PRELIMINARY DESIGN REVIEW

INFERNO

INtegrated Flight-Enabled Rover For Natural disaster Observation

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PRESENTATION OUTLINE

- Project Overview
  - CONOPS
  - FBD
  - Baseline Design
- Feasibility Studies
  - Child Drone
  - Communications
  - Software
- Summary
  - Feasibility Summary
  - Budget
  - Test Plans

PROJECT CONTEXT AND OVERVIEW

INFERNO MISSION STATEMENT

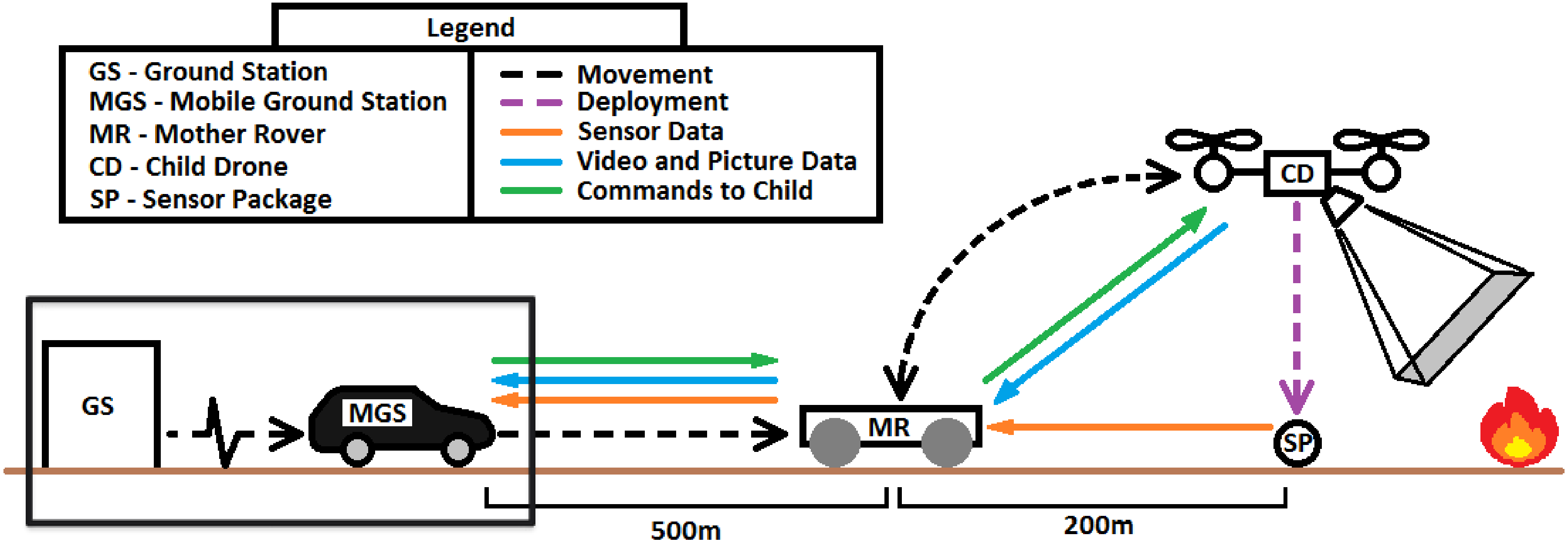
Design and create an ***aerial sensor package delivery system*** *for future integration with a natural disaster observation system.*

INFERNO PROJECT HERITAGE

2008-2009 | 2009-2010 | 2010-2011 | 2011-2012 | 2012-2013 | 2013-2014 | 2014-2015

- TREADS disassembled
- INFERNO is not reliant on heritage systems

FIRE TRACKER SYSTEM



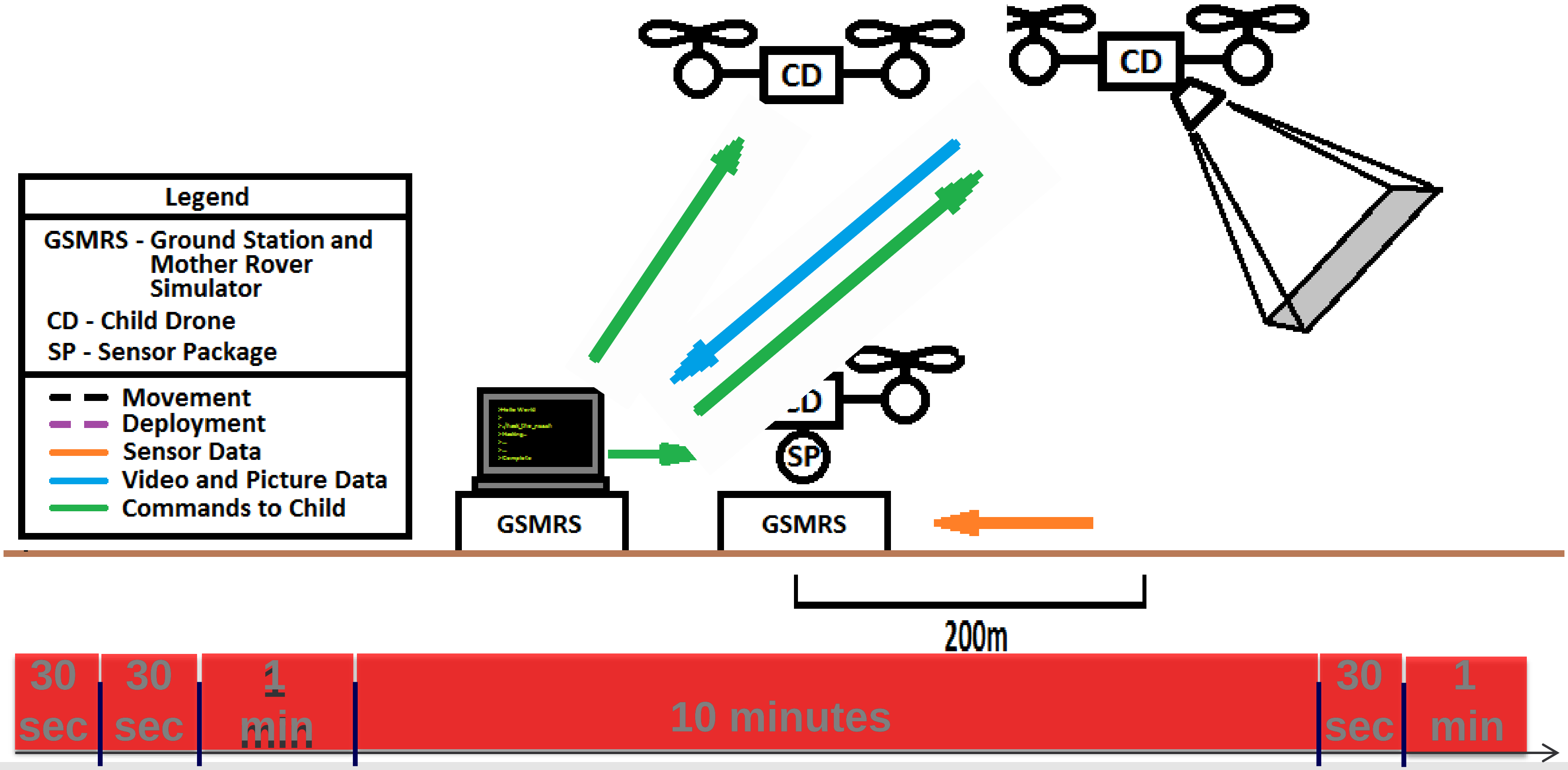
Legend

GS - Ground Station
MGS - Mobile Ground Station
MR - Mother Rover
CD - Child Drone
SP - Sensor Package

▬ ▬ Movement
▬ ▬ Deployment
▬ Sensor Data
▬ Video and Picture Data
▬ Commands to Child

INFERNO SCOPE: CONCEPT OF OPERATIONS

The CD [illegible] This data is transmitted to the GSMRS [illegible] to 5 meter accuracy.



Legend

GSMRS - Ground Station and Mother Rover Simulator
CD - Child Drone
SP - Sensor Package

- ▬ ▬ Movement
- ▬ ▬ Deployment
- ▬ Sensor Data
- ▬ Video and Picture Data
- ▬ Commands to Child

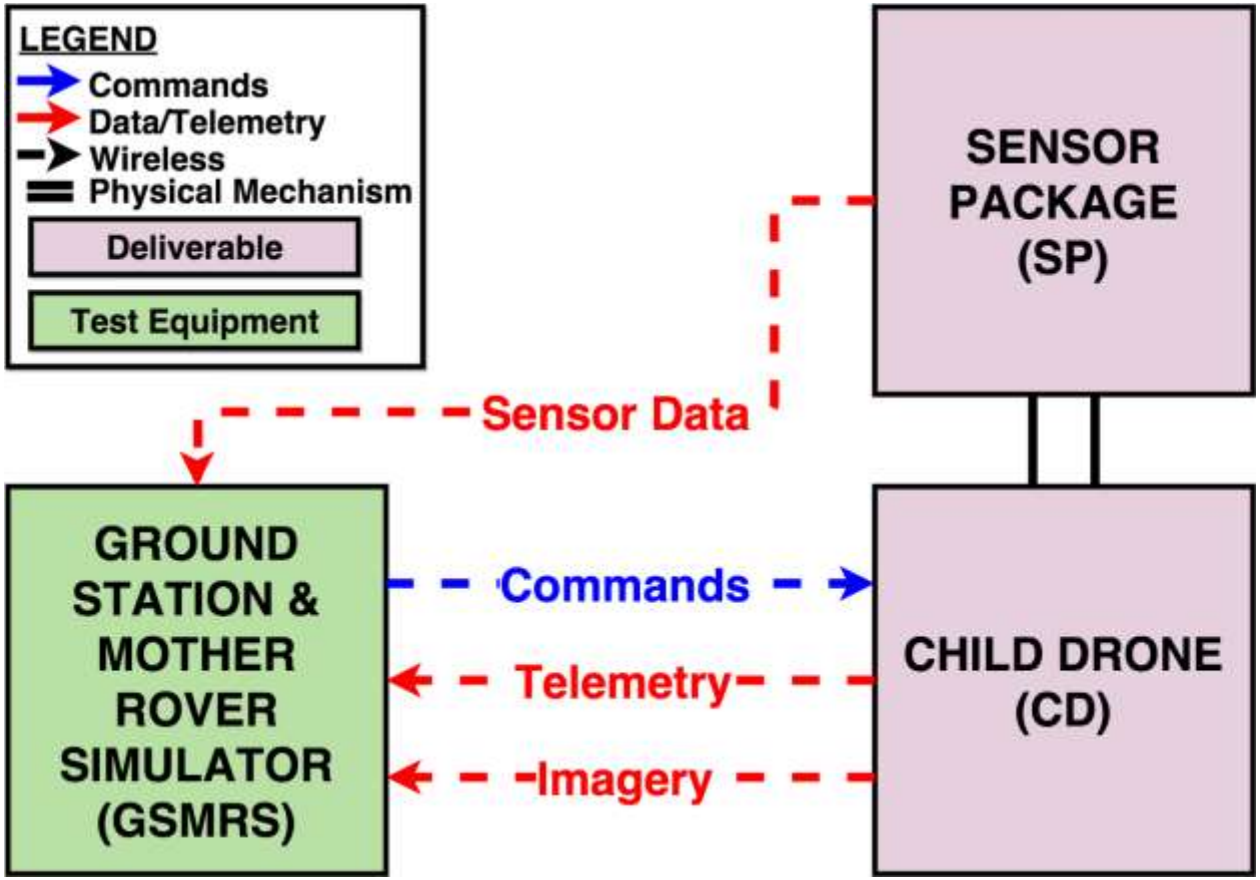
FUNCTIONAL REQUIREMENTS

Functional Requirement	Description
FR 1.0	The GSMRS shall transmit wireless commands to the CD
FR 2.0	The CD shall receive wireless commands from the GSMRS
FR 3.0	The CD shall take off from the GSMRS
FR 4.0	The CD shall fly to GPS coordinates
FR 5.0	The CD shall deploy the SP to a ground location of interest (LOI)
FR 6.0	The CD shall be capable of recording video footage
FR 7.0	The CD shall be capable of capturing photos

FUNCTIONAL REQUIREMENTS

Functional Requirement	Description
FR 8.0	The CD shall transmit wireless data to the GSMRS
FR 9.0	The GSMRS shall receive wireless data from the CD
FR 10.0	The CD shall land on the GSMRS docking bay
FR 11.0	The SP shall acquire ground temperature data after deployment
FR 12.0	The SP shall transmit wireless data to the GSMRS
FR 13.0	The GSMRS shall receive wireless data from the SP

FUNCTIONAL BLOCK DIAGRAM



LEGEND

- Commands
- Data/Telemetry
- Wireless
- Physical Mechanism
- Deliverable
- Test Equipment

SENSOR PACKAGE (SP)

Sensor Data

GROUND STATION & MOTHER ROVER SIMULATOR (GSMRS)

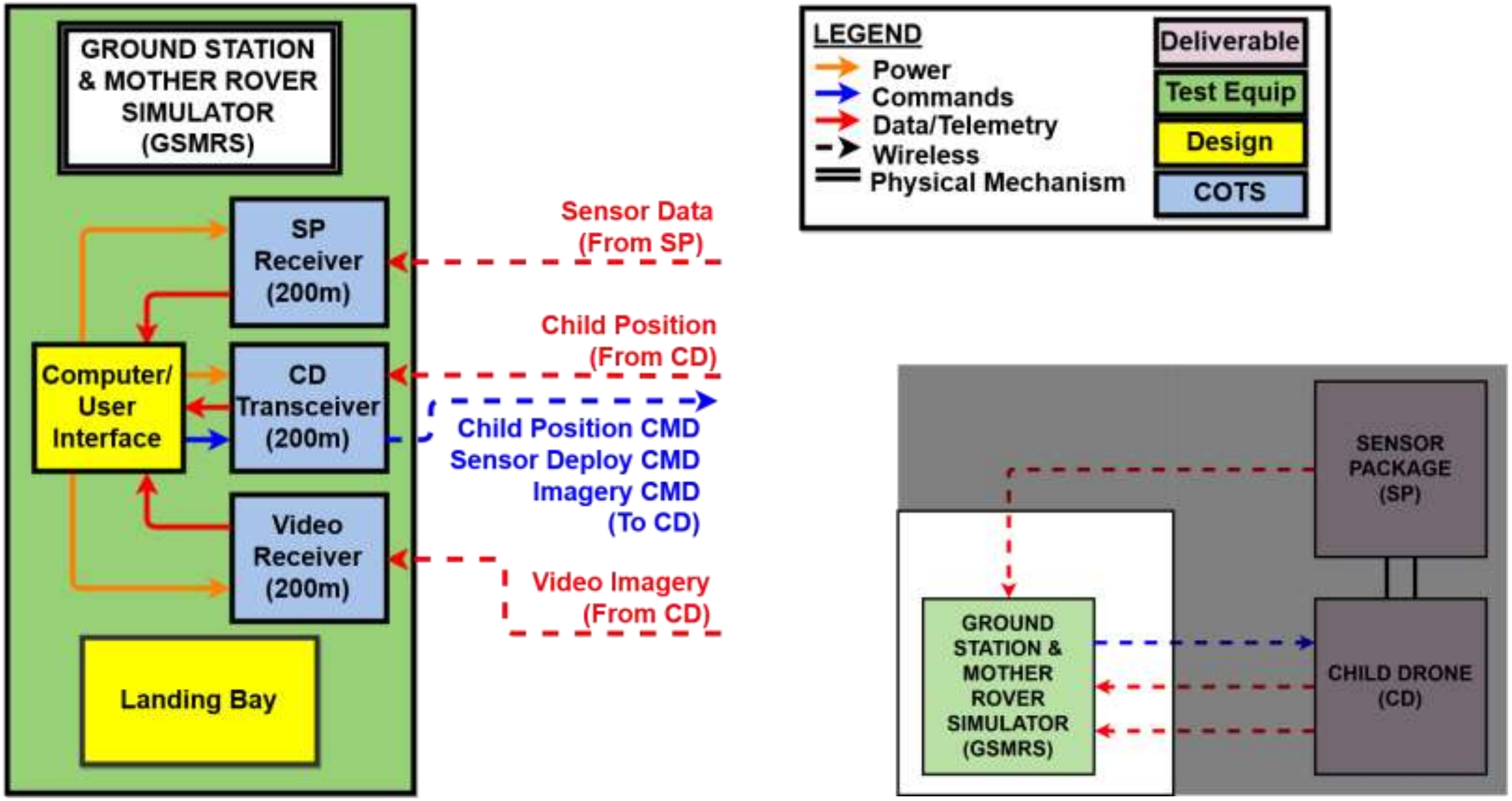
Commands

Telemetry

Imagery

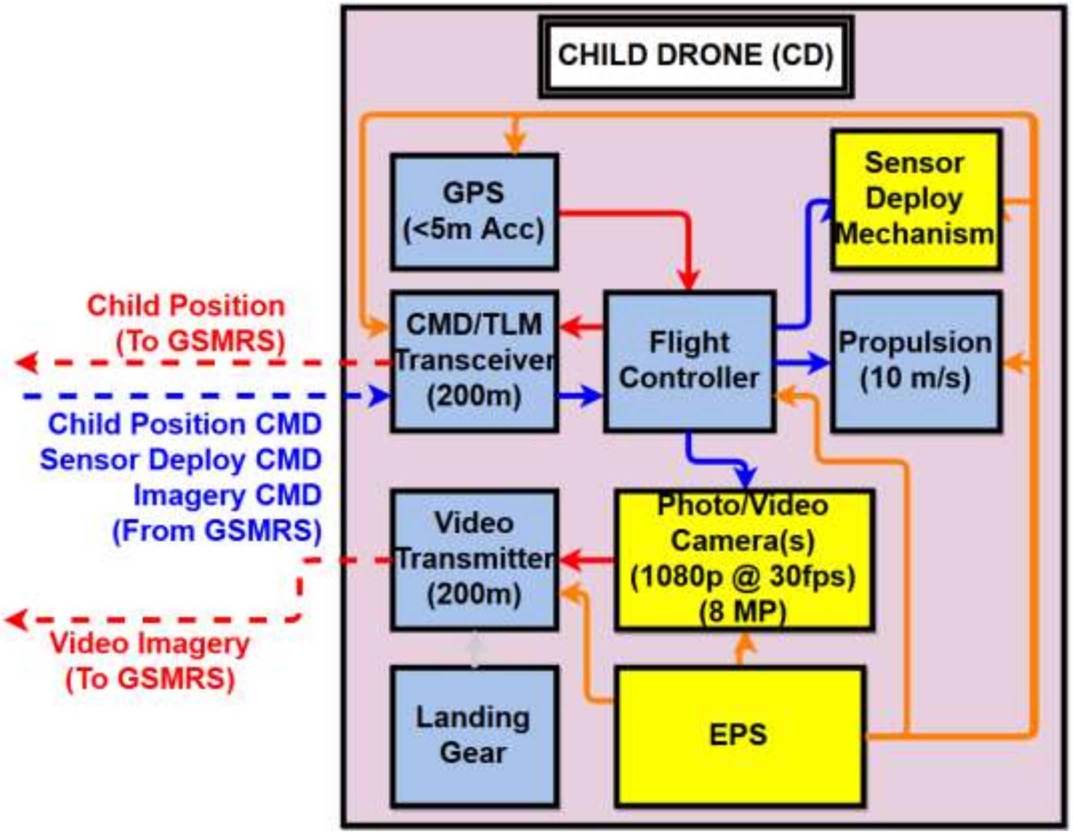
CHILD DRONE (CD)

FUNCTIONAL BLOCK DIAGRAM: GSMRS



Project Context | Child Drone | Communication | Software | Future Work

FUNCTIONAL BLOCK DIAGRAM: CHILD DRONE



CHILD DRONE (CD)

GPS (<5m Acc)

Sensor Deploy Mechanism

CMD/TLM Transceiver (200m)

Flight Controller

Propulsion (10 m/s)

Video Transmitter (200m)

Photo/Video Camera(s) (1080p @ 30fps) (8 MP)

Landing Gear

EPS

Child Position (To GSMRS)

Child Position CMD
Sensor Deploy CMD
Imagery CMD
(From GSMRS)

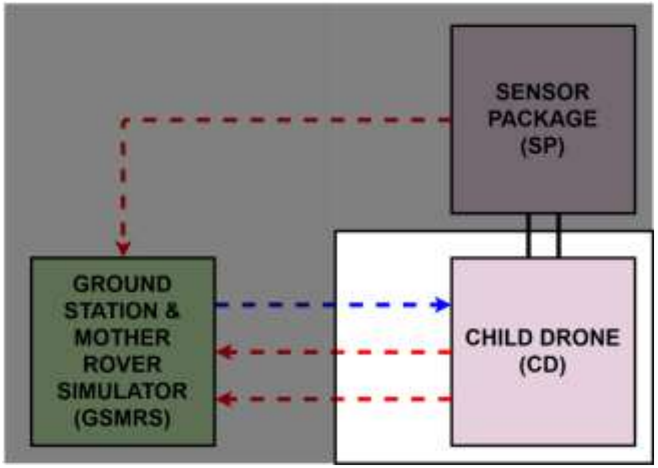
Video Imagery (To GSMRS)

LEGEND

- → Power
- → Commands
- → Data/Telemetry
- - → Wireless
- ═ Physical Mechanism

EPS = Electrical Power Subsystem

- Deliverable
- Test Equip
- Design
- COTS

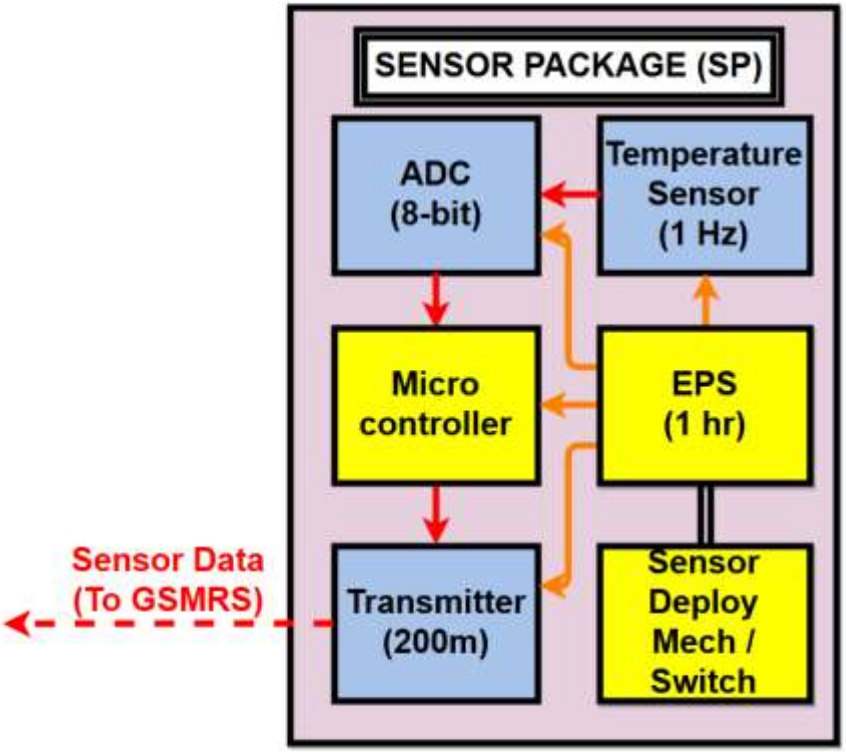


SENSOR PACKAGE (SP)

GROUND STATION & MOTHER ROVER SIMULATOR (GSMRS)

CHILD DRONE (CD)

FUNCTIONAL BLOCK DIAGRAM: SENSOR PACKAGE



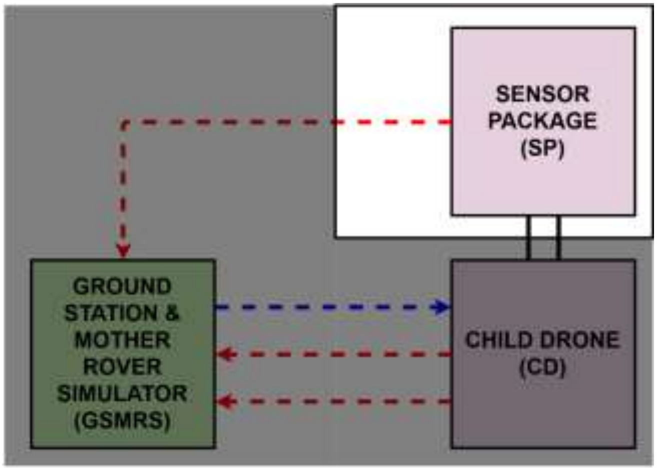
LEGEND

- → Power
- → Commands
- → Data/Telemetry
- - -➤ Wireless
- ═ Physical Mechanism

EPS = Electrical Power Subsystem

- Deliverable
- Test Equip
- Design
- COTS

ADC = Analog/Digital Converter



AIRFRAME TRADE STUDY: RATINGS

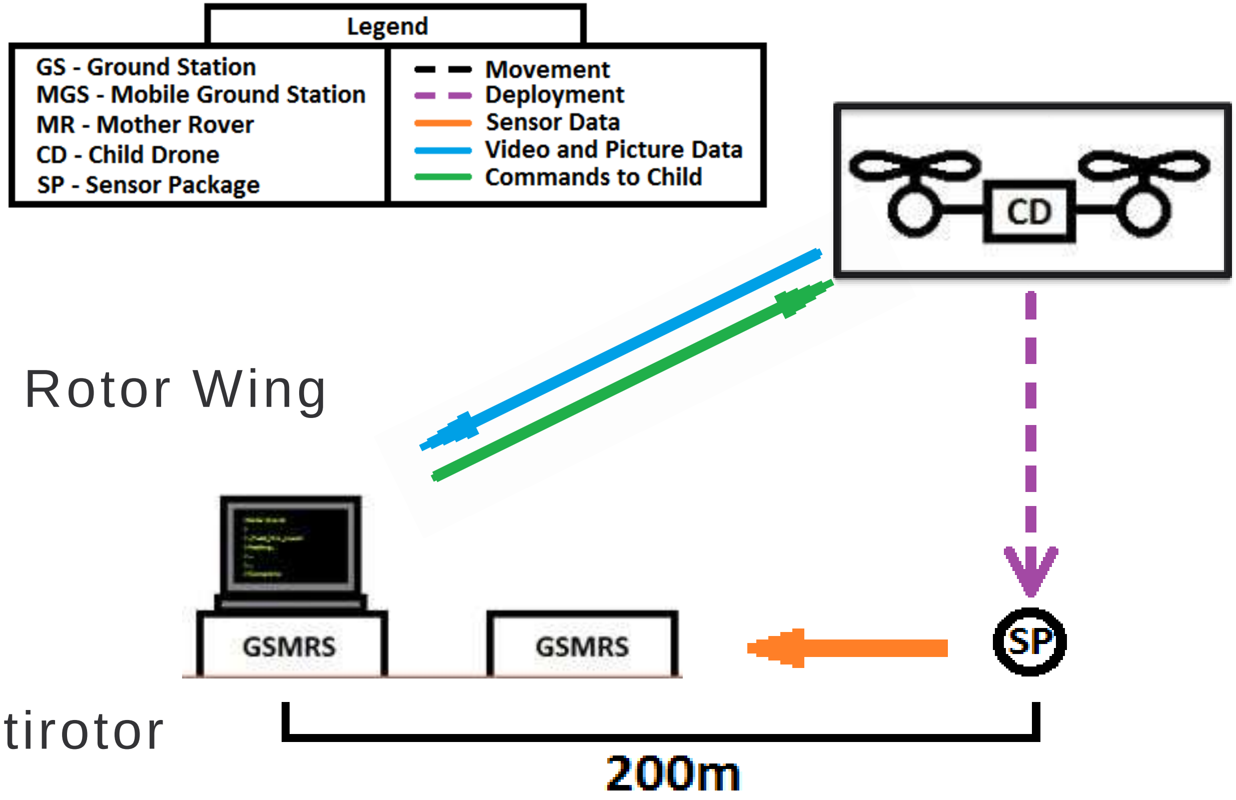
		Helicopter		Multicopter		CoaxCopter	
Criteria	**Weight**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Availability	0.33	**4**	1.32	**4**	1.32	**1**	0.33
SW Integration	0.33	**4**	1.32	**4**	1.32	**2**	0.66
HW Integration	0.20	**3**	0.60	**5**	1.00	**3**	0.60
Ease of Flight/Stability	0.10	**3**	0.30	**5**	0.50	**1**	0.10
Safety	0.04	**1**	0.04	**3**	0.12	**5**	0.20
Total	**1**	**3.58**		**4.26**		**1.89**	

BASELINE DESIGN: INFERNO

- Child drone
  - Fixed Wing
  - Rotor Wing
  - Lighter Than Air

- Down Selected to Rotor Wing
  - Helicopter
  - Multirotor
  - CoaxCopter

- Final Choice: Multirotor



Legend

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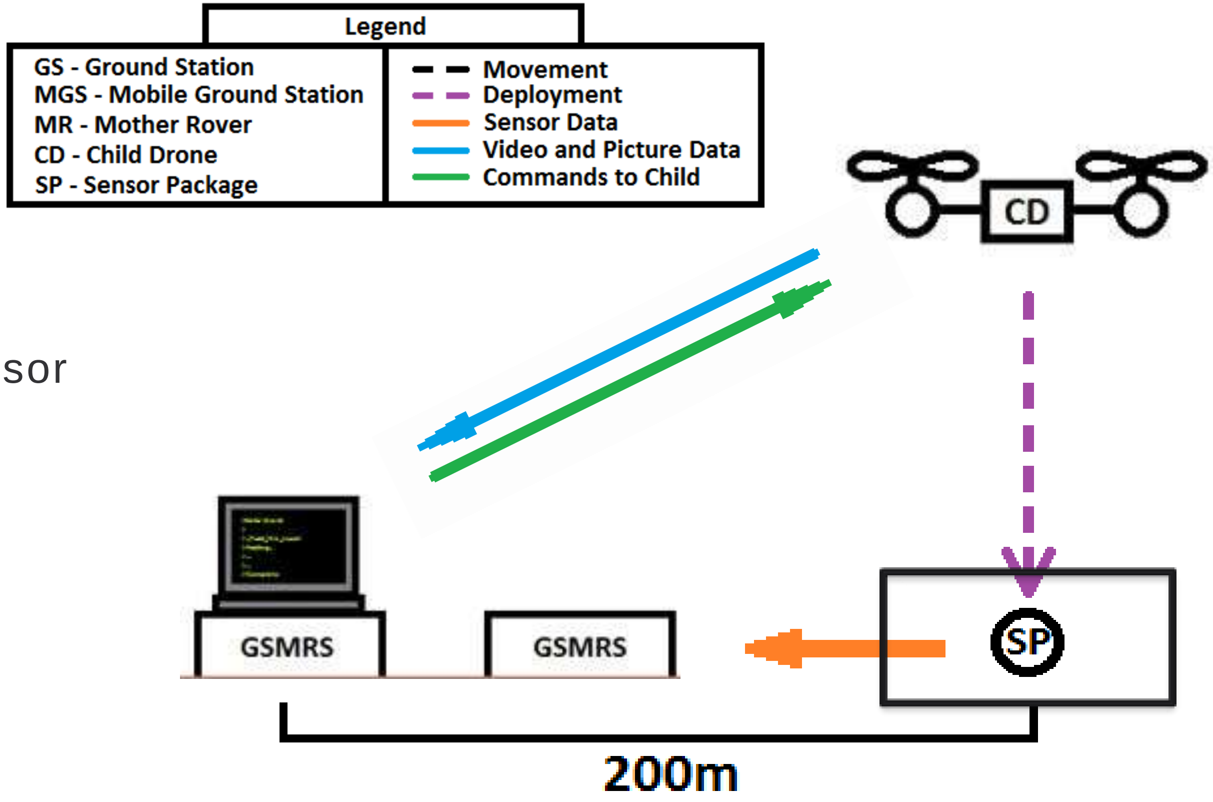
— —	Movement
— —	Deployment
—	Sensor Data
—	Video and Picture Data
—	Commands to Child

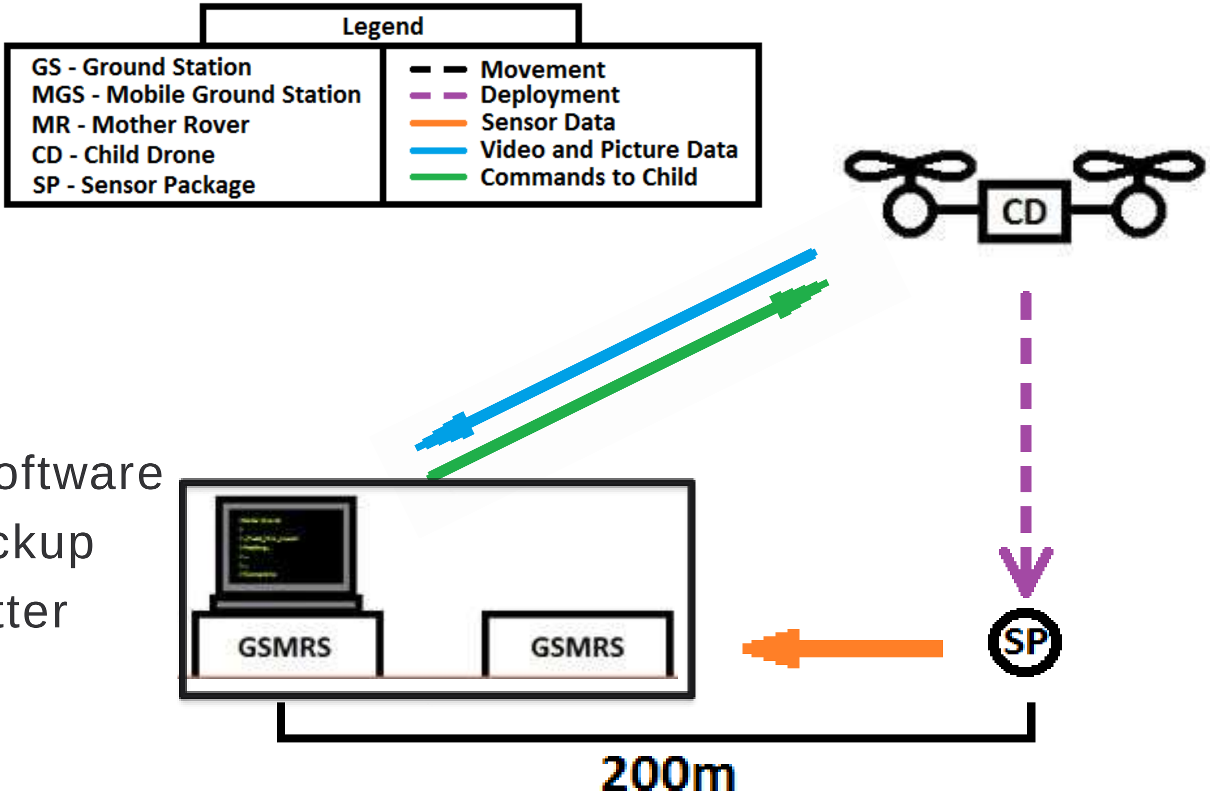
BASELINE DESIGN: INFERNO

- Sensor Package
  - Custom Built
    - Transmitter
    - Power
    - Structure
    - Temperature Sensor
- Design Concerns
  - Mass
  - Survivability
  - Communications



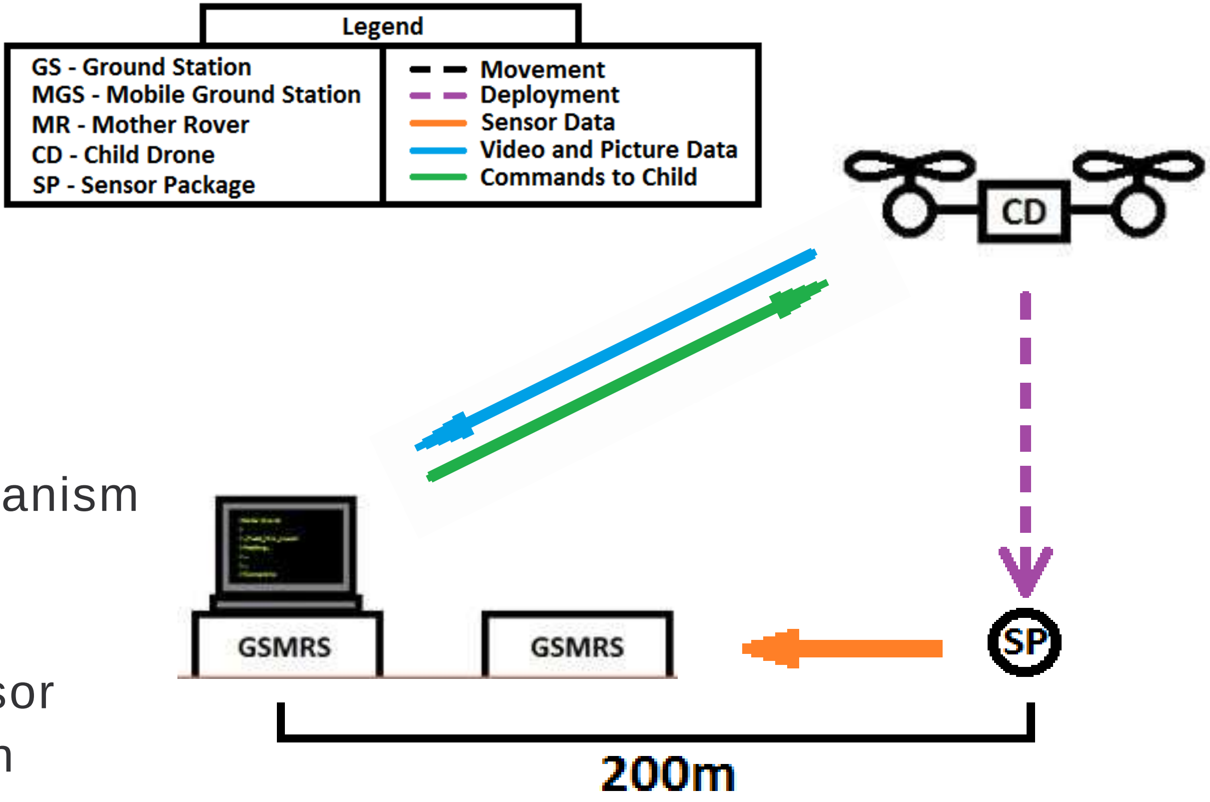
BASELINE DESIGN: INFERNO

- GSMRS
  - Commanding
  - Information Hub
  - Data Processing
- Components
  - Ground Control Software
  - Mother Rover Mockup
  - Receiver/Transmitter
  - Laptop



BASELINE DESIGN: SYSTEM

- GSMRS
  - Laptop
  - COTS Software
- Child Drone
  - Multicopter
  - COTS Software
  - Imaging System
  - Deployment Mechanism
- Sensor Package
  - Custom Built
  - Temperature Sensor
  - Data Transmission



CHILD DRONE FEASIBILITY ANALYSIS

CHILD DRONE: OVERVIEW

Requirement	Description
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CHILD DRONE FEASIBILITY: MASS BUDGET

- Child Drone “BUS”
  - Frame, motors, props, battery lift all mission systems
- Must be able to:
  - Take off/land from GSMRS ***(FRs 3.0, 10.0)***
  - Carry electronics, imaging, and payload ***(FRs 5.0, 6.0, 7.0)***
  - Fly for 15 minutes ***(FR 4.0)***

Components	Estimated Mass (g)
Flight Electronics	80
Imagery System	185
SP/Deployment Mechanism	400
Total	665

CHILD DRONE FEASIBILITY: FLIGHT/POWER MODEL

- Early hovering flight performance/power model ***(FR 4.0)***
  - Worst case scenario
- Assumptions:
  - Steady, incompressible 1D flow
  - Ideal disk actuator
  - Electronics power draw negligible
  - 1630 m altitude
  - $\eta_{motor} * \eta_{prop} = 0.405$

CHILD DRONE FEASIBILITY: POSSIBLE AIRFRAMES

- 3DR X8+
  - **Ready-to-fly coaxial quadcopter**
  - Takeoff weight 2.560 kg
  - Takeoff weight w/ payload 3.144 kg ***(FRs 4.0, 6.0)***
  - 14.8 V battery
  - Small footprint ***(FRs 3.0, 10.0)***
  - Power achievable with LiPo
- **FEASIBLE**

Parameter	Calculated
Total Current	40.0 A
Total Power	591 W
Charge Required (15 min, 25% margin)	12,500 mAh

CHILD DRONE FEASIBILITY: POSSIBLE AIRFRAMES

- DJI F450
  - **Quadcopter kit**
  - Frame weight 0.282 kg
  - Takeoff weight w/ payload 2.136 kg ***(FRs 4.0, 6.0)***
  - 14.8 V battery
  - Small footprint ***(FRs 3.0, 10.0)***
  - Power achievable w/ LiPo
- **FEASIBLE**

Parameter	Calculated
Total Current	24.6 A
Total Power	364 W
Charge Required (15 min, 25% margin)	7,700 mAh

CHILD DRONE FEASIBILITY: POWER BUDGET

Component	Time Used	Current	Capacity
Flight Controller	15 min	50 mA	13 mAh
Transceiver	15 min	215 mA	54 mAh
GPS Module	15 min	20 mA	5 mAh
SP Deployment Module	10 sec	450 mA	2 mAh
		TOTAL:	74 mAh

Percent of Total Charge Consumed:

3DR X8+: 0.7%

DJI F450: 1.3%

CHILD DRONE FEASIBILITY: SUMMARY

Requirement	Feasible?
FR 3.0: Take off from GSMRS	YES
FR 4.0: Fly to GPS waypoints	YES
FR 5.0: Deploy the SP	YES
FR 10.0: Land in GSMRS docking bay	YES

COMMUNICATIONS FEASIBILITY ANALYSIS

COMMUNICATIONS OVERVIEW

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FR 1.0	The GSMRS shall **transmit wireless commands** to the CD
FR 2.0	The CD shall **receive wireless commands** from the GSMRS
FR 8.0	The CD shall **transmit wireless data** to the GSMRS
FR 9.0	The GSMRS shall **receive wireless data** from the CD
FR 12.0	The SP shall **transmit wireless data** to the GSMRS
FR 13.0	The GSMRS shall **receive wireless data** from the SP

Successful Communication is a **Critical Project Element**

Project Context › **Child Drone** › **Communication** › **Software** › **Future Work**

COMMUNICATIONS OVERVIEW

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Successful Communication is a **Critical Project Element**

COMMUNICATIONS: LINK MARGIN CALCULATION

- Initial calculations for link margin based on below equation:

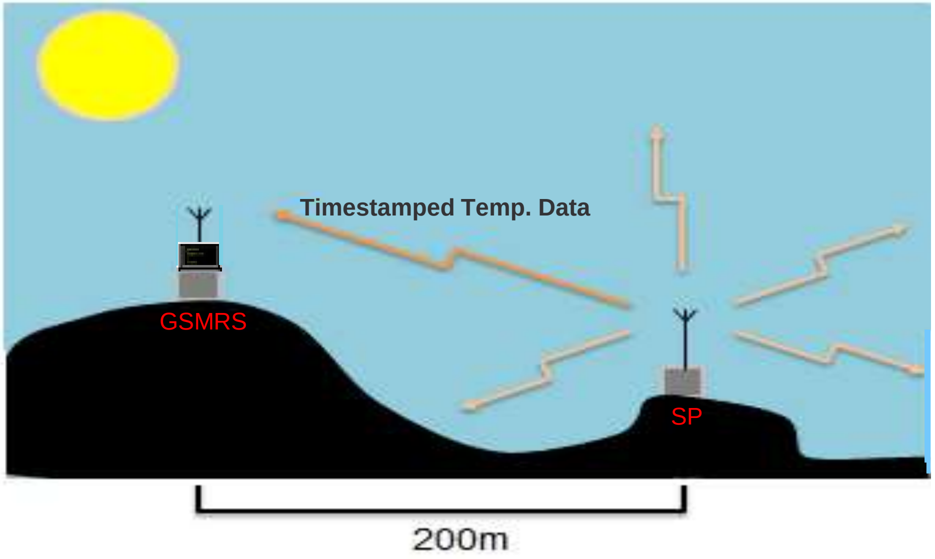
$$\mathit{Transmit\ Power} + \mathit{Transmit\ Gain} + \mathit{Receive\ Gain} - \mathit{Space\ Loss} - \mathit{Fade\ Margin} = \mathit{Power\ Received}$$

- System specifications give values for required minimum power received

- $\mathit{Link\ Margin} = P_r - P_{r_{min}}$

- If $\mathit{Link\ Margin} > \mathit{Design\ Margin}$ then the link is viable

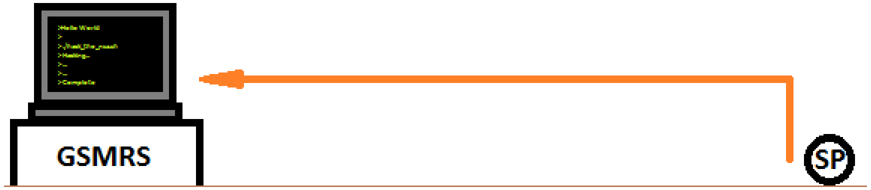
COMMUNICATIONS: SENSOR PACKAGE LINK ASSUMPTIONS



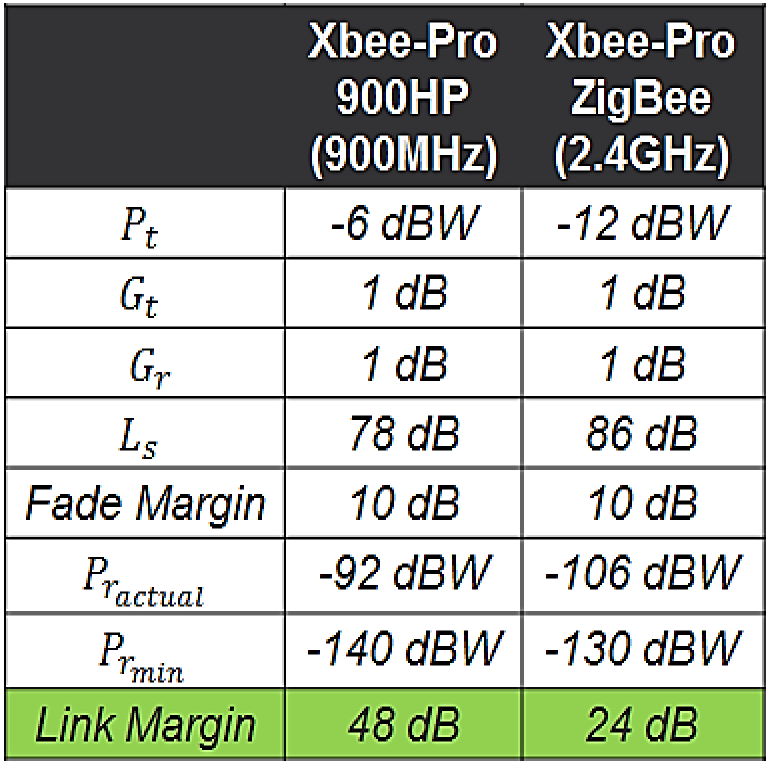
Assumptions
Primary loss: Space path loss
Additional losses accounted for in "Fade Margin"
Design Margin = 6 dB
Isotropic Emission
"Line of Sight" data transmission
Weather conditions free of rain/snow and fog

COMMUNICATIONS: SENSOR PACKAGE LINK FEASIBILITY

Sensor Package Link



- Xbee on both ends of communication link ***(FR 12.0, FR 13.0)***
- Timestamped temperature data rate ~ 110 bps ***(FR 11.0)***



	Xbee-Pro 900HP (900MHz)	Xbee-Pro ZigBee (2.4GHz)
P_t	-6 dBW	-12 dBW
G_t	1 dB	1 dB
G_r	1 dB	1 dB
L_s	78 dB	86 dB
Fade Margin	10 dB	10 dB
$P_{r_{actual}}$	-92 dBW	-106 dBW
$P_{r_{min}}$	-140 dBW	-130 dBW
Link Margin	48 dB	24 dB

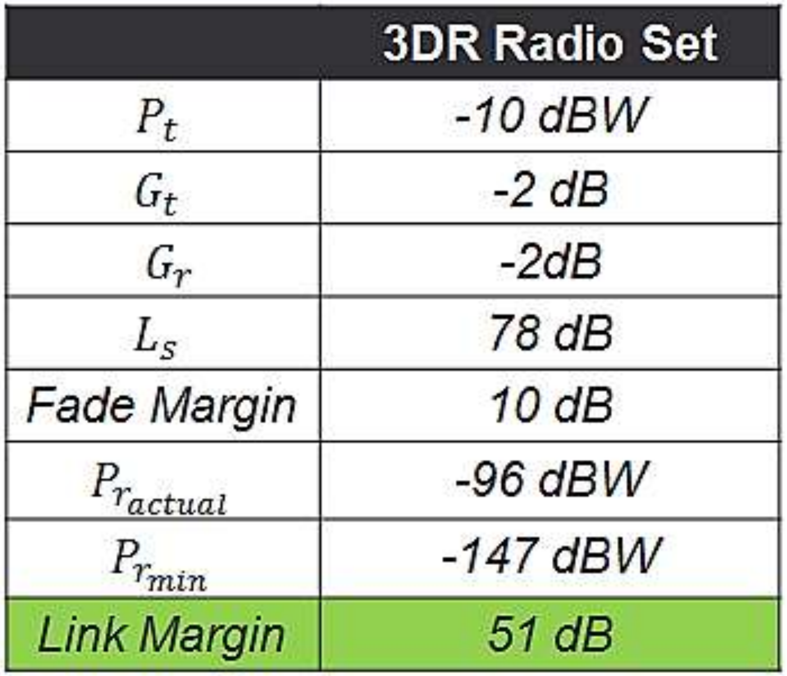
COMMUNICATIONS: CHILD DRONE LINK ASSUMPTIONS

Assumptions
Primary loss: Space path loss
Additional losses accounted for in “Fade Margin”
Design Margin: 8 dB (Uplink) 6 dB (Downlink)
“Line of Sight” data transmission
Weather conditions free of rain/snow and fog

COMMUNICATIONS: CHILD DRONE TELEMETRY/COMMAND LINK

3DR Radio Set

- Allows GSMRS to send commands and receive telemetry ***(FR 1.0, FR 2.0)***
- Allows CD to transmit telemetry and receive commands ***(FR 8.0, FR 9.0)***
- 3DR Radio Set
  - Uplink Data Rate: 64 kbps
  - Downlink Data Rate: 64 kbps



	3DR Radio Set
P_t	-10 dBW
G_t	-2 dB
G_r	-2dB
L_s	78 dB
Fade Margin	10 dB
$P_{r_{actual}}$	-96 dBW
$P_{r_{min}}$	-147 dBW
Link Margin	51 dB

COMMUNICATIONS: CHILD DRONE IMAGING LINK

3DR Video Transmitter

- Allows CD to transmit video ***(FR 6.0, FR 7.0, FR 8.0)***
- Allows GSMRS to receive video ***(FR 9.0)***
- 3DR Video Transmitter
  - Uplink Data Rate: 64 kbps
  - Downlink Data Rate: 7.5 Mbps

	3DR Video Transmitter
P_t	3 dBW
G_t	14 dB
G_r	14 dB
L_s	94 dB
$Fade\ Margin$	10 dB
$P_{r\,actual}$	-73 dBW
$P_{r\,min}$	-120 dBW
$Link\ Margin$	47 dB

COMMUNICATIONS: LINK FEASIBILITY SUMMARY

- Link Margin is feasible for SP-GSMRS and CD-GSMRS

	SP Link	CD Imaging System Link	CD Command Link
P_t	-6 dBW	3 dBW	-10 dBW
G_t	1 dB	14 dB	-2 dB
G_r	1 dB	14 dB	-2 dB
L_s	78 dB	94 dB	78 dB
$Fade\ Margin$	10 dB	10 dB	10 dB
$P_{r\,actual}$	-92 dBW	-73 dBW	-96 dBW
$P_{r\,min}$	-140 dBW	-120 dBW	-147 dBW
$Link\ Margin$	48 dB >> 6 dB	47 dB >> 8 dB	51 dB >> 8 dB

COMMUNICATIONS: LINK FEASIBILITY SUMMARY

Requirement	Feasible?
FR 1.0: GSMRS Transmits commands to the CD	**YES**
FR 2.0: CD receives commands from the GSMRS	**YES**
FR 8.0: CD transmits data to the GSMRS	**YES**
FR 9.0: GSMRS receives data from the CD	**YES**
FR 12.0: SP transmits data to the GSMRS	**YES**
FR 13.0: GSMRS receives data from the SP	**YES**

SOFTWARE FEASIBILITY ANALYSIS

SOFTWARE FEASIBILITY: CHILD DRONE OVERVIEW

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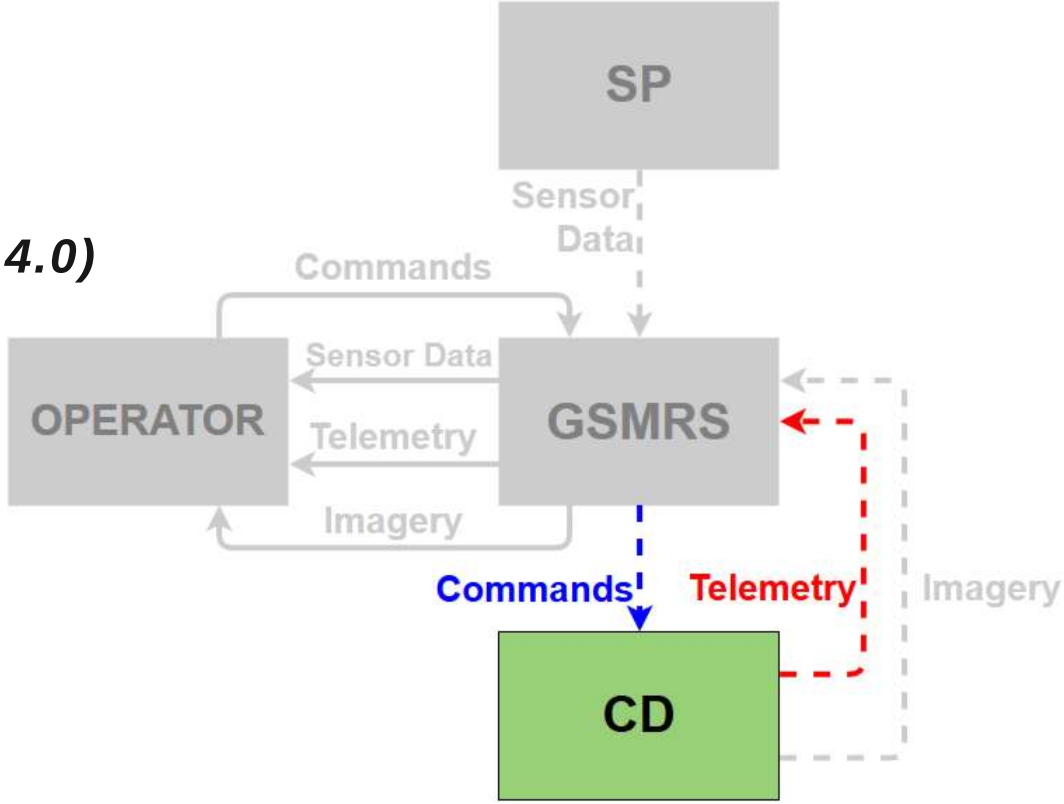
FR 12.0	The SP shall transmit wireless data to the GSMRS
FR 13.0	The GSMRS shall receive wireless data from the SP

SOFTWARE FEASIBILITY: CHILD DRONE FUNCTION

- Read commands from transceiver ***(FR 2.0)***
- Execute commands
  - Flight to coordinates ***(FR 4.0)***
  - Deploy SP ***(FR 5.0)***
- Send telemetry to transceiver ***(FR 8.0)***



SOFTWARE FEASIBILITY: CHILD DRONE

- ArduPilot Software
  - Manual/GPS flight control ***(FR 4.0)***
  - Servo actuation ***(FR 5.0)***
  - 3DR Radio integration ***(FRs 2.0, 8.0)***
  - 5 years of flight heritage
  - Rover integration
- COTS Flight Controllers
  - Pixhawk
  - APM 2
  - Erle-Brain
- **FEASIBLE**

SOFTWARE FEASIBILITY: SENSOR PACKAGE OVERVIEW

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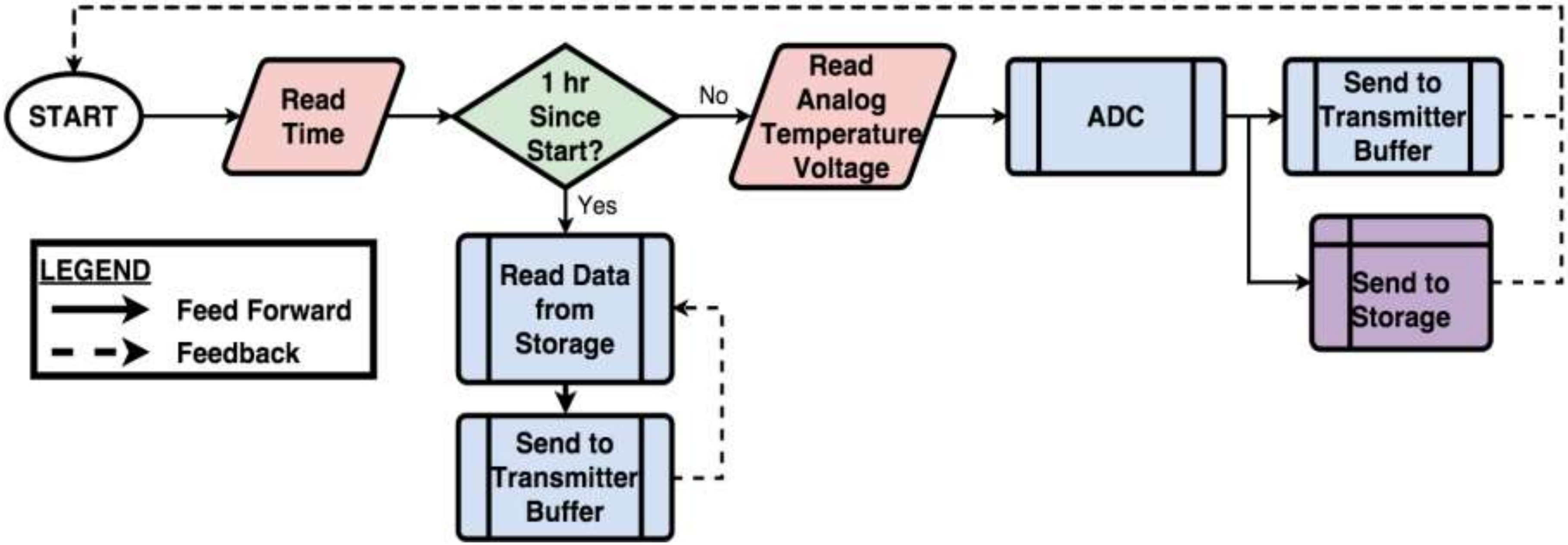
FR 13.0	The GSMRS shall receive wireless data from the SP

SOFTWARE FEASIBILITY: SENSOR PACKAGE FUNCTION

- 1 Hz sample, 8-bit digitize, and timestamp temperature ***(FR 11.0)***
- Send data to transmitter ***(FR 12.0)***
- Store data for retransmission



START

Read Time

1 hr Since Start?

No

Yes

Read Analog Temperature Voltage

ADC

Send to Transmitter Buffer

Send to Storage

Read Data from Storage

Send to Transmitter Buffer

LEGEND

Feed Forward

Feedback

SOFTWARE FEASIBILITY: SENSOR PACKAGE

- Low data rate
- Minimal storage required
- Achievable with microcontrollers
  - PIC18F87K22
    - 10 MHz clock
    - 128 kbyte flash memory
- Team software experience
- Team/faculty microcontroller experience
- **FEASIBLE**

Parameter	Required
Temperature Resolution	8-bit
Time Resolution	96-bit
Bit Rate	104 bit/s
Data Collection Time	3600 s
Total Data	46.8 kbyte

SOFTWARE FEASIBILITY: GSMRS OVERVIEW

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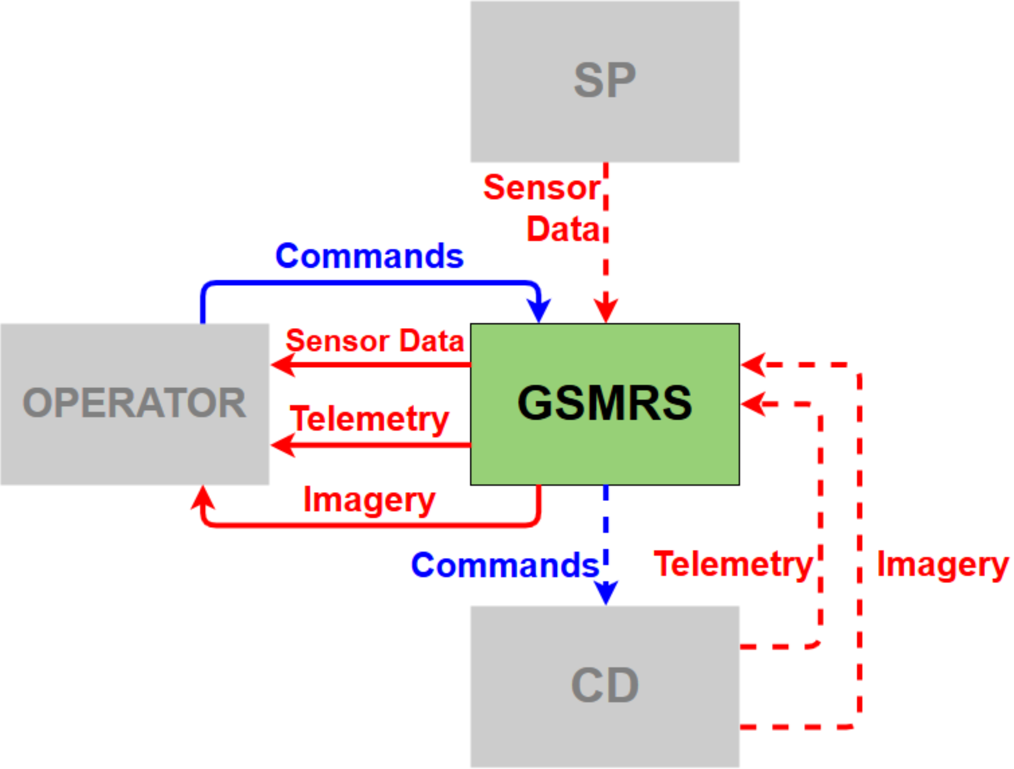
SOFTWARE FEASIBILITY: GSMRS FUNCTION

- Receive/interpret CD telemetry from transceiver ***(FR 9.0)***
- Send commands to CD through transceiver ***(FR 1.0)***
- Receive imagery from receiver ***(FR 9.0)***
- Receive/store sensor data from receiver ***(FR 13.0)***
- User interface for input/output with Operator



SOFTWARE FEASIBILITY: GSMRS

- Open-source ground control programs for ArduPilot Flight Controllers
  - Mission Planner
  - MAVProxy
  - DroneKit-Python API
- Built-in functionality
  - Send/receive through transceiver ***(FR 1.0, FR 8.0)***
  - Manual and GPS control ***(FR 1.0, FR 4.0)***
  - Servo control ***(FR 1.0, FR 5.0)***
  - Camera/gimbal control ***(FR 6.0, 7.0)***
  - Rover support
  - Live video feed
- **FEASIBLE**

SOFTWARE FEASIBILITY: SUMMARY

Subsystem	Requirement	Feasible?
Child Drone	***FR 2.0:*** Receive commands from GSMRS	YES
	FR 4.0: Fly to GPS waypoints	YES
	FR 5.0: Deploy the SP	YES
	FR 8.0: Transmit data to GSMRS	YES
Sensor Package	***FR 11.0:*** Acquire ground temperature data	YES
	FR 12.0: Transmit data to GSMRS	YES
GSMRS	***FR 1.0:*** Send commands to CD	YES
	FR 9.0: Receive data from CD	YES
	FR 13.0: Receive data from SP	YES

STATUS SUMMARY AND FUTURE WORK STRATEGY

STATUS SUMMARY: CHILD DRONE

Requirement	Project Element	Feasibility	
FRs 2.0 & 8.0: Communicates with GSMRS	• Communication	• Positive link margin • COTS flight controller • COTS transceiver	🟩
FRs 3.0 & 10.0: Takes off and lands on GSMRS	• Airframe	• COTS airframe	🟩
FR 4.0: Flies to GPS coordinates	• Power • Flight Controller	• LiPo batteries • COTS flight controller	🟩
FR 5.0: Carries/deploys Sensor Package	• Airframe • SP Integration/Deployment	• COTS airframe • Burn wire/Pull pin	🟩
FRs 6.0 & 7.0: Performs photo/video reconnaissance	• Airframe • Imaging System	• COTS airframe • GoPro or FPV camera	🟩

FUTURE WORK: CHILD DRONE

- SP Deployment Mechanism
  - Burn wire or pull pin
    - Prototyping and final trade studies

- COTS Trade Studies
  - Airframe, flight controller, camera, transceiver

- Acquire COA
  - Submit for COA once airframe is selected
  - Consult with James Mack

- Modeling
  - Update power model for dynamic flight
  - Update CD-GSMRS link budget with accurate antenna models

STATUS SUMMARY: SENSOR PACKAGE

Requirement	Project Element	Feasibility	
***FR 11.0*: Collect & timestamp sensor data**	• Survivability • Power • Data Acquisition & Handling	• Multi-density foam packaging • ~2 Ah to run for 2 hours • Options from Aerospace faculty	🟩
***FR 12.0*: Transmit and buffer sensor data**	• Communication • Data Storage	• Positive link margin • Xbee-PRO transmitter • < 50 kb for 1 hour	🟩

FUTURE WORK: SENSOR PACKAGE

- Testing
  - Xbee-PRO transmitter
    - No-Line-of-Site testing
  - Data acquisition & handling components
  - Structure
    - Prototype and drop to test g-force

- Modeling
  - Build electronic heat generation model
  - Update impact force model
  - Update SP-GSMRS link budget with accurate antenna models

- Trade Studies
  - Xbee-PRO model, microcontroller

STATUS SUMMARY: GSMRS

Requirement	Project Element	Feasibility	
FR 1.0 and 9.0: Communicates with CD	• CD Communications • CD Software	• Positive link margin • COTS ground control SW • COTS transceiver	🟩
FR 13.0: Receive sensor data from SP	• SP Communications • SP Software	• Positive link margin • Xbee-Pro receiver • COTS Data handling SW	🟩

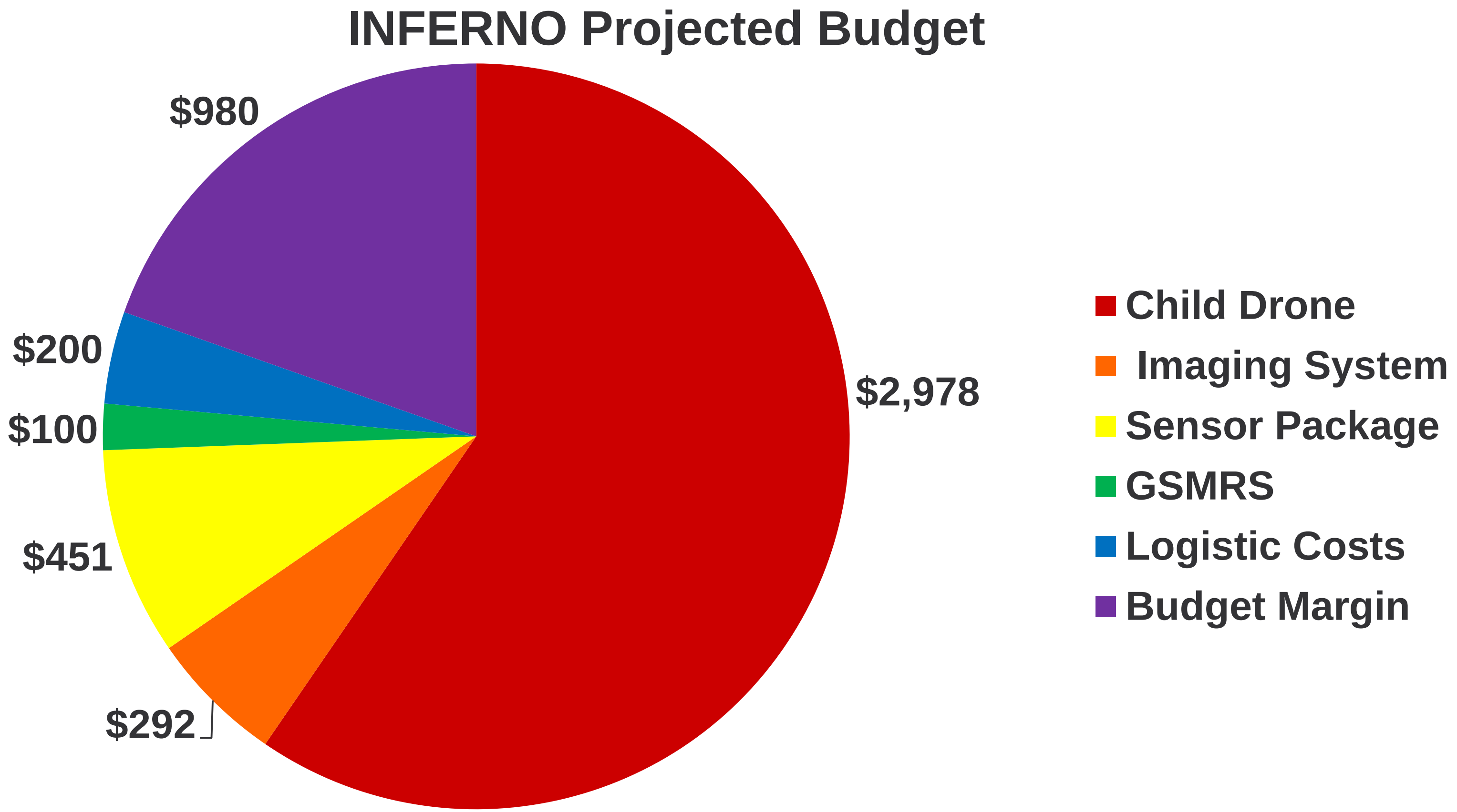
FUTURE WORK: GSMRS

- Testing
  - Xbee-PRO receiver
    - No-Line-of-Site Testing

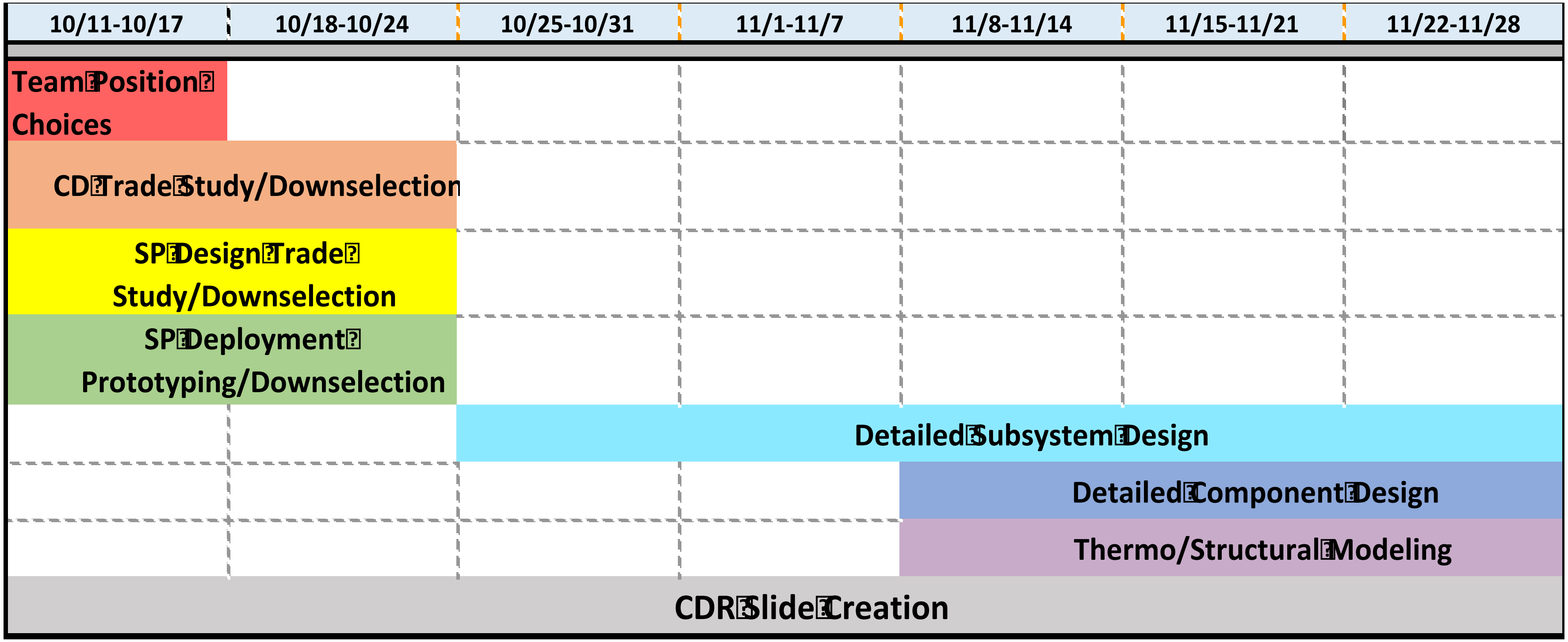
- Modeling
  - Update CD-GSMRS link budget with accurate antenna models
  - Update SP-GSMRS link budget with accurate antenna models

- Trade Studies
  - Ground control SW, data handling SW, Xbee-PRO model

PROJECTED BUDGET



PROJECTED SCHEDULE THROUGH CDR



10/11-10/17	10/18-10/24	10/25-10/31	11/1-11/7	11/8-11/14	11/15-11/21	11/22-11/28
Team Position Choices						
CD Trade Study/Downselection						
SP Design Trade Study/Downselection						
SP Deployment Prototyping/Downselection						
		Detailed Subsystem Design				
				Detailed Component Design		
				Thermo/Structural Modeling		
CDR Slide Creation						

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Questions?

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JET PROPULSION LABORATORY

JPL
Jet Propulsion Laboratory

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Aerospace Engineering

INFERNO BACKUP SLIDES

MISSION OVERVIEW BACKUP SLIDES

MISSION PROFILE

Event	Approximate Time
Take-off	30 s
Movement to Target	30 s
Sensor Deployment	1 min
Reconnaissance	10 min
Return to Mother Rover	30 s
Landing	1 min
Total Flight Time	13.5 min
Sensor Data Collection	1 hr

MISSION PROFILE CALCULATIONS

- Movement to Target: 200m / 10m/s = 20s
- Total Possible Area to Image: ¼ * 3 * 200^2 = 160000m^2
- Area Viewed by Camera: 3 * 10^2 = 300m^2
- Total Time to Image Total Area: 160000 / 300 = 533s = 8.89min

- Assumptions: Height = 10m, Speed = 10m/s, 90° FOV on Camera, 45° Area of Interest

LEVELS OF SUCCESS

Levels	CD	Imaging	Sensor
1	•Wired communication with GSMRS •Simulated deployment of SP •Flight testing with simulated payload	•Burst 8MP photos •Time stamping •Wired communication with CD	•Temperature data taken at 1 Hz with 8-bit resolution •Time stamping •Wired data transmission
2	•Deploy SP on command •Flight Testing with SP in deployment mechanism •15 minute flight duration •Wireless communications link •Piloted landing	•Time stamped video wired to CD •720fps @ 30 fps transmitted to GSMRS	•Flight capable mass and volume (TBD) •Wireless transmission of 1 hour of data
3	•Flight with video-tracked piloting •200 m wireless data/imagery transmission •GPS signal transmission		•Store 1 hour of data on-board •Transmit wirelessly 200 m •Be capable of collecting and transmitting data after deployment
4	•Semi-Autonomous flight via GPS waypoints, and landing within 5 m radius •Full system integration	•Full 1080p, 30fps transmitted to GSMRS	•Retransmission of data in case of signal loss

CHILD DRONE BACKUP SLIDES

CHILD DRONE: MASS BUDGET COMPONENTS

Component	**Mass (g)**
Flight Controller	
3DR Pixhawk	38
Ground Station Comms	
3DR Radio Set	16
GPS	
3DR uBlox GPS/Compass	16.8
Imagery	
3DR Video/OSD System Kit	84
3DR 5.8GHz Cloverleaf Antenna Kit	6
GoPro Hero3	74
Fixed GoPro Mount (research estimate)	20
TOTAL	**254.8**

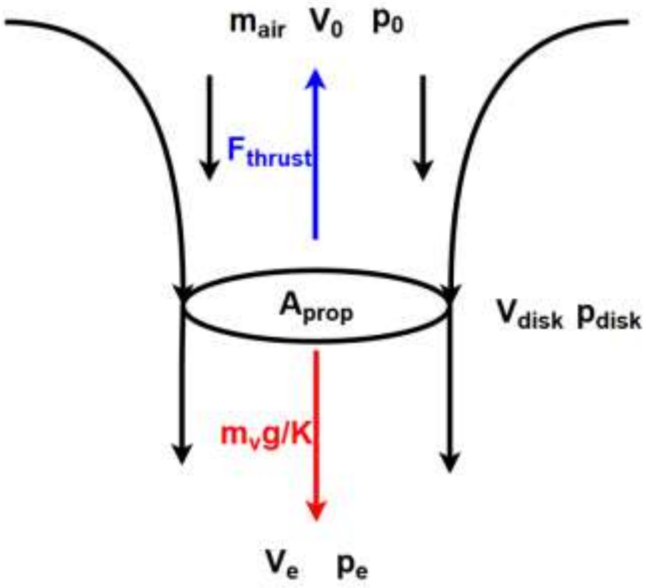
CHILD DRONE FLIGHT MODEL: DJI S900

- Test case for flight model
- Hexacopter
  - Takeoff weight 6.8 kg
  - 22.2 V battery
  - Sea level

Parameter	Manufacturer	Calculated
Total Current	N/A	48.0 A
Total Power	1000 W	1050 W
Charge Required (18 min, 20% margin)	12,000 mAh	17,200 mAh

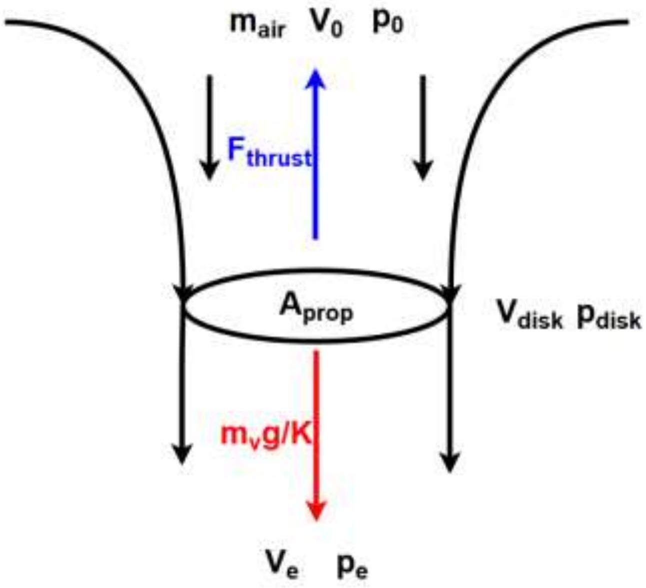
CHILD DRONE FLIGHT MODEL

- Thrust equal to weight of vehicle divided by number of engines
  - $F_{thrust} = \frac{m_v g}{K}$
- Pressure differential and momentum change
  - $F_{thrust} = A_{disk}(p_2 - P_1)$
  - $F_{thrust} = \dot{m}_a(v_e - v_0) = \dot{m}_a v_e$
- Prop power equal to thrust power AND change in air kinetic energy
  - $P_{prop} = F_{thrust} v_{disk} = A_{disk}(p_2 - p_1) v_{disk}$
  - $P_{prop} = \dot{m}_a v_e v_{disk} = \frac{\dot{m}_a v_e^2}{2} \rightarrow \mathrm{v_{disk}} = \frac{\mathrm{v_e}}{2}$



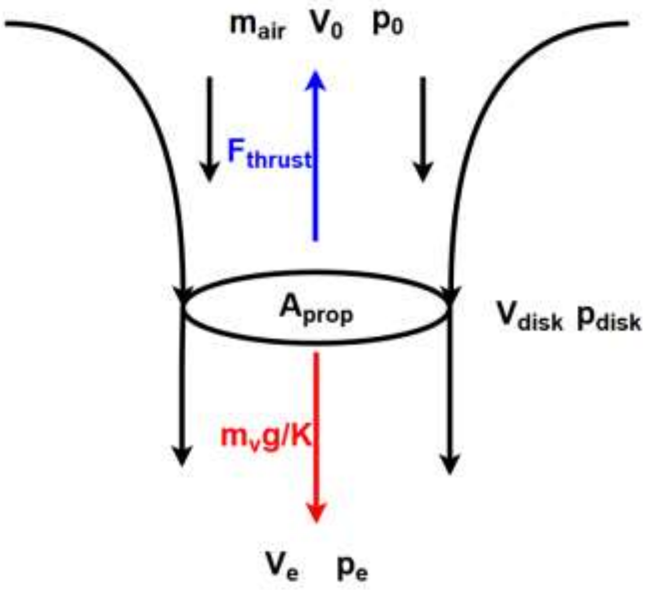
CHILD DRONE FLIGHT MODEL

- Apply Bernoulli
  - $p_{disk} + \frac{1}{2}\rho v_{disk}^2 = p_0$
  - $p_e + \frac{1}{2}\rho v_{disk}^2 = p_0 + \frac{1}{2}\rho v_e^2$
  - $p_e + \frac{1}{2}\rho\left(v_{disk}^2 - v_e^2\right) = p_{disk} + \frac{1}{2}\rho v_{disk}^2$
  - $p_e - p_{disk} = \frac{1}{2}\rho v_e^2$
- Substitute
  - $\dot{m}_a = \rho A_{disk} v_{disk} = \frac{\rho A_{disk} v_e^2}{2}$
  - $F_{thrust} = \frac{\rho A_{disk} v_e^2}{2} = 2\rho A_{disk} v_{disk}^2$



CHILD DRONE FLIGHT MODEL

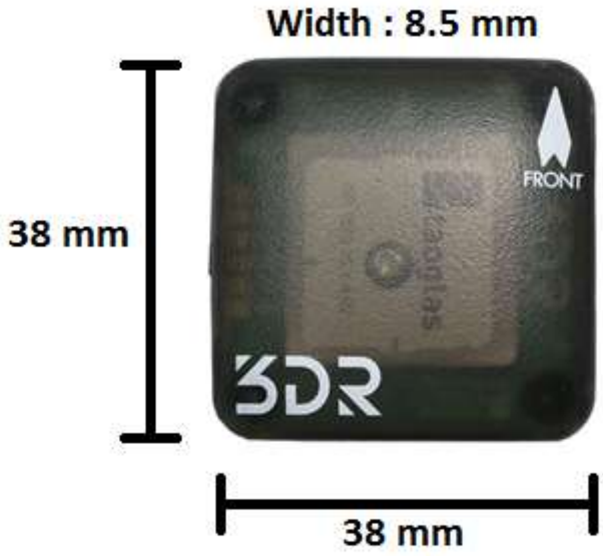
- Solve for power
  - $v_{disk} = \sqrt{\frac{F_{thrust}}{2\rho A_{disk}}}$
  - $P_{thrust} = F_{thrust}\sqrt{\frac{F_{thrust}}{2\rho A_{disk}}}$
  - $P_{motor} = \frac{P_{thrust}}{\eta_{prop}\eta_{motor}}$
  - $P_{total} = KP_{motor}$
- Solve for charge
  - $I = \frac{P_{total}}{V_{batt}}$
  - $Q = It_{flight}$



CHILD DRONE GPS ACCURACY

- **FR 4.0** - The CD shall fly to GPS coordinates
  - **DR 4.1.1.1 -** The CD shall have a GPS receiver with a minimum accuracy of 5m

- 3DR uBlox GPS with Compass
  - u-blox NEO-7 GPS module
    - < 4.2 m error with 95% confidence
  - Built to interface directly with Pixhawk flight computer



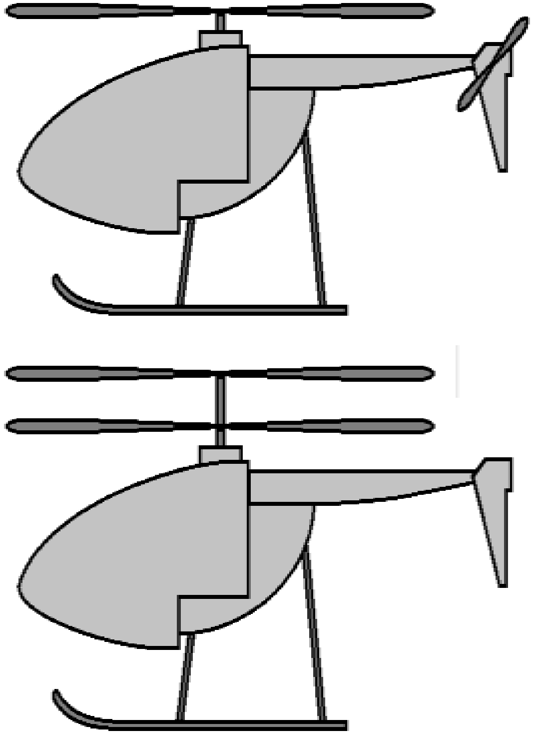
CHILD DRONE: AIRFRAME TRADE STUDY

- Three primary types of rotary wing aircraft
  - Helicopter
  - Multicopter
  - Singlecopter/Coaxcopter
- Key Parameters:
  - Airframe availability
  - Software availability/maturity
  - Hardware expansion
  - Stability
  - Repairability

AIRFRAME TRADE STUDY: HELICOPTERS

- Most common VTOL utility platform
- Conventional vs. coaxial rotors
- Less common for small-scale utility

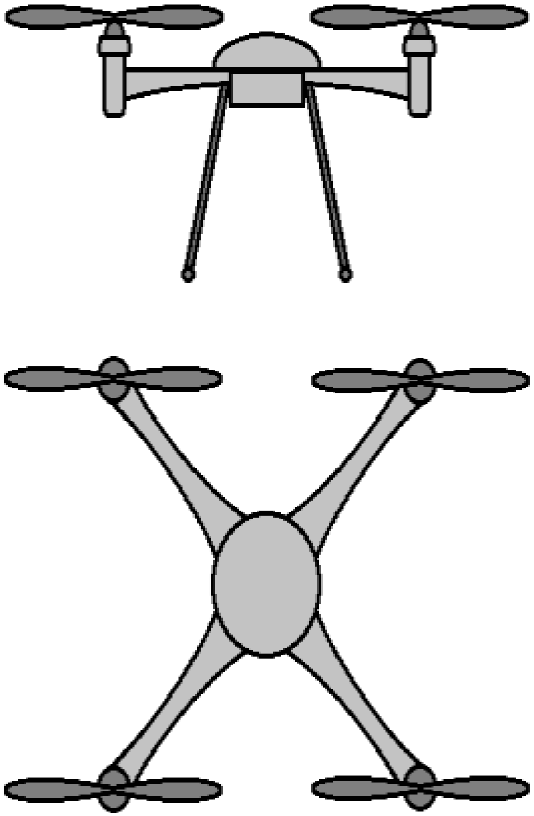
Advantages	Disadvantages
• Commonly used by hobbyists • Open-source flight computers and ground stations • High-efficiency rotors—potentially long endurance • High speed • Inexpensive	• Mechanically complex propulsion • Difficult flight characteristics • Small structure may make complicate hardware integration • Rotors can cause severe injury • Poor crash survivability



AIRFRAME TRADE STUDY: MULTICOPTERS

- Emerging field for small-scale utility
- Simple and stable control scheme
- Lower efficiency

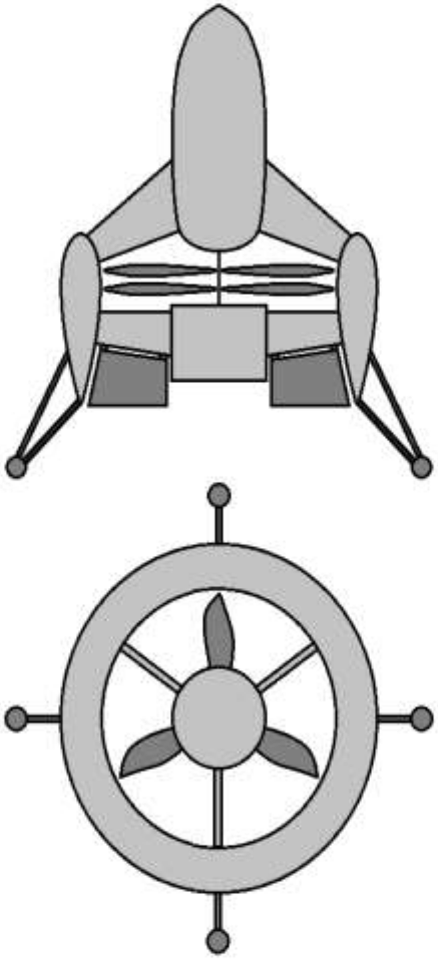
Advantages	Disadvantages
• Commonly used by hobbyists and professionals • Open-source flight computers and ground stations • Simple, stable, intuitive • Structure typically designed for additional hardware • Easily repaired	• Low efficiency—requires large batteries for high endurance • Rotors have potential for injury • More expensive than helicopters



AIRFRAME TRADE STUDY: SINGLE / COAXCOPTERS

- Highly experimental
- Combine control characteristics of coax helicopters, and planes

Advantages	Disadvantages
• Shrouded fan is safer than open rotors • Well-suited to flight near vegetation • Small footprint • High efficiency propulsion	• No COTS airframes—must be custom-built • Open source flight software is highly experimental • Flight dynamics are not well-established • Structure is poorly suited to hardware expansion



AIRFRAME TRADE STUDY: CRITERIA AND WEIGHTING

	Ratings				
Criteria	**1**	**2**	**3**	**4**	**5**
Availability	Aircraft must be custom-built	COTS build kits available, generally unsuited to mission requirements	COTS build kits available, but will require airframe and/or propulsion modification to suit mission requirements	COTS ready-to-fly options available	COTS ready-to-fly options available fulfilling all mission requirements
SW Integration	All software must be written from scratch.	COTS/OS flight software is available, but highly experimental.	Reliable COTS/OS flight software available. Ground station software and other functionality must be written.	Reliable COTS/OS flight and ground station software. Additional SW design required for full INFERNO functionality.	Plug-n-play integration of all required INFERNO functionality.
HW Integration	Airframe unsuited to addition of mission hardware	------	Airframe has limited volume and/or attachment points for additional hardware	------	Airframe may be readily modified with new hardware
Ease of Flight/Stability	Stability and flight characteristics are poorly established and unpredictable	------	Aircraft is generally stable, but has highly sensitive flight controls. Extensive training required for pilots.	------	Aircraft is highly stable, intuitive, and requires minimal training for pilots.
Safety	Exposed moving parts with potential to cause severe injury.	------	Exposed moving parts with minimal potential to cause severe injury	------	Moving parts are contained within a protective casing

AIRFRAME TRADE STUDY: CRITERIA AND WEIGHTING

Criteria	Weight	Justification
Availability	0.33	If the CD airframe requires extensive custom work, it may drain significant time and financial resources required for other project elements.
SW Integration	0.33	Software—especially flight control—is a critical aspect of the CD and INFERNO integration as a whole.
HW Integration	0.2	The CD must have the lift and airframe space to carry expanded hardware, such as imagery and the SP, but all three airframes should be workable.
Ease of Flight/Stability	0.1	If the CD is particularly difficult to fly, it will require significant modeling and/or training for the operators, and presents a higher risk of crash, hardware damage, or injury
Safety	0.04	Exposed rotors provide a measurable safety risk depending on their size and speed, but safety issues can be addressed with proper procedures and PPE.
Total	1	

AIRFRAME TRADE STUDY: RESULTS

- **DECISION: MULTICOPTER**
  - Commercial airframe availability
  - Sufficient endurance
  - Airframe versatility
  - COTS/open-source hardware and software availability
  - Stability and ease of operation
- Going Forward:
  - Selection of specific multicopter model
  - Selection of compatible components/software

VEHICLE TYPE TRADE STUDY: CRITERIA AND WEIGHTING

Criteria	**Ratings**				
	1	2	3	4	5
Position Hold Capability	Cannot hold position within a 5m radius	---	Can hold position within a 5m radius inconsistently	---	Can hold position within 5m consistently
Flight-Ready Cost	>$4000	$3000-$4000	$2000-$3000	$1000-$2000	<$1000
Procurement	The system must be entirely custom designed	Custom software, combination COTS/custom components	COTS software, combination COTS/custom components	Individual components can be obtained COTS, then integrated	System can be obtained COTS with no modifications
Ease of Takeoff and Landing	Can take off and land, but requires additional child drone or mother rover capabilities	Can take off and land but requires manual assistance	---	Can take off or land, but not both without additional capabilities	Can take off and land with no additional required systems or capabilities
Size	Cannot fit within the mother rover	---	Parts of the drone stick out of the mother rover. Or the drone requires modifications to fit.	---	Can fit in the mother rover completely without any modifications
Payload Capacity	Cannot carry the required payload	---	Payload requires significant design considerations	---	Can carry the required payload with no difficulty.

VEHICLE TYPE TRADE STUDY: CRITERIA AND WEIGHTING

Criterion	Weight	Rationale
Position-Hold	10%	Position-hold is weighted at 10% because it is an important mission element, but doesn't affect the design of other systems. The position hold is important for the accurate delivery of the sensor package, as well as visual reconnaissance. However, the limitations of the child drone can be operationally mitigated.
Cost	5%	Cost is weighted low at 5% because although it is a critical element in the project, it does little to drive the design on the system. So long as the system can be created within the budget, it doesn't matter how much it costs. It is only once the project is over budget that it becomes an issue.
Procurement	40%	Procurement is weighted the highest at 40% because it vastly affects all other aspects of the project. If the system must be entirely custom designed, it places far more work on the team than buying COTS components. Designing some of components from scratch, such as a flight computer, could be senior projects by themselves. This category does the most to drive whether the project can be accomplished.
Take-off and Landing	30%	Take-off and Landing is weighted the second most because it is a mission critical aspect that also affects multiple systems. If the child drone requires extensive modifications to the mother rover, or requires the mother rover to have additional capabilities, it complicates the FireTracker system as a whole. This defeats the goal of having future teams be able to easily interface with the INFERNO system.
Size	5%	Size is tied for the lowest weighting because the size of the child drone directly affects the required size of the mother rover. This requires the mother rover to be larger to accommodate the child drone, or parts of the child drone to be exposed during transit. However, this physical size requirement for the mother rover is easier to design than adding capabilities. Therefore it is weighted low.
Payload Capacity	10%	Payload capacity is weighted at 10% because it is drives the required design on the sensor package. If the child drone can carry a relatively high amount of mass, then the sensor package has more freedom in its design. However, if the child drone has a relatively limited payload capacity, mass becomes a much more important aspect of the sensor package design

AIRFRAME TRADE STUDY: RATINGS

		Fixed Wing		**Rotor Wing**		**LTA**	
Criteria	**Weight**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Position-Hold	10%	**1**	0.2	**5**	0.4	**5**	0.4
Cost	5%	**5**	0.25	**4**	0.2	**4**	0.2
Procurement	40%	**4**	1.6	**4**	1.6	**1**	0.8
Take-off and Landing	30%	**1**	0.6	**5**	1.5	**2**	0.6
Size	5%	**3**	0.15	**5**	0.25	**3**	0.15
Payload Capacity	10%	**5**	0.5	**3**	0.3	**3**	0.3
Total	100%	**2.9**		**4.35**		**2.15**	

CHILD DRONE IMAGING SYSTEM: CAMERA OPTIONS

- Camera (**FR 6.0** and **FR 7.0**)
  - Possible Options
    - GoPro Hero3-$300, 74 g
    - FPV Camera & Video Recorder-$60, 19 g
    - Hummingbird HD Tube FPV Camera-$75, 100 g

- 59 mm

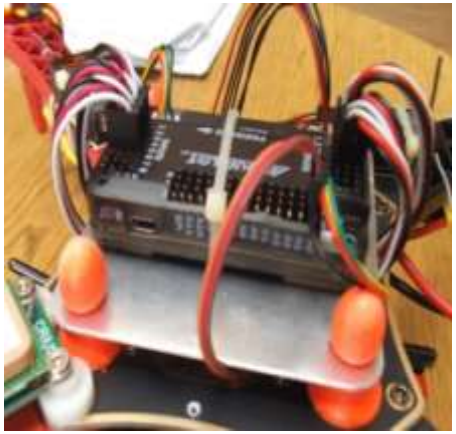
- 41 mm

CHILD DRONE IMAGING SYSTEM: CAMERA OPTIONS

- Camera Selection
  - CCD vs CMOS
    - CCD less susceptible to vibrations but is typically heavier, more expensive, and requires more power
  - Fisheye vs Rectilinear Lens
    - Fisheye lens can have a greater FOV, but causes more distortion
  - Video System Standard (**FR 6.0**)
    - PAL (Phase Alternating Line)
      - 720 x 576 @ 25fps
    - NTSC (National Television System Committee)
      - 720 x 480 @ 30fps
    - DJI Lightbridge
      - Can transmit at 1080p at 30 fps

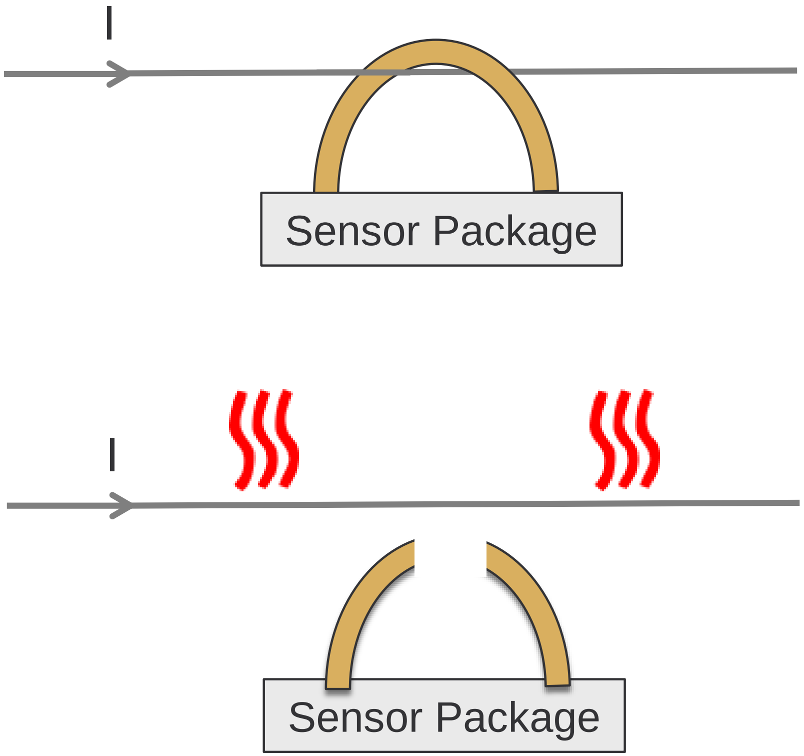
CHILD DRONE IMAGING SYSTEM: VIBRATION DAMPING

- Damping Camera Vibrations:
  - Passive Solutions
    - Lighter, cheaper, and simpler than COTS gimbal devices
    - Isolation platform
    - Damping material
      - Earplugs, Elastomeric material,
  - Planned vibrational tests after PDR



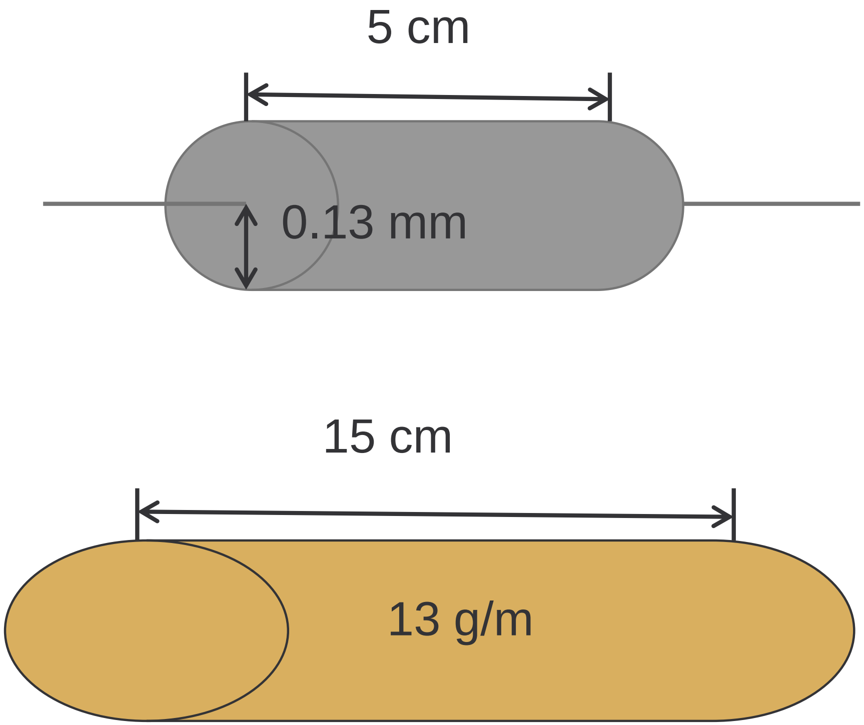
CHILD DRONE: DEPLOYMENT

- Burn Wire
  - Nylon Rope
    - Melting point: 220°C
    - Safe load: **3.19 kg**
  - Nichrome Wire
    - Melting point: 1400°C
  - Power draw: 2.3 W for .9 seconds

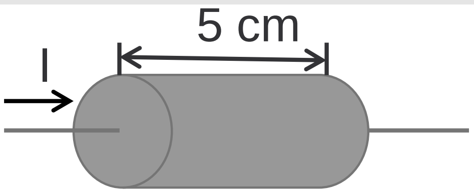


CHILD DRONE: DEPLOYMENT

- Burn Wire
  - Mass < 2 g
    - Nichrome:
      - Density: 8.31g/cm^3
      - Volume = 0.003 cm^3
      - Mass = 0.02 g
    - Nylon 3/16”
      - Density: 13 g/m
      - Length: 15 cm
      - Mass = 1.95 g
  - Safe load: 0.326kN*9.81 m/s^2 = 3.19 kg



CHILD DRONE: DEPLOYMENT



- Nichrome Wire
  - *3% increase in resistance at 220°C*
  - V=IR
  - P=IV
  - t = $\frac{p_d c_p \mathrm{D} T \mathrm{p}^2 r^4}{p_r I^2}$
  - E=Pt

Less time, power, energy for smaller wire

Smaller wire cannot support as much mass

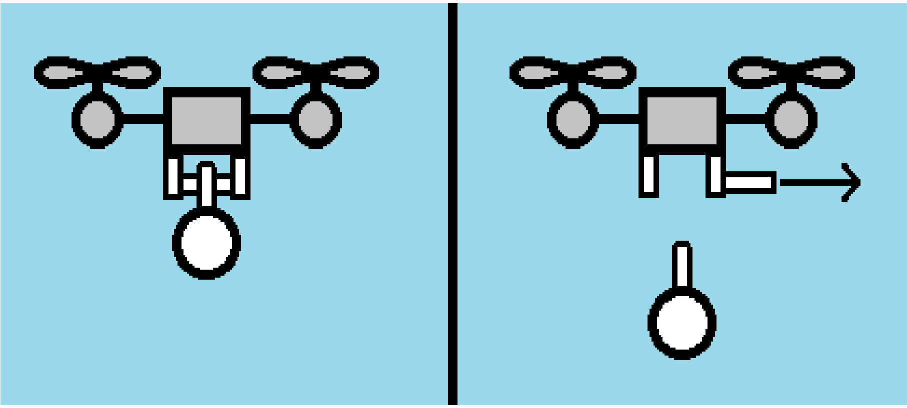
Wire Grade	Resistance in 5 cm (Ω)	Current (A)	Voltage (V)	Power (W)	Time (s)	Energy (J)
24	0.3	3.4	0.91	3.1	2.7	8.3
26	0.4	2.6	1.13	2.9	1.8	5.2
28	0.7	1.95	1.33	2.6	1.2	3.2
30	1.1	1.47	1.59	2.3	0.9	2.1
32	1.7	1.13	1.92	2.2	0.6	1.3

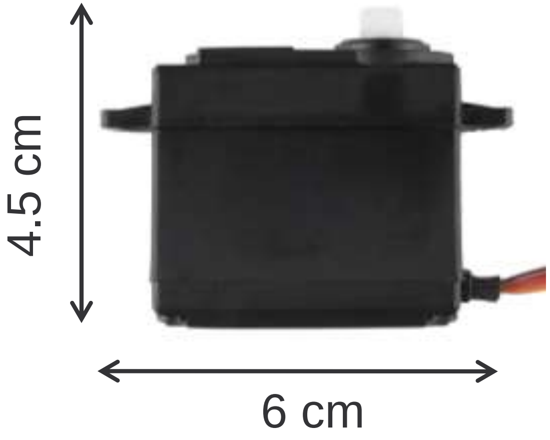
CHILD DRONE: DEPLOYMENT

	Servo Motor	Linear Actuator
Stall Current	1.1 A	450 mA
Voltage	6V	6V
Power = VI	6.6W	2.7W
No load speed	.17 sec/60°	5 mm/sec
Angular/Linear Distance	90°	5 cm
Time	.24 sec	10 sec
Total Energy = Pt	1.58 J	27 J

CHILD DRONE: DEPLOYMENT

- Pull Pin
  - Servo motor
    - 40g
    - 6.6W for 0.24 seconds
  - Linear Actuator
    - 39g
    - 2.7W for 10 seconds





CHILD DRONE: DEPLOYMENT

$$h = 1.7in/44.1mm$$

- Testing confirms that magnetic field will affect accuracy of onboard compass
- Additional concern regarding uncertain affects of magnet on electronic SP components

SENSOR PACKAGE BACKUP SLIDES

SENSOR PACKAGE: DATA STORAGE

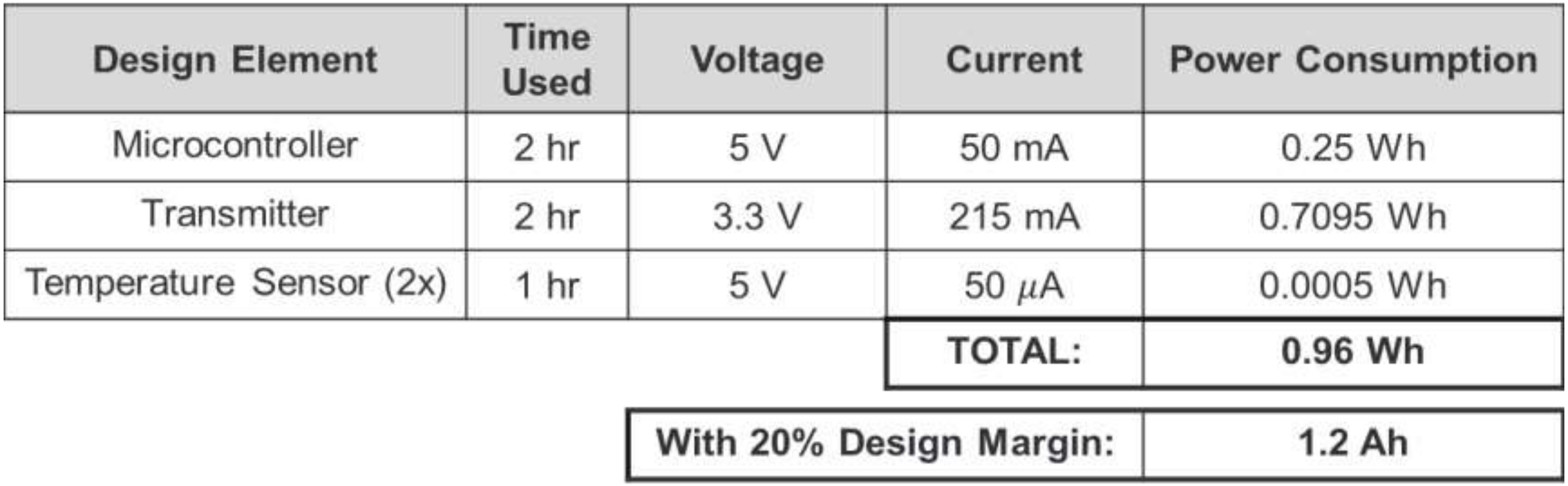
Storage on Microcontroller: 2 Mbits

Data capture rate: 8 bits/s
Timestamp rate: 20 bits/s
Total: 28 bits/s

Taken for 1 hour: 100,800 bits = 0.1008 Mbits

Could take data for 20.81 hours

SENSOR PACKAGE: POWER BUDGET

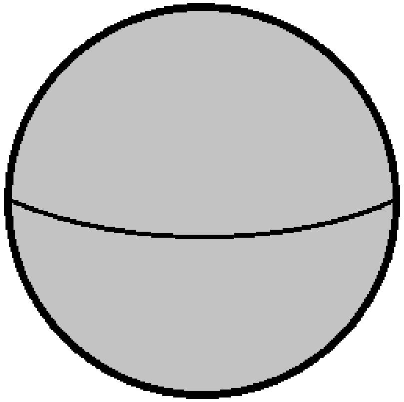


Design Element	Time Used	Voltage	Current	Power Consumption
Microcontroller	2 hr	5 V	50 mA	0.25 Wh
Transmitter	2 hr	3.3 V	215 mA	0.7095 Wh
Temperature Sensor (2x)	1 hr	5 V	50 μA	0.0005 Wh
			TOTAL:	**0.96 Wh**
		With 20% Design Margin:		**1.2 Ah**

SENSOR PACKAGE: STRUCTURE

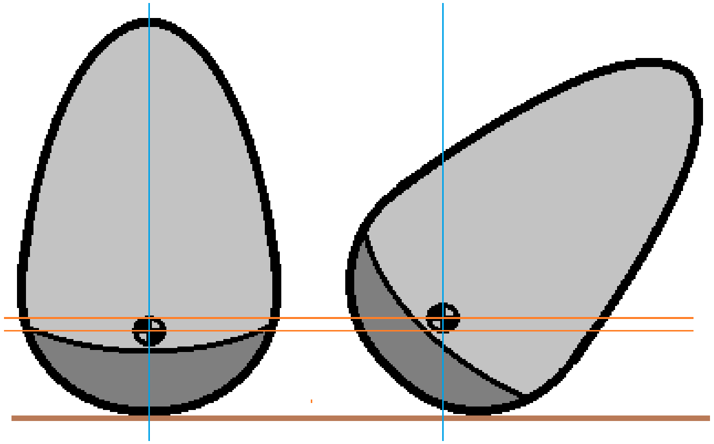
- Primary purpose is to protect electronics from impact with ground
  - Engineering Principals
    - A slower moving object will have a slower impact force
    - Increasing area perpendicular to velocity direction while decreasing weight lowers an objects terminal velocity
    - Upon impact, increasing the time an object takes to come to rest decreases impact force

SENSOR PACKAGE: STRUCTURE – SPHERE



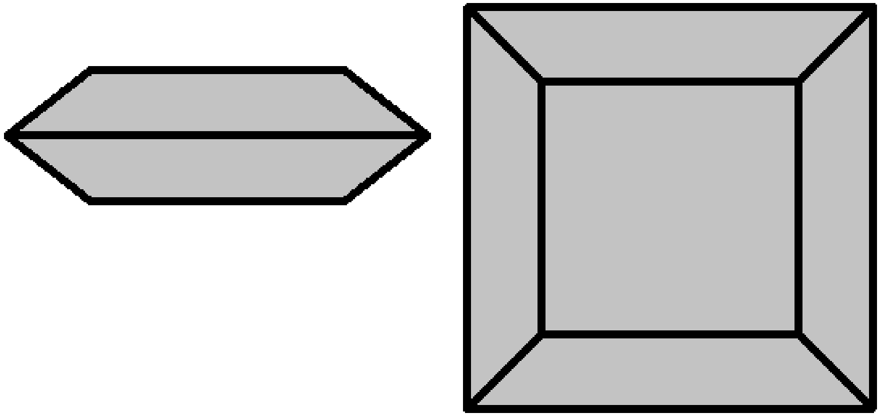
Advantages	Disadvantages
• Simple Design • Naturally strong against impacts and stresses	• Aerodynamic (High Terminal Velocity) • Difficult to integrate with mostly square internal components • May roll away from landing position • Difficult to predict final orientation

SENSOR PACKAGE: STRUCTURE – SELF RIGHTING



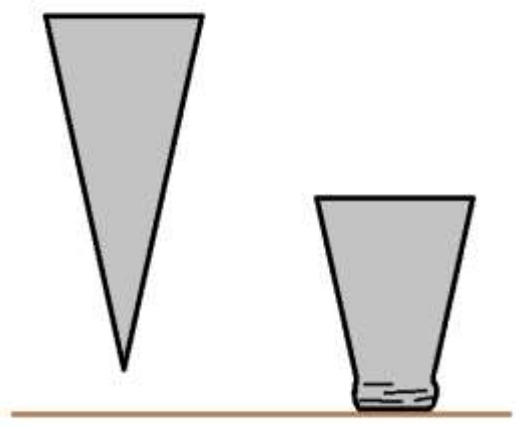
Advantages	Disadvantages
• Final orientation of sensors and transmitters can be accurately predicted • Can correct orientation after bouncing during deployment	• Low tolerances for machining and component placement • Requires a large, empty volume

SENSOR PACKAGE: STRUCTURE – OBLATE OBJECT



Advantages	Disadvantages
• Large surface area results in a slower terminal velocity • Shape naturally stabilizes the structure on descent • Final orientation is limited to 2 possibilities	• Does not efficiently use vertical space underneath child drone • Bulky

SENSOR PACKAGE: STRUCTURE – CRUMPLE ZONE



Advantages	Disadvantages
• Crumple zone absorbs energy, shielding the electronics on impact • Does not easily bounce or roll	• Non-reusable • Final orientation is difficult to predict • Performance depends heavily on precise weight distribution • Restricts

SENSOR PACKAGE: CALCULATING SIZE

To ensure that the Sensor Package does not land and stay on its side:

$$X_g > f$$

Through geometry:

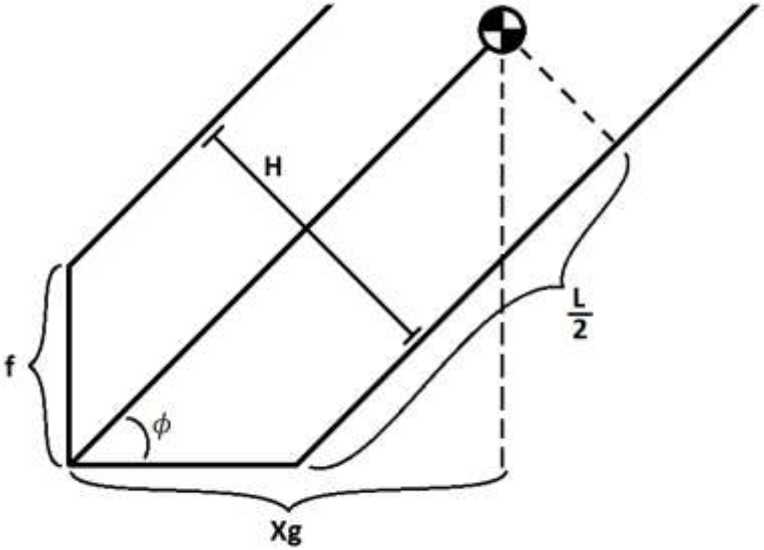
$$X_g = f + \frac{1}{2} L\cos(\phi) - \frac{1}{2} H\sin(\phi) > f$$

$$\frac{L}{H} > \tan(\phi)$$

Also, the width of the package, d, is equal to:

$$d = L + 2f\cos(\phi)$$

$$d = L + \frac{H}{\tan(\phi)}$$



SENSOR PACKAGE: MASS BUDGET

Component	Mass [g]
Microcontroller	17
Transmitter	5
Antenna	10
Temperature Sensor (x2)	1
Wiring	4
Structure	120
LiPo Batteries (x2)	20
Total	177

SENSOR PACKAGE: STRUCTURE

- Protect electronics during ground impact
  - Testing
    - Paper cone with crumple zone

SENSOR PACKAGE: STRUCTURE

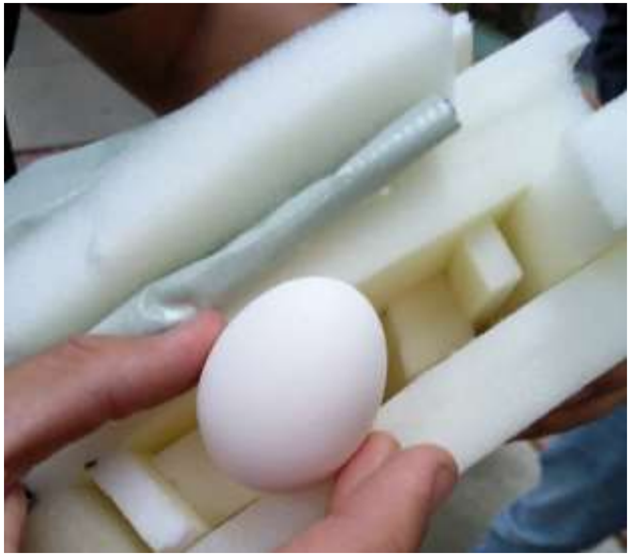
- Protect electronics during ground impact
  - Testing
    - Oblate Object

SENSOR PACKAGE: STRUCTURE

- Protect electronics during ground impact
  - Testing
    - Oblate Object with tapered sides

SENSOR PACKAGE: STRUCTURE

- Protect electronics during ground impact
  - Testing
    - Dropped an egg wrapped in foam from ~40 ft
      - If the egg can withstand the fall, the electronics should be more than capable



SENSOR PACKAGE: MASS COMPONENTS

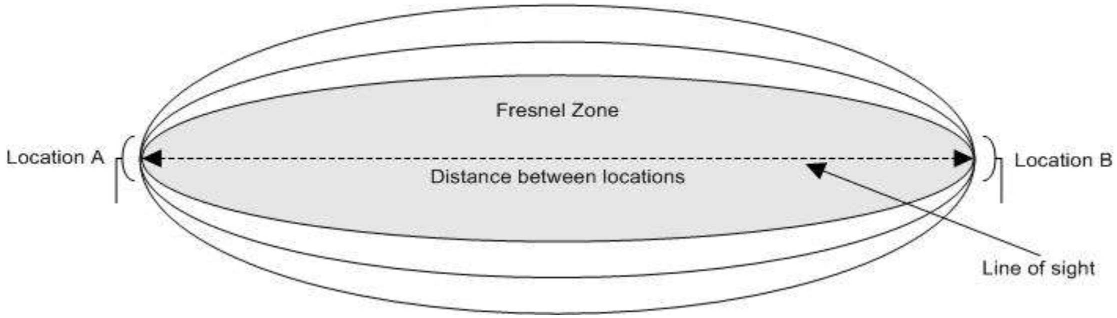
Component	Component Description
Microcontroller	
Transmitter	XBee-PRO XSC
Antenna	Dipole
Temperature Sensor (x2)	TMP37
Wiring	24 gauge
Structure	Foam Structure with Inner Plastic Casing

GSMRS BACKUP SLIDES

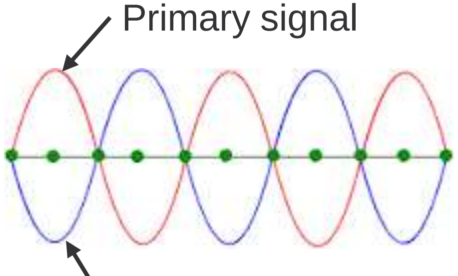
GSMRS
MISSION PLANNER TESTING

COMMUNICATIONS BACKUP SLIDES

FRESNEL ZONE INTERFERENCE



http://www.air-stream.org.au/technical-references/fresnel-zone



Primary signal

“Reflected” signal causing phase cancellation

- What is the Fresnel Zone?
  - Set of concentric ellipsoids encompassing line of site transmission path
  - An object within the Fresnel Zone will result in undesirable multipath signals that are out of phase of primary signal
  - This results in either phase cancelling or in phase enhancement of base signal

COMMUNICATIONS: LINK BUDGET CALCULATIONS

Nomenclature

P_t = Power Transmitted
G_t = Receiving Antenna Gain
G_r = Transmitting Antenna Gain
L_s = Free Space Loss
P_r = Power Received
k = Boltzmann's Constant
L_r = Line Loss
d_r = Receive Antenna Diameter
NF = Noise Figure
T_0 = Reference Temperature
N_0 = Noise Power
T_s = System Noise Temperature
$\frac{E_b}{N_0}$ = Bit Energy to Noise Ratio

System Noise Temp. [k]: $T_s = \frac{T_a}{L_r} + T_0\left(1 - \frac{1}{L_r}\right) + T_0(NF - 1)$

Receive Antenna Gain [dB]: $10\log(\frac{d_r^2\pi^2\eta}{\lambda^2})$

Signal to Noise Ratio [dB-Hz]: $\left(\frac{P_r}{N_0}\right)$

System Noise Power [dB]: $N_0 = 10\log(k * T_s)$

Power Received [dB]: $P_r = P_t + G_t + G_r - L_s - Fade\ Margin$

Minimum Signal to Noise Ratio [dB-Hz]:

$$\left(\frac{P_r}{N_0}\right)_{min} = Bit\ Rate + Design\ Margin + \frac{E_b}{N_0}$$

Link Margin [dB]: $\left(\frac{P_r}{N_0}\right) - \left(\frac{P_r}{N_0}\right)_{min}$

- Values for above calculations obtained from data sheets and literature

COMMUNICATIONS: CHILD DRONE ERROR CORRECTION

- 3DR Radio uses 12/24 Golay error correction code
  - Send 24 bits for every 12 bits of data
  - Correct 3 bit errors per 12 data bits
  - Reduce usable data from 64 kb/s to 32 kb/s

COMMUNICATIONS: CHILD DRONE COMBINED LINK

DJI Lightbridge 2

- Allows GSMRS to send commands and receive telemetry and video ***(FR 1.0, FR 2.0, FR 9.0)***
- Allows CD to transmit telemetry, receive commands, and transmit video ***(FR 6.0, FR 7.0, FR 8.0)***
- Allows CD to transmit video
- DJI Lightbridge 2
  - Uplink Data Rate: 64 kbps
  - Downlink Data Rate: 12 Mbps

	DJI Lightbridge 2
P_t	$-8\ dBW$
G_t	$2\ dB$
G_r	$3\ dB$
L_s	$86\ dB$
$Fade\ Margin$	$10\ dB$
$P_{r_{Actual}}$	$-98\ dBW$
$P_{r_{Min}}$	$-131\ dBW$
$Link\ Margin$	$32\ dB$

FUTURE WORK/ REQUIREMENTS BACKUP SLIDES

BUDGET: CHILD DRONE AND IMAGING SYSTEM

Child Drone Manufacturing

Part Name	Description	Unit Cost	Quantity	Discounts	Total Cost
DJI S900	Child Drone Frame, Props, Motor	$1,400.00	1	0.00%	$1,400.00
3DR Pixhawk	Flight Controller	$200.00	1	15.00%	$170.00
APM Power Module	Power Module	$25.00	1	15.00%	$21.25
Lumenier 16000 mAh 6s LiPo	Battery	$270.00	3	0.00%	$810.00
3DR uBlox GPS/Compass	GPS	$90.00	1	15.00%	$76.50
Misc. Electrical Parts		$500.00	1	0.00%	$500.00
				Child Drone Total	**$2,977.75**

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
Misc. Electrical Parts		$300.00	1	0.00%	$300.00
				Imaging System Total	**$291.60**

BUDGET: GSMRS, SENSOR PACKAGE, AND ADDITIONAL COSTS

Sensor Package Manufacturing

Part Name	Description	Unit Cost	Quantity	Discounts	Total Cost
Xbee Pro	900 MHz (Comm to GSMRS)	$43.00	2	0.00%	$86.00
Microcontroller		$200.00	1	0.00%	$200.00
Temperature Sensor		$3.00	5	0.00%	$15.00
Structural Materials		$100.00	1	0.00%	$100.00
Machining Costs		$50.00	1	0.00%	$50.00
				Sensor Package Total	**$451.00**

GSMRS Manufacturing

Part Name	Description	Unit Cost	Quantity	Discounts	Total Cost
3DR Radio Set	Telemetry Comms System	$100.00	1	0.00%	$100.00
				GSMRS Total	**$100.00**

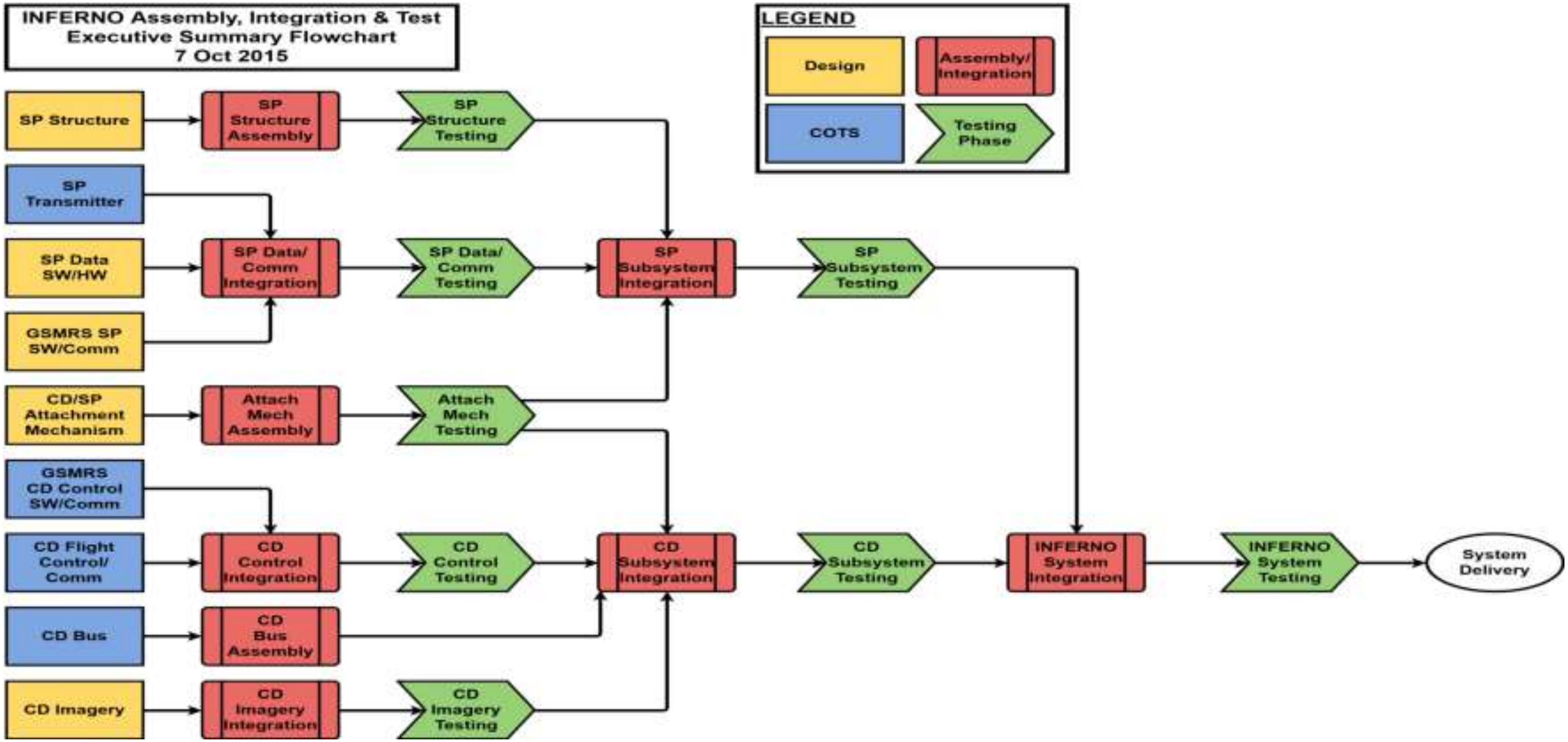
OTHER COSTS

Description	Unit Cost	Quantity	Discounts	Total Cost
Printing	$200.00	1	0.00%	$200.00
			Other Costs Total	**$200.00**

BUDGET: GSMRS, SENSOR PACKAGE, AND ADDITIONAL COSTS

SUMMARY	
Category	**Category Total**
Manufacturing	$3,820.35
Testing	$0.00
Shipping	$0.00
Other Costs	$200.00
Budget	**$5,000.00**
Total Funding Spent	**$4,020.35**
Total Funding Remaining	**$979.65**

TEST PLAN: AI&T FLOW



INFERNO Assembly, Integration & Test
Executive Summary Flowchart
7 Oct 2015

LEGEND
- 🟨 Design
- 🟥 Assembly/ Integration
- 🟦 COTS
- 🟩 Testing Phase

SP Structure → SP Structure Assembly → SP Structure Testing → SP Subsystem Integration

SP Transmitter → SP Data/ Comm Integration

SP Data SW/HW → SP Data/ Comm Integration → SP Data/ Comm Testing → SP Subsystem Integration → SP Subsystem Testing → INFERNO System Integration

GSMRS SP SW/Comm → SP Data/ Comm Integration

CD/SP Attachment Mechanism → Attach Mech Assembly → Attach Mech Testing → SP Subsystem Integration, CD Subsystem Integration

GSMRS CD Control SW/Comm → CD Control Integration

CD Flight Control/ Comm → CD Control Integration → CD Control Testing → CD Subsystem Integration → CD Subsystem Testing → INFERNO System Integration → INFERNO System Testing → System Delivery

CD Bus → CD Bus Assembly → CD Subsystem Integration

CD Imagery → CD Imagery Integration → CD Imagery Testing → CD Subsystem Integration

TEST PLAN: GSMRS

- Closed-loop CD simulator testing
  - Procedures
  - Manual flight controller integration
- Command/Telemetry w/ CD
  - Workbench wired/wireless
  - Outdoor/Long-range
  - Control
- SP Data Reception
  - Workbench
  - Wireless
  - Long-range

TEST PLAN: CHILD DRONE

- Workbench testing
  - Wired CD communication
  - Wireless CD communication
- Outdoor non-flight testing
  - GPS
  - Long-range communication
- Indoor flight testing
  - Takeoff/landing
  - Manual control
- Outdoor flight testing
  - Takeoff/landing
  - Manual/GPS control
  - Deployment

TEST PLAN: SENSOR PACKAGE

- Workbench testing
  - Temperature collection/digitization
  - Wired data to GSMRS
  - Wireless data to GSMRS
  - Battery life
  - Deployment mechanism
- Outdoor testing
  - Long-range data transmission
  - Drop testing
- Integrated testing
  - Flight deployment

REQUIREMENTS

Requirement	Description
FR 1.0	The GSMRS shall transmit wireless commands to the CD
DR 1.1	The GSMRS shall be able to command the CD to take off
DR 1.2	The GSMRS shall be able to transmit GPS coordinate commands to the CD
DR 1.3	The GSMRS shall be able to command the CD to deploy the SP
DR 1.4	The GSMRS shall be able to command the CD to record video
DR 1.5	The GSMRS shall be able to command the CD to record photos

REQUIREMENTS

Requirement	Description
FR 2.0	The CD shall receive wireless commands from the GSMRS
DR 2.1	The CD shall receive takeoff command(s) from the GSMRS
DR 2.2	The CD shall receive GPS coordinate commands from the GSMRS
DR 2.3	The CD shall receive SP deployment command(s) from the GSMRS
DR 2.4	The CD shall receive commands to record video from the GSMRS
DR 2.5	The CD shall receive commands to record photos from the GSMRS

REQUIREMENTS

Requirement	Description
FR 3.0	The CD shall take off from the GSMRS
DR 3.1	The CD shall fit in the GSMRS landing bay
DR 3.1.1	The CD shall have a footprint no greater than TBD
DR 3.1.2	The CD shall have overall dimensions no greater than TBD

REQUIREMENTS

Requirement	Description
FR 4.0	The CD shall fly to GPS coordinates
DR 4.1	The CD shall have an autopilot
DR 4.1.1	The CD shall be capable of holding position at GPS coordinates with an accuracy no less than 5m
DR 4.1.1.1	The CD shall have a GPS receiver with a minimum accuracy of 5m
DR 4.2	The CD shall have a flight endurance of a minimum of 20 minutes under ambient conditions similar to those of Colorado during peak wildfire season.
DR 4.2.1	The CD shall have a flight service ceiling of a minimum of 5400 ft / 1646 m ASL
DR 4.2.2	The CD shall operate with ground temperatures between 50°F / 10°C and 118°F / 47.8°C
DR 4.2.3	The CD shall operate in wind speeds a maximum of 10 mph / 4.5 m/s
DR 4.2.3.1	The CD shall be capable of flight at a minimum of airspeeds of 22.4 mph / 10 m/s
DR 4.2.4	The CD shall operate in a maximum humidity of 80%

REQUIREMENTS

Requirement	Description
FR 4.0	The CD shall fly to GPS coordinates
DR 4.3	The CD shall have a minimum operational radius of 200 m away from the MR
DR 4.3.1	The GSMRS shall be capable of sending all required commands a minimum of 200 m
DR 4.3.2	The CD shall be capable of sending all required data a minimum of 200 m
DR 4.3.3	The SP shall be capable of sending all required data a minimum of 200 m

REQUIREMENTS

Requirement	Description
FR 5.0	The CD shall deploy the SP to a ground location of interest (LOI)
DR 5.1	The CD shall be capable of housing the SP
DR 5.1.1	The SP shall have a maximum mass of TBD
DR 5.1.2	The SP shall have maximum dimensions of TBD
DR 5.2	The CD shall be capable of releasing the SP during flight
DR 5.3	The SP shall remain within 5 m of the LOI after deployment

REQUIREMENTS

Requirement	Description
FR 6.0	The CD shall be capable of recording video footage
DR 6.1	The CD shall have a video camera
DR 6.1.1	The video camera shall record video at a minimum of 1080p resolution.
DR 6.1.2	The video camera shall record video at a minimum of 30 frames per second
DR 6.1.3	The video camera shall record video with a minimum of 100° field of view
DR 6.1.4	The video camera shall have a maximum mass of TBD
DR 6.1.5	The video camera shall have maximum dimensions TBD
DR 6.2	Captured video data shall be timestamped

REQUIREMENTS

Requirement	Description
FR 7.0	The CD shall be capable of recording photos
DR 7.1	The CD shall have a photo camera
DR 7.1.1	The photo camera shall record photos at a minimum of 8 MP resolution
DR 7.1.2	The photo camera shall have a maximum mass of TBD
DR 7.1.3	The photo camera shall have maximum dimensions of TBD
DR 7.2	Captured photo data shall be timestamped

REQUIREMENTS

Requirement	Description
FR 8.0	The CD shall transmit wireless data to the GSMRS
DR 8.1	The CD shall transmit GPS position data to the GSMRS
DR 8.2	The CD shall transmit video imagery to the GSMRS
DR 8.3	The CD shall transmit photo imagery to the GSMRS
DR 8.4	The CD shall be capable of transmitting all data from its maximum operational radius

REQUIREMENTS

Requirement	Description
FR 9.0	The GSMRS shall receive wireless data from the CD
DR 9.1	The GSMRS shall receive GPS position data from the CD
DR 9.2	The GSMRS shall receive video imagery from the CD
DR 9.3	The GSMRS shall receive photo imagery from the CD

REQUIREMENTS

Requirement	Description
FR 10.0	The CD shall land in the GSMRS docking bay
DR 10.1	The CD shall land under operator control

REQUIREMENTS

Requirement	Description
FR 11.0	The SP shall acquire ground temperature data after deployment
DR 11.1	The SP shall acquire data for 1 hour
DR 11.2	The SP shall acquire data at 1 Hz frequency
DR 11.3	The SP shall acquire data at 8-bit resolution
DR 11.4	The SP shall timestamp data

REQUIREMENTS

Requirement	Description
FR 12.0	The SP shall transmit wireless data to the GSMRS
DR 12.1	The SP shall transmit timestamped temperature data to the GSMRS
DR 12.2	The SP shall be capable of retransmitting temperature data
DR.12.2.1	The SP shall be capable of buffering up to 1 hour of timestamped temperature data

REQUIREMENTS

Requirement	Description
FR 13.0	The GSMRS shall receive wireless data from the SP
DR 13.1	The GSMRS shall receive temperature data from the SP