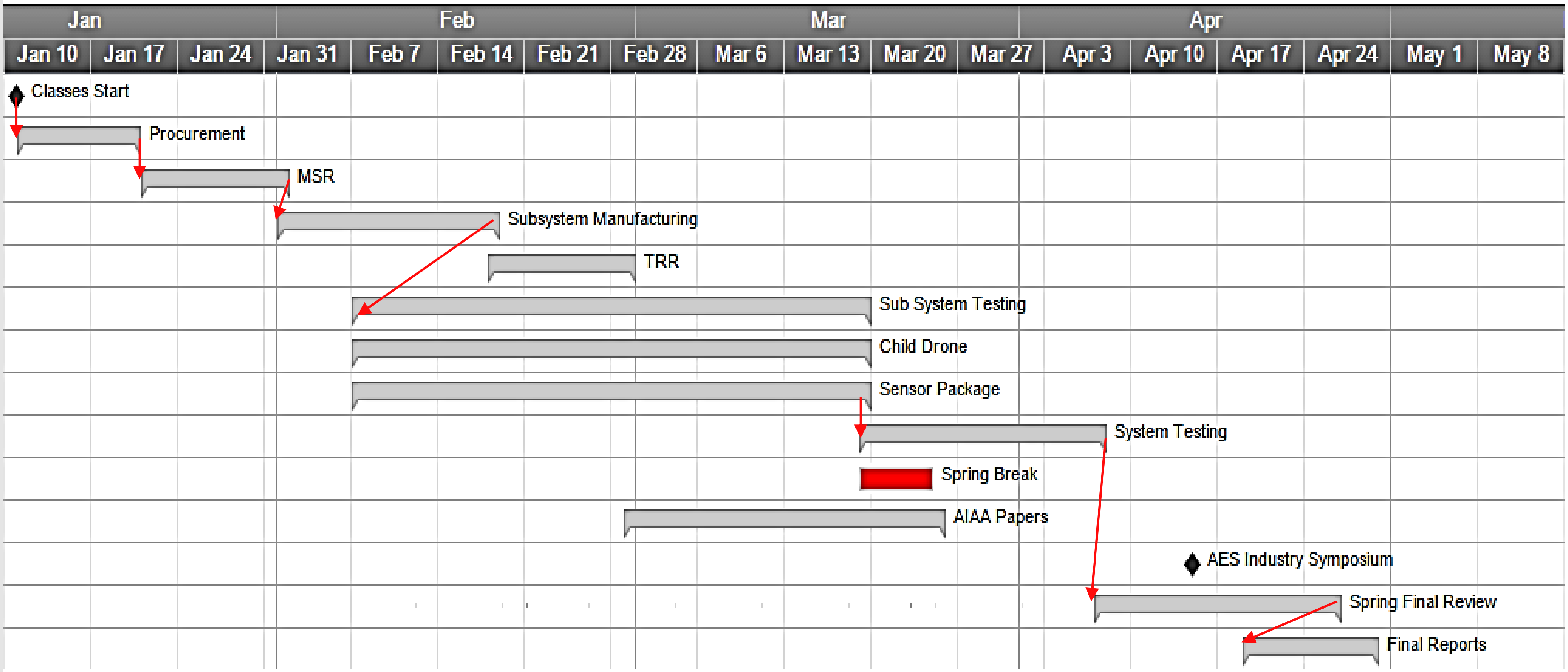


# WORK BREAKDOWN STRUCTURE



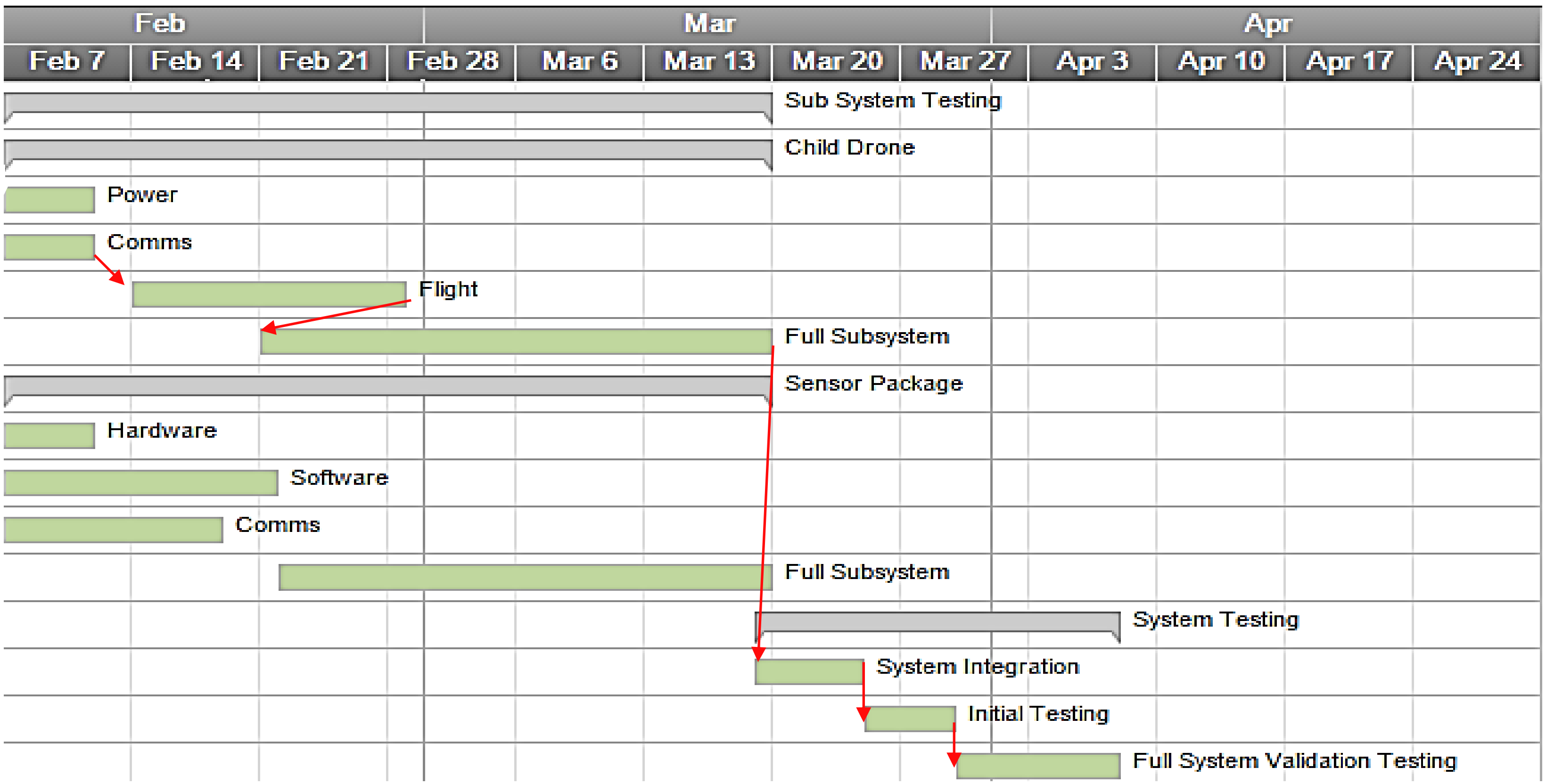

Project Context | Design Solution | Critical Elements | Requirements | V&V Plans | Project Risk | **Project Planning**

# WORK PLAN



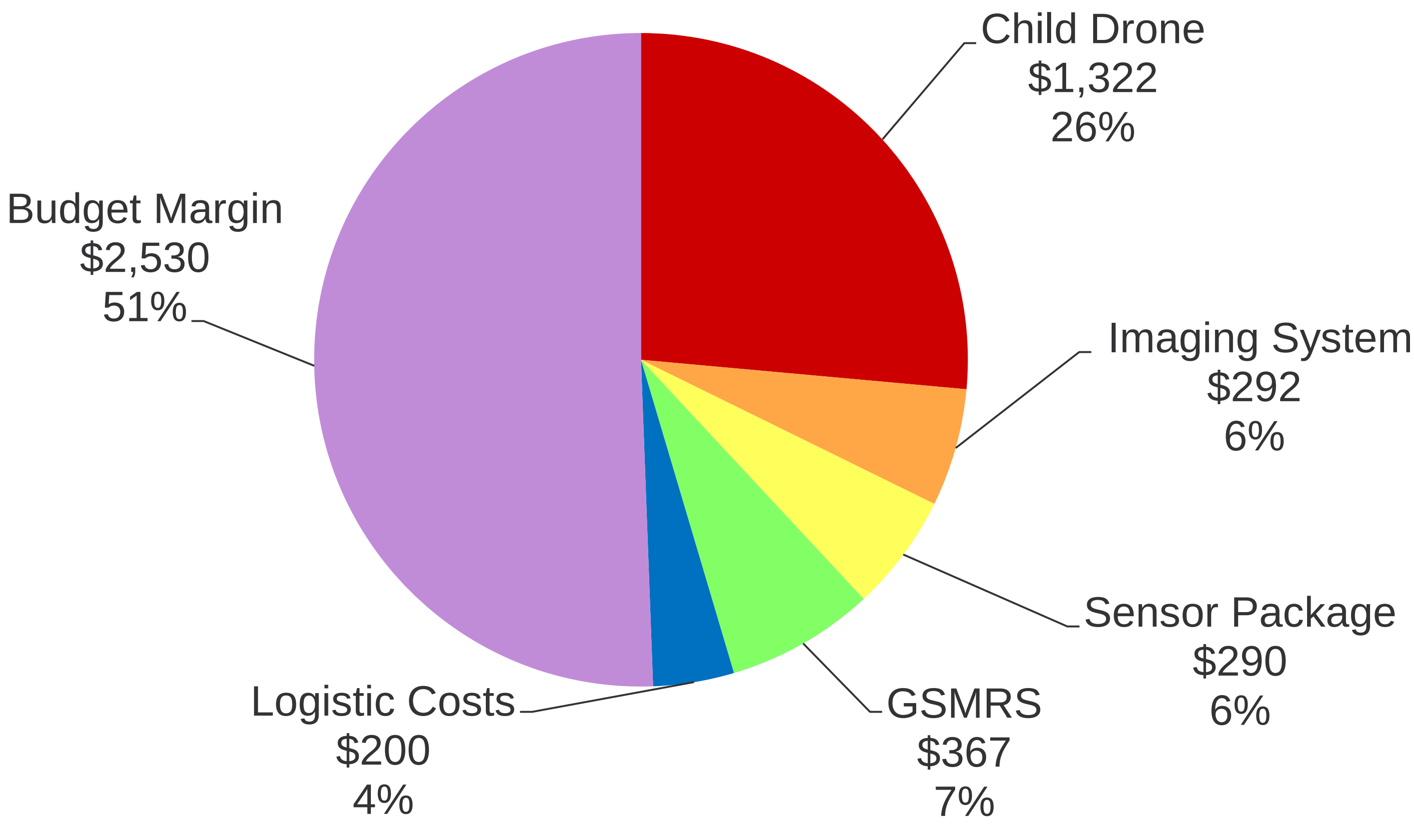

Project Context | Design Solution | Critical Elements | Requirements | V&V Plans | Project Risk | **Project Planning**

# TEST PLAN




Project Context | Design Solution | Critical Elements | Requirements | V&V Plans | Project Risk | **Project Planning**

# COST PLAN


Child Drone
$1,322
26%
Imaging System
$292
6%
Sensor Package
$290
6%
GSMRS
$367
7%
Logistic Costs
$200
4%
Budget Margin
$2,530
51%

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[] “Tech Stuff-Wireless-Fresnel Zones and their Effects” URL:http://www.zytrax.com/tech/wireless/fresnel.htm [cited 11 October 2015].

[] “XBee Buying Guide” URL: https://www.sparkfun.com/pages/xbee_guide[cited 11 October 2015]


[17] Blake, L. V. "Antenna And Receiving-System Noise-Temperature Calculation.” URL: http://www.dtic.mil/dtic/tr/fulltext/u2/265414.pdf [cited 11 October 2015].

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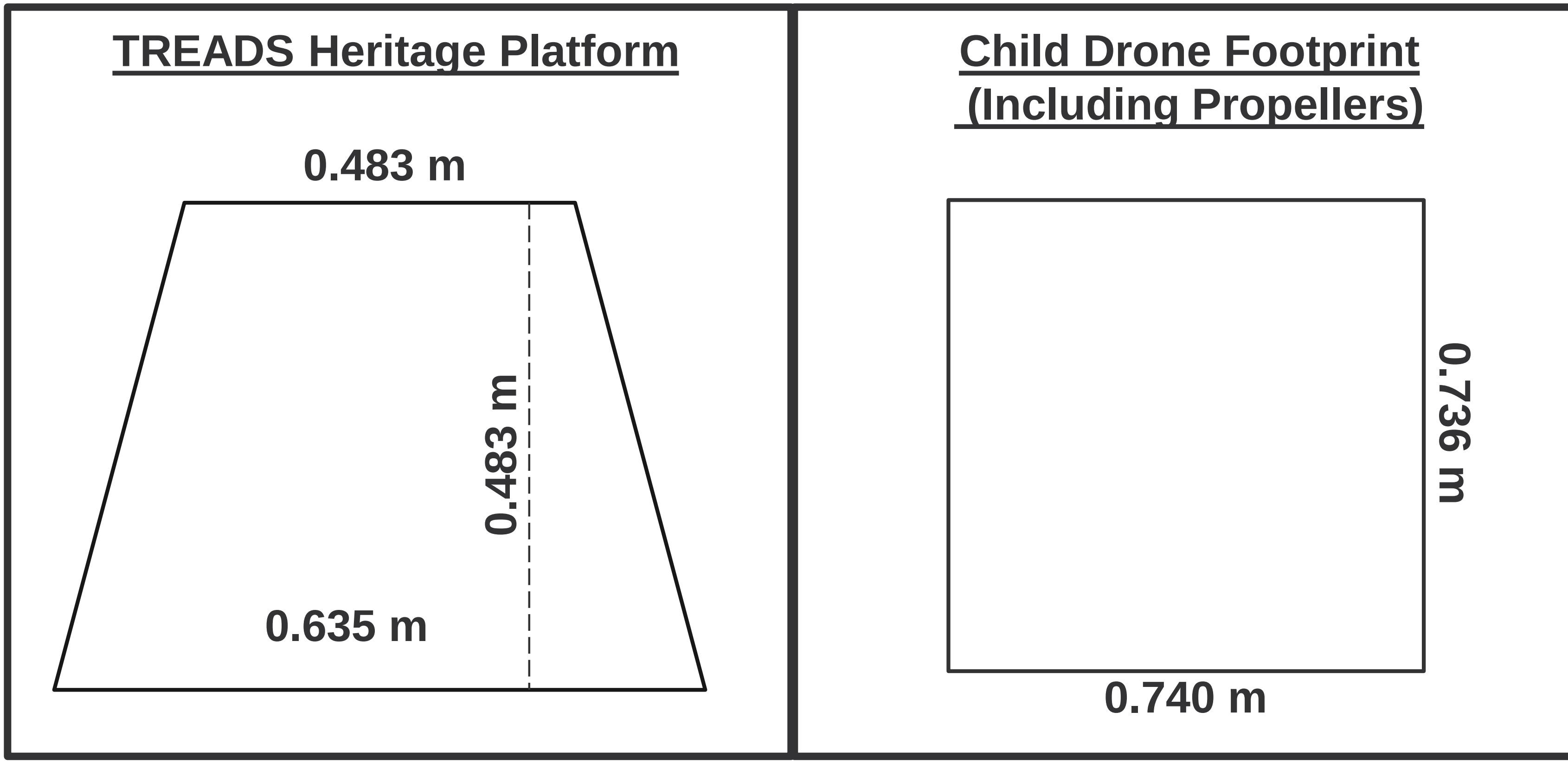
[] “XBee Buying Guide” URL: https://www.sparkfun.com/pages/xbee_guide[cited 11 October 2015]

# Questions?

# INFERNO BACKUP SLIDES

# FOOTPRINT DETERMINATION



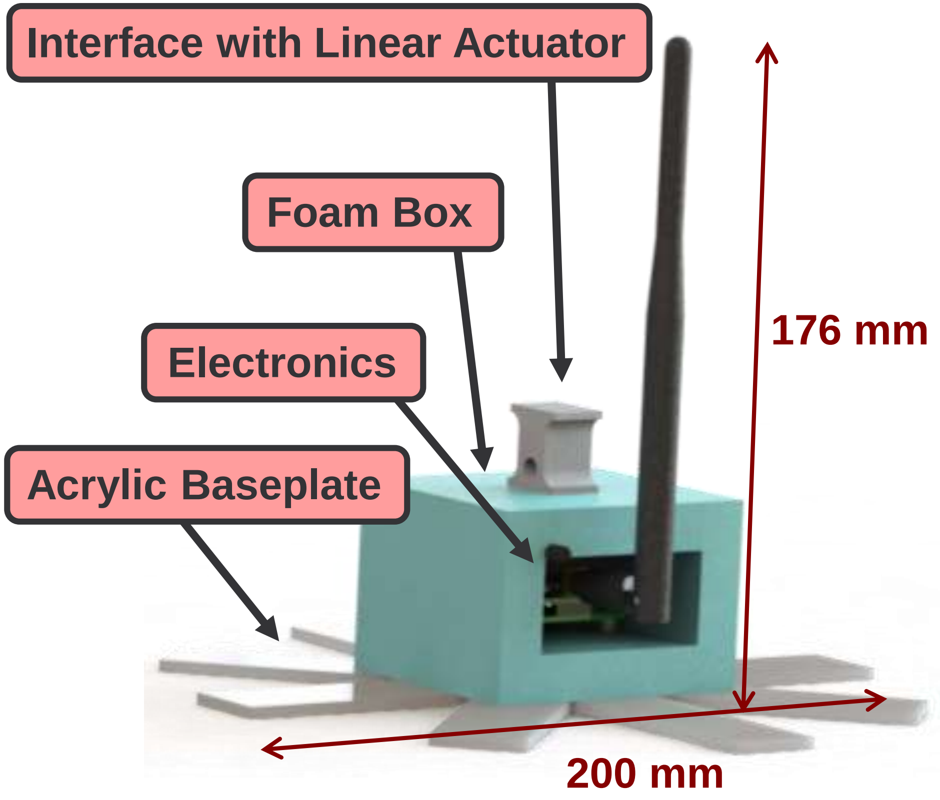

**Suggested by RECUV: 50% area margin for landing**

**$(0.736 \times 0.74) * 1.5^2 = 1.104 \times 1.110$ m = $1.225\ m^2$**

# SENSOR PACKAGE – STRUCTURE

| Component | Mass [g] |
|---|---|
| Foam | 10 |
| 3D Printed Attachment | 15 |
| Acrylic Base | 63 |
| Electronics | 44 |
| Antenna | 20 |
| **Total** | **152** |

| Sensor Package | |
|---|---|
| Package Height | 75.1 mm |
| Height w/ Antenna | 164.9 mm |
| **Ground Clearance** | **74.76 mm** |
| Footprint Radius | 97.2 mm |



# CHILD DRONE - SOFTWARE

- Pixhawk Capabilities
  - GPS
  - Telemetry transmission
  - Video transmission
  - Motors
  - PWM signal
- Development Needs
  - Gain Tuning for our specific aircraft
  - Shut down 3DR radio set to avoid interference with Xbee’s

# DERIVED REQUIREMENTS

| | | |
|---|---|---|
| **FR 1.0** | | **The system shall collect 1 Hz ambient temperature data at ground level for 60 minutes at the LOI.** |
| DR 1.1 | | The system shall contain a disposable sensor package capable of collecting 1 Hz ambient temperature data for 60 minutes. |
| | DR 1.1.1 | The sensor package shall contain a sensor capable of measuring temperature between 10˚C and 47.8˚C with a minimum accuracy of ±2.78˚C. |
| | DR 1.1.2 | The sensor package shall be capable of operating continuously for a minimum of 60 minutes. |
| | DR 1.1.2.1 | The sensor package shall contain a power system capable of sustaining operations for 60 minutes. |
| | DR 1.1.2.2 | The sensor package shall have a minimum storage capacity of 10.8 kilobytes. |
| | DR 1.1.3 | The sensor package shall contain a CDH system capable sampling the temperature sensor at a minimum frequency of 1 Hz. |
| DR 1.2 | | The system shall be capable of carrying a disposable sensor package a minimum horizontal range of 200 meters to the LOI. |
| | DR 1.2.1 | The system shall contain a drone with a minimum horizontal range of 200 meters. |
| | DR 1.2.2 | The system shall contain a drone with a minimum airspeed of 10 meters per second. |
| DR 1.3 | | The system shall deploy a disposable sensor package at the LOI with a maximum error of 5 horizontal meters. |
| | DR 1.3.1 | The drone shall be capable of holding translational position at the LOI with a maximum horizontal error of 5 meters. |
| | DR 1.3.2 | The drone shall possess a deployment system capable of deploying the sensor package to the LOI with a maximum horizontal error of 5 meters. |

# DERIVED REQUIREMENTS

| | | | |
|---|---|---|---|
| **FR 2.0** | **The drone shall carry an imaging system capable of capturing 1080P video at 30 fps with TBD quality for 15 minutes.** | | |
| | DR 2.1 | The drone shall carry an imaging system capable of capturing 1080P video at 30 fps with TBD quality for 15 minutes. | |
| | | DR 2.1.1 | The imaging system shall have a minimum FOV of 90˚. |
| | | DR 2.1.2 | The imaging system shall have a maximum mass of 200 g. |
| | | DR 2.1.3 | The imaging system shall have a minimum storage capacity of 1.35 GB. |
| | DR 2.2 | The drone shall have a minimum flight endurance of 15 minutes. | |

| | | | |
|---|---|---|---|
| **FR 3.0** | **The system shall collect 8MP aerial pictures.** | | |
| | DR 3.1 | The drone shall carry an imaging system capable of capturing 8MP pictures. | |
| | | DR 3.1.1 | The imaging system shall have a minimum storage capacity of 1.35 GB. |

# DERIVED REQUIREMENTS

| | | |
|---|---|---|
| **FR 4.0** | **The system shall wirelessly receive commands at a minimum horizontal range of 200 meters.** | |
| | DR 4.1 | The drone shall possess a communication system capable of receiving commands at a minimum horizontal range of 200 meters. |

| | | |
|---|---|---|
| **FR 5.0** | **The system shall wirelessly transmit data at a minimum horizontal range of 200 meters.** | |
| | DR 5.1 | The drone shall possess a communication system capable of transmitting position data at a minimum horizontal range of 200 meters. |
| | DR 5.2 | The drone shall possess a communication system capable of transmitting **TBD** quality video data at a minimum horizontal range of 200 meters. |
| | DR 5.3 | The sensor package shall possess a communication system capable of transmitting data at a minimum horizontal range of 200 meters. |

| | | | |
|---|---|---|---|
| **FR 6.0** | **The system shall have a maximum footprint of 0.545 $m^2$.** | | |
| | DR 6.1 | The drone shall have a maximum footprint of 0.545 $m^2$ with the imaging system and sensor package attached. | |
| | | DR 6.1.1 | The drone shall have a maximum length of 0.740 m with the imaging system and sensor package attached. |
| | | DR 6.1.2 | The drone shall have a maximum width of 0.736 m with the imaging system and sensor package attached. |

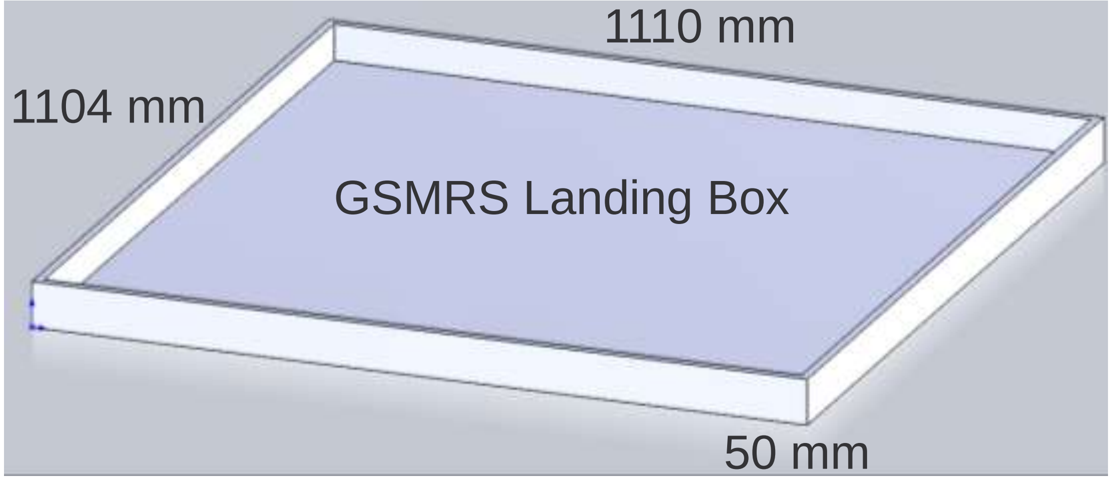
# CERTIFICATE OF AUTHORIZATION

- FAA COA required for outdoor flight testing
  - Submitted 4 November 2015 through RECUV
  - **Approved 9 November 2015**
- Flight testing authorized at Table Mountain Test Facility
  - North of Boulder, CO
  - Require FAA-licensed Private Pilot
- Future work
  - Multiple Pilots available for flight testing
  - FAA Class 2 Medical for Observers
  - COA Renewal in December/January
  - Aircraft registration


<u>Conclusions:</u>
- COA and test site approved

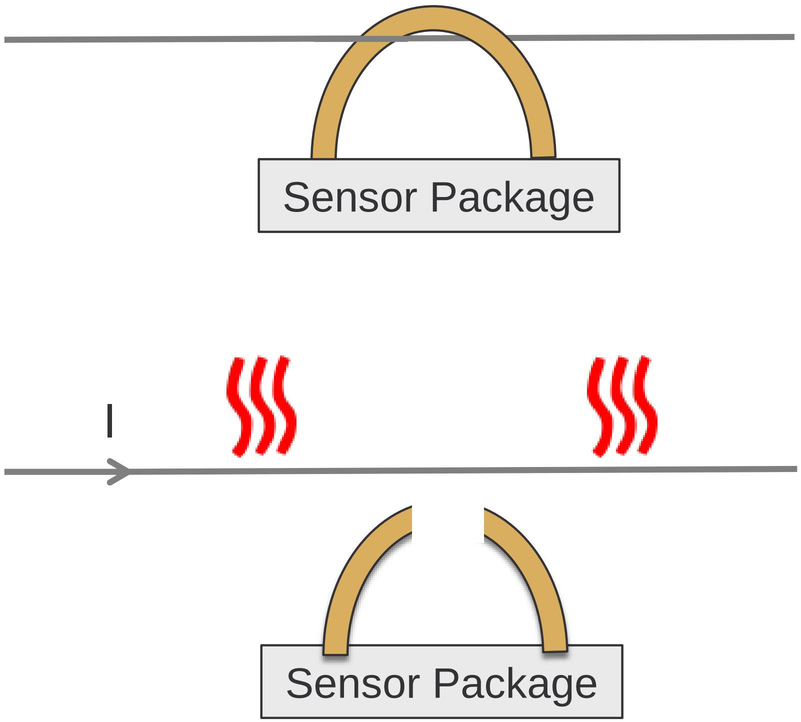
# GSMRS - STRUCTURE

Landing box size determination:
Based on James Mack’s recommended safety margin.
50% additional margin added to aircraft’s size.



# DEPLOYMENT MECHANISM – BURN WIRE

- Burn Wire
  - Nylon/Dacron Rope
    - Melting point: 220°C
  - Nichrome Wire
    - Melting point: 1400°C
  - Mass: <2 g



# DEPLOYMENT MECHANISM – BURN WIRE TESTING

- 3cm of Mystery wire with Nylon chord (1/8”) Results:

| Current (A) | Voltage (V) | Power (W) | Time (s) | Energy (J) |
|---|---|---|---|---|
| 2.0 | 0.68 | 1.36 | - | - |
| 3.0 | 1.06 | 3.18 | 8 | 25 |
| 3.5 | 1.27 | 4.45 | 7 | 31 |
| 4.0 | 1.42 | 5.68 | 5 | 28 |
| 4.5 | 1.75 | 7.88 | 3 | 24 |

# DEPLOYMENT MECHANISM – BURN WIRE TESTING

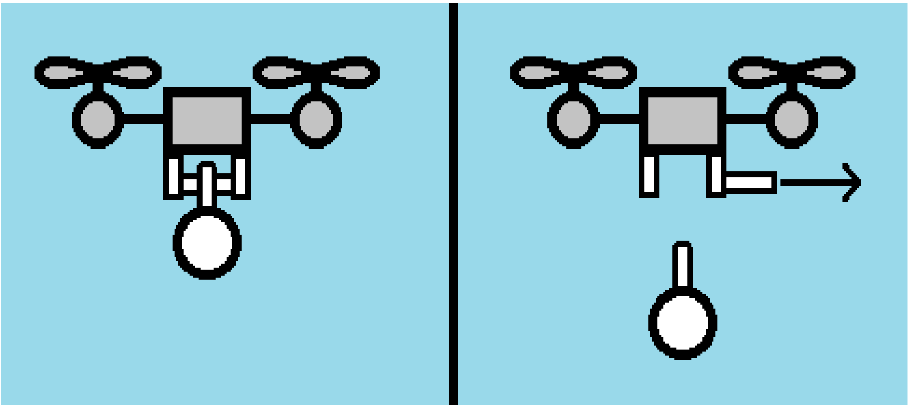
- 3cm of Mystery wire with Dacron chord (3/64”) Results:

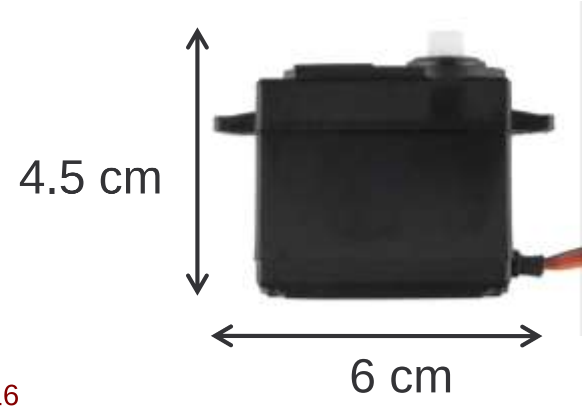
| Current (A) | Voltage (V) | Power (W) | Time (s) | Energy (J) |
|---|---|---|---|---|
| 2.0 | 0.68 | 1.36 | - | - |
| 3.0 | 1.02 | 3.06 | 5.9 | 18 |
| 3.5 | 1.18 | 4.13 | 3.9 | 16 |
| 4.0 | 1.36 | 5.44 | 3.1 | 17 |
| 4.5 | 1.50 | 6.75 | 1.7 | 11 |

# DEPLOYMENT MECHANISM – BURN WIRE

| Advantages | Disadvantages |
|---|---|
| • All parts are available from labs on campus at no cost<br>• Lightweight | • Can't solder wire – need mechanical connection<br>• Wire becomes brittle after multiple uses<br>• Cord needs to be replaced for every use<br>• Difficult to securely attach to CD<br>• Individual power converter circuit required<br>• ~4A of current draw |

# DEPLOYMENT MECHANISM – SERVO MOTOR






# DEPLOYMENT MECHANISM – PULL PIN

| Advantages | Disadvantages |
| --- | --- |
| • Flight controller has built in PWM control<br>• Secure connection to CD and SP | • Must design mechanical interface for the pull pin |

| Advantages | Disadvantages |
| --- | --- |
| • Reusable – likely won't need to replace any parts<br>• Mechanically simple to interface with CD & SP<br>• Secure connection to CD and SP | • Will need extra circuitry for withdraw/extend commands |

# DEPLOYMENT MECHANISM – TRADE STUDY

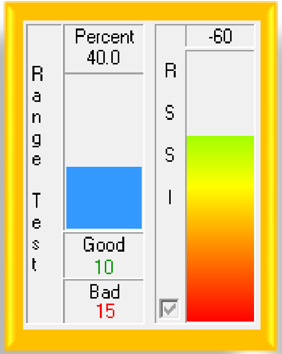
| | | Servo motor Pull Pin | | Linear Actuator Pull Pin | | Burn Wire | |
|---|---|---|---|---|---|---|---|
| Criteria | Weight | Rating | Score | Rating | Score | Rating | Score |
| Mechanical Complexity | 40% | 3 | 1.2 | 5 | 2 | 4 | 1.6 |
| Electrical Complexity | 5% | 3 | 0.15 | 3 | 0.15 | 1 | 0.05 |
| Effects on CD | 20% | 4 | 0.8 | 4 | 0.8 | 1 | 0.2 |
| Aquirability of Supplies | 10% | 3 | 0.3 | 1 | 0.1 | 5 | 0.5 |
| Reusability | 25% | 5 | 1.25 | 5 | 1.25 | 3 | 0.75 |
| **Total** | **100%** | 3.7 | | 4.3 | | 3.1 | |

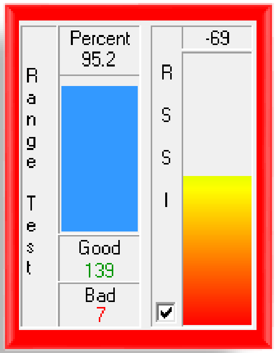
# DEPLOYMENT MECHANISM – TRADE STUDY

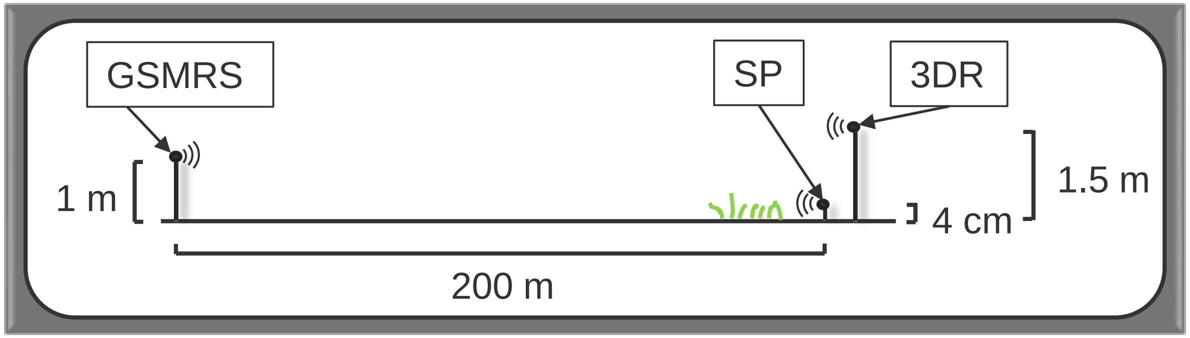
| Criteria | 1 | 2 | 3 | 4 | 5 | Weight | Justification |
|---|---|---|---|---|---|---|---|
| Number of Parts | 5+ mechaniclaly separate parts to interface with CD and SP | 4 mechaniclaly separate parts to interface with CD and SP | 3 mechaniclaly separate parts to interface with CD and SP | 2 mechaniclaly separate parts to interface with CD and SP | 1 part interfaces with the CD controller and the SP | 40% | Extra mechanical components will require integration, more mass, and higher risk of failure. |
| Electrical Complexity | The mechanism will need its own power converter circuit | - | The mechanism will need to be plugged into the CD controller as well as an external power supply | - | The design can be "plugged in" to the CD controller | 5% | Extra circuit components will require more mass and labor. Additionally, a more complex circuit will add another chance for the deployment mechanism to fail. However, this is not weighted high because circuit elements do not weigh much and have low chances of failure. |
| Effects on CD | The SP will be loosely connected to the drone and will be able to sway and effect the motion of the CD | - | SP does not shake but experiences vibrations during flight | - | SP can be designed to not shake during flight and experiences no vibration | 20% | A secure attachment will allow for favorable flight characteristics for the CD. Less swaying will increase the flight efficiency and increase flight duration as a result. |
| Aquirability of Supplies | All parts need to be ordered online | - | All parts can be aquired at stores within 30 minutes | All but 1-2 parts can be found on campus; others can be acquired at stores within 30 minutes | All parts are available from labs on campus at no cost | 10% | If any parts break, the INFERNO team needs to be able to replace them quickly in order to continue being able to perform testing. However, the team can order multiple of each part ahead of time. |
| Reusability | All parts must be replaced for each test | Half of the parts must be replaced for each test | No parts will last the duration of the project | 1-2 parts will need to be replaced throughout the year | All parts can be re-used throughout duration of project with no need to replace | 25% | While all parts will be less than 1% of the budget, the constant need to replace parts will require labor. Additionally, if the CD and SP are to be used in the coming years, future operators might have problems replacing the components. |

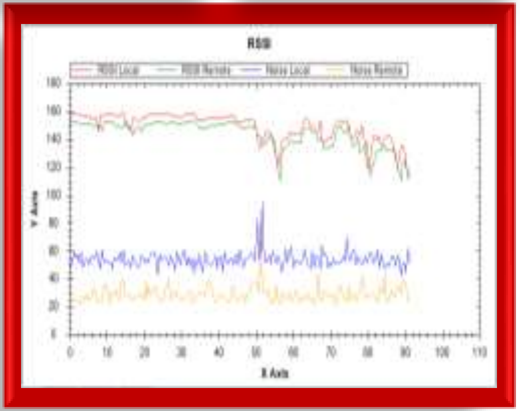
# 3DR/XBEE INTERFERENCE

| INFERNO Simultaneous SP/CD Comms Testing Results | |
|---|---|
| Top Left | XBee link with 3DR turned on |
| Top Right | XBee link with 3DR turned off |
| Bottom Right | 3DR link with XBee communication |
| Bottom Middle | Communications testing setup |
| Conclusion | Significant interference between systems; wait to transmit from XBees until CD returns to GSMRS |

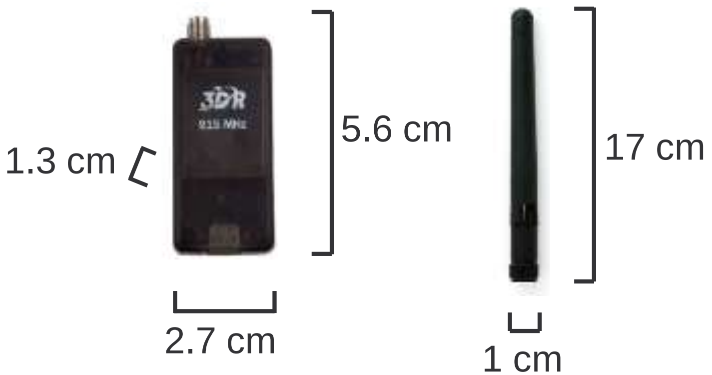


# CHILD DRONE – COMMUNICATIONS



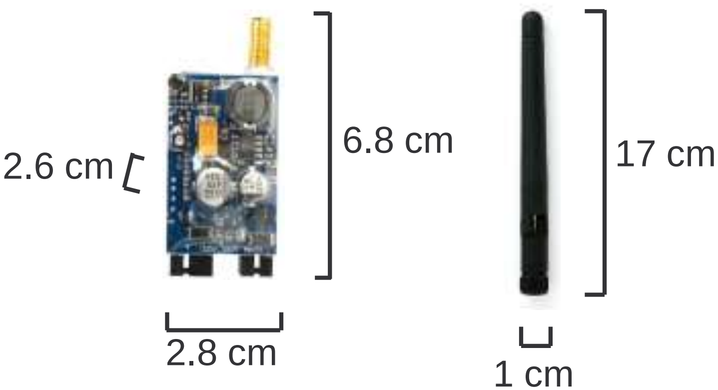

## 3DR connection to Pixhawk


## 3DR Radio Set

| 3DR Radio Set Specifications | |
|---|---|
| Interfacing Mode | UART |
| Transmit Current Draw | 100 mA |
| Receive Current Draw | 25 mA |
| Supply Voltage | 3.3 VDC |
| Power output [ $P_t$ ] | 20 dBm |
| Dipole Antenna Gain | 2 dBi (+2 dB of $P_t$) |

INFERNO:
- 3DR Radio Set will integrate with CD system
- 3DR Radio Set meets following requirements:
  - DR 4.1, DR 5.1

# CHILD DRONE – COMMUNICATIONS




## 3DR connection to Pixhawk

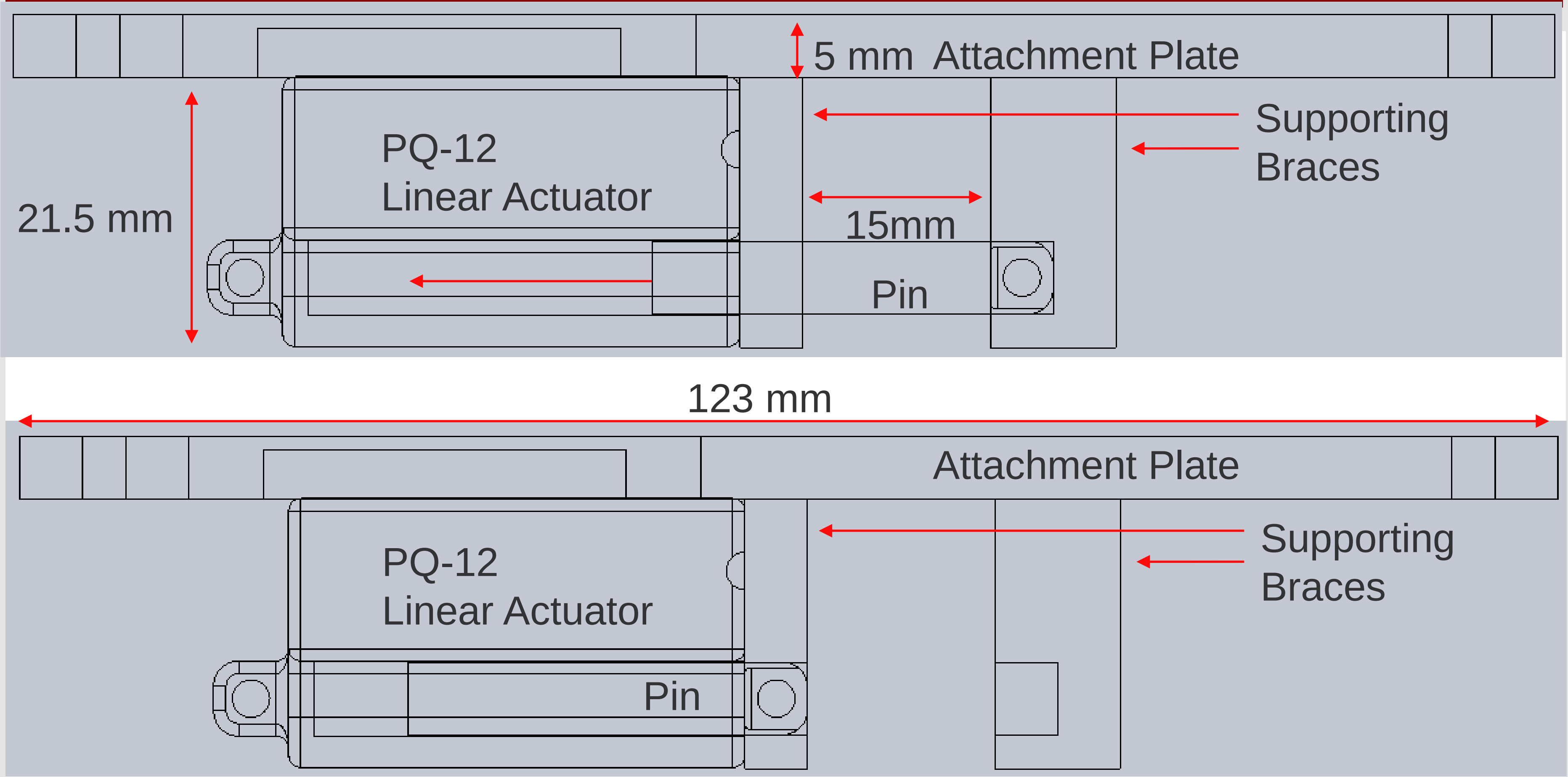

## 3DR Video Set

| 3DR Video Set Specifications | |
|---|---|
| Transmit Current Draw | 850 mA |
| Receive Current Draw | 150 mA |
| Supply Voltage | 12 VDC |
| Power Output [ $P_t$ ] | 33 dBm |
| Dipole Antenna Gain | 2 dBi (+2 dB of $P_t$) |

INFERNO:

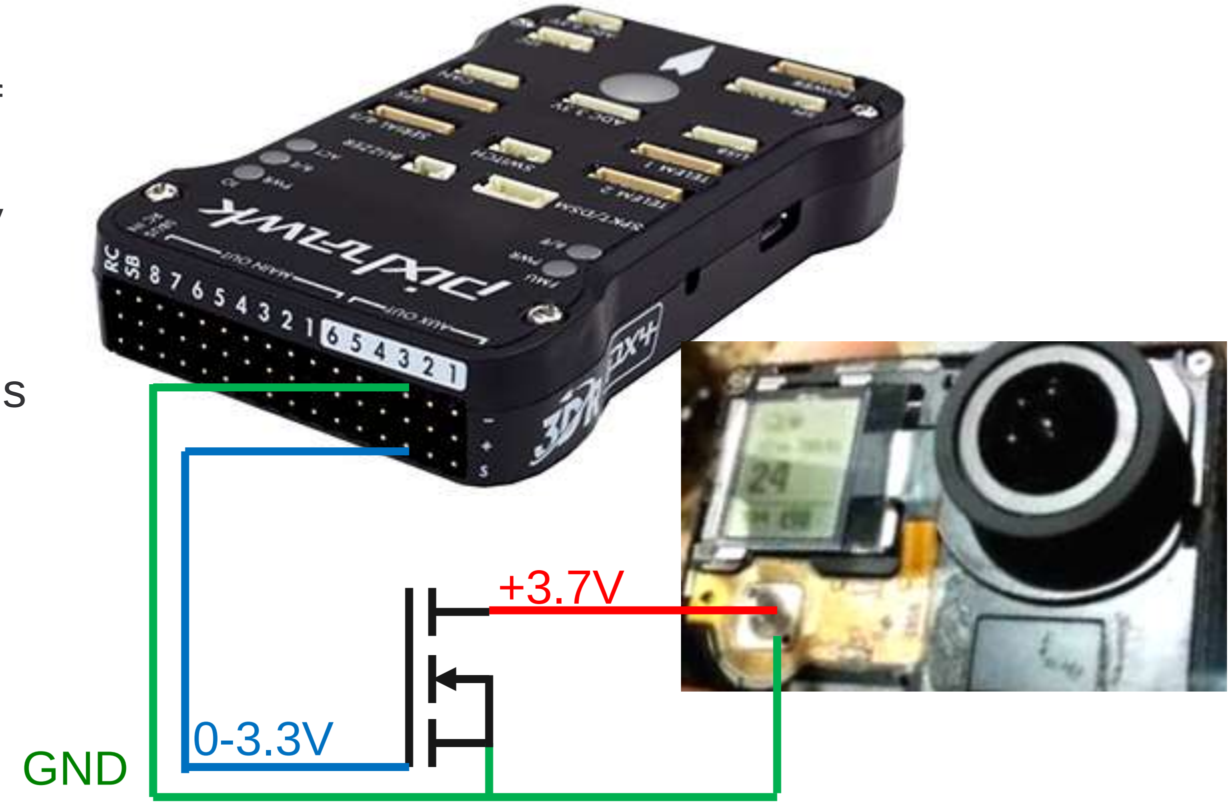
- 3DR Video Set will integrate with CD system
- 3DR Video Set meets following requirements:
  - DR 5.2

# DEPLOYMENT MECHANISM - STRUCTURE



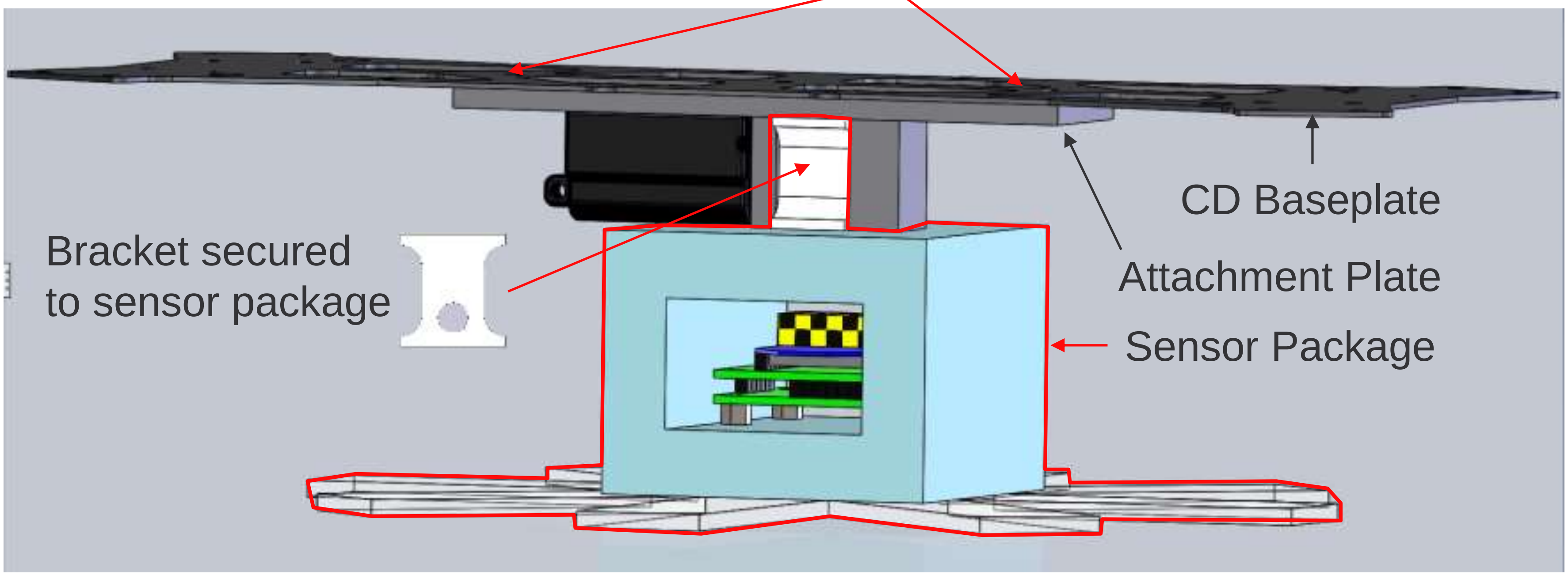
# IMAGING SYSTEM – CONTROL SWITCH

- MOSFET n-channel switch to power on/off
- Initiated by voltage sent by Pixhawk relay
- Can be controlled through Mission Planner or with Taranis RC transceiver



# CHILD DRONE SUBSYSTEM INTEGRATION – IMAGE SYSTEM

M3x5 mm screws attaching CD baseplate
& deployment mechanism structure



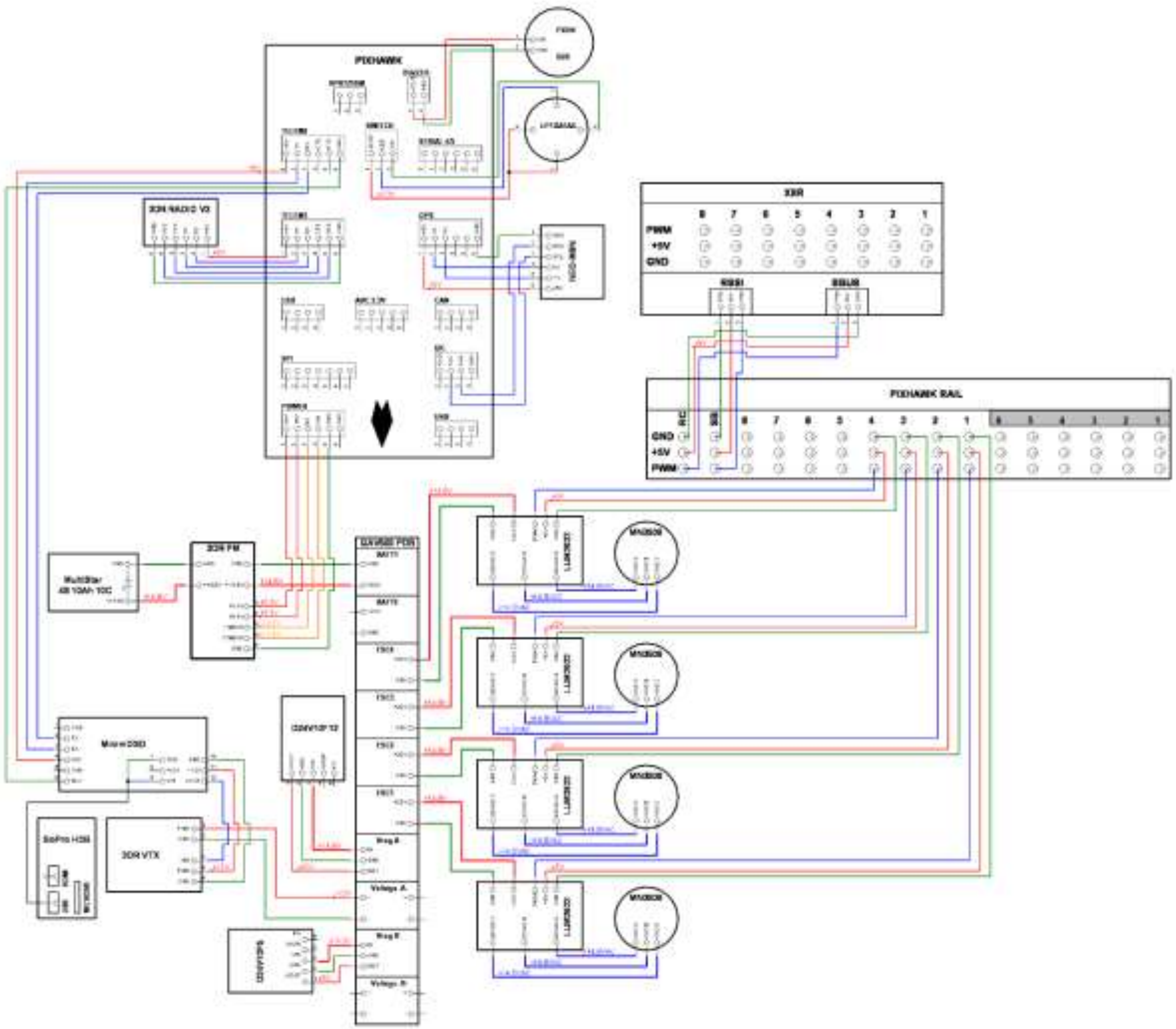
# CHILD DRONE TESTING – DEPLOYMENT MECHANISM

| Voltage | Time | Current |
|---|---|---|
| 6 V | 2.0 s | 0.09 A |
| 5 V | 2.6 s | 0.07 A |

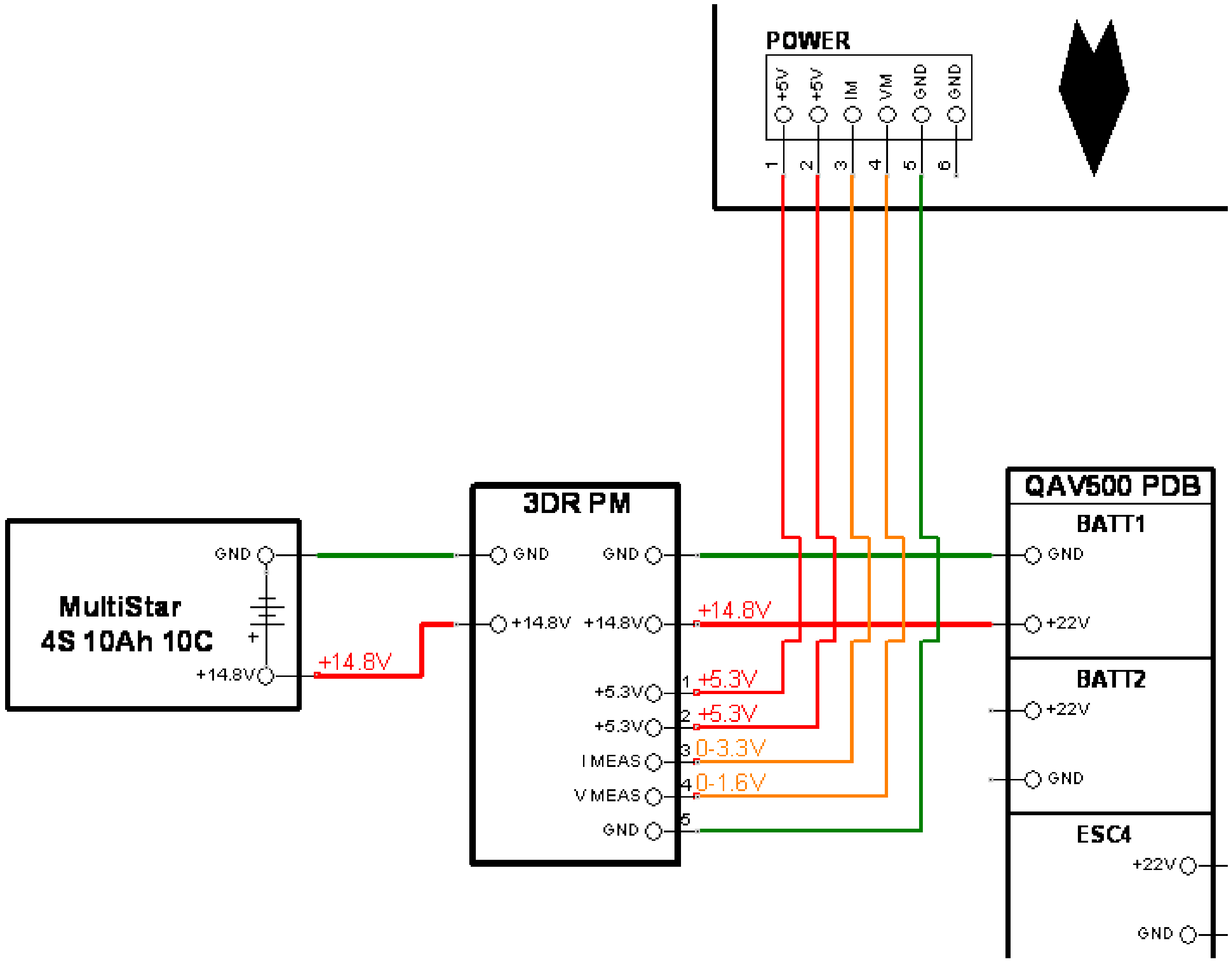
Trials: 10 at each voltage

All trials were successful

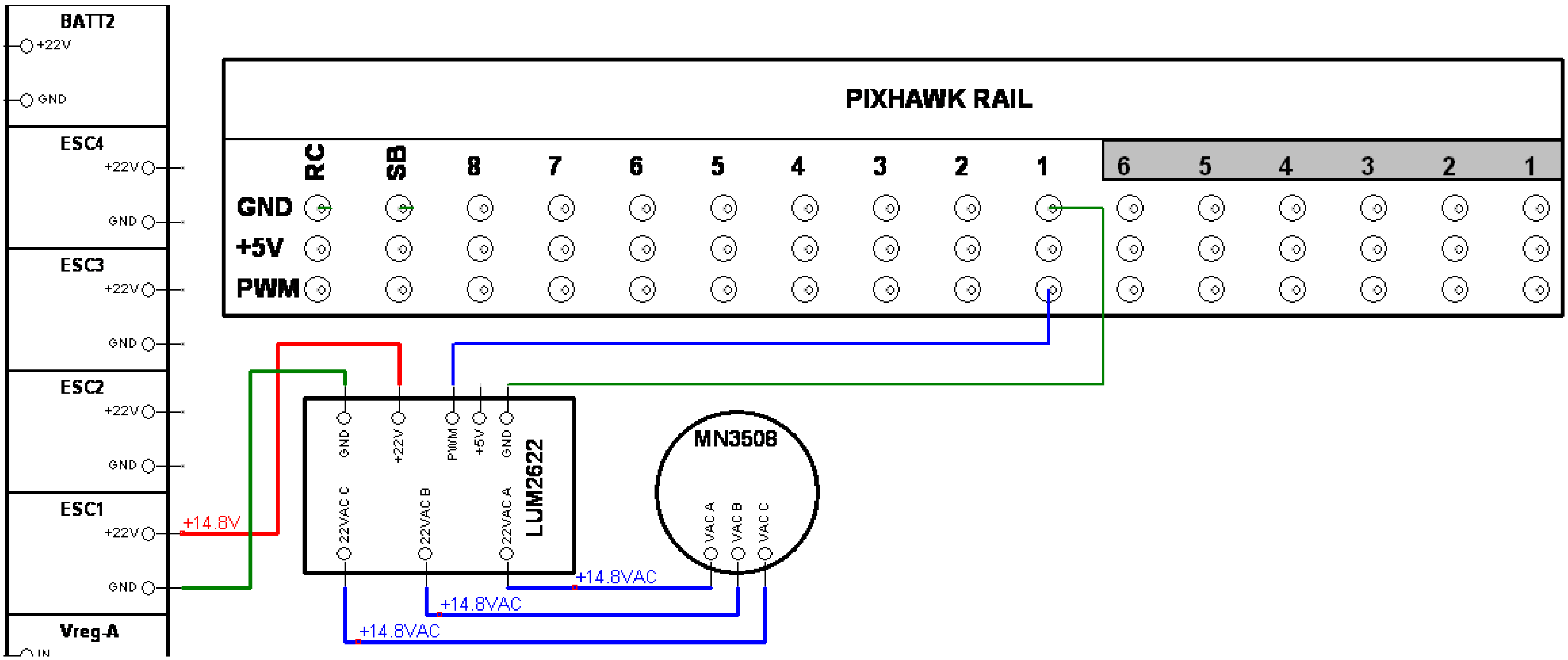
# CHILD DRONE WIRING – FULL



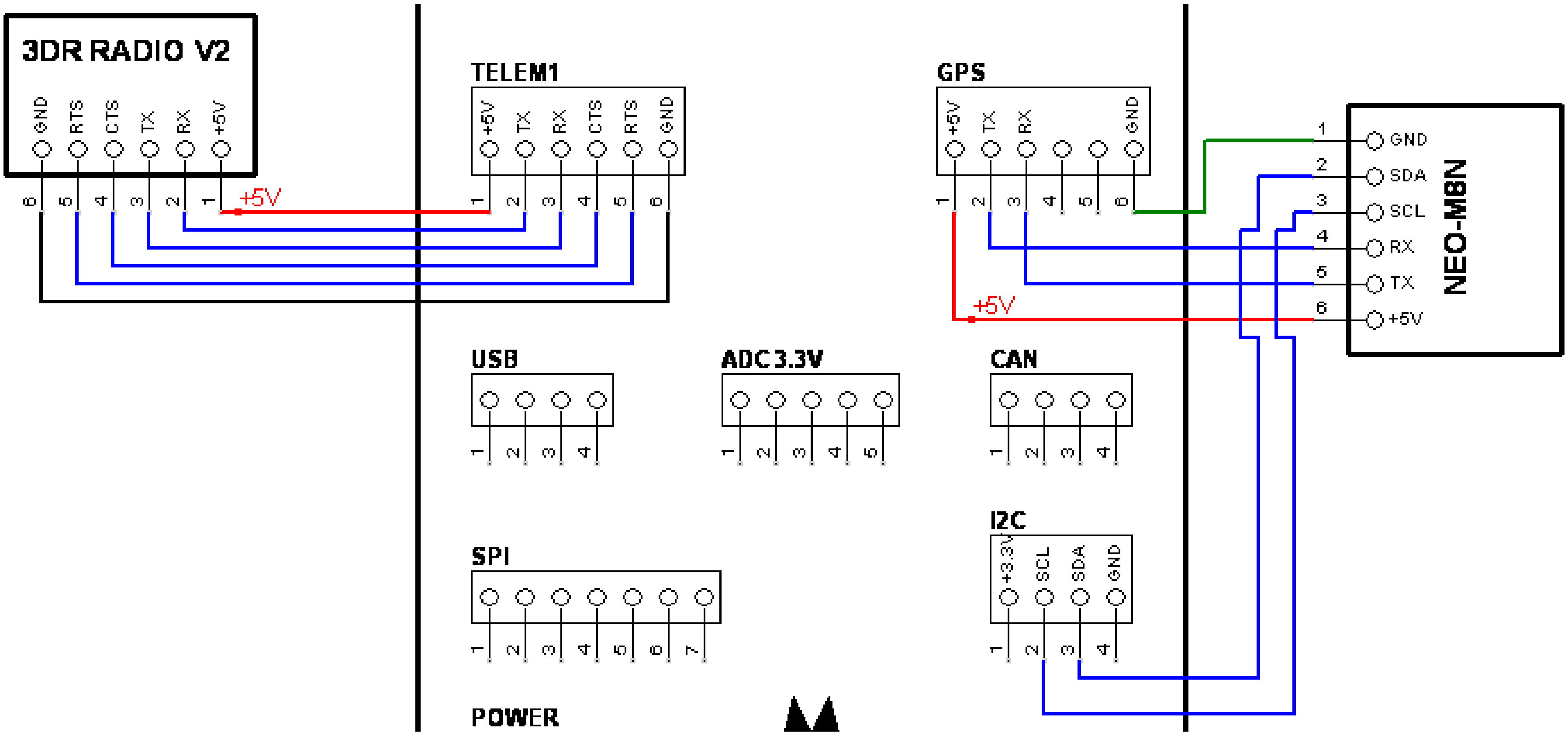
# CHILD DRONE WIRING – PRIMARY POWER



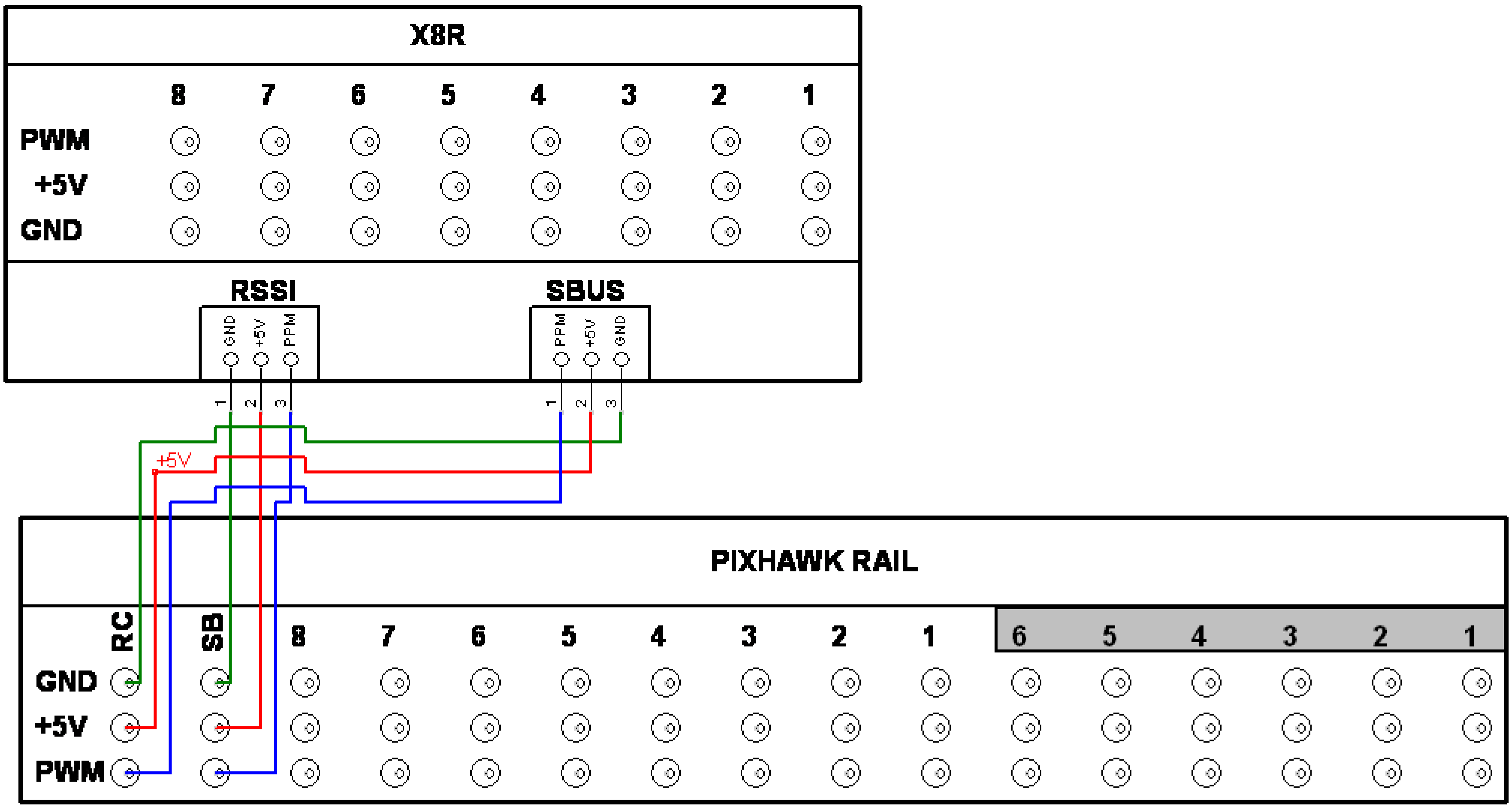
# CHILD DRONE WIRING – MOTORS



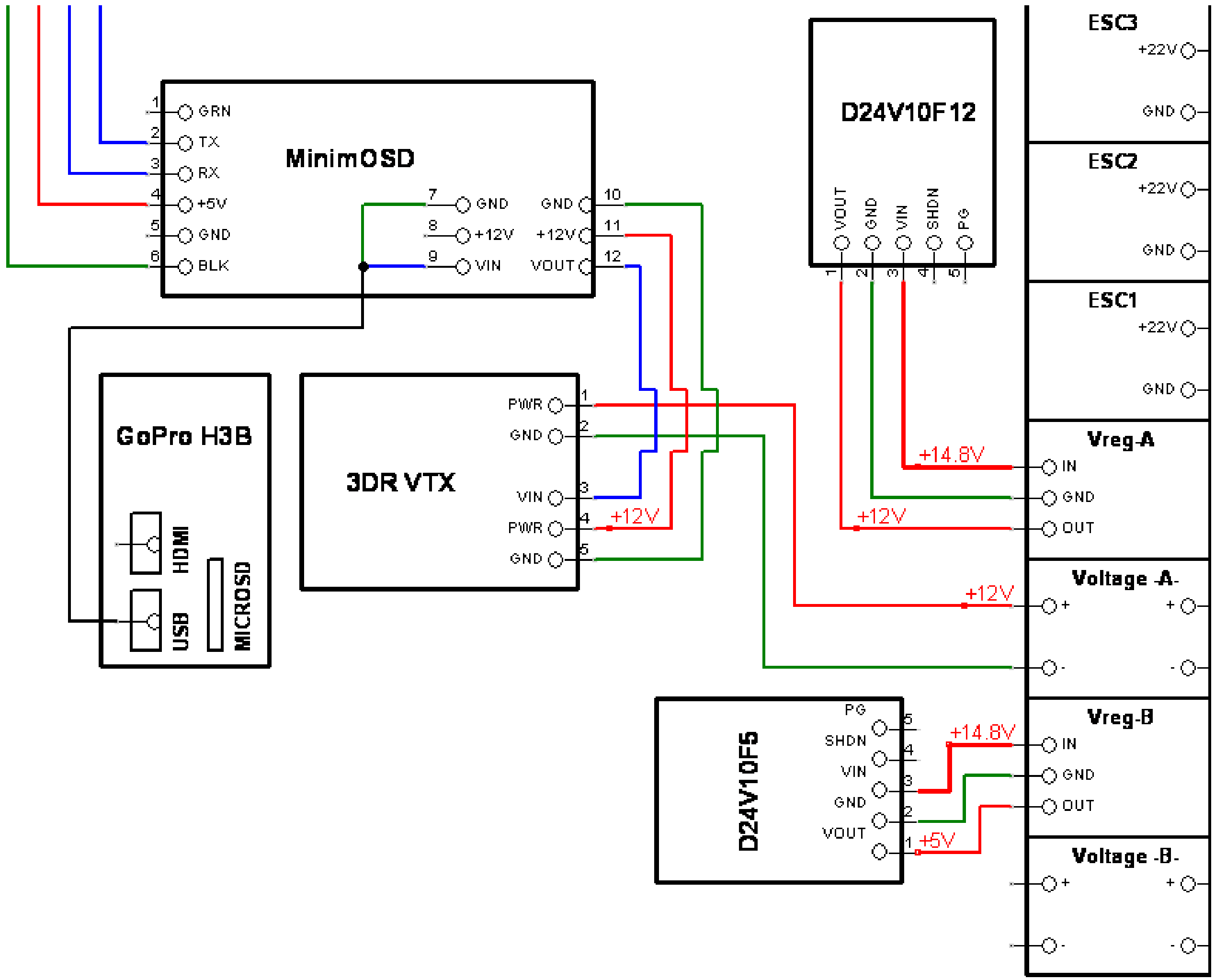
# CHILD DRONE WIRING – 3DR RADIO AND GPS



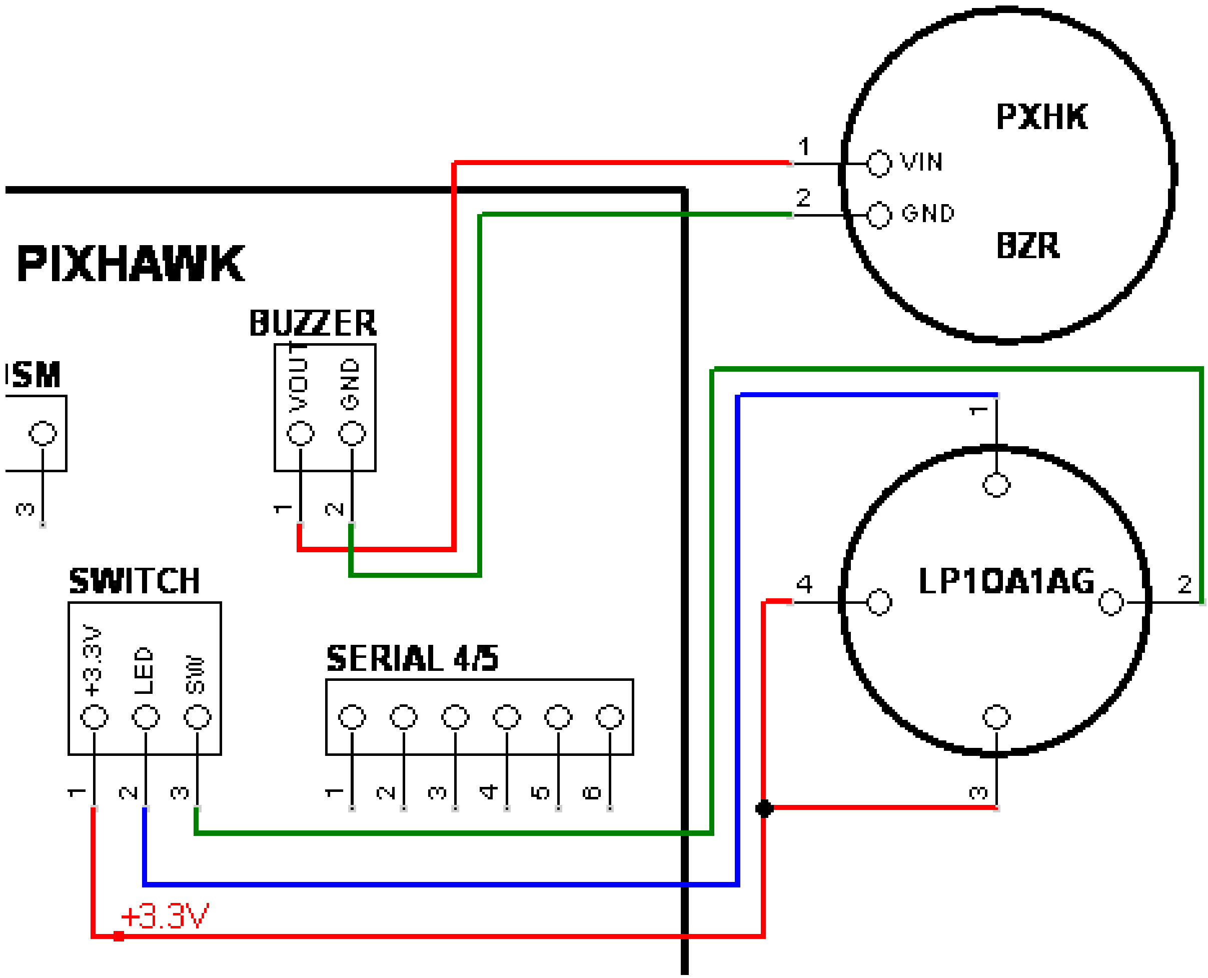
# CHILD DRONE WIRING – RC TRANSCEIVER



# CHILD DRONE WIRING – VIDEO AND VOLTAGE REGULATORS

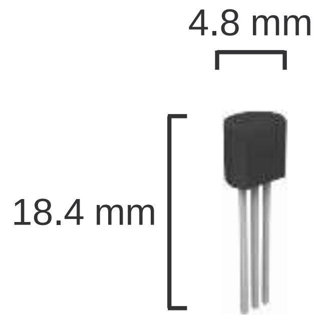


# CHILD DRONE WIRING – PIXHAWK SWITCH AND BUZZER



# TEMPERATURE SENSOR SELECTION

| | | LM34CA | | TMP37 | | LM34AH | |
|---|---|---|---|---|---|---|---|
| Criteria | Weight | R | W | R | W | R | W |
| Accuracy | 30% | 2 | 0.6 | 1 | 0.3 | 3 | 0.9 |
| Current Draw | 40% | 2 | 0.8 | 3 | 1.2 | 1 | 0.4 |
| Range | 15% | 1 | 0.15 | 1 | 0.15 | 3 | 0.45 |
| CU Experience | 15% | 3 | 0.45 | 1 | 0.15 | 1 | 0.15 |
| Total | 100% | 2 | | 1.8 | | 1.9 | |
| R: Raw Score | | | | W: Weighted Score | | | |

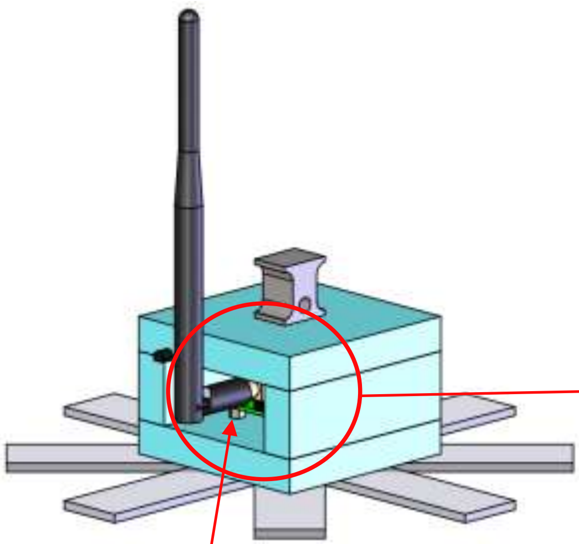



| Feature | INFERNO Requirement | Characteristic |
|---|---|---|
| Accuracy | 5°C [DR 1.1.1] | 2°F |
| Range | 10°C – 47.8°C [DR 1.1.1] | -40°F – 230°F |
| Conclusion | The LM34CA meets all sensor requirements and package constraints | |

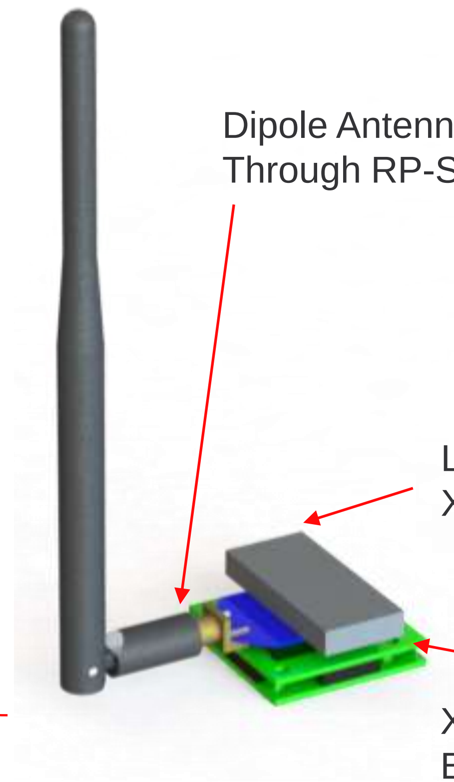
INFERNO:

- Use one LM34CA on SP
- Able to fall back on other options if necessary due to close trade study results → Multiple viable options

# SENSOR PACKAGE SUBSYSTEM INTEGRATION



Microcontroller Baseboard
Secured with 4mm 3M Standoffs



Dipole Antenna Connects to XBee
Through RP-SMA Connector

LiPo Battery Secured to
XBee Board Using Velcro

XBee Interfaces with Altimeter
Board Through Custom PCB

# TEMPERATURE SENSOR SELECTION

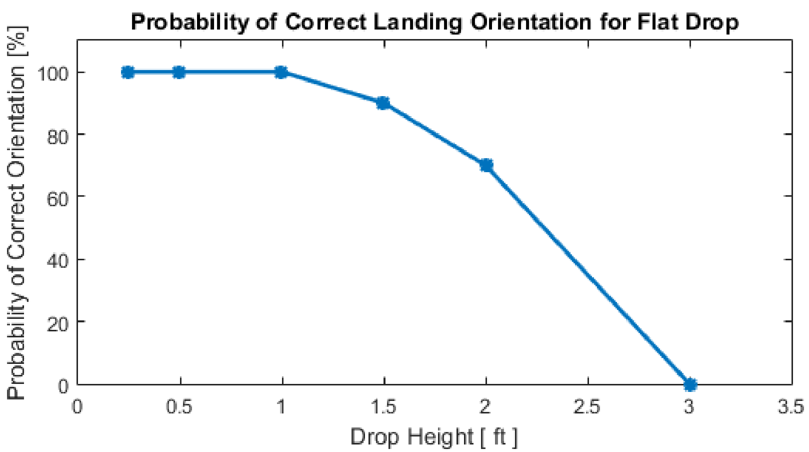
| Criteria | Weight | Justification |
|---|---|---|
| Accuracy | 30% | Sensor must have adequate range for data to be meaningful |
| Current Draw | 40% | Each component must draw minimal power due to small SP battery |
| Range | 15% | Must be capable of collecting useful data within possible temperature range |
| CU Experience | 15% | Previous knowledge of functionality/reliability beneficial |

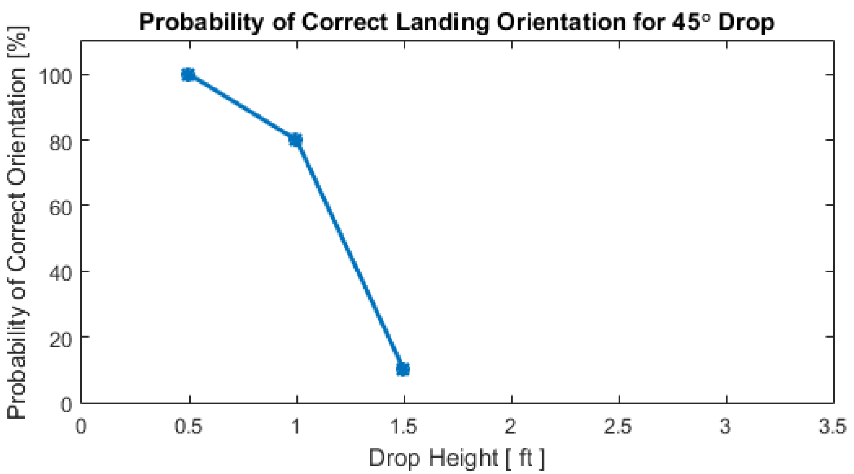
| Criteria | R: 1 | R: 2 | R: 3 |
|---|---|---|---|
| Accuracy | 4 $^{0}$F | 3 $^{0}$F | 2 $^{0}$F |
| Current Draw | 120  A | 120 < A  70 | A < 70 |
| Range | -40 < $^{0}$F < 230 | -45 < $^{0}$F < 260 | -50 < $^{0}$F < 300 |
| CU Experience | No Experience | Faculty Experience | Faculty/INFERNO Experience |

# SENSOR PACKAGE – LANDING

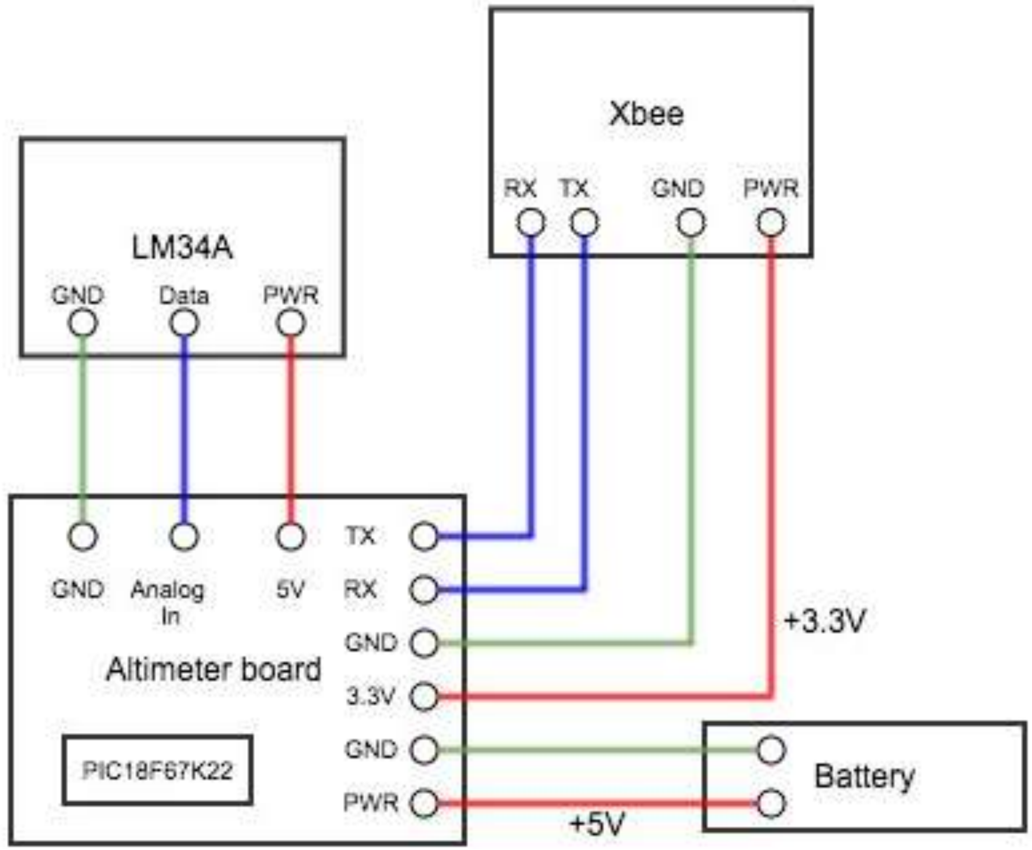
- Tests conducted on hard surface
  - High impact force
  - High coefficient of restitution

- Each test conducted 20 times

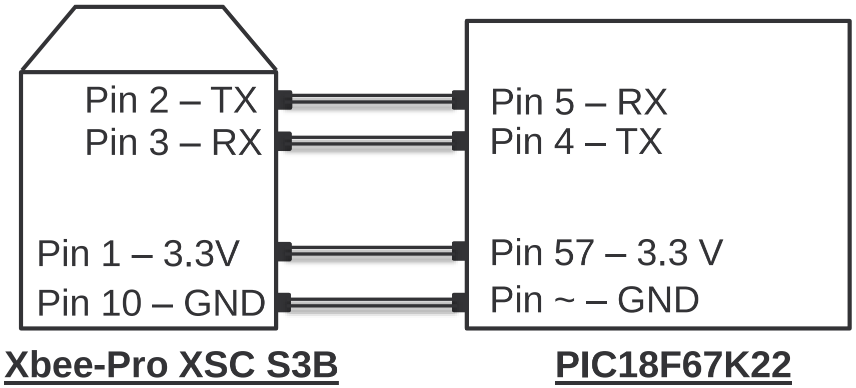


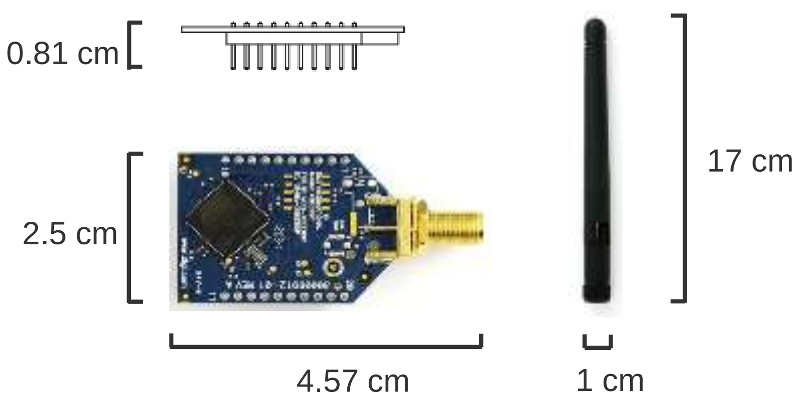



# SENSOR PACKAGE - ELECTRICAL



# SENSOR PACKAGE - COMMUNICATIONS




## Xbee-Pro XSC S3B

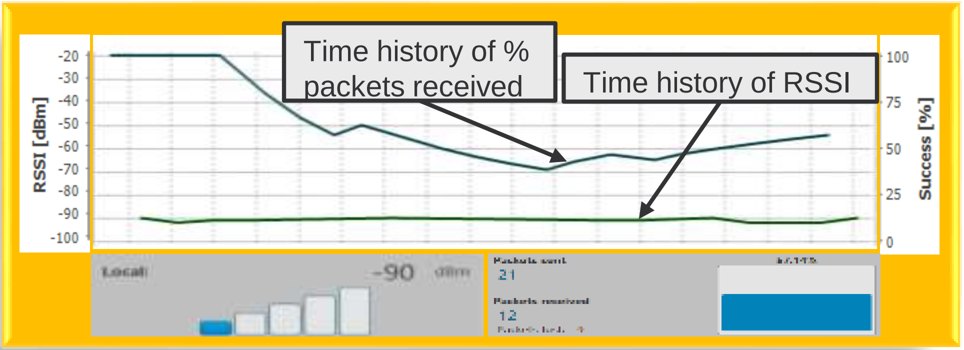
| XBee-Pro XSC S3B Specifications | |
|---|---|
| Interfacing Modes | SPI or UART |
| Transmit Current Draw | 215 mA |
| Idle Current Draw | 2.5 A |
| Supply Voltage | 2.4 – 3.6 VDC |
| Dipole Antenna Gain | 2 dBi (+2 dB of $P_t$) |

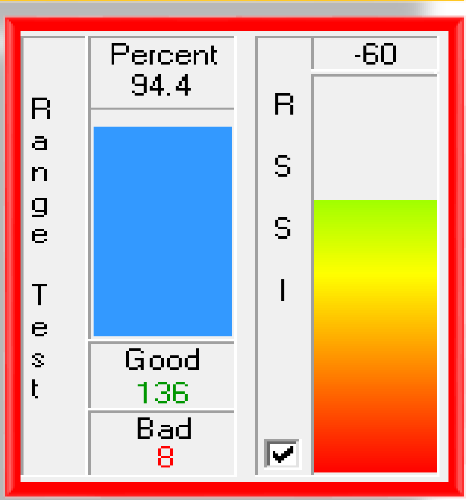
INFERNO

- Requires 2 XBees: 1 at SP and 1 at GSMRS
- Mainly operates in idle mode
- Employ USART interfacing
- Data sent in discrete packets

# SP COMMUNICATIONS SELECTION

| INFERNO Comms Testing Results | |
|---|---|
| Top | Old XBee Model |
| Bottom | New XBee Model |
| Conclusion | New model provides far greater success: INFERNO will use XBee-Pro XSC S3B |




Testing Conditions:

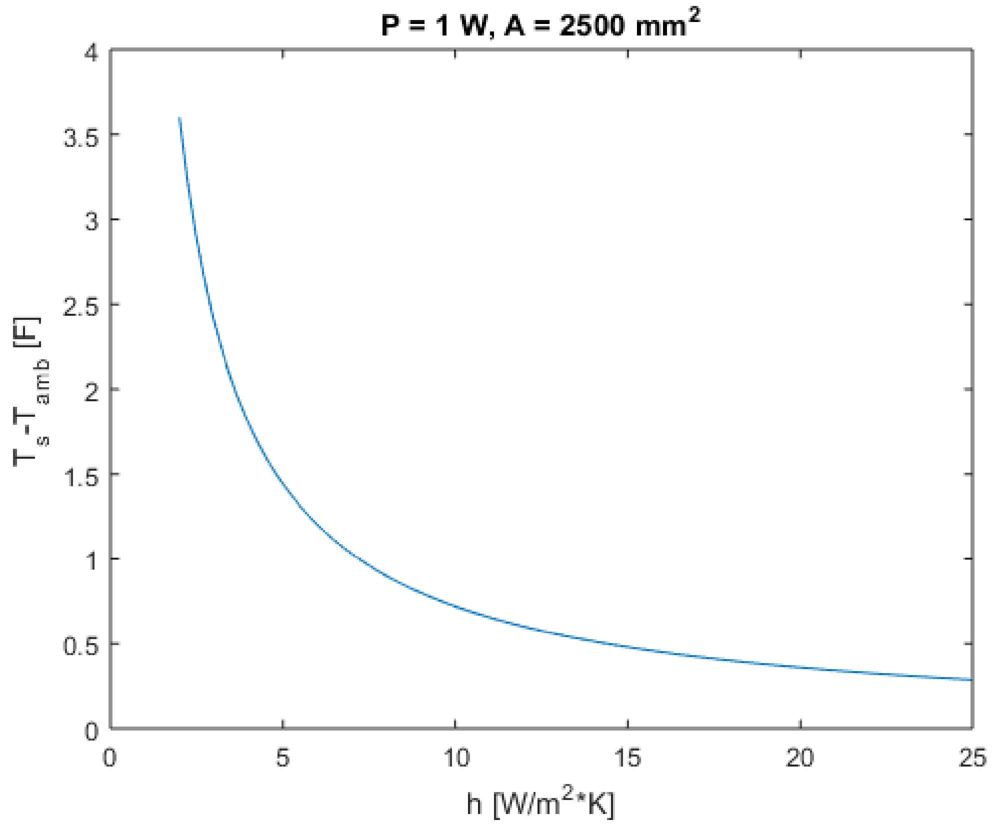
- XBees were fixed in both cases
- Both tests performed with identical conditions and XBee configurations
- Different link software used for each XBee model → different figure styles

Conclusion:

- Some degree of packet loss over time for both models
- Superior packet receive rate for new model
- Superior received signal strength for new model

# SENSOR PACKAGE THERMAL ANALYSIS

- Assumes 1D heat convection through open sides
- Ignores heat conduction through foam
- Heat transfer coefficient based on range for a free convection gas



# SENSOR PACKAGE - ELECTRICAL

- Xbee Power Requirements
  - 9600 baud
  - 30 Bytes every 10 seconds = 240 bits
  - 240 bits/9600 bits/sec = 0.025 seconds every 10 seconds
    - Transmitting only 0.25% of the time

# MULTIROTOR TRADE STUDY: QAV500 V2

- Quadcopter utilizing DJI Flamewheel frame arms

| Advantages | Disadvantages |
|---|---|
| • Elongated body allows for more payload space<br>• Frame arm configuration allows for large (13”) props<br>• Clean vs. dirty bay construction provides easier electrical integration<br>• Bottom plate design is friendly to payload integration | • Heaviest airframe considered<br>• Quadrotor design limits available takeoff weight |

# MULTIROTOR TRADE STUDY: TBS DISCOVERY

- Quadcopter utilizing DJI Flamewheel frame arms

| Advantages | Disadvantages |
|---|---|
| • Elongated body allows for more payload space<br>• Frame arm configuration allows for large (13”) props<br>• Lightest Airframe Considered | • Bottom plate is not easily modifiable for payload deployment system integration<br>• Quadrotor design limits available takeoff weight |

# MULTIROTOR TRADE STUDY: DJI F550

- Hexacopter from the DJI Flamewheel family of airframes

| Advantages | Disadvantages |
|---|---|
| • Hexacopter design allows for higher available takeoff weight<br>• Lightweight for a hexacopter | • Bottom plate is not easily modifiable for payload deployment system integration<br>• Hexacopter design limits propeller size<br>• Control scheme is more complex and harder to tune than a quadcopter |

# MULTIROTOR TRADE STUDY: 3DR SOLO

- Ready to fly 3DR Quadcopter

| Advantages | Disadvantages |
|---|---|
| • Ready to Fly<br>• Capable of streaming 720p video<br>• 800 m Range and 20 minute Flight Time<br>• WiFi Comm System<br>• Capable of Servo Control | • 420 g Payload (Not including camera and gimbal)<br>• Expensive ($1000-1400)<br>• Airframe Modification Required to Mount Deployment Module |

# MULTIROTOR TRADE STUDY: DJI PHANTOM

- Ready to fly DJI Quadcopter

| Advantages | Disadvantages |
| --- | --- |
| • Ready to Fly<br>• Capable of streaming 720p video and record 1080p at 30 FPS<br>• 17 minute Flight Time<br>• Camera/Gimbal Included<br>• Capable of Servo Control | • 450 g Payload<br>• Expensive $1000<br>• Airframe Modification Required to Mount Deployment Module |

# MULTIROTOR TRADE STUDY: WEIGHTING JUSTIFICATION

| | Weighting | |
|---|---|---|
| **Criteria** | **Weight** | **Justification** |
| Size | 5% | The airframe must be of a reasonable size such that a rover may be designed by a future senior projects group to transport it, however, the INFERNO project is not constrained by specific child drone size requirements |
| Ease of Assembly | 26% | The INFERNO team must be capable of assembling the airframe correctly and efficiently. Time is an important resource, thus a read-to-fly airframe is preferable over a more time-consuming kit. |
| Payload Integration | 21% | The airframe must be capable of integrating with the designed payload and deployment mechanism. Because this is the main purpose of the child drone, compatibility and reliability of this interface is key to the mission. |
| Max Payload | 7% | The chosen airframe and motor combination must be capable of lifting the weight of the entire assembly including the airframe, battery, and payload. If this cannot be accomplished, no mission can be attempted. |
| Cost | 8% | The chosen airframe must fit within the budget for the INFERNO project. Money must also be allocated to the Sensor Package and other project elements, thus a small cost is important in the selection. |
| Serviceability | 34% | Despite the INFERNO team's best efforts to avoid it, there is a likely chance that the chosen airframe will need to withstand a crash during the project timeline. Thus, the serviceability of the chosen airframe will be key to keeping such an event from bring all project progress to a halt. |

# MULTIROTOR TRADE STUDY: CRITERIA RANKINGS

| Criteria | 1 | 2 | 3 | 4 | 5 | Weight |
|---|---|---|---|---|---|---|
| Size | > 1000 mm | 800 - 1000 mm | 600 - 800 mm | 400 - 600 mm | < 400 mm | 5% |
| Ease of Assembly | Airframe is do-it-yourself (DIY): requires custom design and manufacturing of airframe and integration of all components | Airframe is almost-ready-to-fly (ARF): Most components necessary are included, but require assembly; requires procurement and integration of a battery, transmitter, and receiver | Airframe is plug-and-fly (PNF): Most components necessary are included and preassembled; requires procurement and integration of a battery, transmitter, and receiver | Airframe is bind-and-fly (BNF): All components necessary are included and preassembled with the exception of a transmitter | Airframe is ready-to-fly (RTF); the airframe is fully assembled and ready to operate out of the box | 26% |
| Payload Integration | Airframe cannot mount payload and/or imaging systems externally | Airframe requires structural modification to mount external imaging and payload systems | Airframe requires structural modification to mount external imaging system | Airframe requires structural modification to externally mount payload | Airfame can accommodate external payload/imaging without permanent modification | 21% |
| Max Payload | < 200 g | 200 - 300g | 300 - 500 g | 500 - 600 g | 600+ g | 7% |
| Cost | >$3000 | $3000-$2500 | $2500-$2000 | $2000-$15000 | <$1500 | 8% |
| Serviceability | Cannot service or exchange parts; must use COTS supplier for maintanence | Able to replace some components with same brand parts, but cannot use other brands; cannot service all components | Able to replace all components with same brand parts | Able to exchange some components with other brand parts | Able to fully exchange and upgrade all components with other brand parts | 34% |

# MULTIROTOR TRADE STUDY

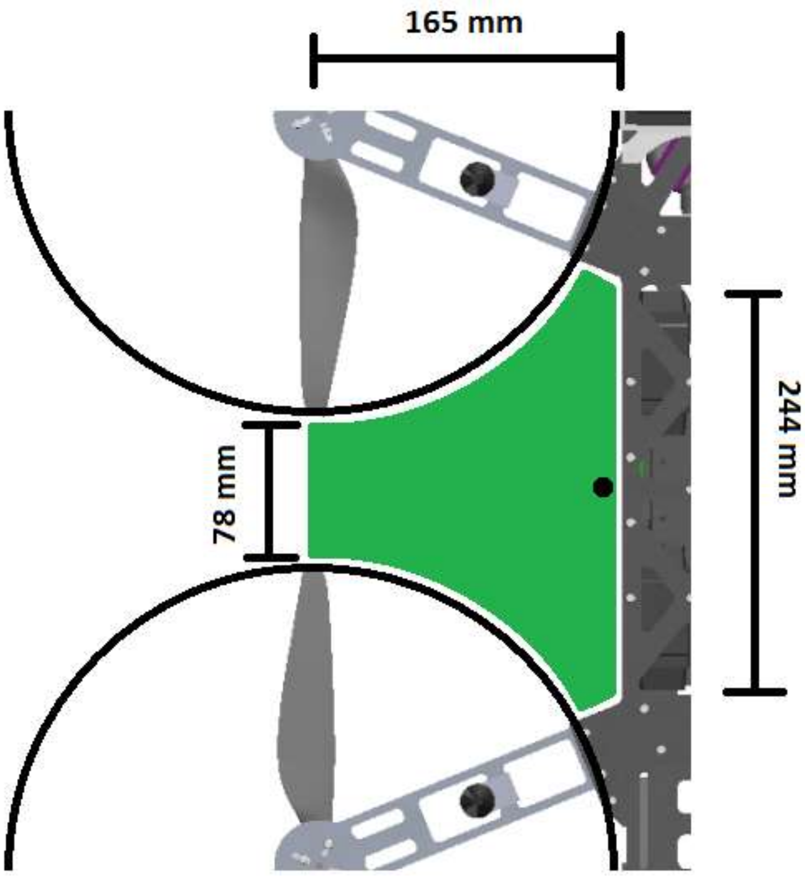
| | | TBS Discovery | | DJI F550 | | QAV500 V2 | | 3DR Solo | | DJI Phantom 3 | | DJI S900 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Criteria | Weight | Rating | Score | Rating | Score | Rating | Score | Rating | Score | Rating | Score | Rating | Score |
| Size | 5% | 4 | 0.2 | 4 | 0.2 | 4 | 0.2 | 4 | 0.2 | 4 | 0.2 | 2 | 0.1 |
| Ease of Assembly | 26% | 1 | 0.26 | 2 | 0.52 | 1 | 0.26 | 5 | 1.3 | 5 | 1.3 | 2 | 0.52 |
| Payload Integration | 21% | 3 | 0.63 | 3 | 0.63 | 5 | 1.05 | 4 | 0.84 | 4 | 0.84 | 3 | 0.63 |
| Available Payload | 7% | 4 | 0.26 | 5 | 0.325 | 3 | 0.195 | 1 | 0.065 | 3 | 0.195 | 5 | 0.325 |
| Cost | 8% | 4 | 0.3 | 4 | 0.3 | 4 | 0.3 | 5 | 0.375 | 5 | 0.375 | 2 | 0.15 |
| Serviceability | 34% | 5 | 1.7 | 5 | 1.7 | 5 | 1.7 | 3 | 1.02 | 2 | 0.68 | 4 | 1.36 |
| Total | 100% | 3.35 | | 3.675 | | 3.705 | | 3.8 | | 3.59 | | 3.085 | |

# AVAILABLE AREA FOR ANTENNA PLACEMENT

Full Sensor Package Height – 179 mm

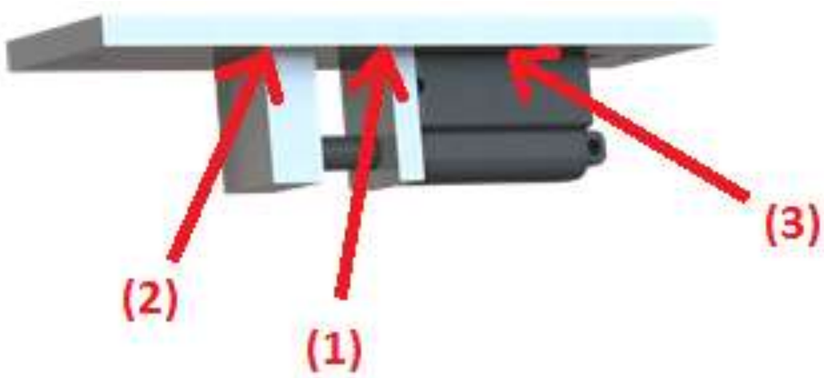
Propeller Height Off Ground – 180 mm

Antenna Largest Diameter – 10 mm



# AVAILABLE AREA FOR ANTENNA PLACEMENT

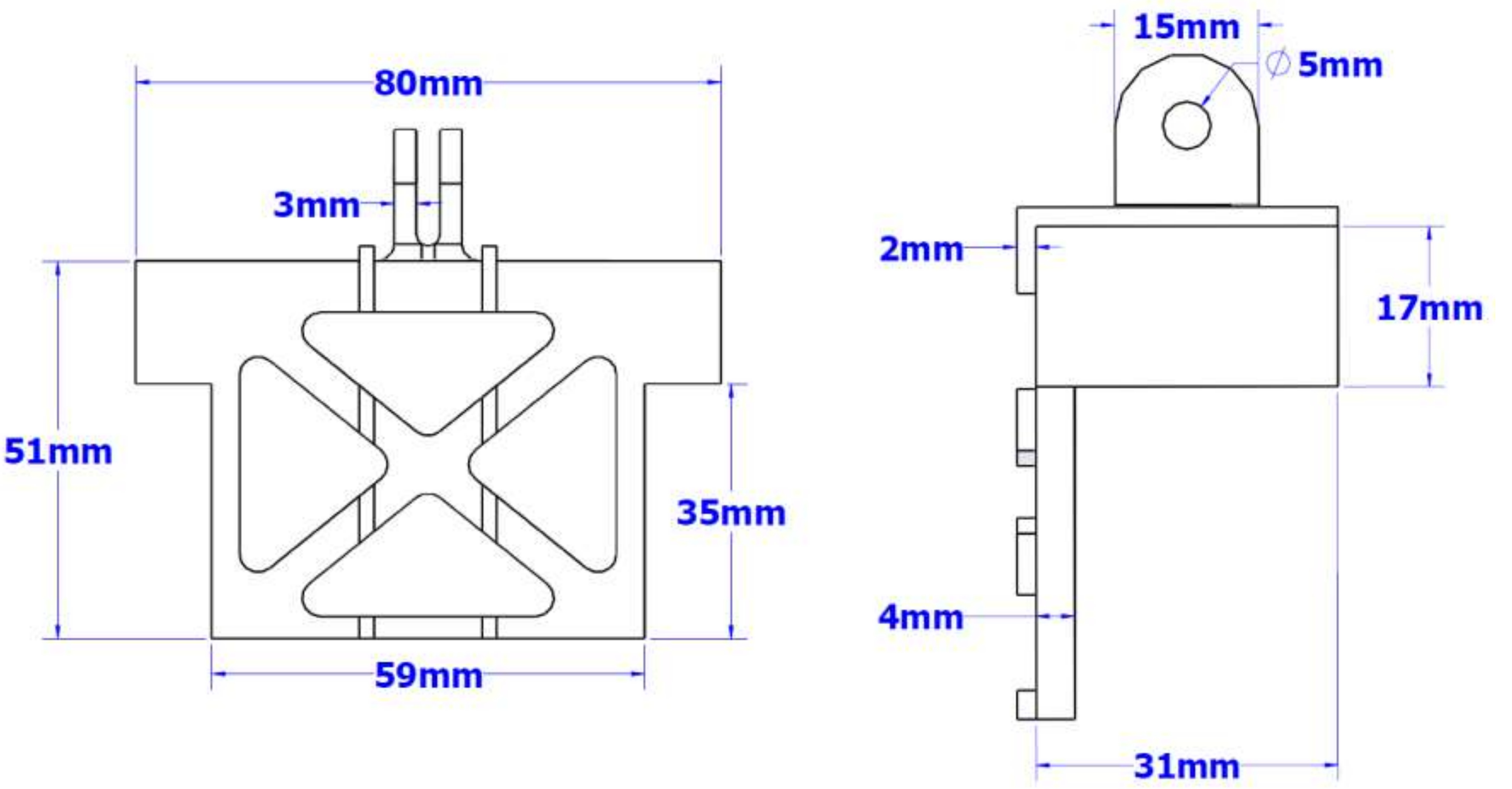
| Material Strengths | |
|---|---|
| ABSplus 3D Printed Material | |
| Tensile Strength | 31 MPa |
| Flexure Strength | 35 MPa |
| Epoxy Resin | |
| Tensile Strength | 85 MPa |



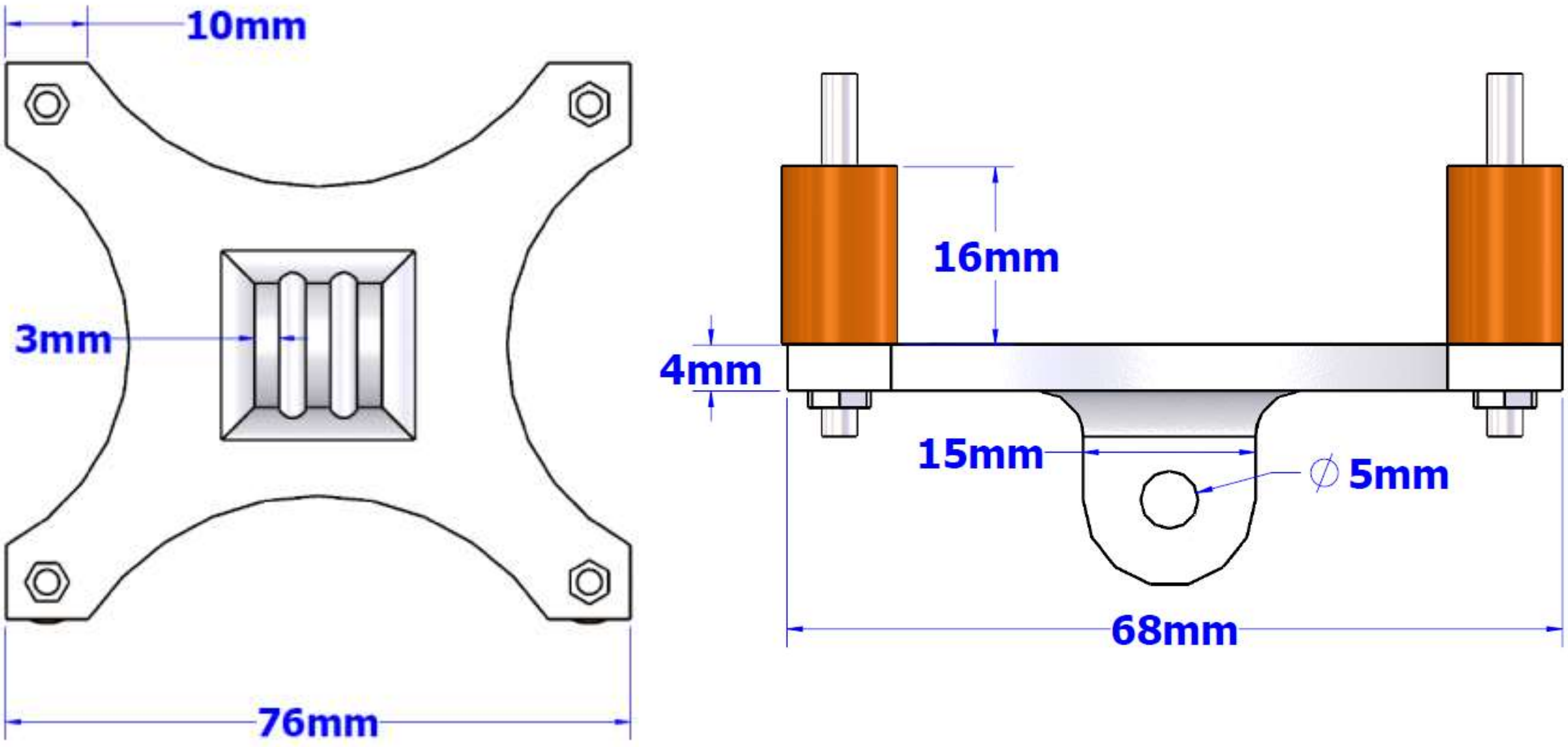

| Minimum Areas | |
|---|---|
| ABSplus 3D Printed Material | |
| Tension (1) | 225 $mm^2$ |
| Flexure (2) | 250 $mm^2$ |
| Epoxy Resin | |
| Tension (3) | 375 $mm^2$ |

| Factor of Safety | |
|---|---|
| ABSplus 3D Printed Material | |
| Tension | 4678 |
| Flexure | 5868 |
| Epoxy Resin | |
| Tension | 21,376 |

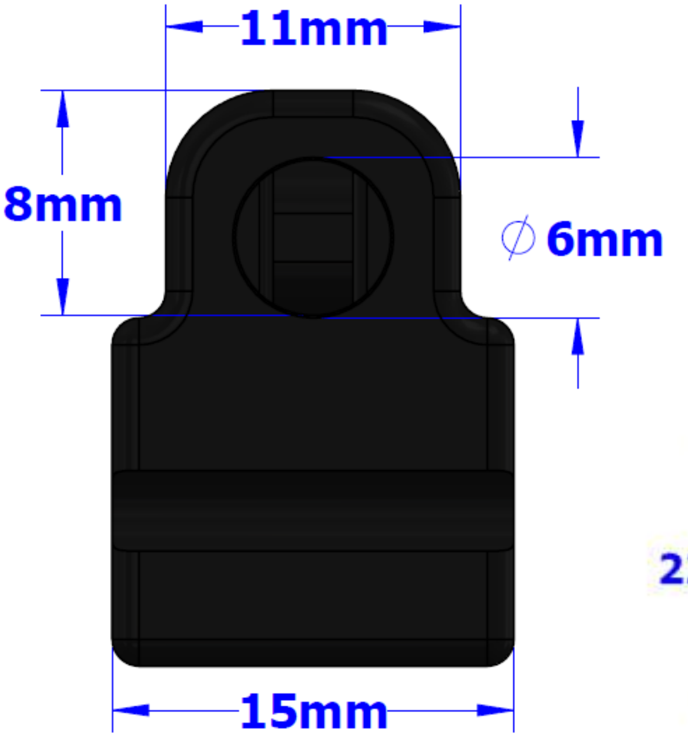
# CAMERA MOUNT DIMENSIONS

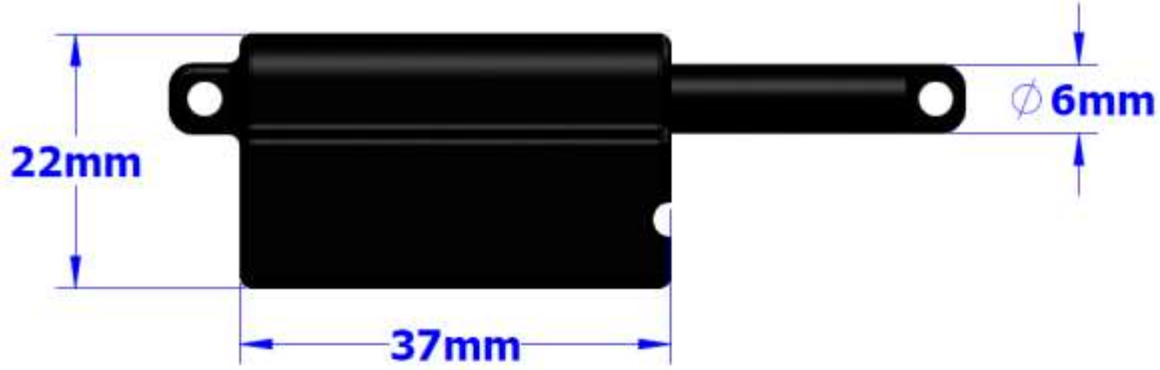


# ISOLATION PLATE DIMENSIONS

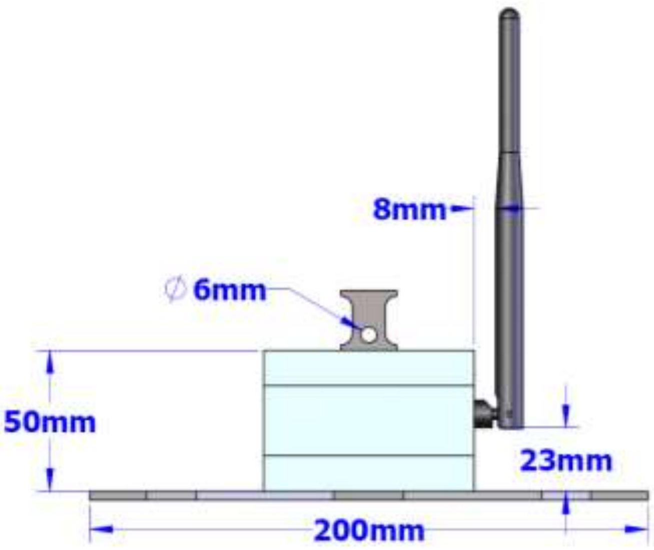


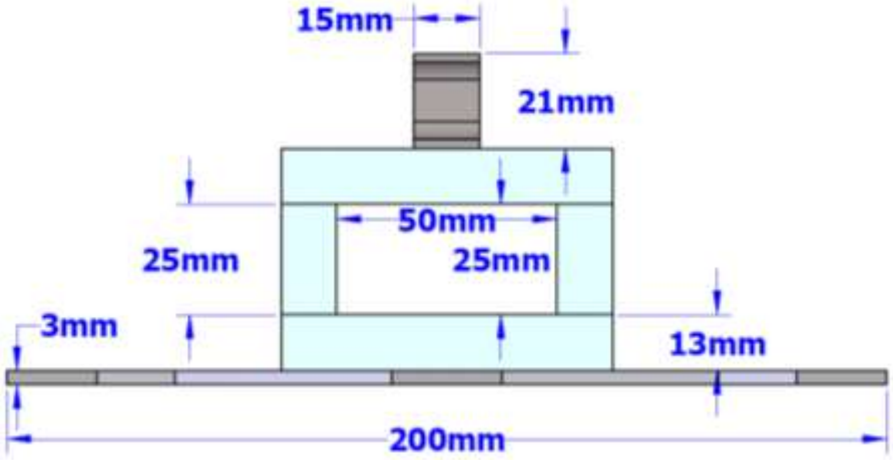
# LINEAR ACTUATOR DIMENSIONS

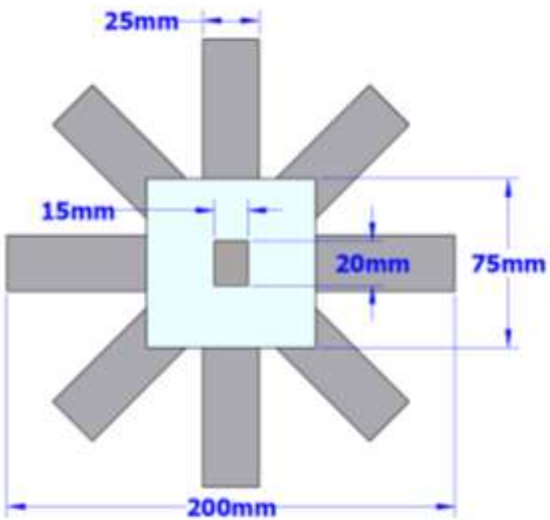


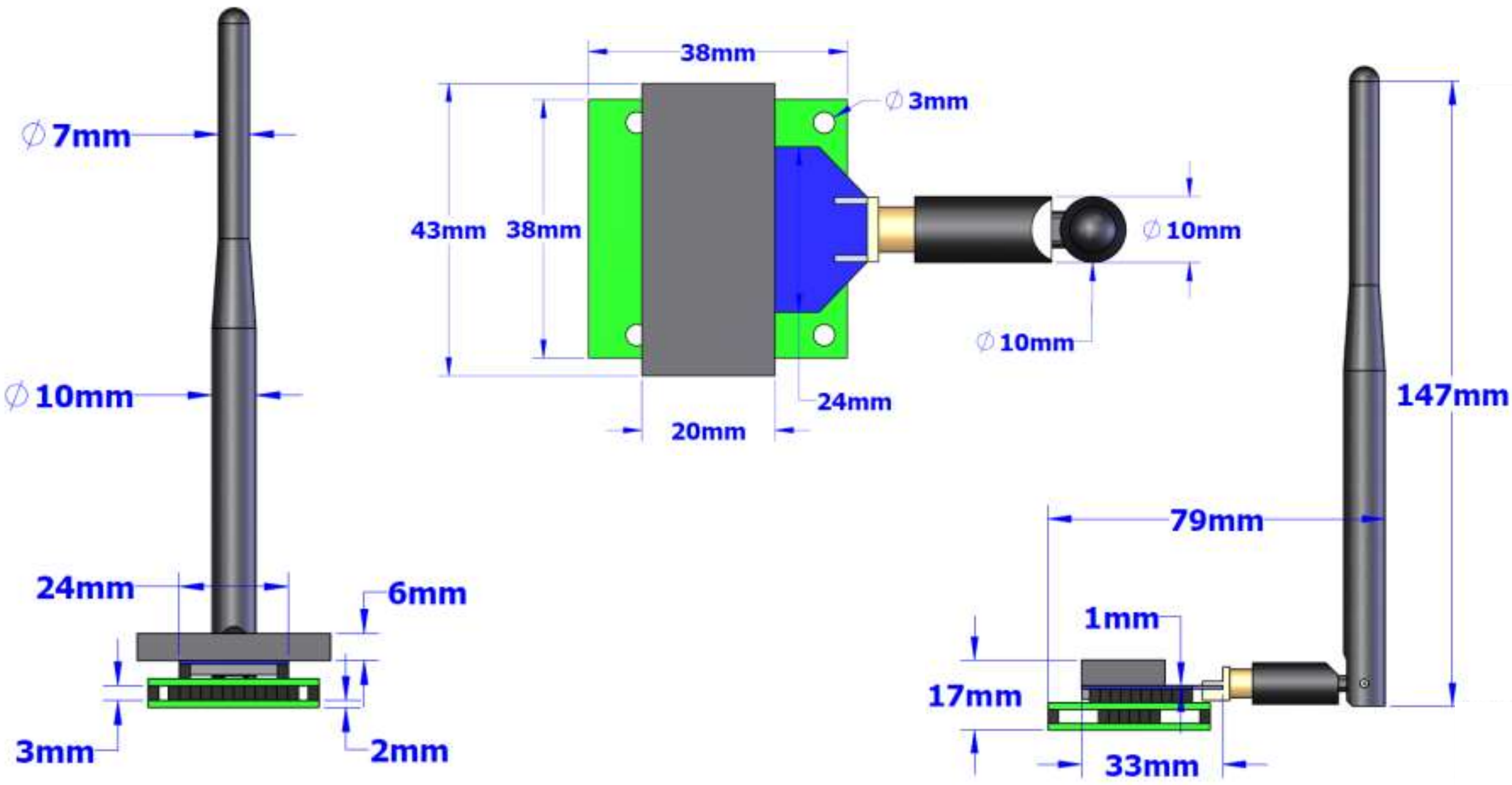
# SENSOR PACKAGE DIMENSIONS



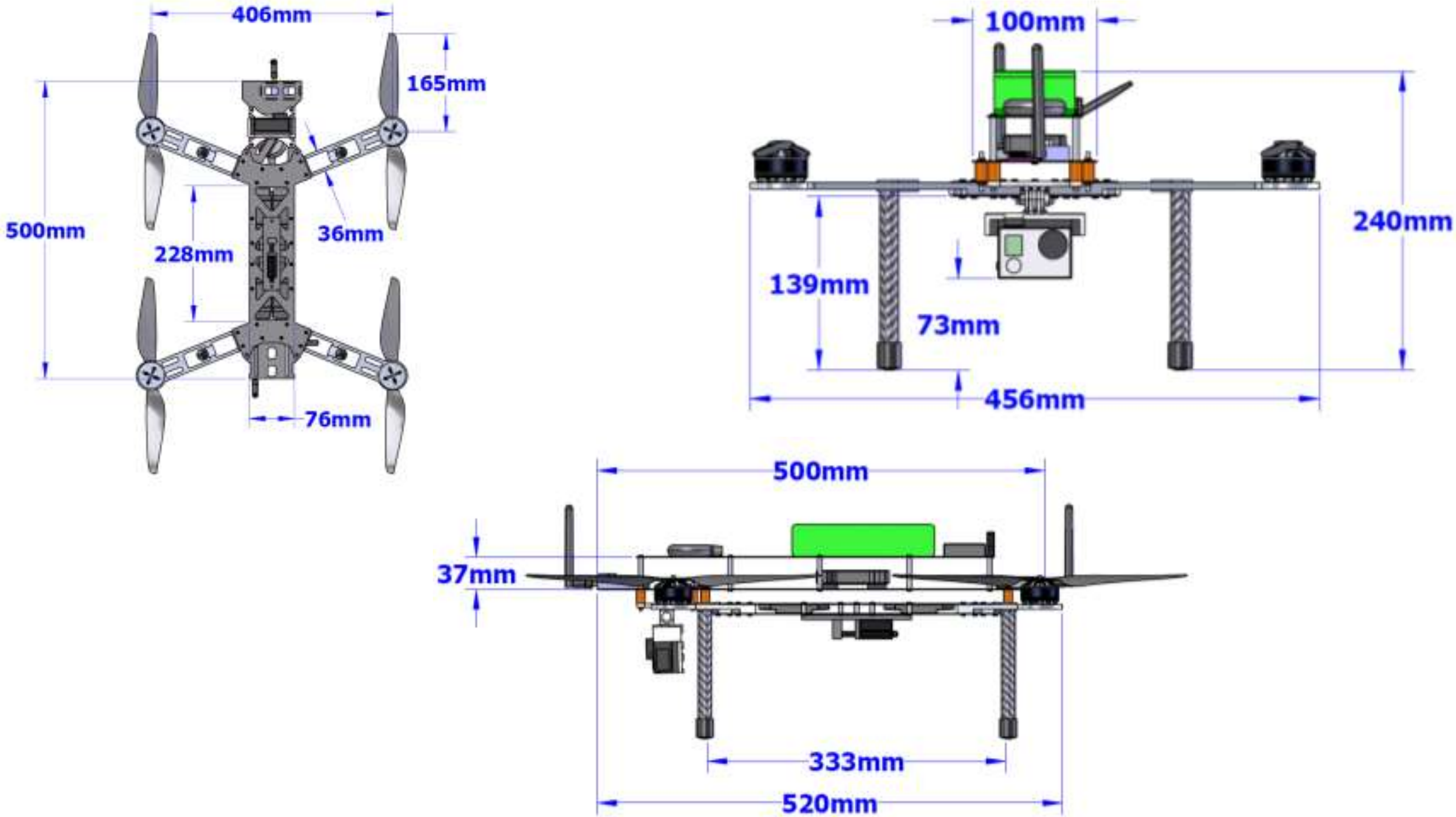



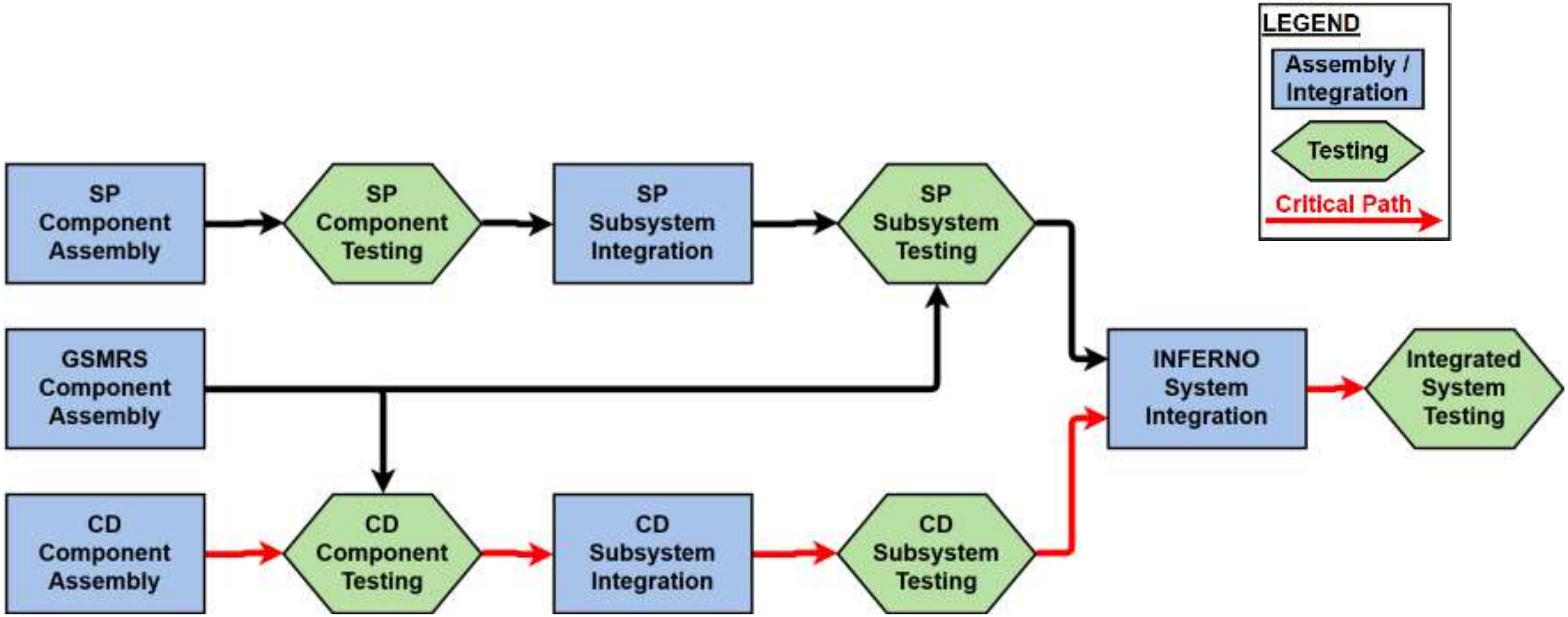
# SENSOR PACKAGE ELECTRONICS DIMENSIONS



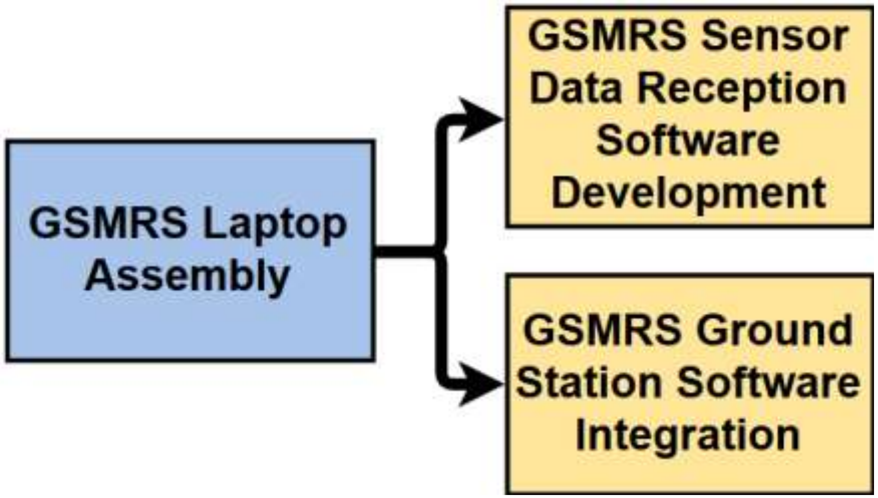
# CHILD DRONE DIMENSIONS

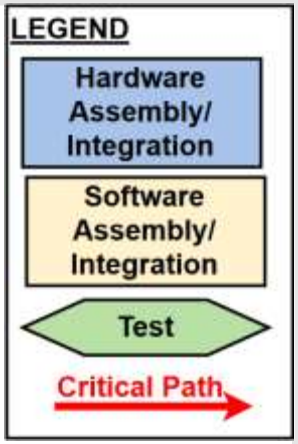


# ASSEMBLY, INTEGRATION & TEST (AI&T) FLOW

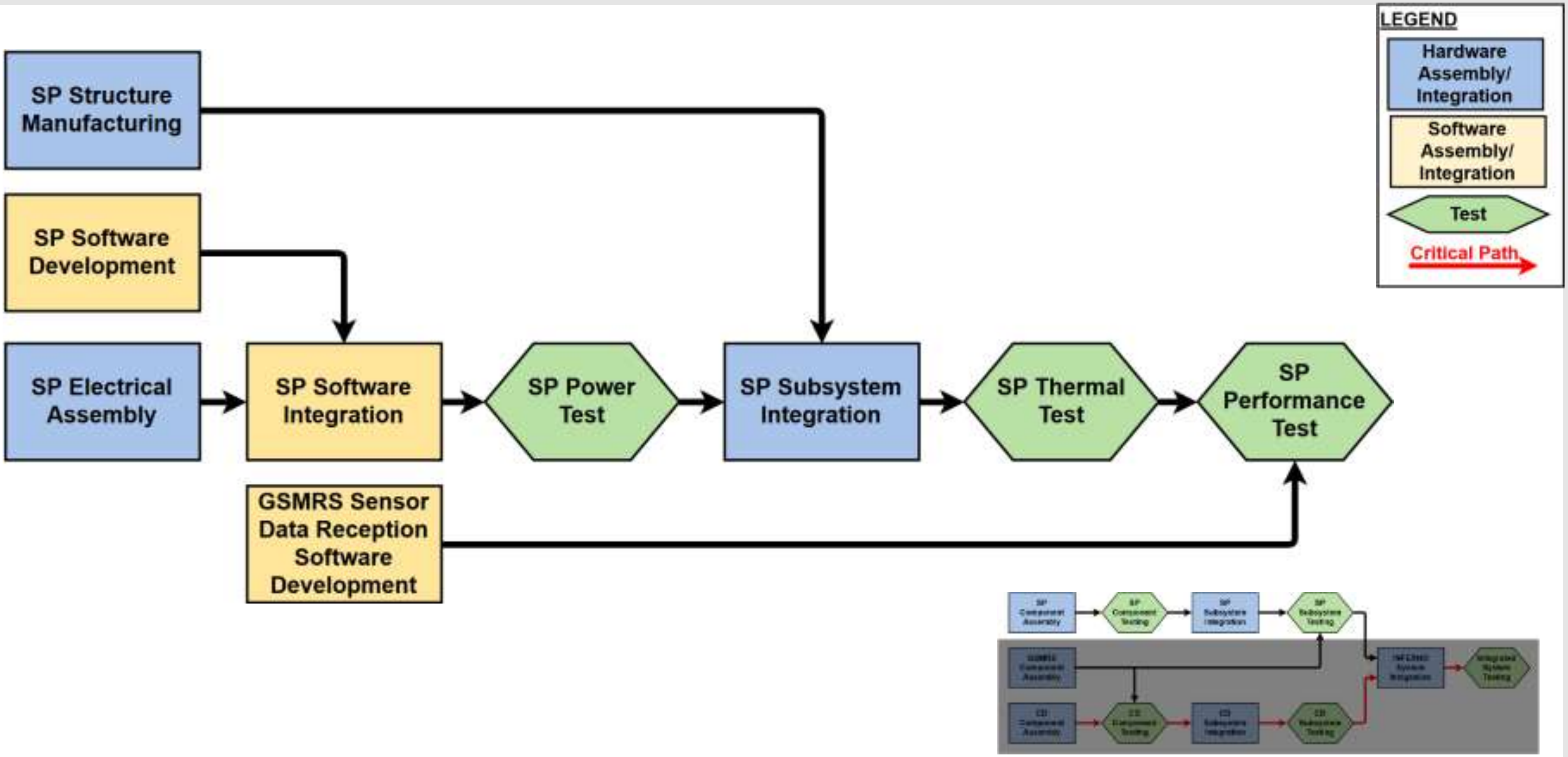


# AI&T FLOW – GSMRS

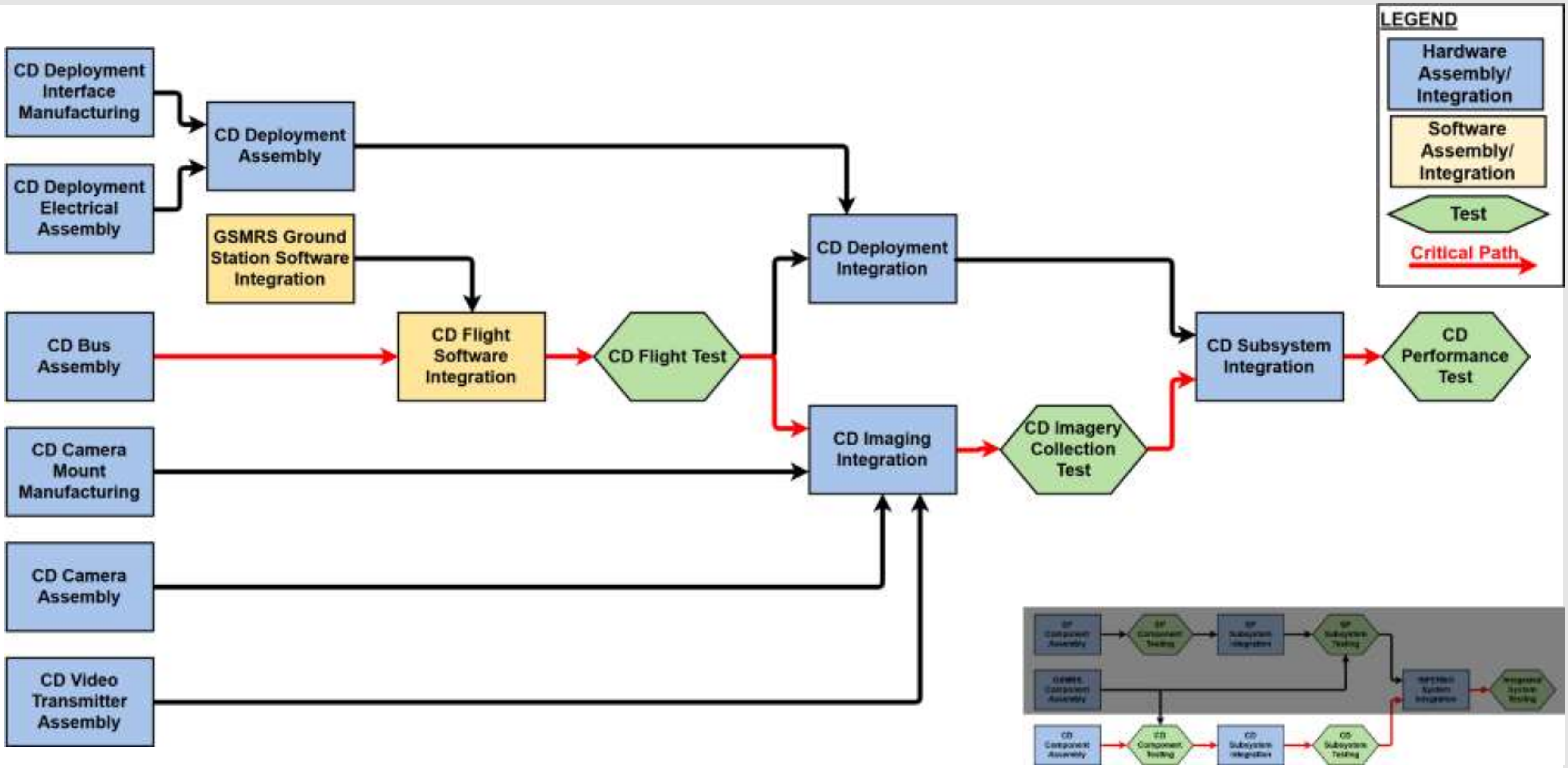


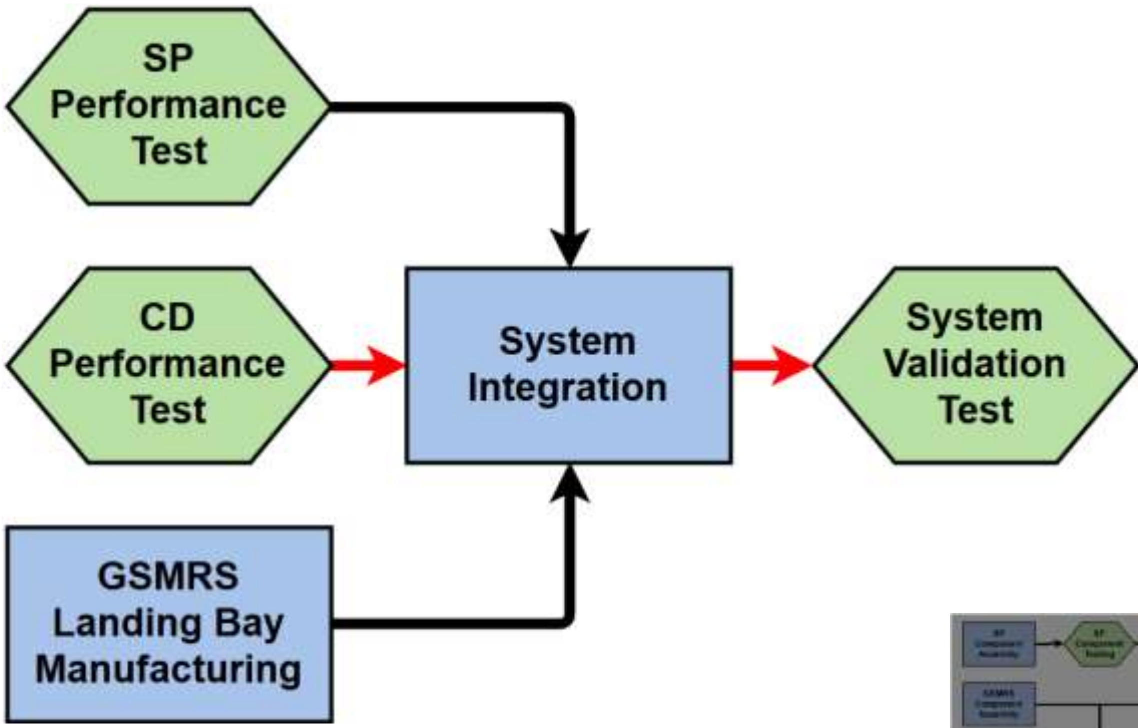

# AI&T FLOW – SENSOR PACKAGE

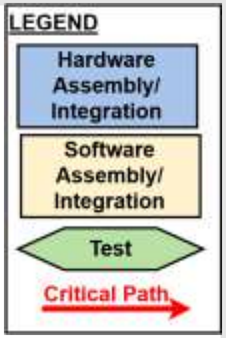


# AI&T FLOW – CHILD DRONE



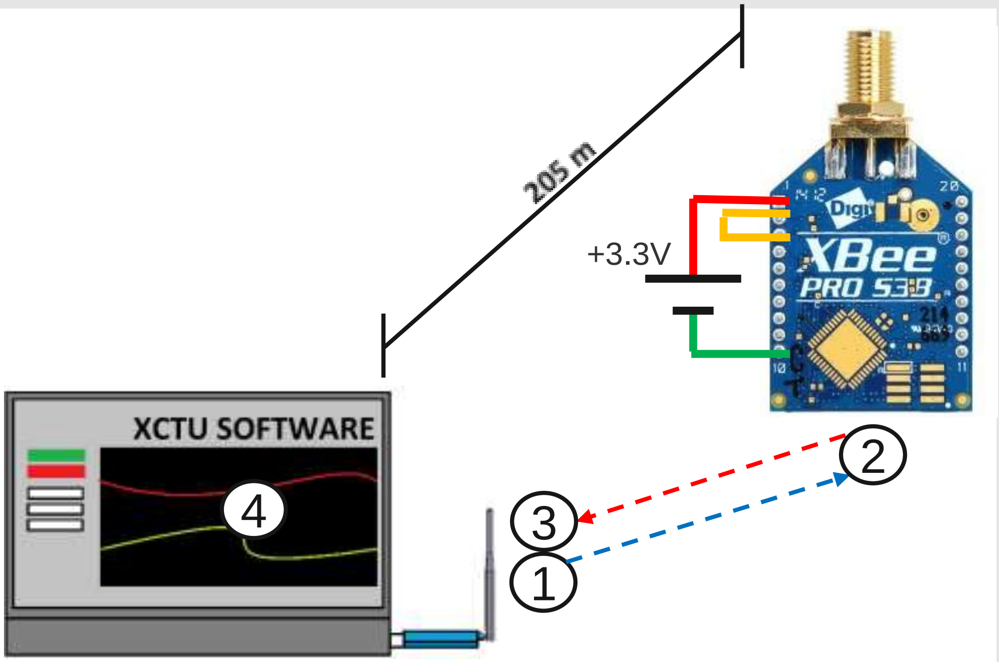
# AI&T FLOW – INTEGRATED SYSTEM




# V&V – SENSOR PACKAGE LINK BUDGET VERIFICATION

- Executed at South Campus
- Comparison of analytical link budget with RSSI during testing
- Identical test setup already used for communications prototyping



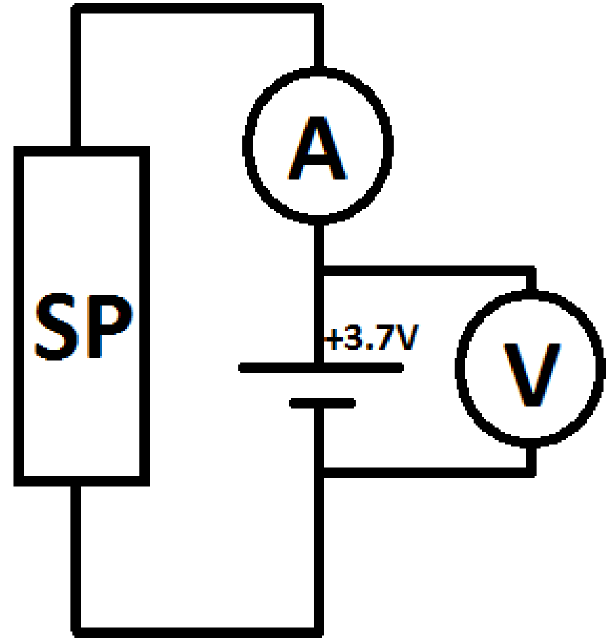

- Overview
  1. Local XBee running XCTU transmits pre-defined data packets
  2. Remote XBee receives and re-transmits data packets
  3. XCTU calculates RSSI in dB
  4. RSSI compared with analytical link budget results

**Conclusions:**
- Test setup already prototyped
- Does not require any subsystem integration

# V&V – SENSOR PACKAGE POWER TEST

- Executed at ITLL or Aerospace Labs
- Verify SP power system and storage capability
  - ***DRs 1.1.2.1, 1.1.2.2, 1.1.3***
- Verifies SP power models
- Requires electronic/software integration of SP

- Overview:
  - Ammeter/voltmeter at battery terminals
  - SP collects/stores/transmits data for 1 hour
  - Voltage and current determine power/charge consumed
  - Will enable refinement of thermal model

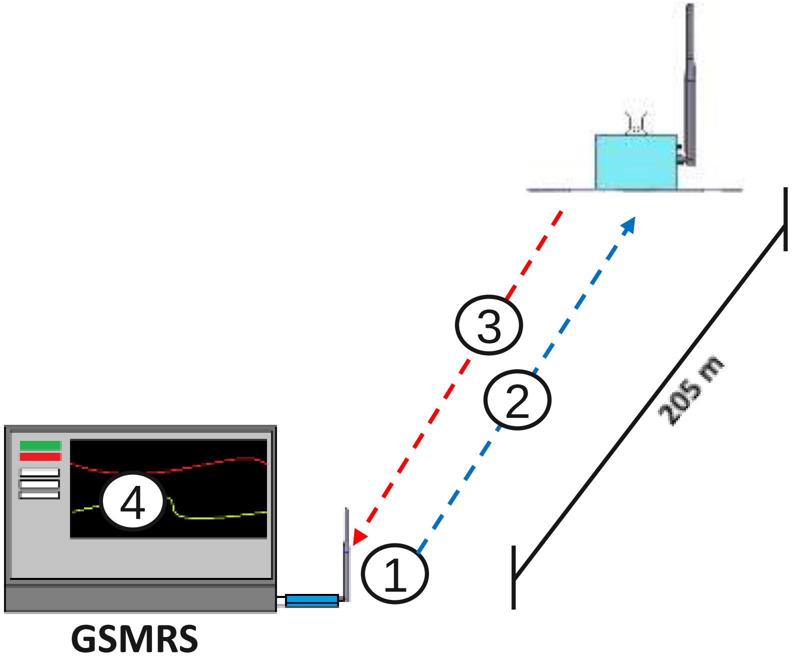



<u>Conclusions:</u>
- Testing facilities available
- Requires minimal resources

# V&V – SENSOR PACKAGE PERFORMANCE TEST

- Executed at South Campus
- Verify integrated SP subsystem data collection, transmission, and reception under operational conditions
  - ***DRs 1.1, 1.1.2, 5.3***

- Overview:
  1. Sensor Package placed 205m from GSMRS
  2. GSMRS commands SP to collect/transmit data
  3. GSMRS receives and plots data through 1 hour
  4. Data analyzed for compliance with requirements

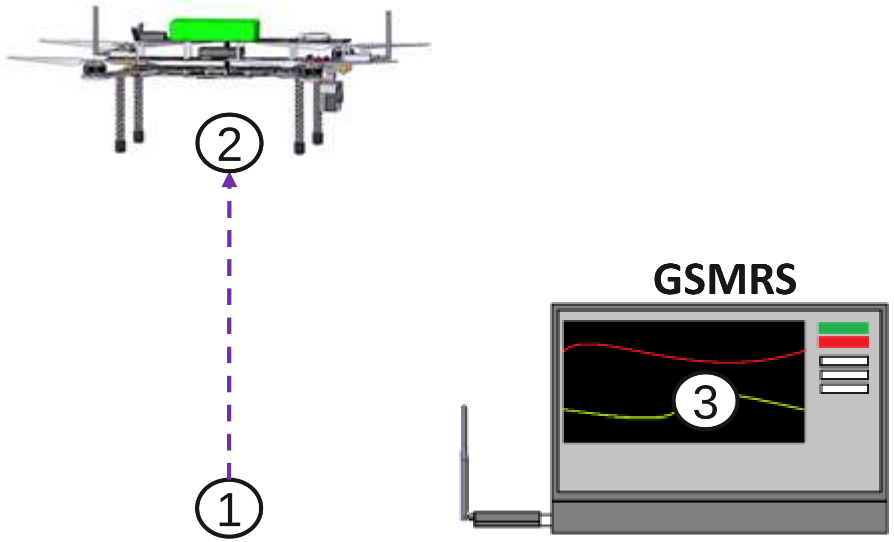



**Conclusions:**
- Completes verification of SP subsystem

# V&V – CHILD DRONE FLIGHT POWER MODEL VERIFICATION

- Executed at RECUV
- Verify CD hovering power model
- Requires CD bus/flight software integration

- Overview:
  1. CD commanded to takeoff and hover
  2. CD remains at hover for 10 minutes, then lands
  3. Battery power/charge consumption assessed through voltage/current telemetry logs (10 Hz sample rate)

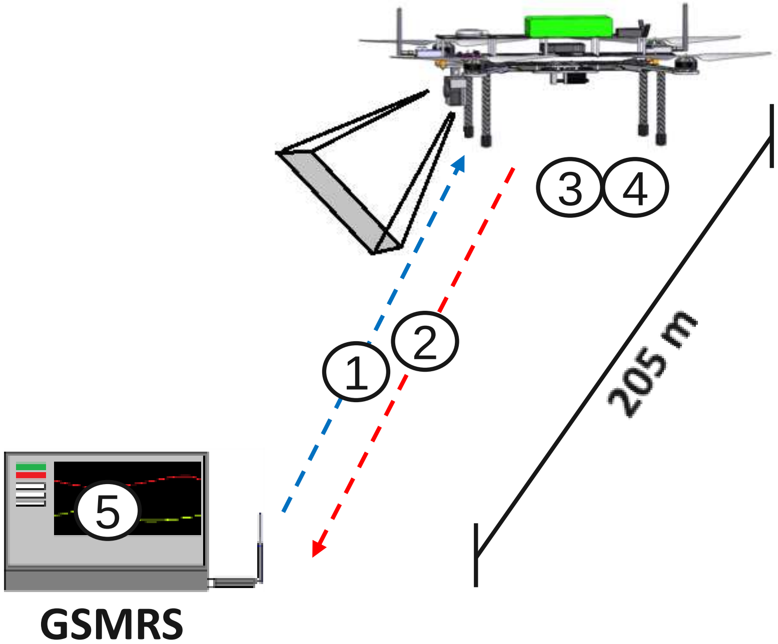



**Conclusions:**
- Key developmental test
- Verifies CD power model

# V&V – CHILD DRONE IMAGE COLLECTION TEST

- Executed at ITLL/Aerospace Labs and Table Mountain
- Verify image quality, recording, and transmission during flight
  - ***DRs 2.1, 2.1.1, 2.1.3, 3.1, 3.1.1, 5.2***

- Overview:
  1. CD placed >205 m away from GSMRS, then commanded to begin image recording/transmission
  2. GSMRS receives and displays video from CD
  3. CD commanded to takeoff and hover for 15 minutes
  4. CD commanded to land and stop recording
  5. Imagery post-processed to verify compliance with requirements



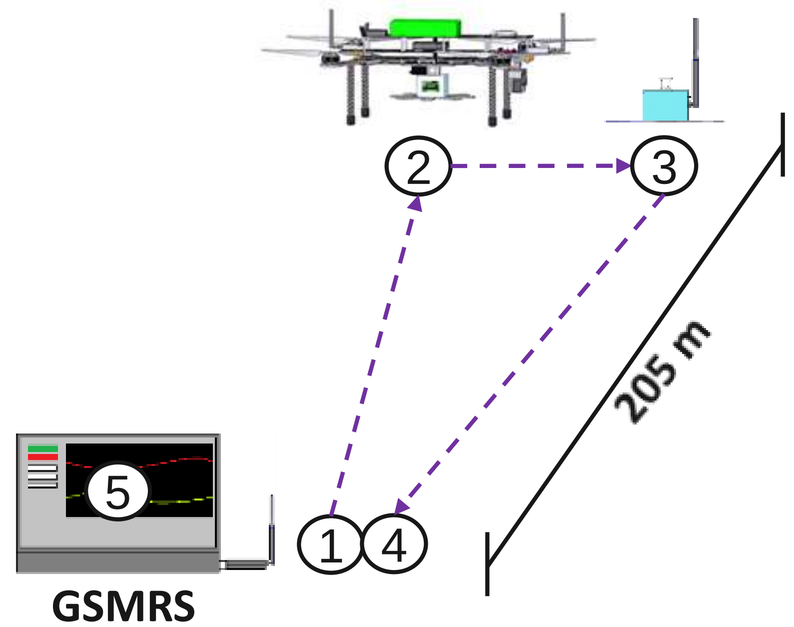

<u>Conclusions:</u>

- Verifies image recording and transmission requirements

# V&V – CHILD DRONE PERFORMANCE TEST

- Executed at Table Mountain
- Verifies integrated CD range, airspeed, hovering, deployment with SP mass simulator
  - ***DRs 1.2, 1.2.1, 1.2.2, 1.3.1, 1.3.2***

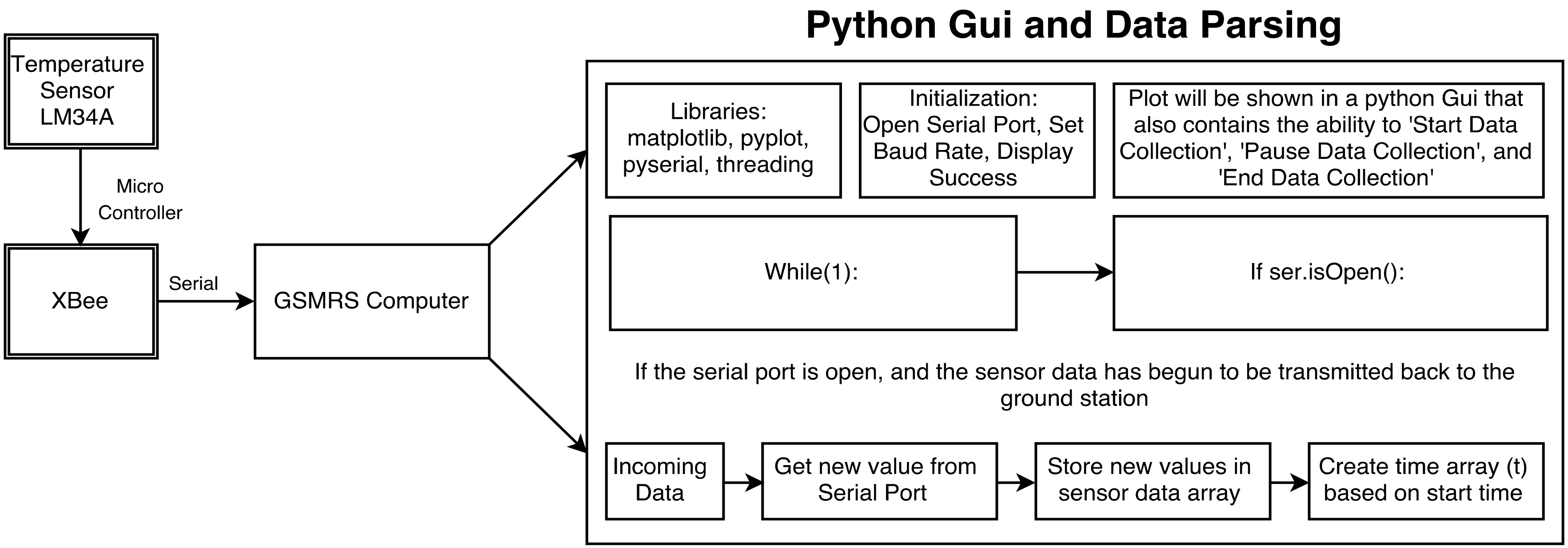
- Overview:
  1. CD commanded to begin imagery and takeoff
  2. CD flies to LOI at >10 m/s and remains at hover until 5 min have elapsed
  3. CD lands and deploys SP mass simulator
  4. CD returns to GSMRS and hovers until 15 min have elapsed, then lands
  5. SP positioning and telemetry logs post-processed to ensure compliance




<u>Conclusions:</u>
- Verifies CD flight as complete subsystem

# GSMRS - SOFTWARE (DATA INTERPRETATION)

- The temperature data that is obtained needs to be displayed to the users are the ground station



# GSMRS - COMMUNICATIONS


## **GSMRS Comms Integration**

| GSMRS Communications Components | | | |
|---|---|---|---|
| | XBee-Pro XSC S3B | 3DR Radio Set | 3DR Video Set |
| Frequency | 900 MHz | 900 MHz | 5.8 GHz |
| Sensitivity | -109 dBm | -117 dBm | -90 dBm |
| Software | XCTU | Mission Planner | Mission Planner |

INFERNO:

- GSMRS will integrate each communication system
- GSMRS meets the following requirements:
  - FR 4.0, FR 5.0

# LEVELS OF SUCCESS

| Levels | CD | Imaging | Sensor | GSMRS |
|---|---|---|---|---|
| **1** | - Capable of flight with simulated payload<br>- Deployment of SP simulated<br>- Manually piloted | - Time stamped video at 420p at 30fps<br>- Wired communication with CD<br>- 8MP pictures taken on command | - Wired communication with GSMRS<br>- Time stamped temperature data collected at 1 Hz, 8 bit resolution | - Stationary workbench<br>- Wired data transmission and reception |
| **2** | - 10 minute loaded flight time<br>- Translational flight capable<br>- Lands and deploys SP upon command | - Wireless communication with CD<br>- Time Stamped video recorded at 720p at 30fps | - Established wireless communication or handshake with GSMRS at 200m<br>- Store 1 hour of data | - Wireless data transmission and reception |
| **3** | - 15 minute loaded flight time<br>- 5 m/s translational flight<br>- Lands and deploys SP at LOI within 10m upon command<br>- Manually piloted takeoff and landing with autonomous waypoints for translation | - Time stamped video recorded at 1080p at 30 fps | - >50% wireless data transmission to GSMRS at 200m | - Portable simulator |
| **4** | - 10 m/s translational flight capable<br>- Lands and deploys SP at LOI within 5m upon command<br>- Fully autonomous with the exception of landing on GSMRS | - Time stamped video transmitted at 720p at 30 fps | - >90% wireless data transmission to GSMRS at 200m<br>- Retransmission of data possible | - Data transmission and reception GUI |

# BUDGET DETAILS – CHILD DRONE

| Child Drone Manufacturing | | | | | |
|---|---|---|---|---|---|
| Part Name | Description | Unit Cost | Quantity | Discounts | Total Cost |
| Lumenier QAV500 V2 | Airframe w/ Aluminum Arms | $318.00 | 1 | 0.00% | $318.00 |
| 3DR Pixhawk | Flight Controller | $200.00 | 1 | 15.00% | $170.00 |
| Tall CF Landing Gear | From Lumenier for QAV500 | $40.00 | 1 | 0.00% | $40.00 |
| T-Motor MN3508-16 700 kV | Propeller Motors | $70.00 | 4 | 0.00% | $280.00 |
| Multistar Timber 13x4.5 Props | Propellers (pair) | $18.00 | 4 | 0.00% | $72.00 |
| Lumenier 30A ESC | Elec. Speed Controllers | $25.00 | 4 | 0.00% | $100.00 |
| Multistar 4S 10Ah 10C | Battery | $59.00 | 1 | 0.00% | $59.00 |
| Rctimer NEO-M8 GPS/Compass | GPS | $50.00 | 1 | 0.00% | $50.00 |
| Polou 12V, 2.2A Step-Down Reg | Voltage Regulator | $10.00 | 1 | 0.00% | $10.00 |
| Polou 5V, 1A Step-Down Reg | Voltage Regulator | $8.00 | 1 | 0.00% | $8.00 |
| Polou 5V Step-Up Reg | Voltage Regulator | $5.00 | 2 | 0.00% | $10.00 |
| Orange RC Bobbins (4pcs with nuts) | Silicone Bobbins (set of 4) | $13.00 | 2 | 0.00% | $26.00 |
| P30N06LE | Mosfet Switches | $0.95 | 4 | 0.00% | $3.80 |
| Misc. Electrical Parts | | $100.00 | 1 | 0.00% | $100.00 |
| 3D printed Deployment Attachment | | $10.00 | 1 | 0.00% | $10.00 |
| Firgelli PQ12 | Linear Actuator | $65.00 | 1 | 0.00% | $65.00 |
| Screws | M3 10 mm | $0.04 | 2 | 0.00% | $0.08 |
| | | | | Child Drone Total | $1,322 |

# BUDGET DETAILS – IMAGING

| Imaging System Manufacturing | | | | | |
|---|---|---|---|---|---|
| Part Name | Description | Unit Cost | Quantity | Discounts | Total Cost |
| GoPro Hero 3 | Camera | $300.00 | 1 | 100.00% | $0.00 |
| 3DR Video/OSD System Kit | Video Transmission System | $190.00 | 1 | 15.00% | $161.50 |
| 3DR MinimOSD Cable for Pixhawk | Cables to connect video to flight controller | $4.00 | 1 | 15.00% | $3.40 |
| 3DR 5.8 GHz Cloverleaf Antenna Kit | High gain antenna | $17.00 | 6 | 15.00% | $86.70 |
| AV to USB Adapter | | $30.00 | 1 | 0.00% | $30.00 |
| Tarot Gimbal FPV/OSD Video Cable | | $10.00 | 1 | 0.00% | $10.00 |
| 3D Print - Damping Base and Top Plate | 10 Prints to account for damaged / iterations | $10.00 | 10 | 0.00% | $100.00 |
| Misc. Electrical Parts | | $100.00 | 1 | 0.00% | $100.00 |
| | | | | Imaging System Total | $292 |

# BUDGET DETAILS – SENSOR PACKAGE

| Sensor Package Manufacturing | | | | | |
|---|---|---|---|---|---|
| Part Name | Description | Unit Cost | Quantity | Discounts | Total Cost |
| Xbee Pro 900 MHz | XBP9B-XCST-001 | $42.00 | 1 | 0.00% | $42.00 |
| In-House PCB | | $88.00 | 2 | 0.00% | $176.00 |
| Temperature Sensor | LM34CA | $8.00 | 2 | 0.00% | $16.00 |
| Structural Materials | Foam | $20.00 | 1 | 0.00% | $20.00 |
| | Acrylic | $10.00 | 1 | 0.00% | $10.00 |
| PCB Mounting | Standoffs | $0.45 | 4 | 0.00% | $1.80 |
| | Screws | $0.40 | 4 | 0.00% | $1.60 |
| Battery - 450 mAh 3.7 V | Tenergy (company) | $7.59 | 1 | 0.00% | $7.59 |
| Antenna - 900 MHz | | $10.00 | 1 | 0.00% | $10.00 |
| 3D printed attachment point | | $5.00 | 1 | 0.00% | $5.00 |
| | | | | Sensor Package Total | $290 |

# BUDGET DETAILS – GSMRS AND MISCELLANEOUS

| GSMRS Manufacturing | | | | | |
|---|---|---|---|---|---|
| Part Name | Description | Unit Cost | Quantity | Discounts | Total Cost |
| 3DR Radio Set | Telemetry Comms System | $100.00 | 1 | 0.00% | $100.00 |
| FrSky Taranis X9D-Plus and X8R | Manual Control System | $225.00 | 1 | 0.00% | $225.00 |
| Xbee Pro 900 MHz | XBP9B-XCST-001 | $42.00 | 1 | 0.00% | $42.00 |
| | | | | GSMRS Total | $367 |

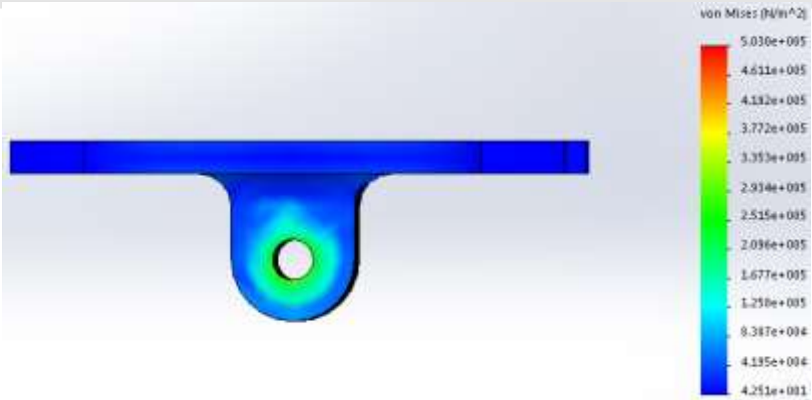
| Additional Costs | | | | | |
|---|---|---|---|---|---|
| Part Name | Description | Unit Cost | Quantity | Discounts | Total Cost |
| Printing | Poster, Final Report | $200.00 | 1 | 0.00% | $100.00 |
| | | | | GSMRS Total | $367 |

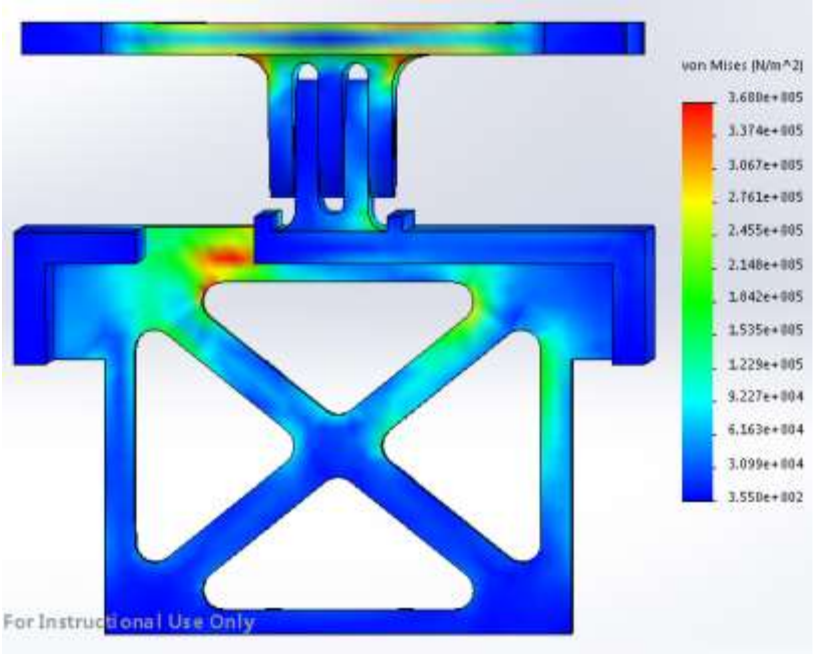
# IMAGING SYSTEM – STRESS ANALYSIS

- Evaluated under static 2g load
- ABSplus P430 plastic
- Static frictional coefficient 0.08

- Moment and normal force calculated analytically
  - Moment = 0.0779 N-m
  - Normal Force = 276N

| Calculation | Maximum Stress [MPa] | Yield Stress [MPa] | Factory of Safety |
|---|---|---|---|
| Analytic | 1.170 | 30 | 25.7 |
| SolidWorks FEM | 0.503 | | 59.6 |



# WORK BREAKDOWN STRUCTURE