Preliminary Design Review

CHIMERA

CHIld drone deployment MEchanism and Retrieval Apparatus

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Advisor: Jelliffe Jackson

Mission Statement

CHIMERA (<u>CHI</u>ld drone deployment <u>ME</u>chanism and <u>R</u>etrieval <u>A</u>pparatus) will support the autonomous deployment, landing, and securing of the INFERNO unmanned aerial system and act as a communications relay to assist firefighters in the monitoring and mitigation of wildfires.

Project Overview

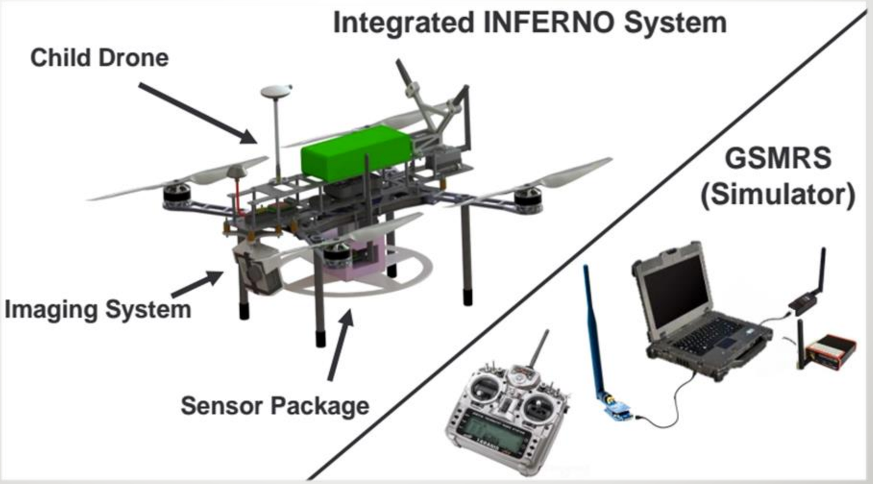
- Wildfire containment and mitigation efforts are a primary concern for those living in or near wildfire-prone regions of the United States
- Autonomous vehicle systems are an active area of research and development for a wide range of applications
- An **autonomous drone** and **mother rover** surveying system can support long-range missions
- Such systems will be able to **perform reconnaissance** operations and **assist firefighters** that are unable to reach remote locations of interest

Project Heritage

INFERNO

INtegrated **F**light **E**nabled **R**over for **N**atural disaster **O**bservation[2]

- 2015-2016 JPL sponsored senior design project
- Semi-autonomous drone capable of delivering temperature-sensing package to wildfire area of interest
- **CHIMERA** will utilize existing **INFERNO** hardware shown:
- INFERNO Capabilities:
  - **Mission Duration:** 13.5 minutes
  - **Fully Autonomous Takeoff**
  - **10 m/s Translational Flight**
  - **Video/Imaging**: 720p at 30fps
  - **Sensor Package**: >90% transmission of SPS data



Project Overview | Autonomous Landing | Securing | Charging | Communication | Conclusion

Definitions

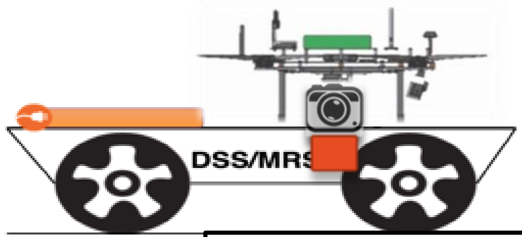
- **Alight:** To descend from the air and settle
- **Charge:** Transfer of electricity from MRS battery to CDS battery
- **Deploy:** The CDS vertically ascends from DSS
- **Disarm:** CDS is no longer capable of flight
- **Drive:** MRS motors are initiated on axle, propelling MRS in a forward direction
- **Land:** CDS alights with all four feet on DSS
- **Mission:** The CDS is deployed from the DSS, flies to area of interest, drops SPS, returns to MRS, and lands on DSS
- **Secure:** DSS electromagnets are activated, restraining CDS on the DSS

Acronyms

- CDS: Child Drone System
- COM: Communication System
- CRG: Charging System
- DSS: Drone Securing System
- GND: Ground Station
- MRS: Mother Rover System
- SPS: Sensor Package System
- SRS: Sensor Package Release System
- WLS: Wheel Locking System
- FOV: Landing Camera Diagonal Field of View
- P_R = Power received
- P_T = Transmitted Power
- G_T = Transmit Gain
- G_R = Received Gain
- L_S = Space Loss
- L_L = Line Loss

Concept of Operations

Deployment



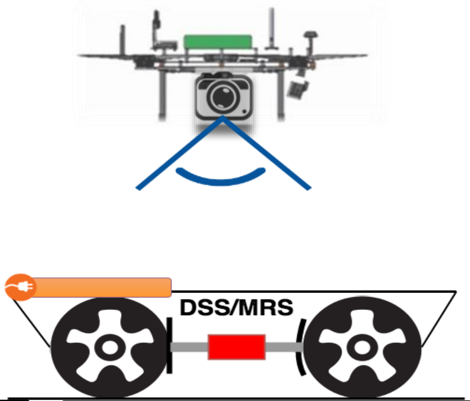
Command: MRS to Drive
GND → MRS

Release SPS

End of CONOPS

Transmit CDS Video
GND ← CDS

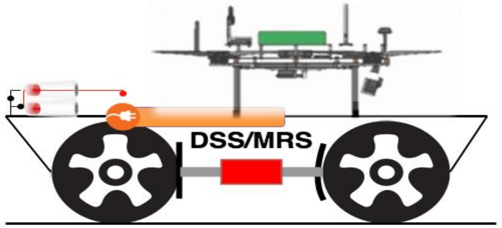
Transmit SPS Data
GND ← SPS



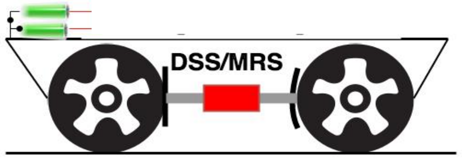
Landing

Command: Charge
GND → MRS → CRG

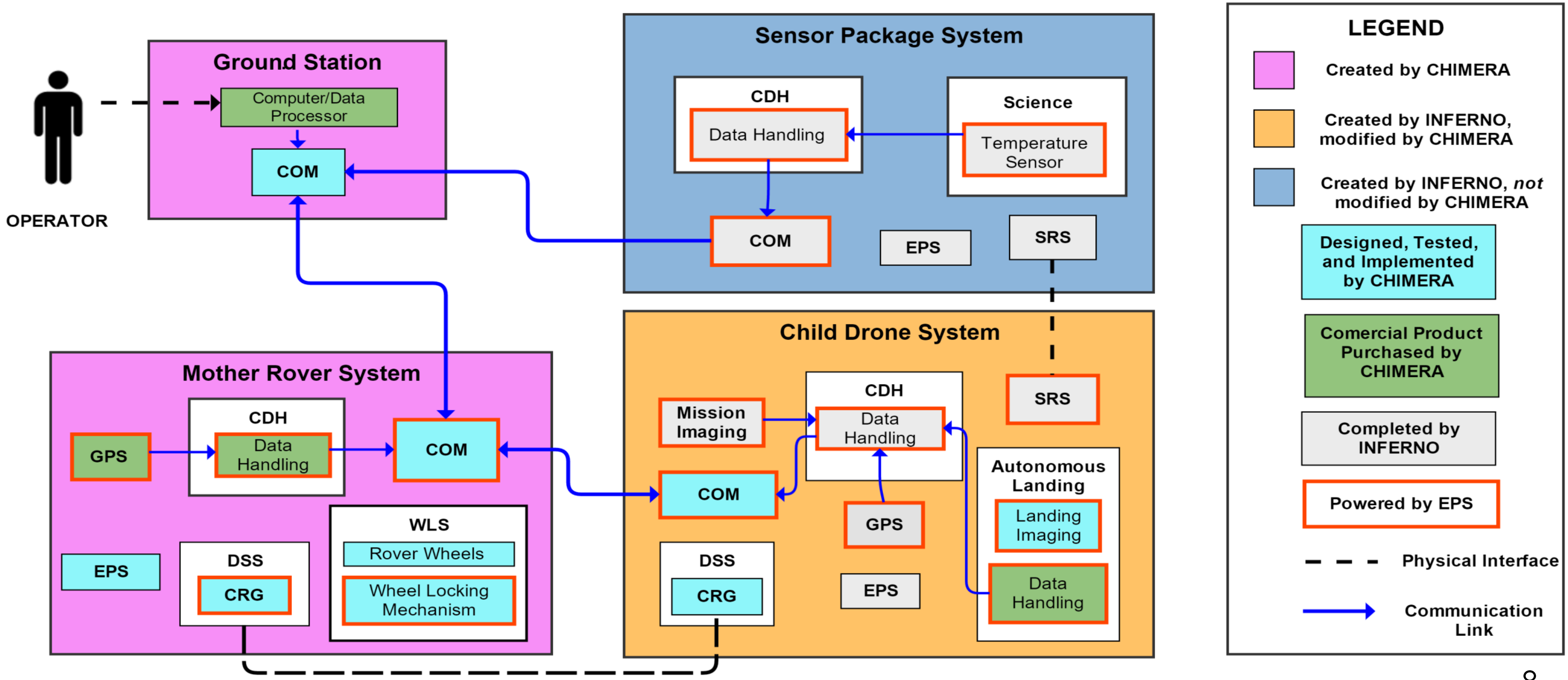
Re-Deploy



Charging



Functional Block Diagram: System Level



Functional Requirements

Functional Requirement	Description
FR 1.0	**The CDS shall autonomously land on DSS.**
FR 2.0	**The CDS shall autonomously deploy from the DSS.**
FR 3.0	**The DSS shall secure the CDS using electromagnets.**
FR 4.0	The MRS shall drive forward a minimum of 10 meters on a flat level paved surface.
FR 5.0	The COM shall wirelessly transmit data at a minimum horizontal range of 200 meters at 915 MHz.
FR 6.0	The COM shall wirelessly receive data at a minimum horizontal range of 500 meters at 915 MHz.
FR 7.0	The COM shall wirelessly receive SPS data at a minimum horizontal distance of 700 meters at 900 MHz.
FR 8.0	The COM shall wirelessly receive video at a maximum horizontal range of 700 meters at 5.8 GHz.
FR 9.0	**The CRG shall autonomously increase the CDS battery voltage.**

Design Requirements

Autonomous Landing

Functional Requirement	Description
FR 1.0	**The CDS shall autonomously land on DSS.**
Design Requirement	**Description**
DR 1.1	The CDS shall land within a 1.1 by 1.1 m^2 area.
DR 1.2	The CDS shall land within 15 minutes of deployment.
DR 1.3	The CDS shall autonomously land under 3 minutes after landing command is sent.

Functional Requirement	Description
FR 2.0	**The CDS shall autonomously deploy from the DSS.**
Design Requirement	**Description**
DR 2.1	The CDS shall deploy to a minimum height of 1 m above the DSS.

Design Requirements

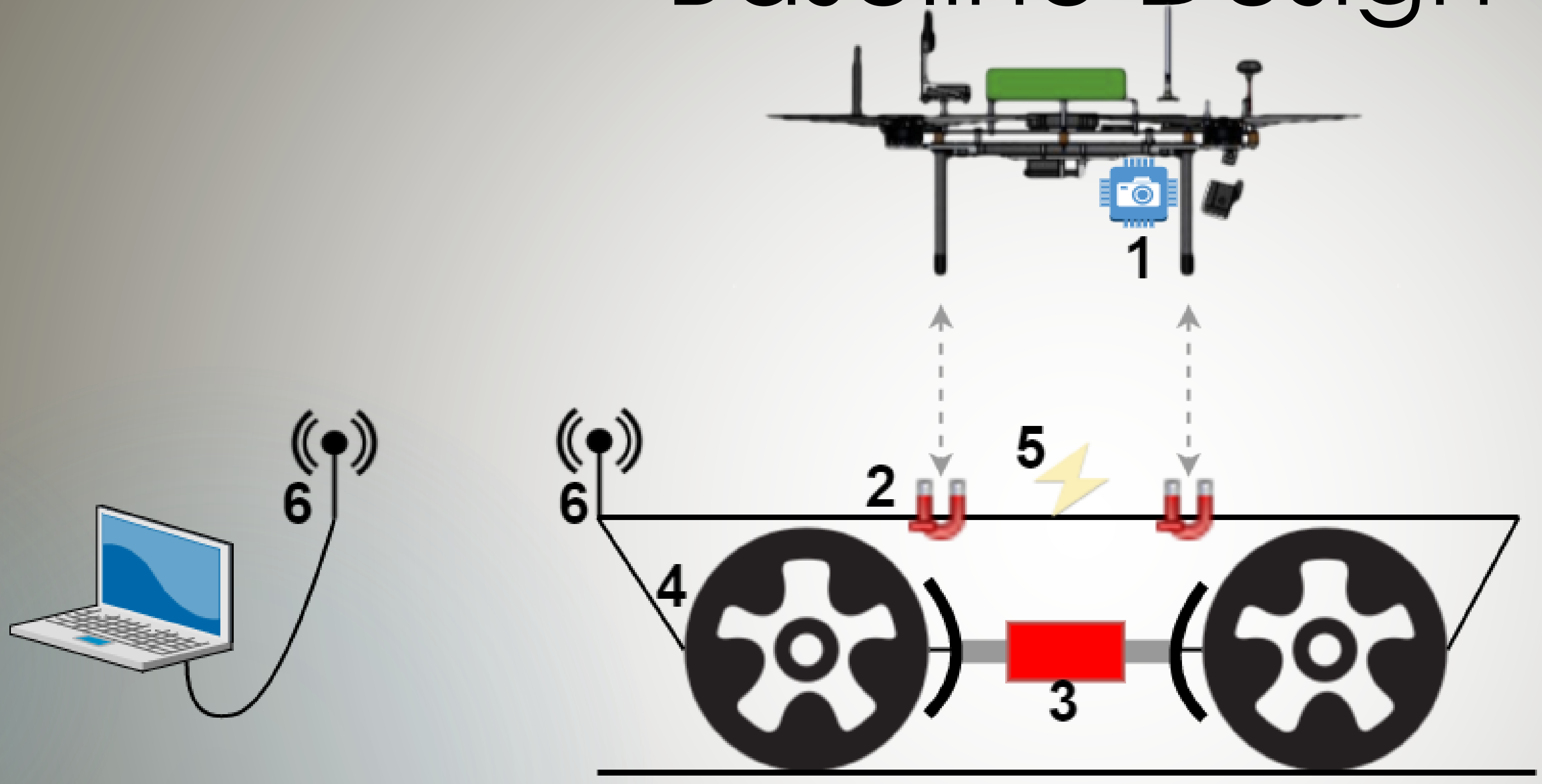
Securing

Functional Requirement	Description
FR 3.0	**The DSS shall secure the CDS using electromagnets.**
Design Requirement	**Description**
DR 3.1	The DSS shall secure the CDS while MRS is driving.
DR 3.2	The DSS shall command the electromagnets off prior to CDS deployment.

Charging

Functional Requirement	Description
FR 9.0	**The CRG shall autonomously increase the CDS battery voltage.**
Design Requirement	**Description**
DR 9.1	The CRG shall charge the CDS battery one time by a minimum of 1 Volt.
DR 9.2	The CRG shall adjust CDS orientation on DSS for maximum landing yaw error of 45°.

Baseline Design



Critical Project Elements

1. Image Recognition (Autonomous Landing)	2. Securing System	3. Wheel Locking System	4. Wheeled MRS	5. Charging System	6. Communication System

Autonomous Landing

Autonomous Landing

0:40 ▶ CDS uses GPS to get MRS in FOV of camera

1:10 ▶ IRS finds center of DSS platform and sends position command

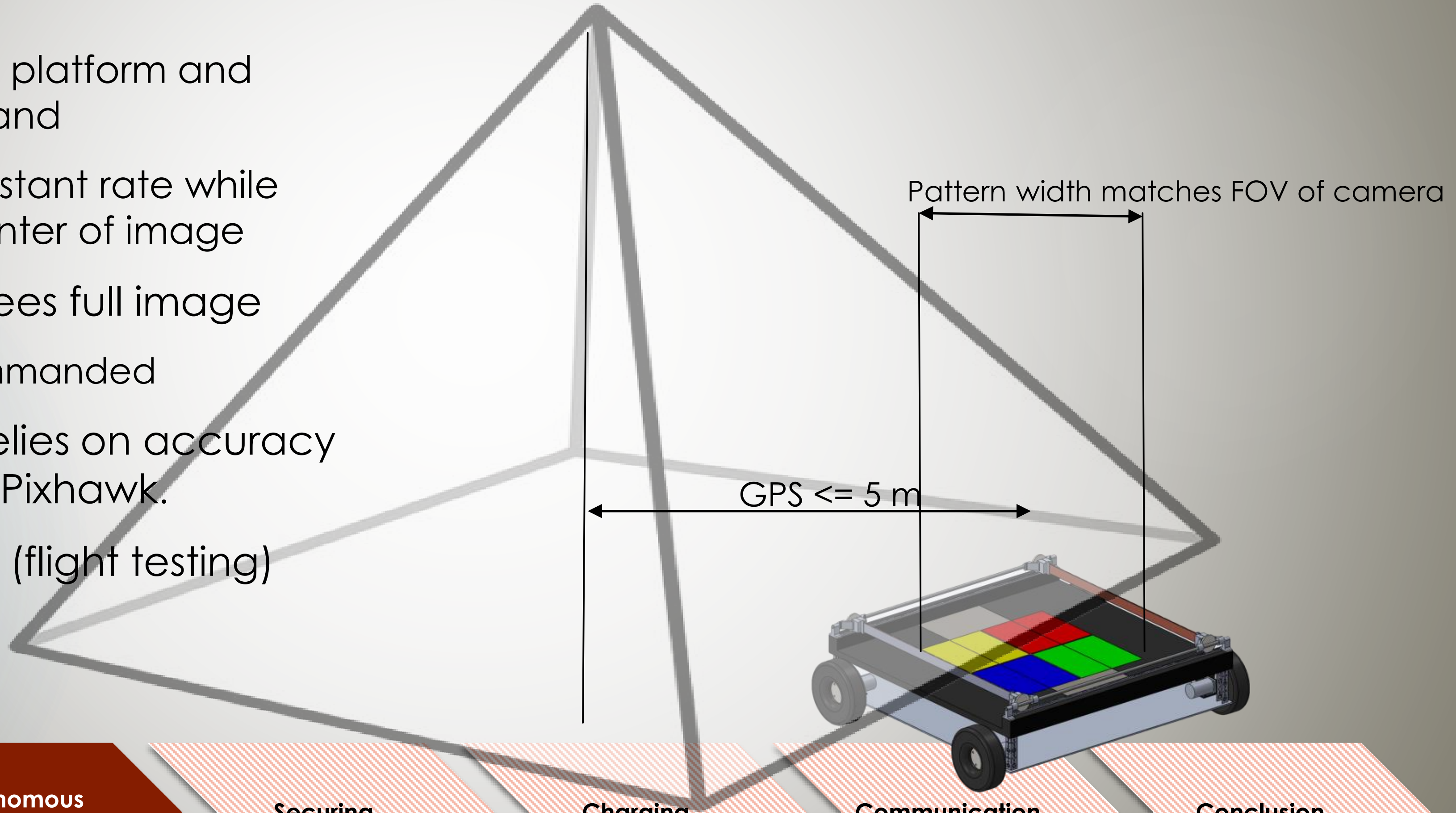
2:50 ▶ CDS descends at constant rate while maintaining DSS in center of image

▶ Camera no longer sees full image

  ▶ Last position is commanded

3:00 ▶ Landing accuracy relies on accuracy of accelerometer in Pixhawk.

▶ Landing timeline TBR (flight testing)



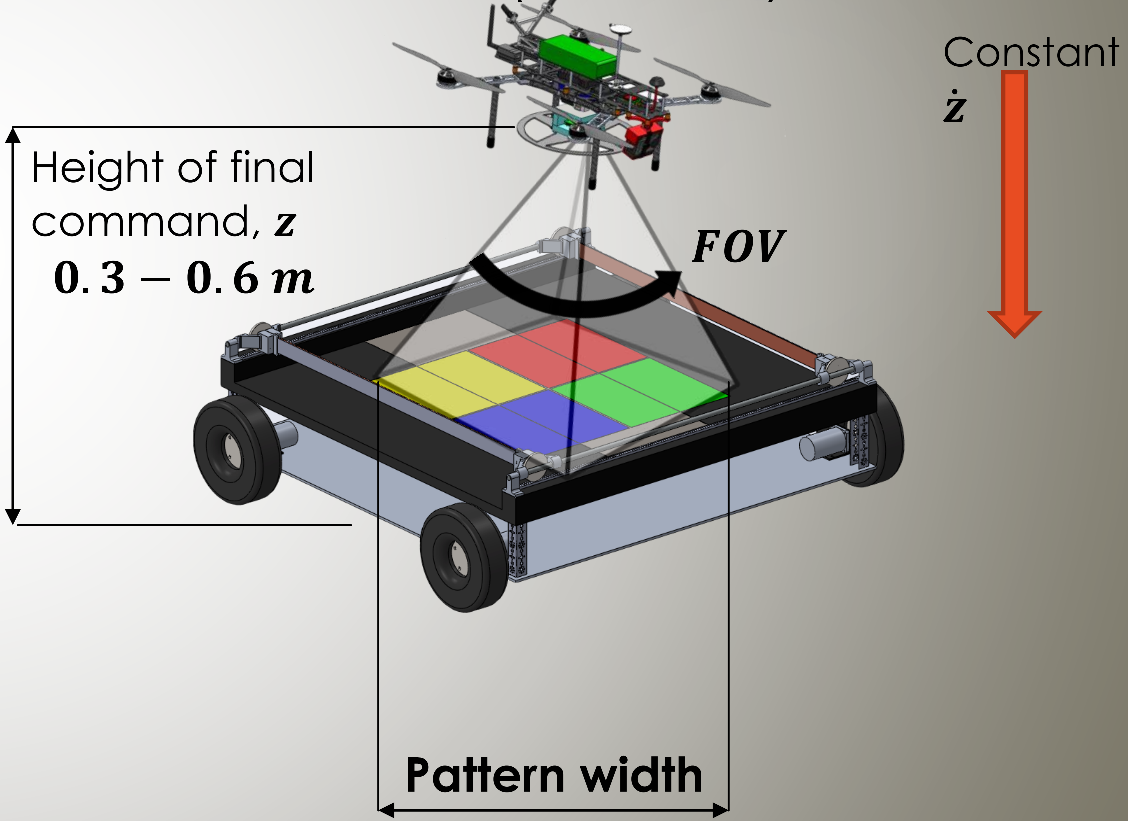
Project Overview | **Autonomous Landing** | Securing | Charging | Communication | Conclusion

Landing Feasibility

- Assumptions:
  - After **platform fills camera FOV**, accurate position can no longer be determined
  - **Camera height** is z-position of CDS legs
  - CDS **offset from center** and **wind effects** accounted for with **20% design margin**
  - Max camera **resolution** error of **1 pixel**
  - **Constant** descent rate
  - Camera mounted on CDS **geometric center**
- Known Pixhawk Error
  - Gyro error: **0.1 [deg/s]**
  - Accelerometer error: **1.11 x 10^{-3} g [m/s^2]**

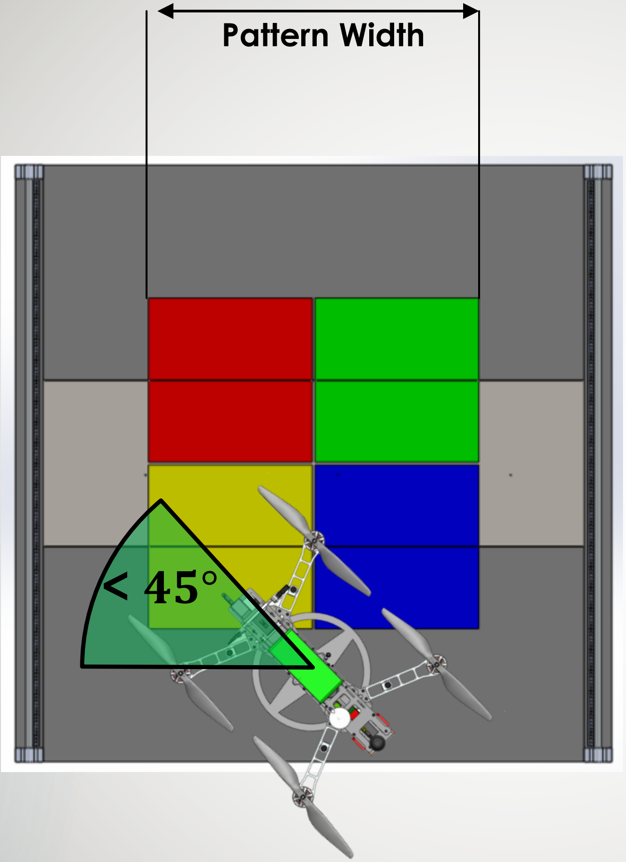
z affected by:

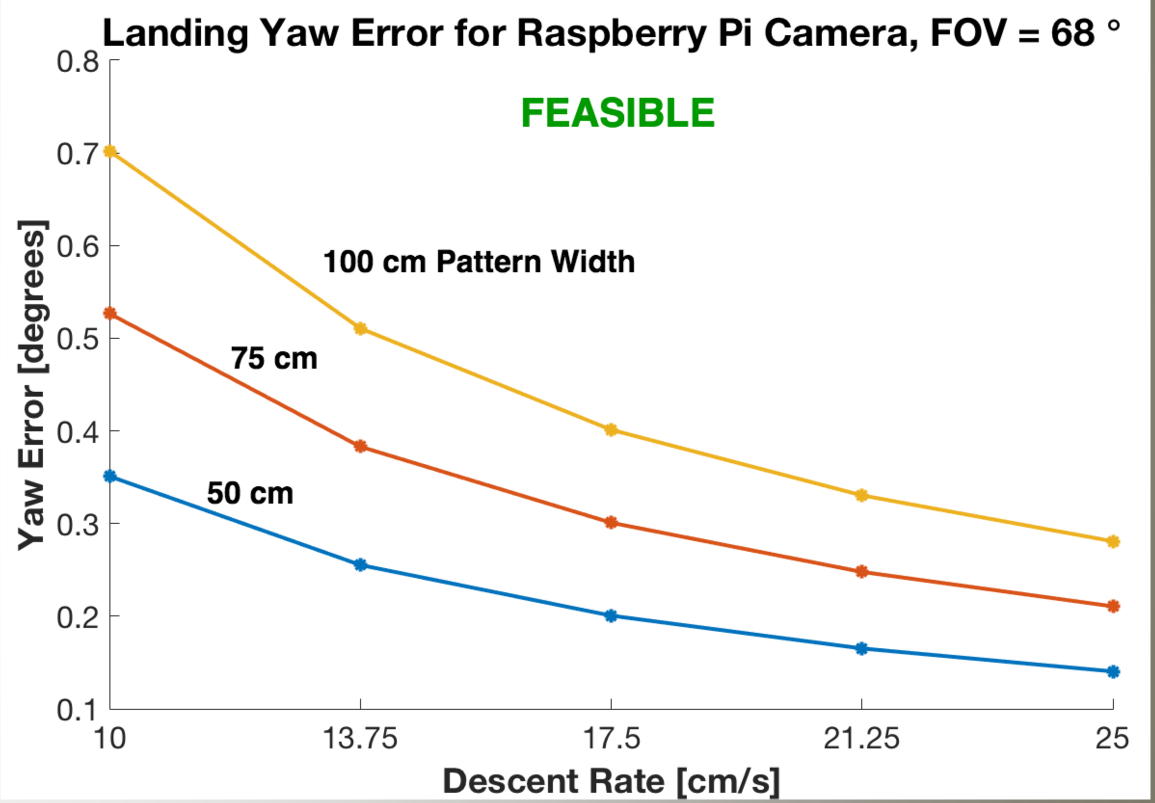
- FOV (68^o)
- $\dot{z}$ $(0.1 - 0.25\frac{m}{s})$
- Pattern width (50-100 cm)



Landing Feasibility

- Sensitivity parameters:
  - Camera **FOV**
  - Descent rate, $\dot{z}$
  - Platform **pattern width**
- Requirements for feasibility:
  - Land within a radius of **55 cm. (FR 1.0, DR 1.1)**
  - Land with yaw error **less than 45°. (FR 9.0, DR 9.2)**





Project Overview | Autonomous Landing | Securing | Charging | Communication | Conclusion

Landing Feasibility

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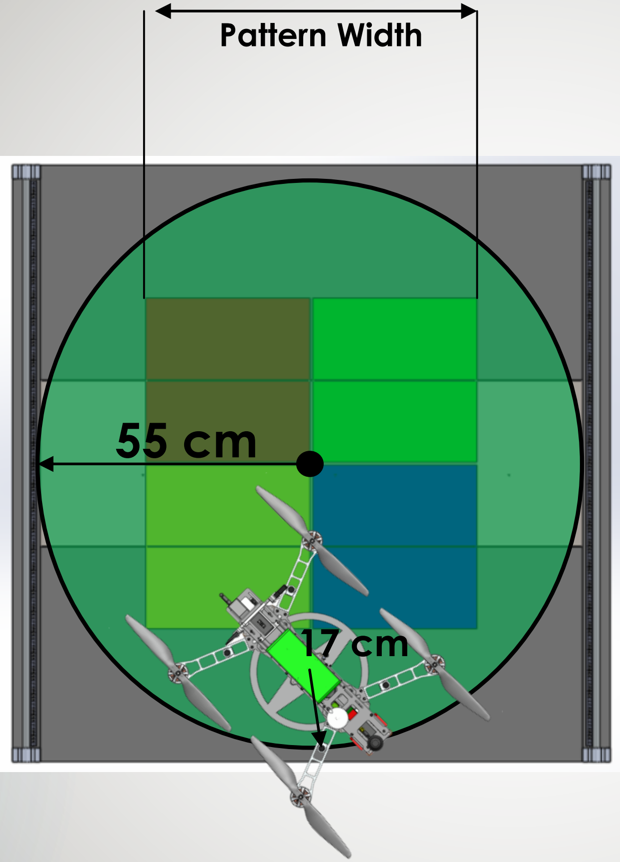
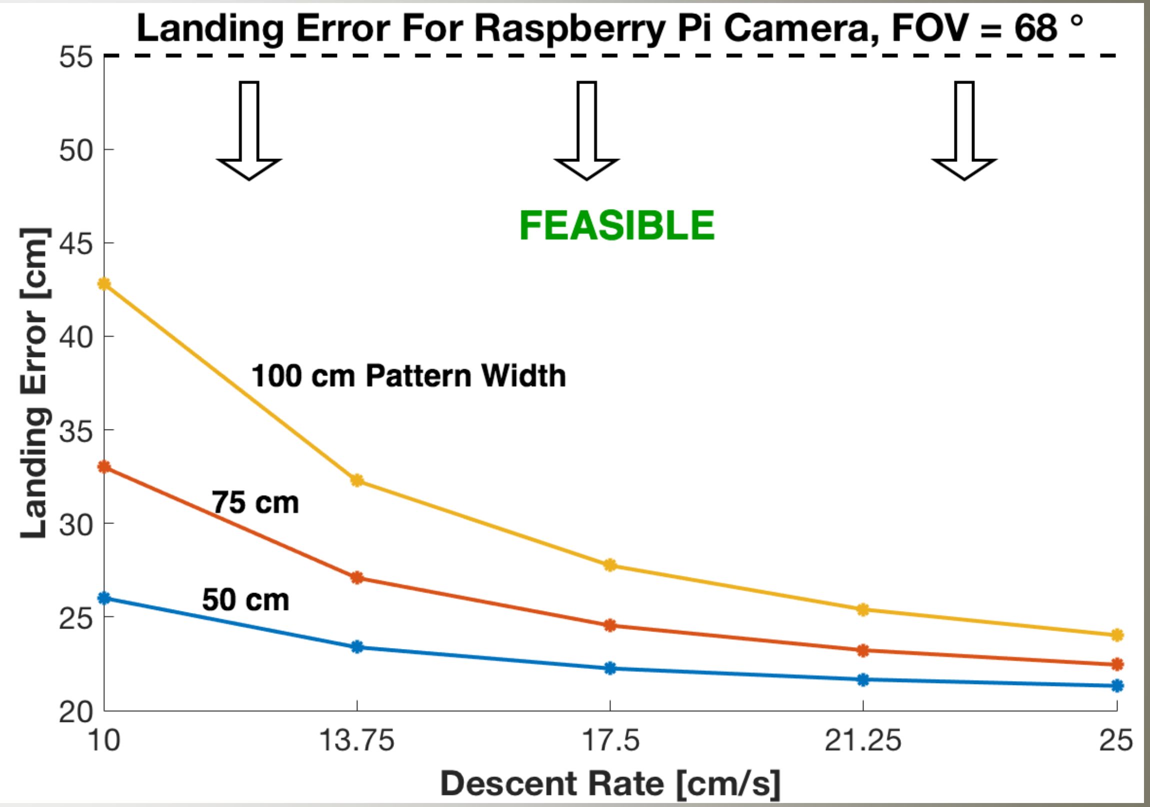
- **FEASIBLE** by analysis

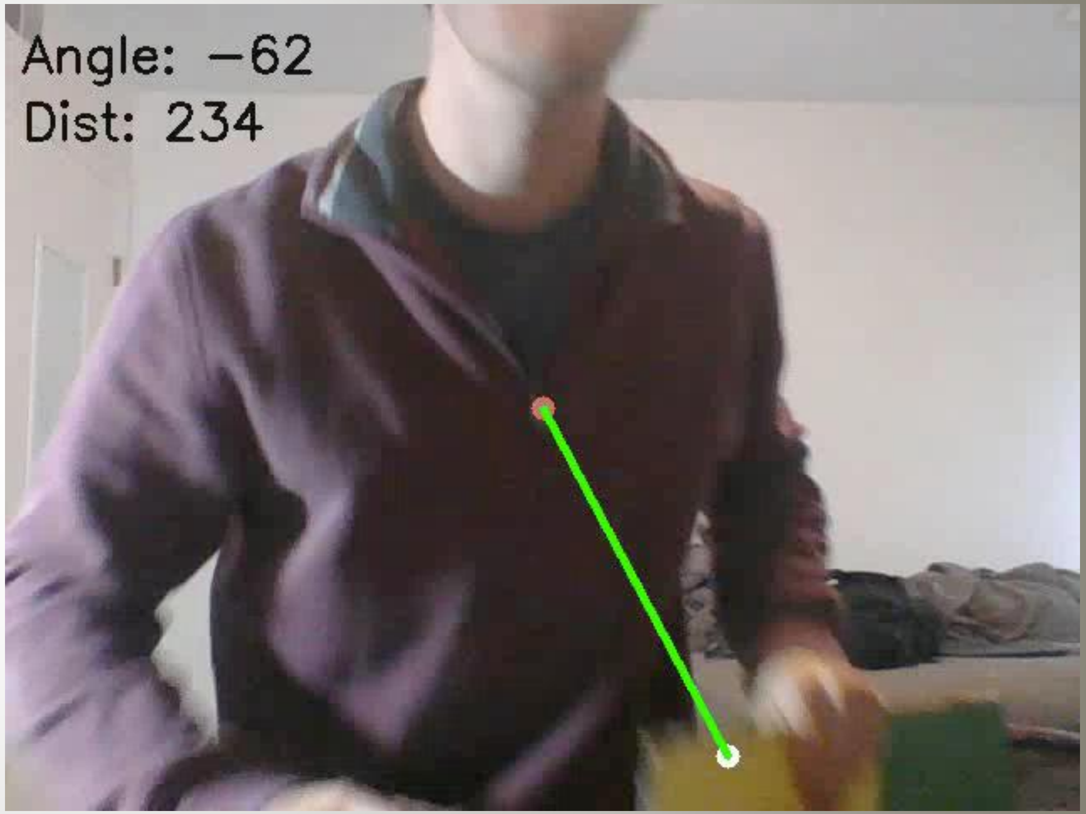




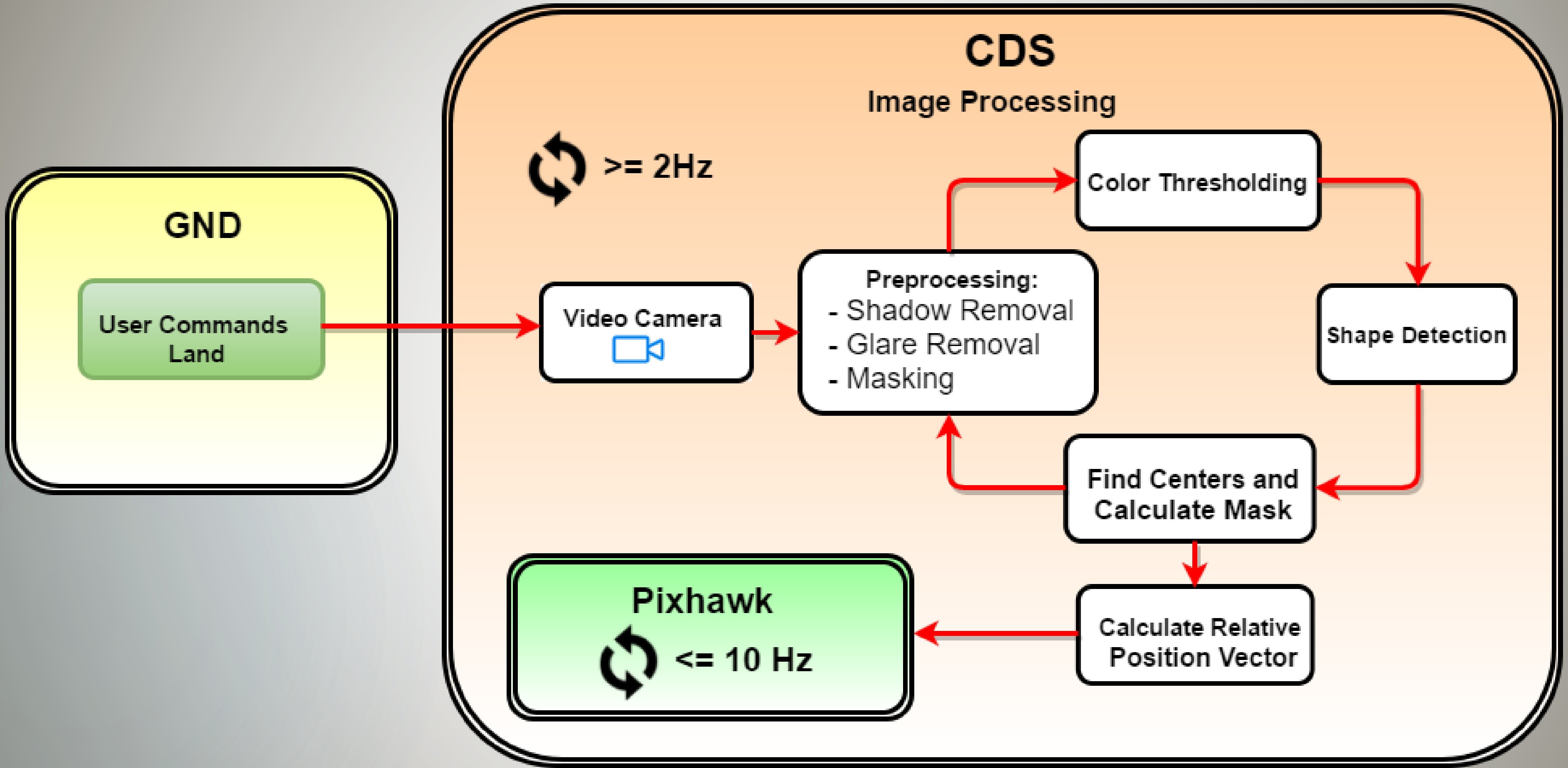
Project Overview | Autonomous Landing | Securing | Charging | Communication | Conclusion

Image Recognition Feasibility

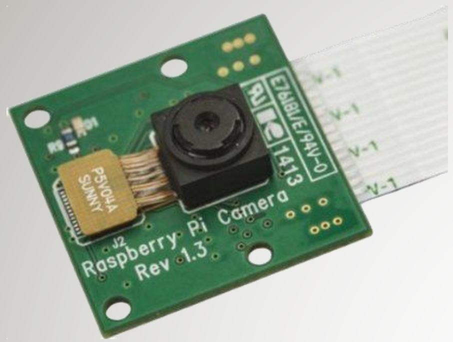
- Find center of **four** different **hues** to get center of MRS platform.
  - Color **thresholding**, **shape detection**, and **image masking** can improve performance.
- Convert **pixel offset** of MRS platform from center of image to distance using **known dimensions** of platform.
- Testing method: Flight simulation software, pilot override option
- **FEASIBLE** by demonstration



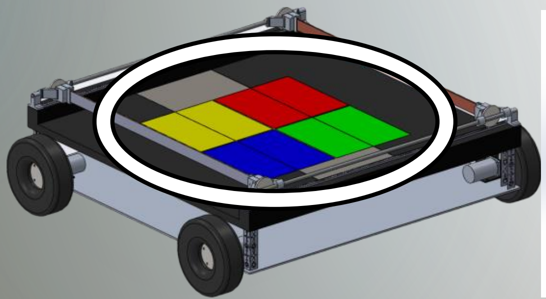
Autonomous Landing: Image Recognition Flowchart

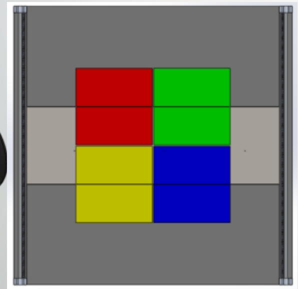


Hardware/Software Components



MAVLINK
MICRO AIR VEHICLE COMMUNICATION PROTOCOL



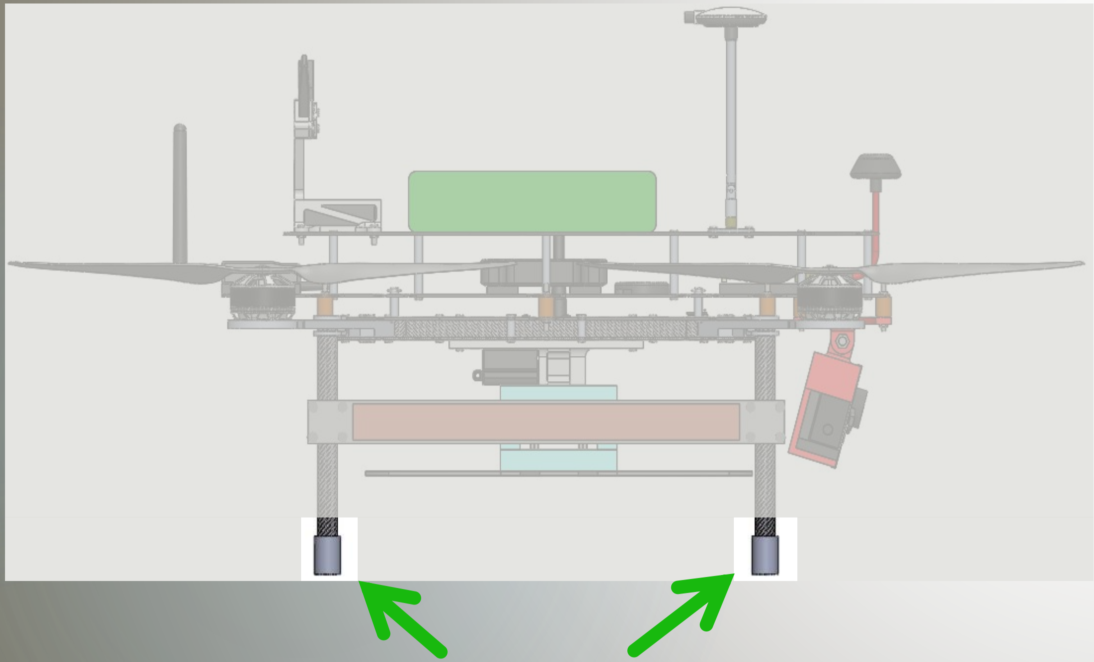


- Camera module
  - Higher FOV preferred
- Companion computer on INFERNO
- IRS prototyped from Python libraries
- Pixhawk flight controller (**already equipped**)
  - MAVLink communication protocol
- DSS pattern for recognition

Securing

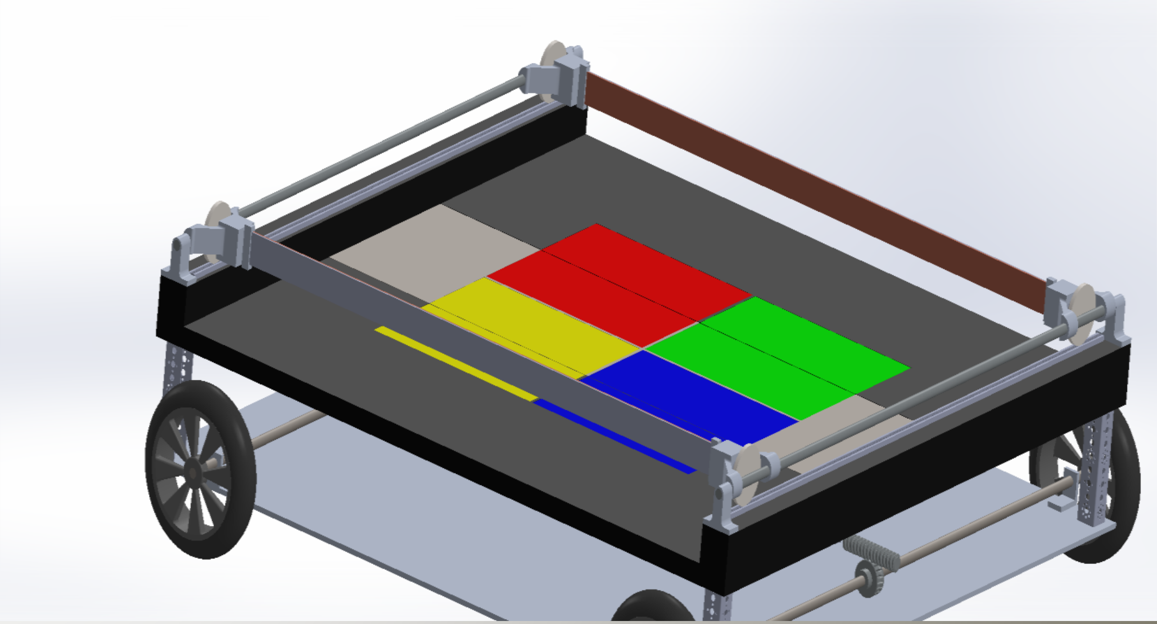
Securing

- Modifications to CDS:
  - Replace rubber feet with high carbon steel



Steel feet

- Design of DSS:
  - High carbon steel across DSS platform
  - 3 electro-permanent magnets

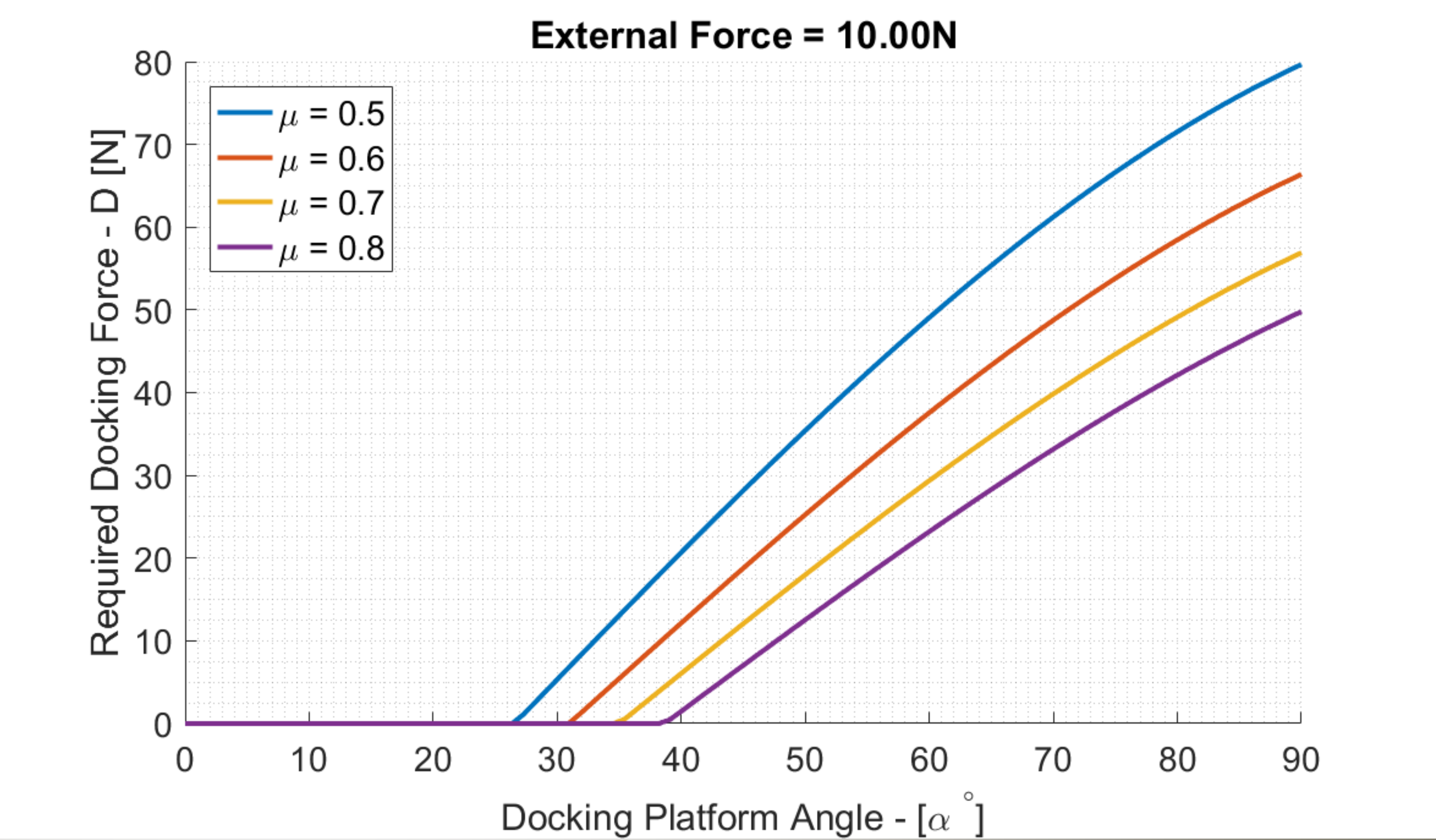


Magnet placement **under** DSS Platform

Magnetic Securing Feasibility

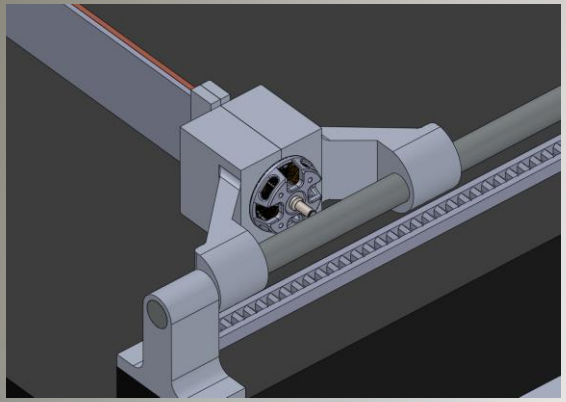
- Maximum securing force needed: **~80 N**
- Maximum magnetic force available: **200 N**
- Assumptions:
  - External force: **10 N**
  - Coefficient of friction for steel on steel **(0.5-0.8)**
- **FR 3.0, DR 3.1**

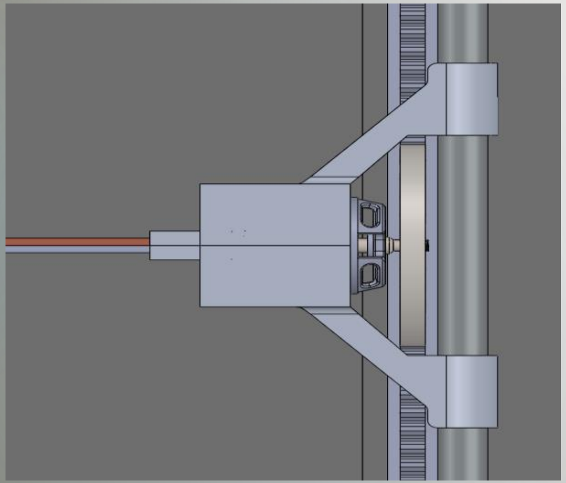
- **FEASIBLE** by analysis

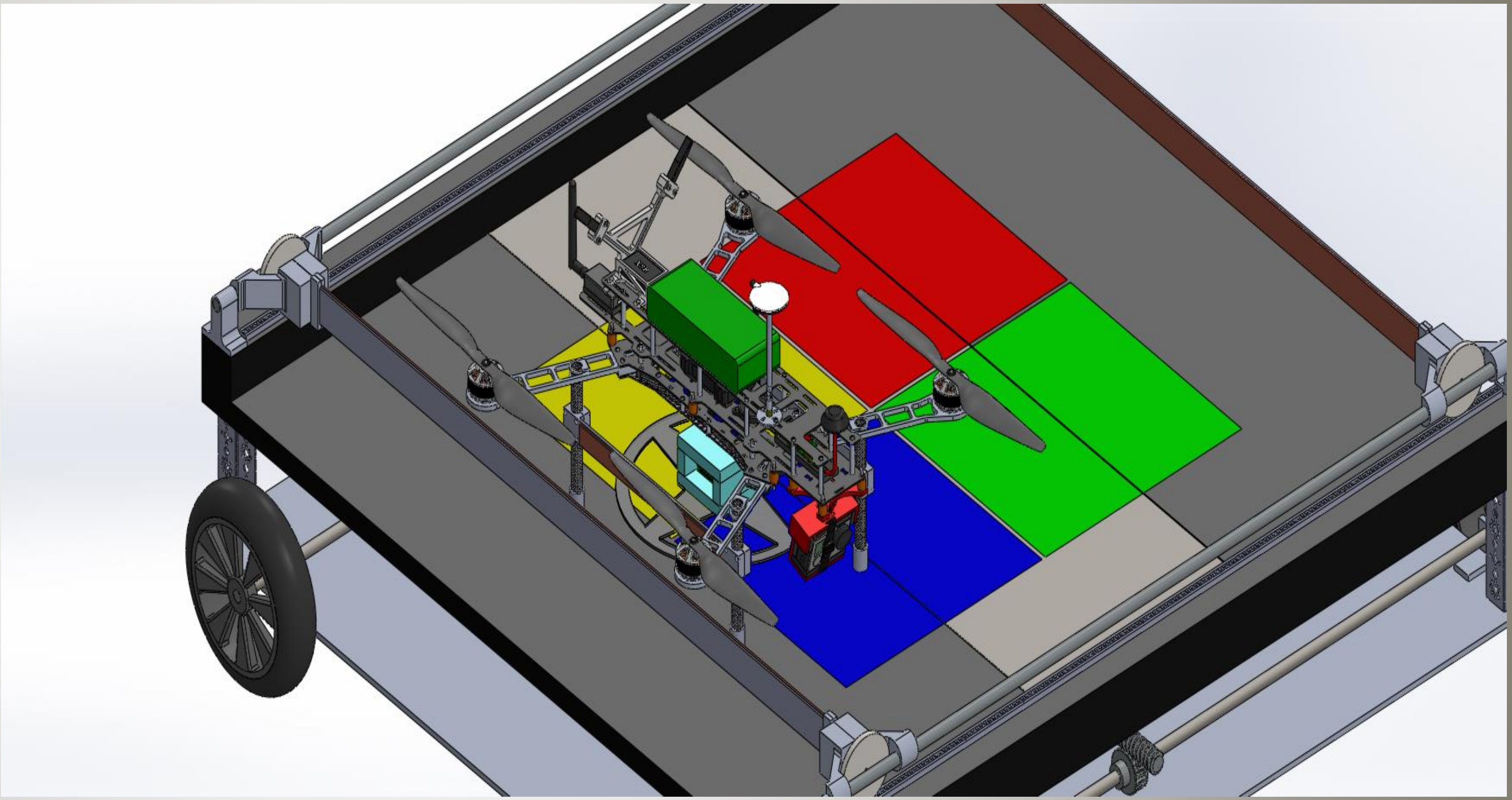


Project Overview | Autonomous Landing | **Securing** | Charging | Communication | Conclusion

Centering CDS on DSS Platform





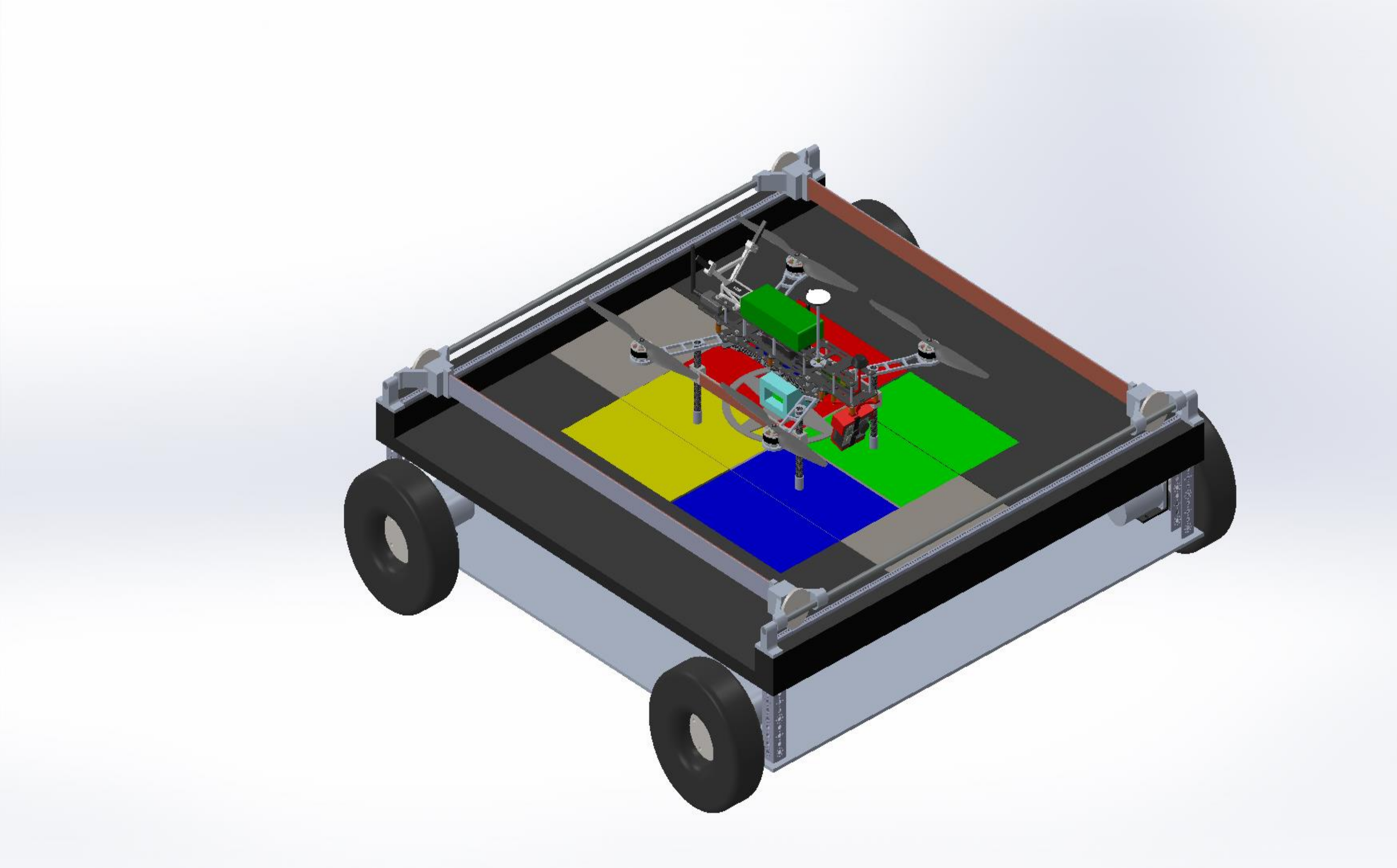


Charging

Charging Mechanism on DSS

- Charge bars positioned on either side of DSS
- Motors will slide charging bars onto CDS
- Once CDS is disarmed charging will initiate

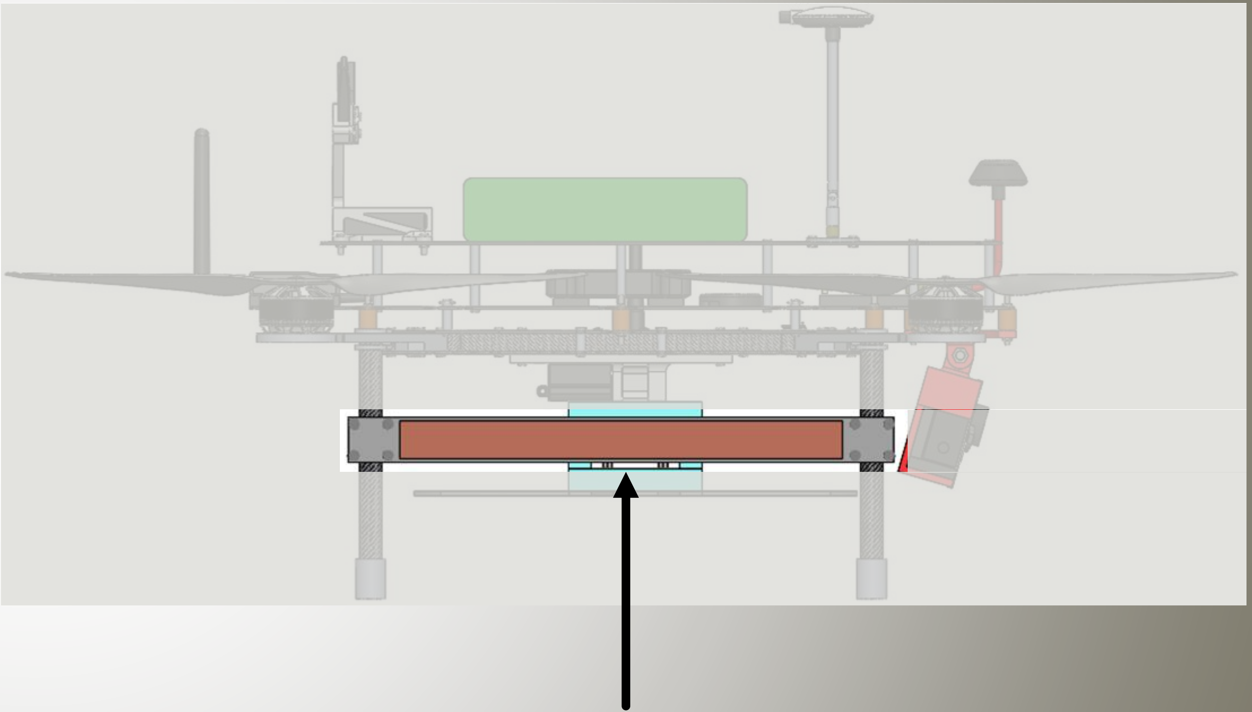
- **Future Work**: Ensure quality copper contact, INFERNO stability, safety precautions



Charging Modifications to CDS

- Copper plate on two faces of CDS
- Bracket and support structure will be attached to CDS legs
- Bracket does not interfere with SPS deployment or GoPro FOV
- INFERNO baseline mass: **2520 g**
- Estimated added mass: **521 g**
- Estimated final mass: **3041 g**
- Maximum allowable mass for 15 minute flight: **3530 g**
- **FEASIBLE** by analysis

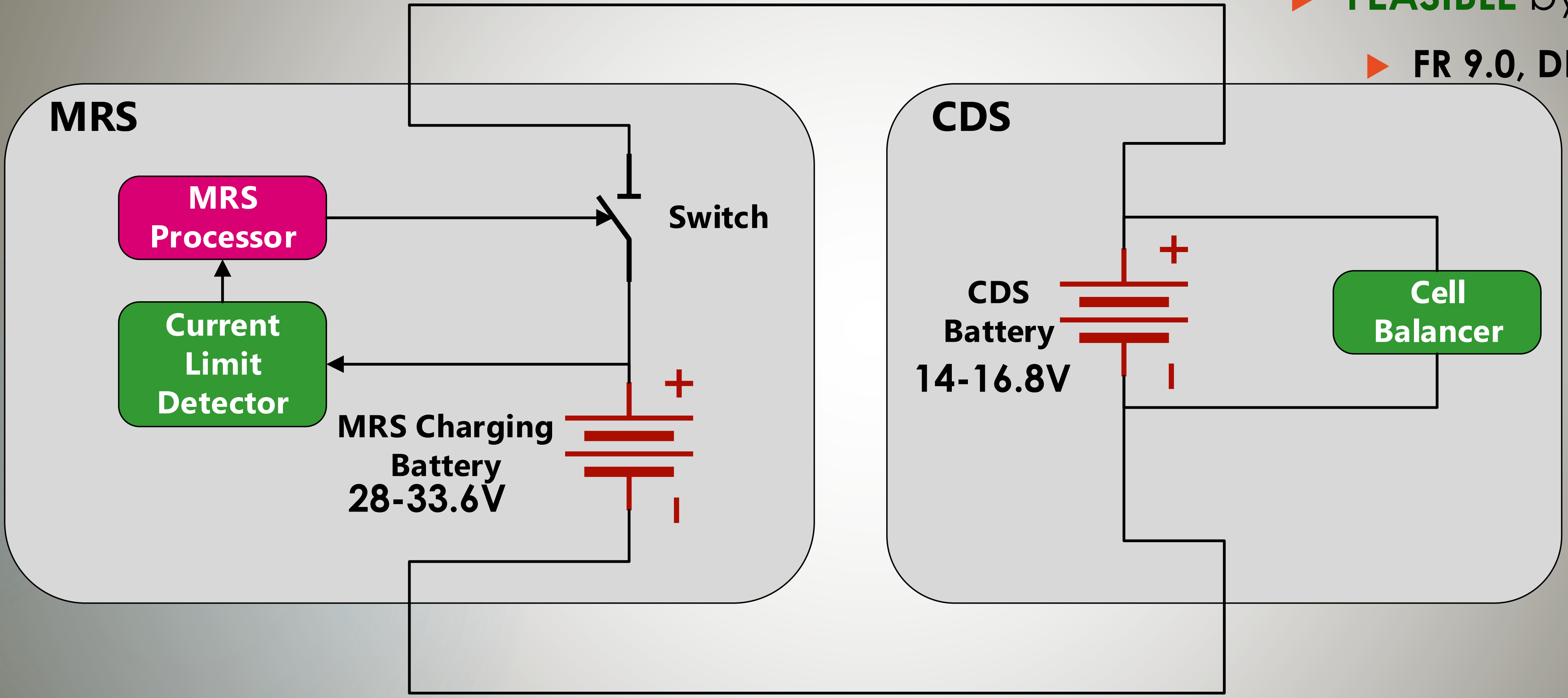
INFERNO: Side view



CDS charging bracket

Charging Schematic

- **FEASIBLE** by analysis
  - FR 9.0, DR 9.1



Communication

Link Margin Analysis

- Link Margin for INFERNO Child Drone System Video Transmission

Immersion RC (5.8 GHz)	Transmitter (INFERNO)	Receiver (GND)
Power Transmitted (P_T)	-2 dBW	-2 dBW
Gain Transmit (G_T)	1 dBi	N/A
Gain Received (G_R)	N/A	10 dbi
Space Loss (L_S)	-105 dB	-105 dB
Additional Error (Line Loss) (L_L)	-0.5 dB	-0.5 dB
Power Received (Actual) (P_R)	-109 dB	-99 dB
Power Received (Minimum) ($P_{R,min}$)	-118 dB	-117 dB
Link Margin	**9 dB**	**18 dB**

- Immersion RC Video Tx/Rx (600 mW)
- 5.8 GHz at Data Rate of 2500 kbps
- Max: 700 meter distance
- **FR 5.0, 6.0, 7.0, 8.0**

Feasible by analysis

Conclusion

Verification and Validation

Functional Requirement	Testing
FR 1.0	**Demonstration and Visual Inspection** – CDS landing will be demonstrated and visually inspected
FR 2.0	**Test and Demonstration** – CDS deployment will be demonstrated and height will be measured.
FR 3.0	**Test and Demonstration** – CDS will be secured to the MRS using electromagnets.
FR 4.0	**Test and Demonstration** – The ability for MRS to drive forward will be demonstrated and the distance will be measured.
FR 5.0	**Test and Demonstration** – Data will be transmitted at a horizontal range of 200 m.
FR 6.0	**Test and Demonstration** – Data will be received at a horizontal range of 500 m.
FR 7.0	**Test and Demonstration** – SPS data will be received from a horizontal distance of 700 m.
FR 8.0	**Test and Demonstration** – Video will be received over a maximum range of 700 m.
FR 9.0	**Test** – Battery voltage will be measured.

Charging - Safety

- Safety Procedure for Operating High voltage
  - De-energize equipment before working
  - Touch circuit with back of your hand first
  - Keep one hand in your pocket
  - Wear rubber shoes
- Charging Tests
  - Unit testing will occur throughout design and manufacturing process
  - Controlled, away from equipment
  - Fire precautions (CO_2 fire extinguisher, BBQ grill, etc.)

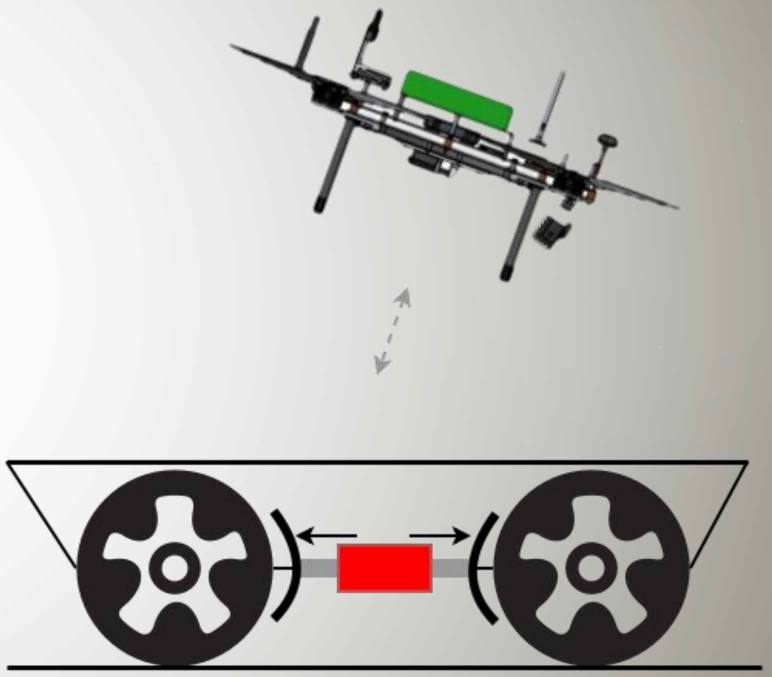
Facilities and Resources

- **Required Facilities**
  - RIFLE: RECUV Indoor Flight Environment
  - Boulder South Campus (flight testing)
  - Flat, open area
    - 10 m radius for MRS
    - 700 m open area for COM testing
- **Required Resources**
  - Pilot
  - Spectrum analyzer (COM testing)
  - Multimeter

In Development…

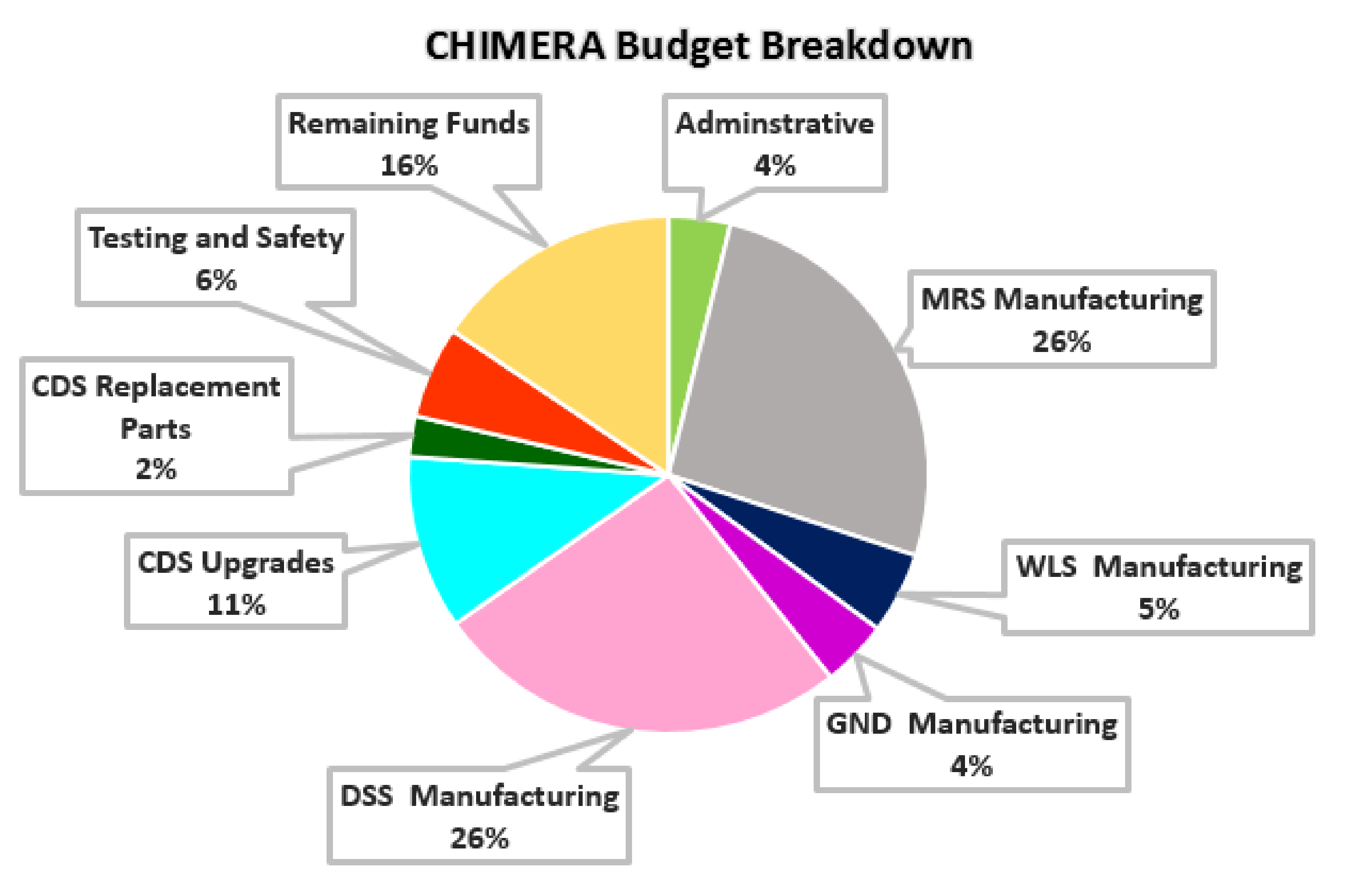
Wheel Locking Mechanism

- **Problem**: If the CDS lands on (or deploys from) the MRS with a horizontal velocity component, the MRS could move
- **Solution**: Prevent the wheels from moving by applying a horizontal force to each wheel
- **Determining if necessary through analysis and test**



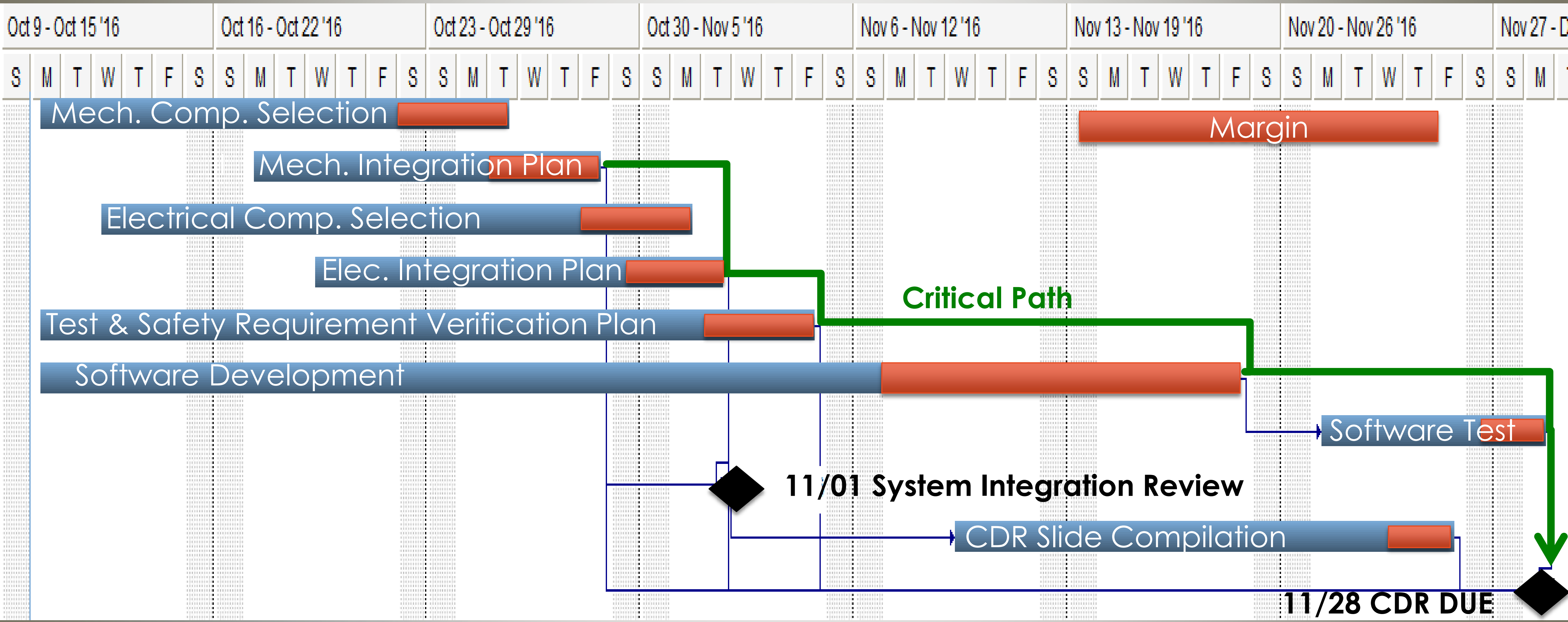
Budget

SUMMARY	
System	**System Cost**
Adminstrative	$ 192.00
MRS Manufacturing	$ 1,310.40
WLS Manufacturing	$ 254.40
GND Manufacturing	$ 207.60
DSS Manufacturing	$ 1,298.40
CDS Upgrades	$ 543.60
CDS Replacement Parts	$ 127.20
Testing and Safety	$ 288.00
Remaining Funds	**$ 778.40**
Budget	**$ 5,000.00**



Design Margin: 1.2

Schedule to CDR



Conclusion

Preliminary Design Summary

Critical Project Element	Design Solution	Feasible?
Autonomous Landing	Image Recognition	Yes
Securing	Electromagnets	Yes
Charging	Conduction Brackets	Yes
Communications	Rx/Tx Connection	Yes

QUESTIONS?

References

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Backup Slides

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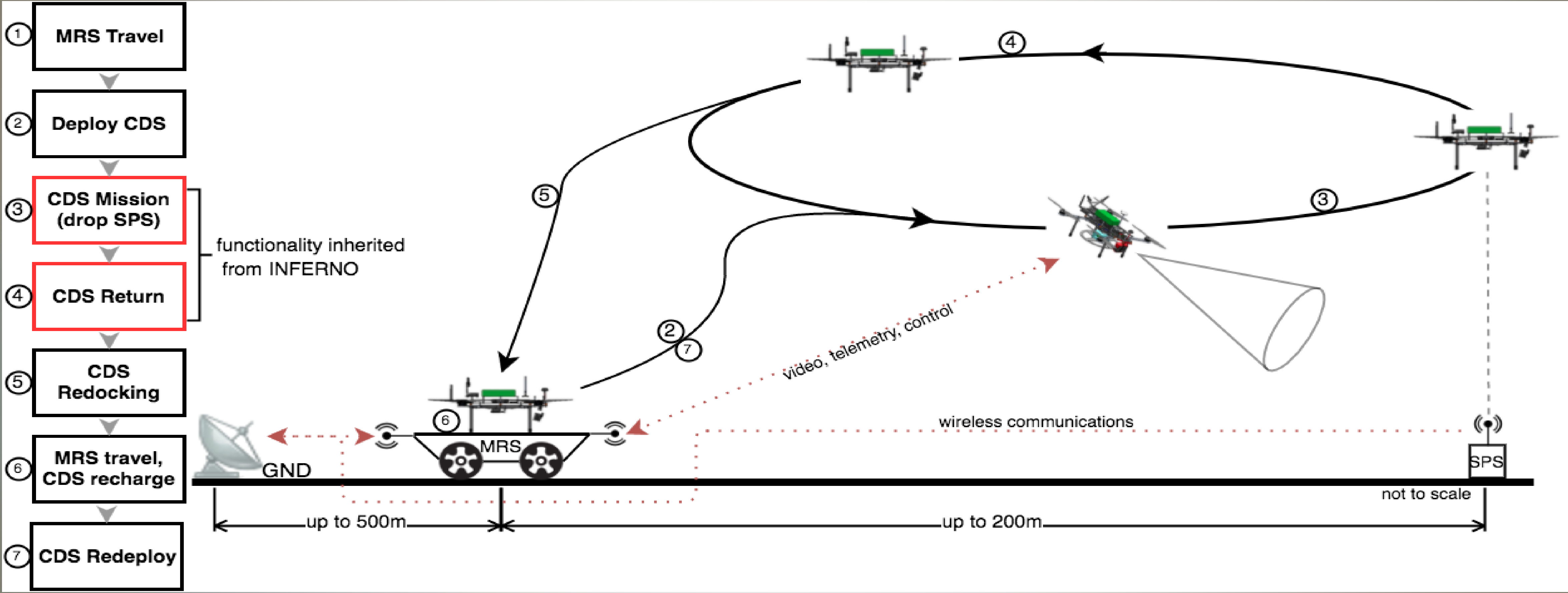
Concept of Operations

Mission



Project Overview | Autonomous Landing | Securing | Charging | Communication | Conclusion

Design Requirements

Securing

Functional Requirement	Description
FR 3.0	The DSS shall secure the CDS using electromagnets.
Design Requirement	**Description**
DR 3.1	The DSS shall secure the CDS while MRS is driving.
DR 3.2	The DSS shall command the electromagnets off prior to CDS deployment.

Driving

Functional Requirement	Description
FR 4.0	The MRS shall drive forward a minimum of 10 meters on a flat level paved surface.
Design Requirement	**Description**
DR 4.1	The MRS shall remain stationary during the entire CDS mission.

Design Requirements

Communication

Functional Requirement	Description
FR 5.0	**The COM shall wirelessly transmit data at a minimum horizontal range of 200 meters at 915 MHz.**
Design Requirement	**Description**
DR 5.1	The DSS COM shall be designed with a signal strength to noise ratio margin of at least 6dB to CDS.
DR 5.2	The DSS COM shall transmit commanded GPS waypoints to the CDS COM.
DR 5.3	The DSS COM shall command the CDS COM to begin landing sequence.
DR 5.4	The DSS COM shall command the CDS COM to begin take off sequence.
DR 5.5	The DSS COM shall transmit a command to release the mechanism that secures the CDS.

Design Requirements

Communication

Functional Requirement	Description
FR 6.0	The COM shall wirelessly receive data at a minimum horizontal range of 500 meters 915 MHz.
Design Requirement	**Description**
DR 6.1	The DSS COM shall be designed with a signal strength to noise ratio margin of at least 6dB to GND.
DR 6.2	The DSS COM shall receive commanded GPS waypoints from the GND
DR 6.3	The DSS COM shall receive the command for the CDS to begin landing sequence
DR 6.4	The DSS COM shall receive the command for the CDS to begin take off sequence
DR 6.5	The DSS COM shall receive the command to release the mechanism that secures the CDS

Design Requirements

Communication

Functional Requirement	Description
FR 7.0	The COM shall wirelessly receive SPS data at a minimum horizontal distance of 700 meters at 900 MHz.
Design Requirement	**Description**
DR 7.1	The DSS COM shall wirelessly transmit video at 720p at 30 fps.
DR 7.2	The DSS COM shall wirelessly transmit 5 minutes of video
DR 7.3	The DSS COM shall wirelessly transmit CDS telemetry.

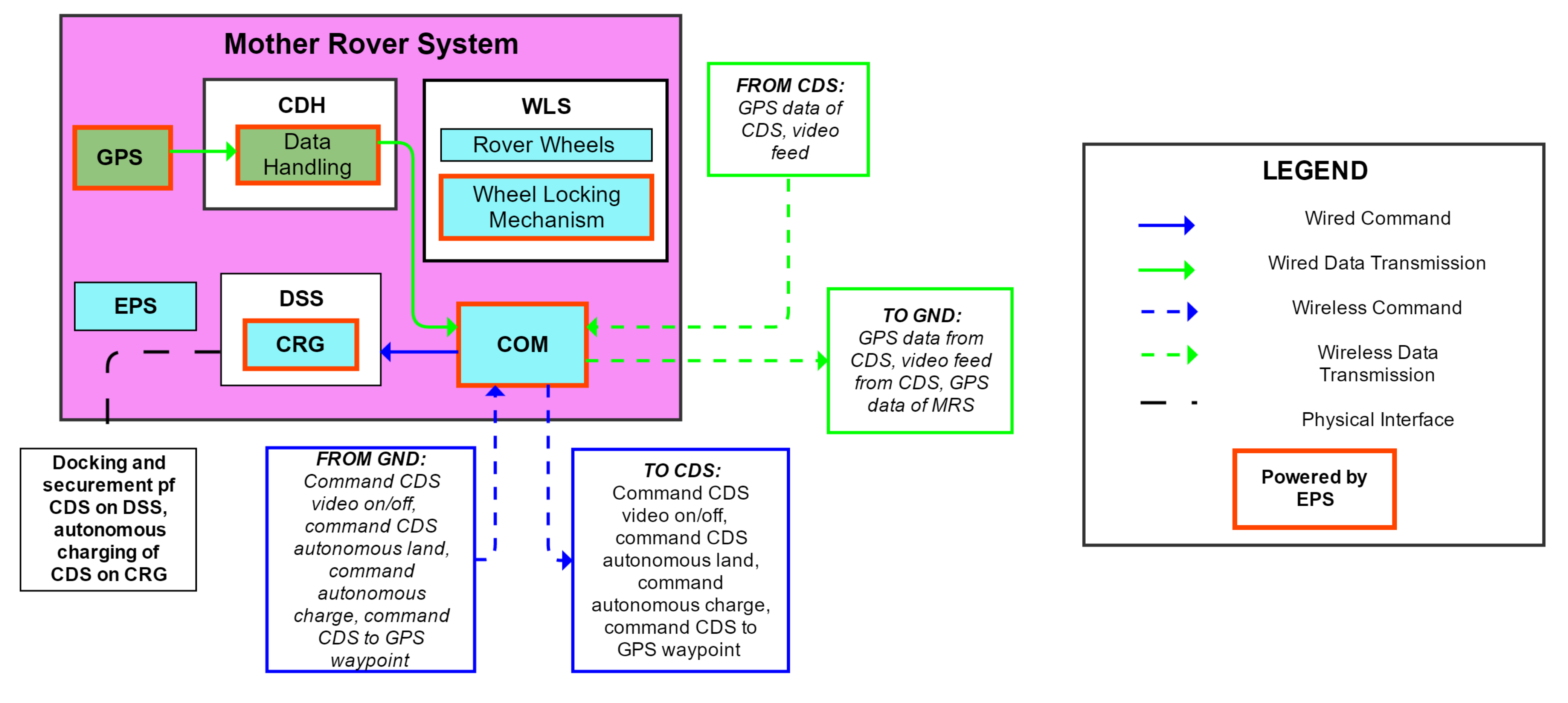
Functional Requirement	Description
FR 8.0	The COM shall wirelessly receive video at a maximum horizontal range of 700 meters at 5.8 GHz.
Design Requirement	**Description**
DR 8.1	The GND COM shall wirelessly receive video at 720p at 30 fps.
DR 8.2	The GND COM shall wirelessly receive 5 minutes of video
DR 8.3	The GND COM shall wirelessly receive data from the SPS.

Design Requirements

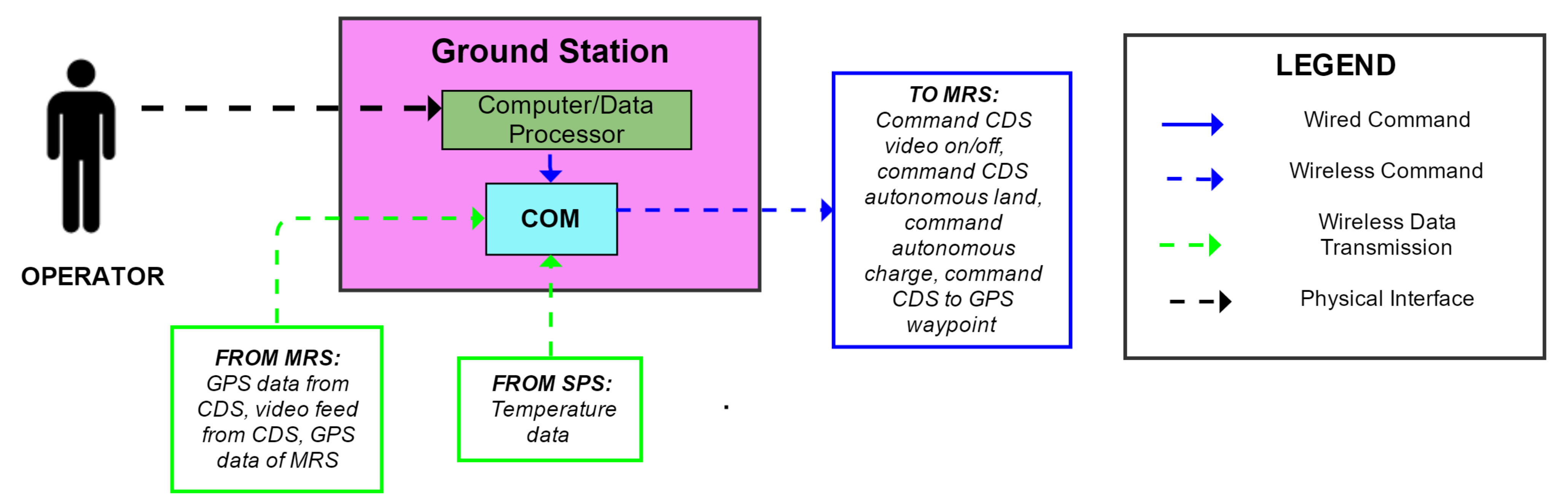
Charging

Functional Requirement	Description
FR 9.0	**The CRG shall autonomously increase the CDS battery voltage.**
Design Requirement	**Description**
DR 9.1	The CRG shall charge the CDS battery one time by a minimum of 1 Volt.
DR 9.2	The CRG shall adjust CDS orientation on DSS for maximum landing yaw error of 45°.

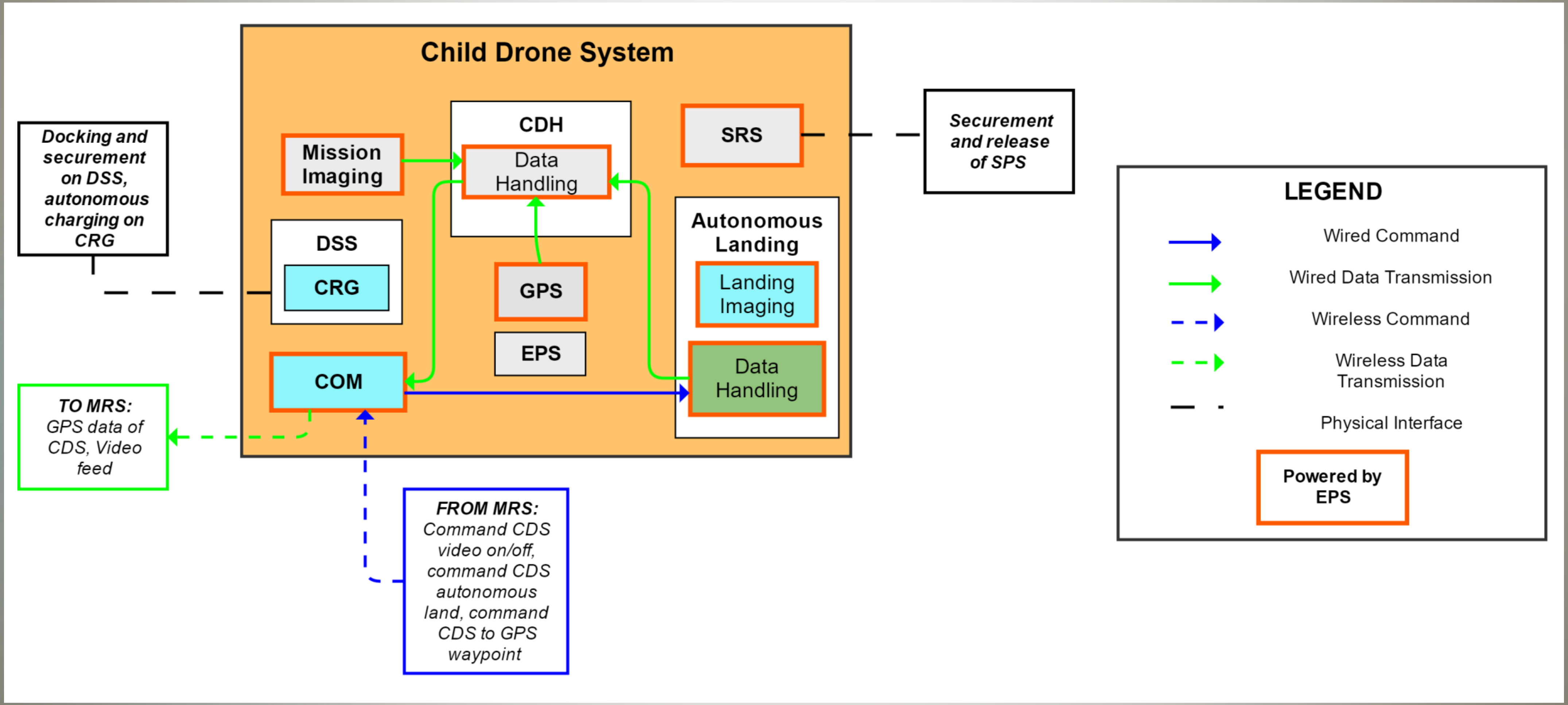
Functional Block Diagram: Mother Rover System



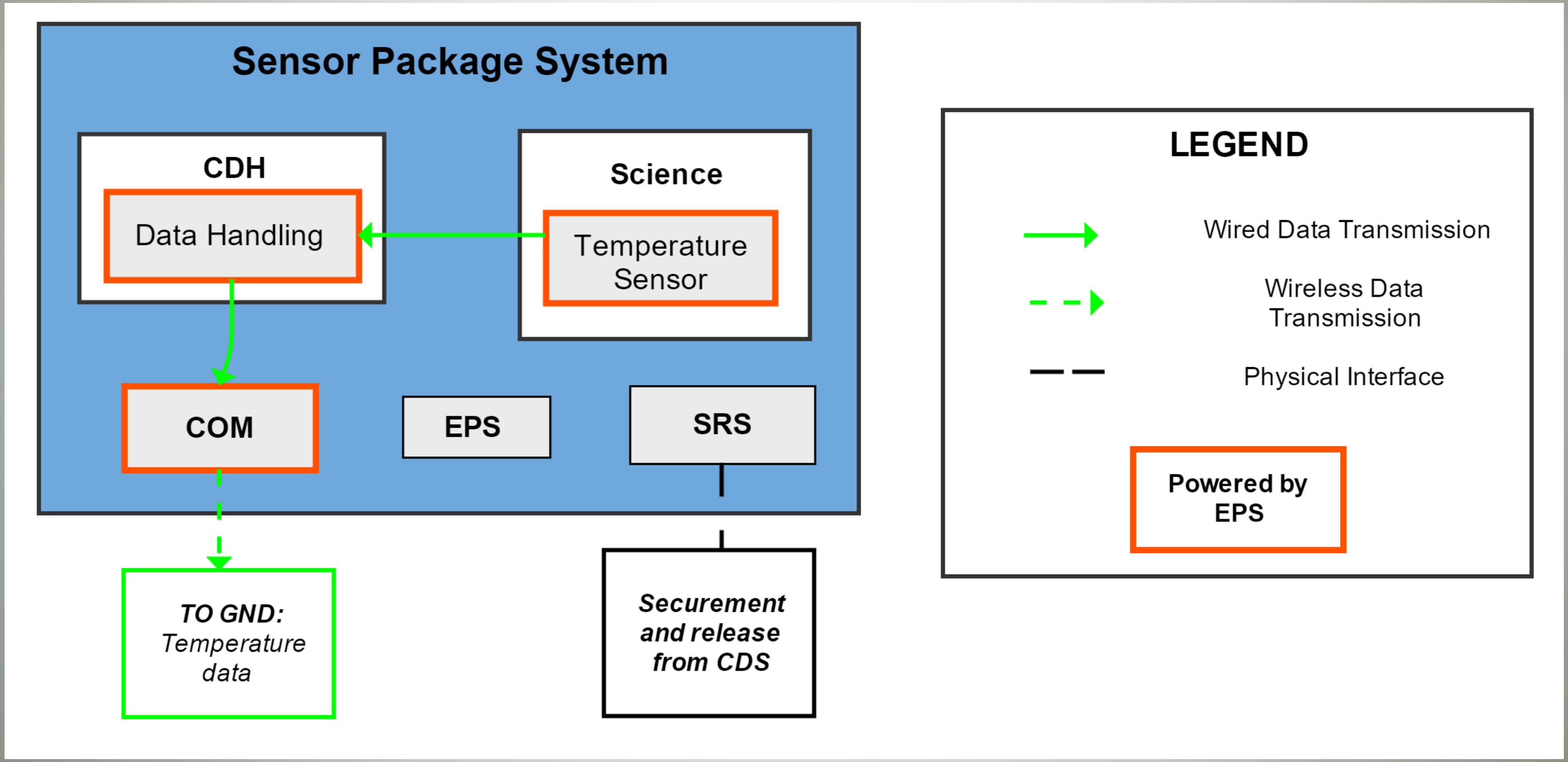
Functional Block Diagram: Ground Station



Functional Block Diagram: Child Drone System

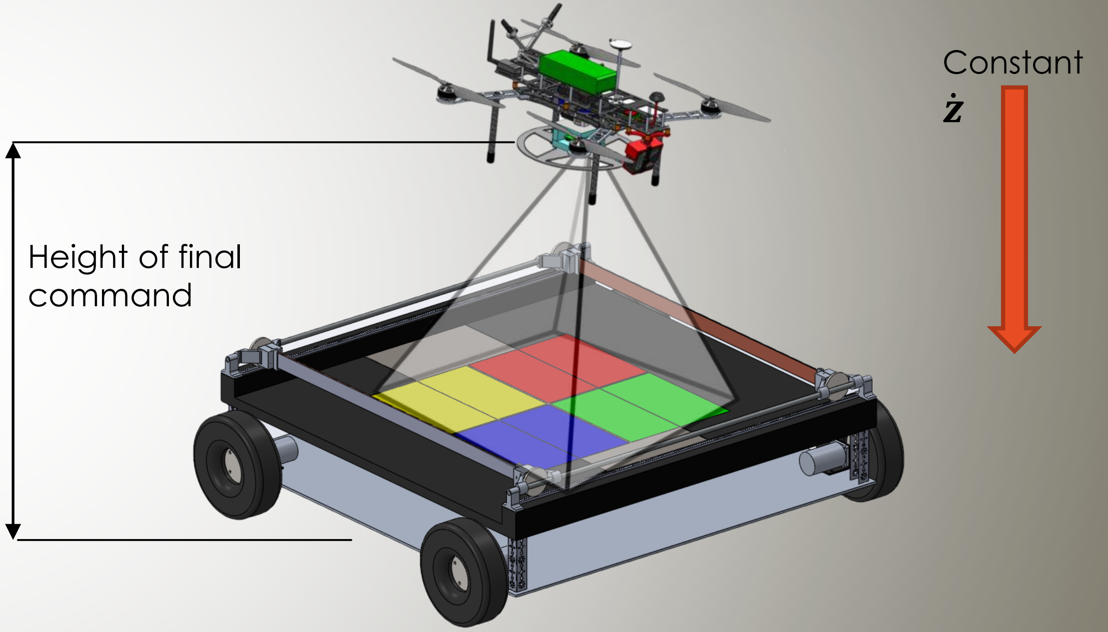


Functional Block Diagram: Sensor Package System



Landing Feasibility

- Assumptions:
  - After **platform fills camera FOV**, accurate position can no longer be determined
  - **Camera height** is z-position of CDS legs
  - CDS **offset from center** and **wind effects** accounted for with **10% design margin**
  - Error due to camera **resolution** is a max of **1 pixel**
  - **Constant** descent rate
  - Camera mounted on **geometric center** of CDS
- Knowns (from Pixhawk spec sheet):
  - Pixhawk gyro error: **0.1 [deg/s]**
  - Pixhawk accelerometer error: **1.11 x 10^{-3} g [m/s^2]**



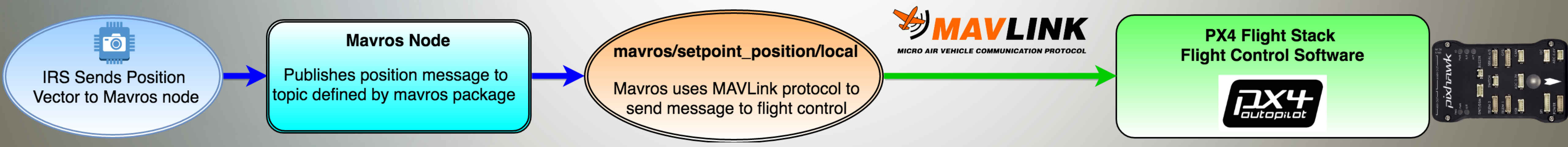
Software Architecture

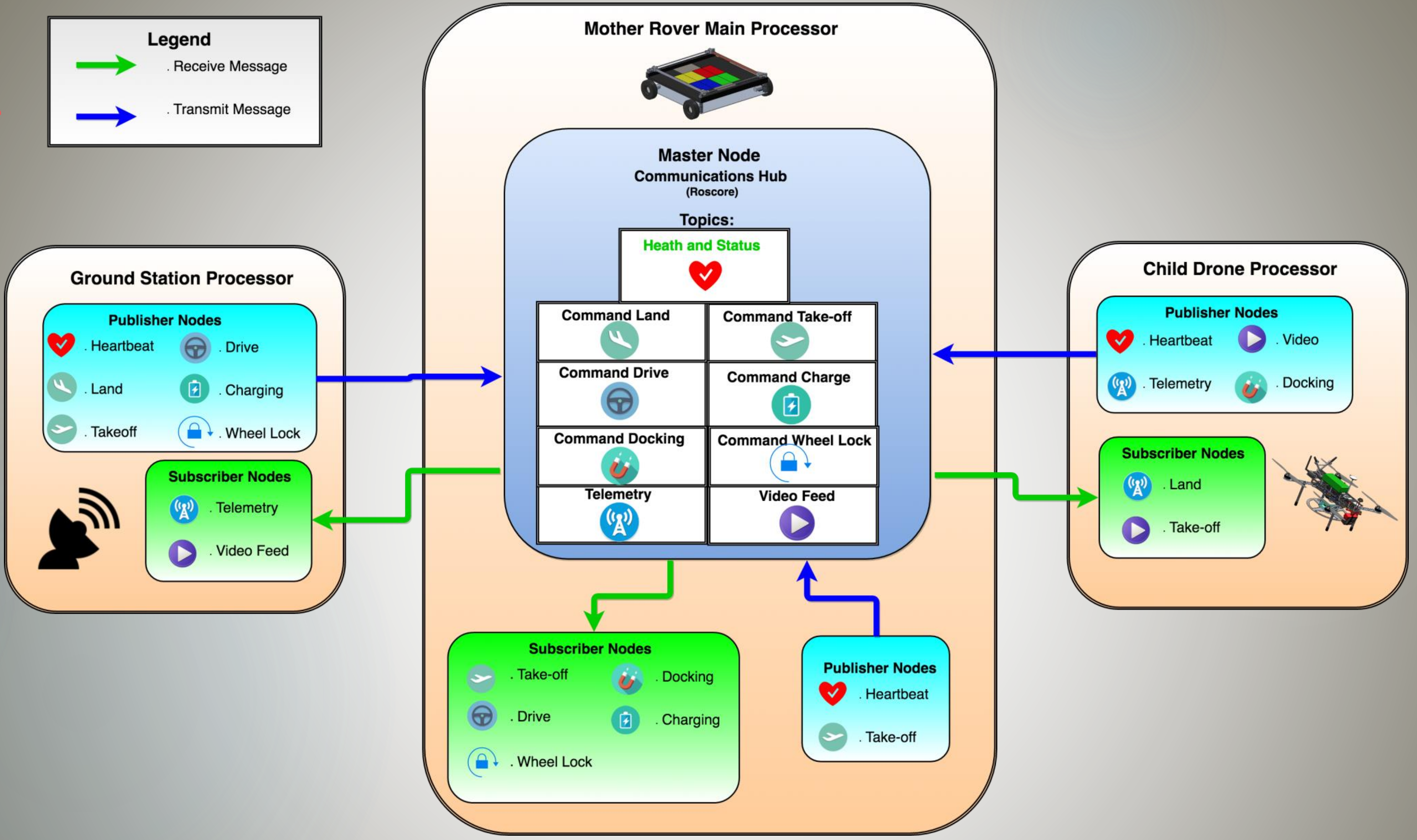
- **ROS** – Robot Operating System
- **Libraries** and **packages**
- Easy **communication** and **message-passing** between processes
- **Nodes** are medium through which information is **streamed** and are written in **C++** or **Python:**
  - **Topic - Named buses** over which nodes exchange messages
  - **Publisher -** Sends messages **to** specified topic
  - **Subscriber -** Receives messages **from** specified topic.
  - **Master** - Acts as **communications hub** to route information between nodes.
- Allows easy message customization to send:
  - **Sensor** data
  - **Control** or **actuator** commands
  - **State** and **planning** information

Software Architecture

ROS Packages Available

- **Mavros**
  - **MAVLink** extendable communication node
  - **Driver** for various autopilots with MAVLink protocol
    - Set **Mode**
    - **Arm** drone
    - Command local **position**
- **Camera Packages**
  - Standard USB cameras
  - OpenCV with cameras
  - Raspberry Pi camera module
- **Motor Drivers**
  - Serial Roboteq motor controllers
  - Various brushed DC motor devices





Legend
. Receive Message
. Transmit Message
Mother Rover Main Processor
Master Node
Communications Hub
(Roscore)
Topics:
Heath and Status
Command Land
Command Take-off
Command Drive
Command Charge
Command Docking
Command Wheel Lock
Telemetry
Video Feed
Ground Station Processor
Publisher Nodes
. Heartbeat
. Drive
. Land
. Charging
. Takeoff
. Wheel Lock
Subscriber Nodes
. Telemetry
. Video Feed
Child Drone Processor
Publisher Nodes
. Heartbeat
. Video
. Telemetry
. Docking
Subscriber Nodes
. Land
. Take-off
Subscriber Nodes
. Take-off
. Docking
. Drive
. Charging
. Wheel Lock
Publisher Nodes
. Heartbeat
. Take-off

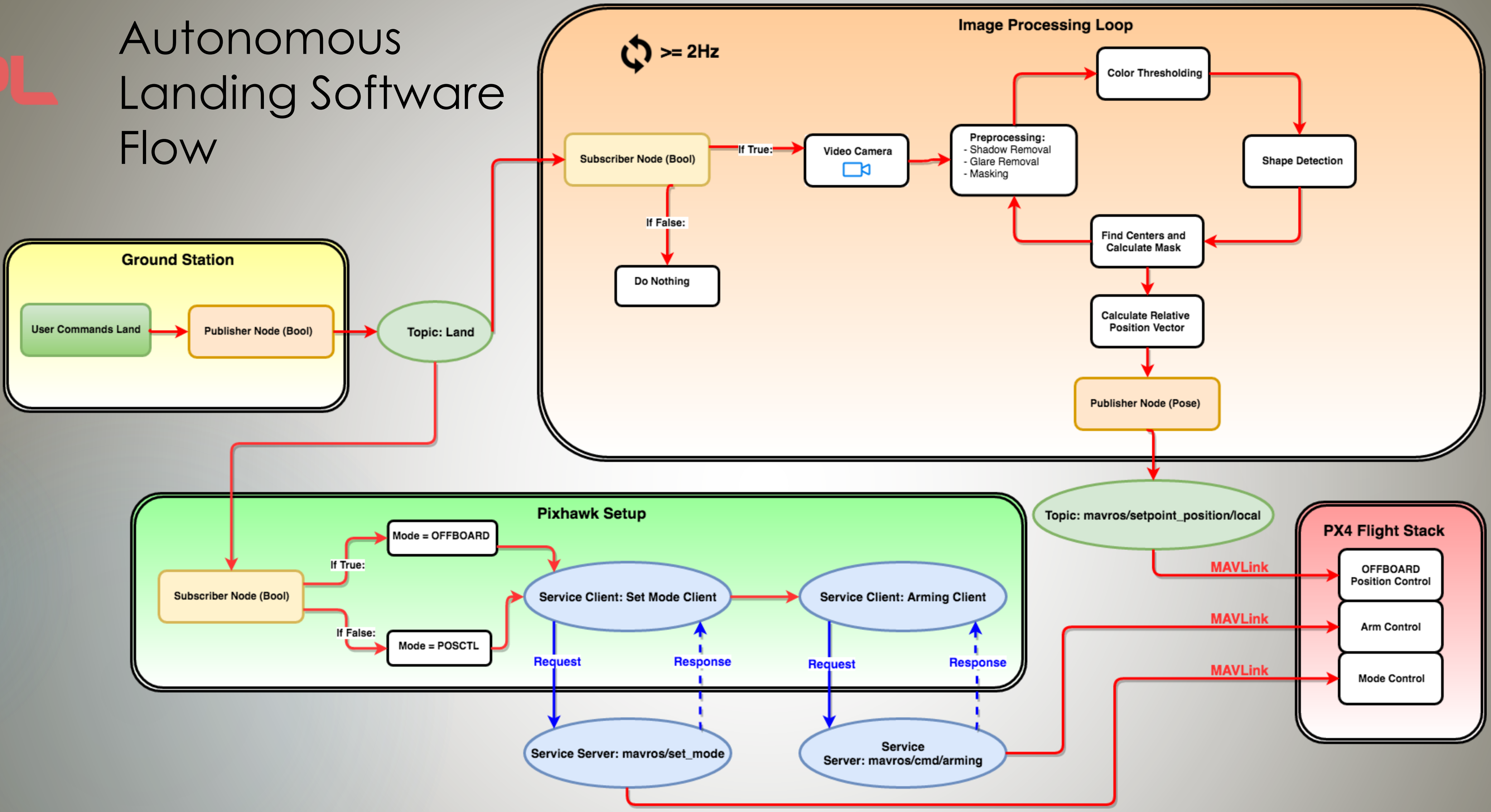
Autonomous Landing

Metric	Weight	Image Recognition	Differential GPS	Sonar
Time Required	35%	4	5	3
Performance/ Effectiveness	35%	5	3	3
Complexity	15%	4	5	3
Cost	15%	4	4	5
Total	100%	4.35	4.15	3.30

Autonomous Landing Metric Levels

Criteria	1	2	3	4	5
Time Required	> 100 hrs	50 -100 hrs	25 – 50 hrs	10 – 25 hrs	< 10 hrs
Performance/ Effectiveness	Performance does not meet requirements; accuracy is unacceptable	Performance is relatively poor; accuracy is below expectations	Performs with a moderate level of accuracy; Autonomous landing meets expectations	Performs to a relatively high degree of accuracy; Autonomous landing goes beyond what is required	Autonomous landing system performs to the highest level of accuracy
Complexity	Requires in-house manufacturing and assembly with custom design; rewriting all of open source code to meet expectations	Requires in-house manufacturing and assembly with custom design; most source code needs to be modified	System is a mix of manufactured and purchased components; some source code needs to be modified	System uses off the shelf components with assembly required; little source code needs to be modified	System is "plug and play" with all off the shelf components; source code needs no modifications
Cost	> $1000	$500 - $1000	$250 - $500	$100 - $250	< $100

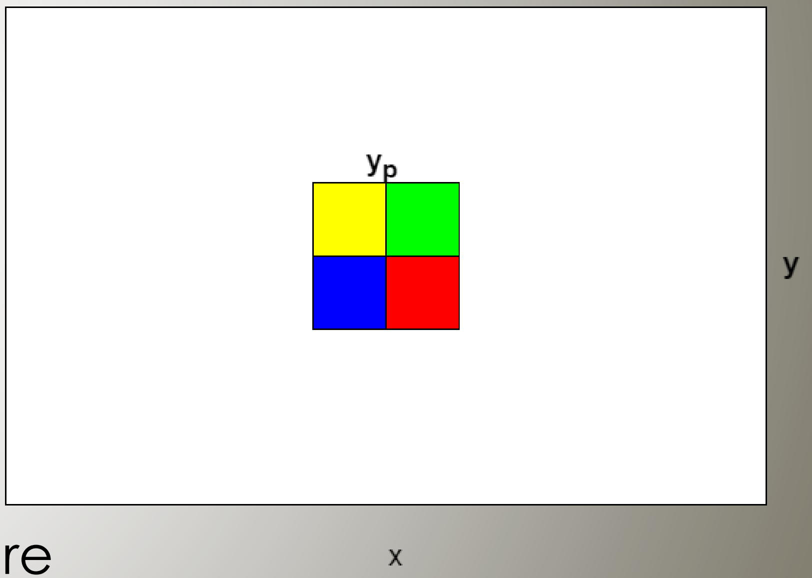
Autonomous Landing Software Flow



Autonomous Landing Backup: Approach View

- $z = \frac{y}{2*\tan(\frac{FOV_V}{2})}$; $y = 10$ ($GPS\ accuracy\ of \pm 5m$)
  - Height required to see image on approach to MRS
- $\% = \frac{y_p^2}{x*y} * 100$; $x = 2 * z * \tan\left(\frac{FOV_H}{2}\right)$
- Percent of picture filled by image on MRS
  - Must be >0.25% (TBR – testing) for recognition
- Using Rpi Camera: Platform image fills 0.27% of picture
  - **FEASIBLE**

View on approach



Autonomous Landing Backup: Landing Model Derivation (Position)

- Equations:
  - →
- Assumptions:
  - After **platform fills camera FOV**, accurate position can no longer be determined
  - **Camera height** is z-position of CDS legs
  - CDS **offset from center** and **wind effects** accounted for with **10% design margin**
  - Error due to camera **resolution** is a max of **1 pixel**
  - **Constant** descent rate
  - Camera mounted on **geometric center** of CDS
- Known Parameters:

Autonomous Landing Backup: Landing Model Derivation (Position)

- $x_{error,accelerometer} = \iint_0^{t_{land}} a_{error} dt^2; \;\; t_{land} = \frac{z}{\dot{z}}$
- $z = \frac{1.1 * y_p}{2 * \tan(\theta)} \;\; ; \;\; \theta = \frac{FOV}{2}, \;\; 1.1 * y_p = platform\ image\ width\ with\ 10\%\ margin$
- $x_{error,pixel} = 2 * z * \frac{\tan(\theta)}{n} \;\; ; \;\; n = \#of\ pixels$
- $x_{error,quad\ geometry} = d; \;\; d = distance\ from\ geometric\ center\ to\ leg\ of\ INFERNO$

- $x_{error} = d + \frac{1.1 * y_p}{n} + 0.0013611 * \left(\frac{1.1 * y_p}{\dot{z} * \tan(\theta)}\right)^2$

Autonomous Landing Backup: Landing Model Derivation (Yaw)

- Equations:
  - $\theta = \int \omega dt$
  - $d = r * t \; (distance = rate * time)$
- Assumptions are the same as Position Derivation
- Known Parameters:
  - $gyro\ error: 0.1 \frac{deg}{s}$
- $\psi_{error} = \int_0^{t_{land}} 0.1 * dt \, ; t_{land} = \frac{z}{\dot{z}}, z = \frac{1.1 * y_p}{2\tan(\theta)}$
- $\psi_{error} = 0.05 * \frac{1.1 * y_p}{\dot{z} * \tan(\theta)} \; (degrees)$

Estimated Flight Time from CDS Modifications

- INFERNO Nominal Mass: **2520 g**
- Estimated Mass Addition: **521 g**
  - Steel feet (x4): **18.6 g (74.4 g)**
  - IRS: **75 g**
  - Charging (x2): **186 g (372 g)**
- Estimated Final Mass: **3041 g**
- Estimated Endurance: **18.2 min**

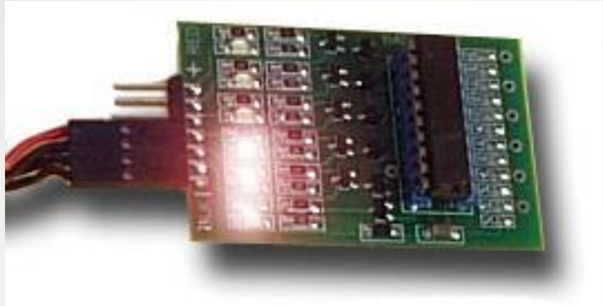
*All values TBR (component selection)

Possible Alternate System	
Endurance (min)	**Maximum Mass (g)**
15	3530
18	3130
20	2910
25	2515

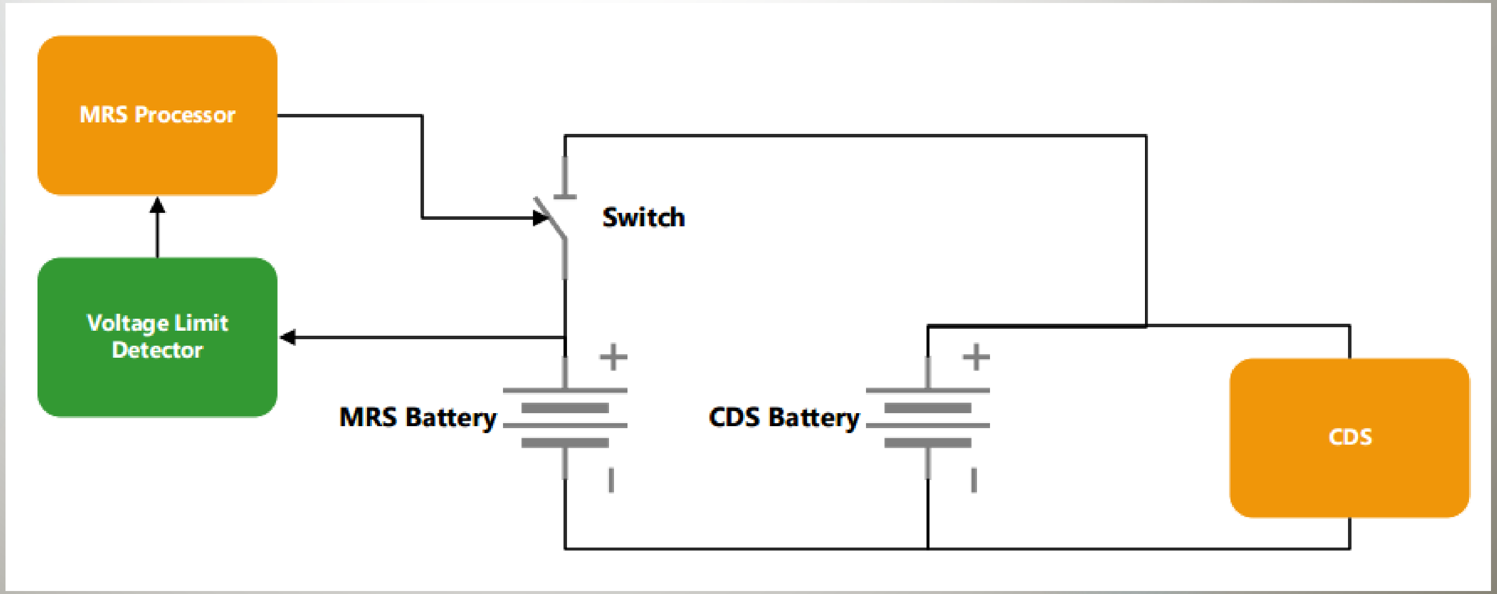
From INFERNO SFR

Charging Modifications to CDS

- Blinky Battery Balancer
  - Low Cost: ~$35
  - Low mass: 0.014 kg
  - Balances 4s LiPo Batteries while they charge



- Recharge circuit:



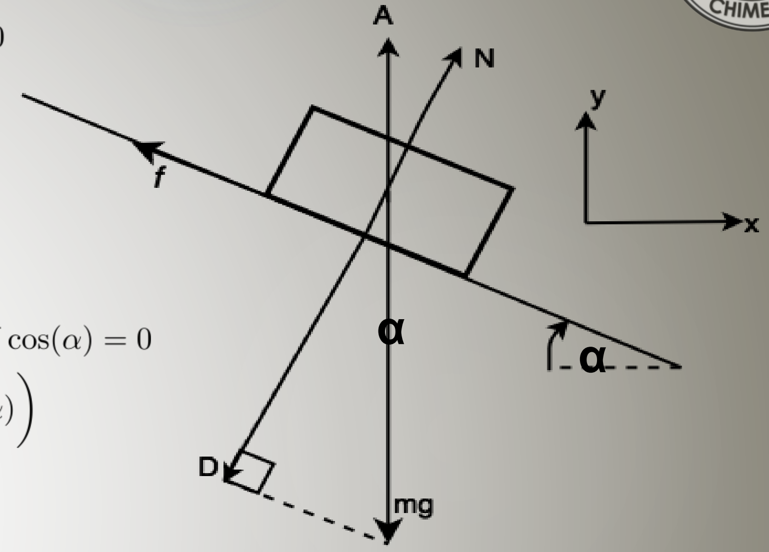
Required Docking Force Model

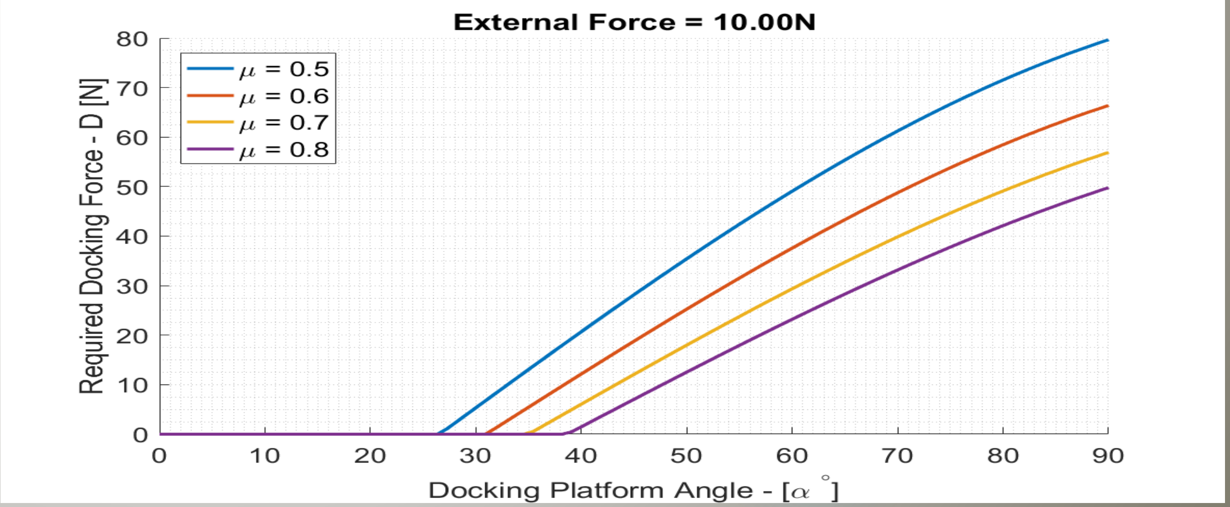
- Assumptions:
  - CDS can be modeled as a point mass
  - Air resistance/ drag is negligible
  - All forces are acting on the CDS' center of mass
  - All forces are instantaneous
  - Gravity is constant
  - Applied force acts vertically
  - Docking force acts perpendicular to platform

$$\Sigma F_x = f\cos(\alpha) + D\sin(\alpha) - N\sin(\alpha) = 0$$
$$f = f_{max} = \mu N$$
$$D\sin(\alpha) = N\Big(\sin(\alpha) - \mu\cos(\alpha)\Big)$$
$$D = N\Big(1 - \mu\cot(\alpha)\Big)$$

$$\Sigma F_y = A - mg - D\cos(\alpha) + f\sin(\alpha) + N\cos(\alpha) = 0$$
$$D\cos(\alpha) = A - mg + N\Big(\mu\sin(\alpha) + \cos(\alpha)\Big)$$
$$N = -\frac{\sin(\alpha)}{\mu}\Big(A - mg\Big)$$

$$\boxed{D = \frac{\sin(\alpha)}{\mu}\Big(mg - A\Big)\Big(1 - \mu\cot(\alpha)\Big)}$$



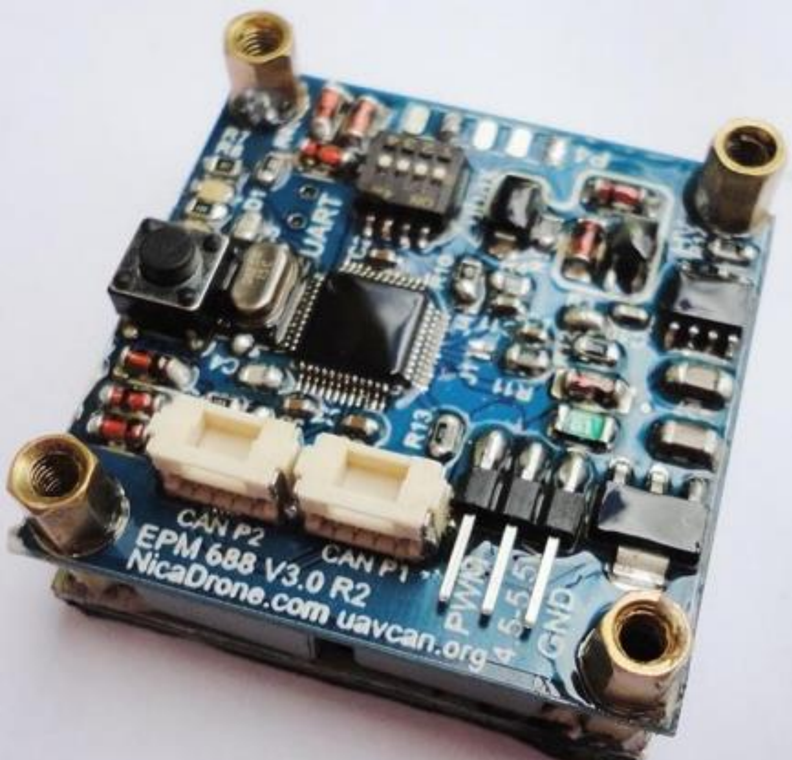


Securing

<u>Magnetic Securement Component Feasibility</u>

- Electro-permanent magnet
- Low power draw: ~50 mW nominal
- Compact form factor
- Low cost: ~$54

	Nominal
F_max	200 [N]
V_supply	5.0 [V]
I_steady	10 [mA]
I_peak	1000 [mA]
mass	65 [g]



http://nicadrone.com/index.php?id_product=66&controller=product

Power Budget:
MRS Power Supply

- Power Supply
  - Chemistry: Lithium Polymer
  - Nominal Voltage: 14.8V
  - Minimum Voltage: 14V
  - Capacity: 10Ah
  - Maximum Constant Discharge Current: 100A
  - Maximum Peak Discharge Current: 200A
  - Maximum Discharge: 70%

- Power Regulation
  - 5V Linear Regulator

    Minimum Voltage: 7V
  - 3.3V Linear Regulator

    Minimum Voltage: 5V
  - 12V Linear Regulator

    Minimum Voltage: 14V

Power Budget:
MRS Power Consumption

Components	Average Current[A]	Maximum Current[A]	Quantity	Voltage[V]
DC Motor	12	30	4	12
Actuator	0.4	1	4	12
Antenna	0.4	1	4	3.3
Processor	0.5	1	1	3.3
Totals	**13.3**	**33**		

Power Budget:
MRS Battery Lifetime

$$T_{avg} = \left(\frac{C}{I_{Lavg}}\right) D_{max} = \left(\frac{10Ah}{13.3A}\right) 0.7 = 0.7h = 30min$$

$$I_{Lmax} \leq I_{Omax} = 33A \leq 100A$$

$$T_{min} = \left(\frac{C}{I_{Lmax}}\right) D_{max} = \left(\frac{10Ah}{33A}\right) 0.7 = 0.7h = 20min$$

$$V_{reg\,min} \leq V_{batt\,min} = 14V \leq 14V$$

$D_{max} = Max\ Discharge$

$I_{Lavg} = Average\ Load\ Current$

$I_{Lmax} = Max\ Load\ Current$

$C = Capacity$

$T_{avg} = Average\ Time$

$T_{min} = Minimum\ Time$

$I_{Omax} = Max\ Constant\ Output\ Current$

$V_{reg\,min} = Minimum\ Input\ Voltage$

$V_{batt\,min} = Minimum\ Output\ Voltage$

Power Budget:
MRS Power Supply

- Power Supply
  - Chemistry: Lithium Polymer
  - Nominal Voltage: 14.8V
  - Minimum Voltage: 14V
  - Capacity: 10Ah
  - Maximum Constant Discharge Current: 100A
  - Maximum Peak Discharge Current: 200A
  - Maximum Discharge: 70%

- Power Regulation
  - 5V Linear Regulator

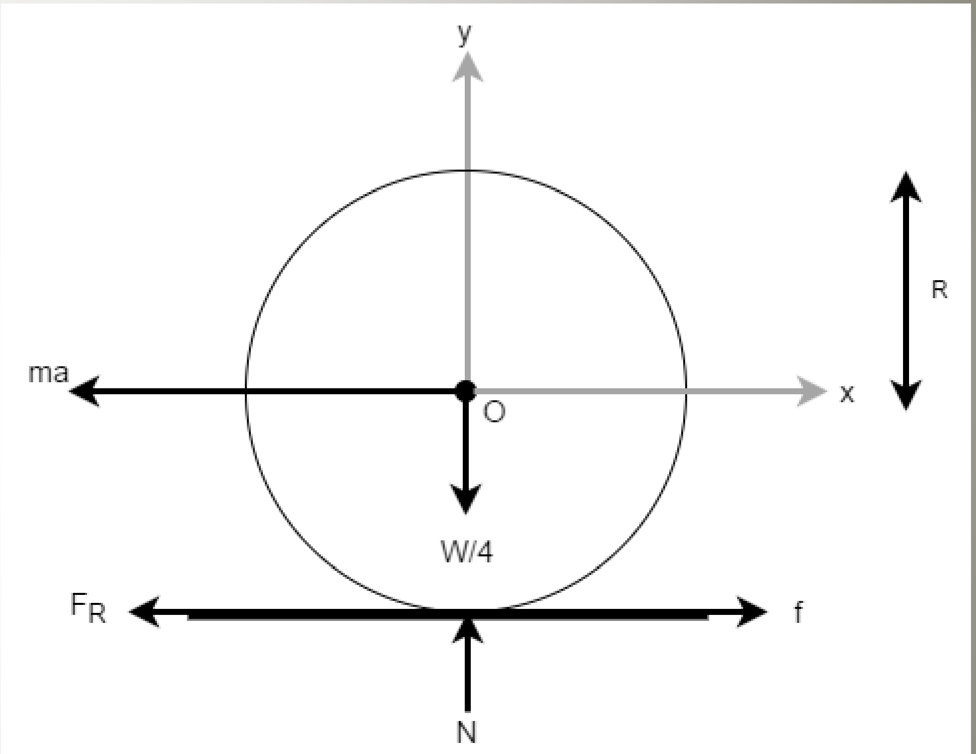
    Minimum Voltage: 7V
  - 3.3V Linear Regulator

    Minimum Voltage: 5V
  - 12V Linear Regulator

    Minimum Voltage: 14V

Motor Torque Model

- Assumptions:
  - Rubber-concrete contact between the wheel and road.
  - The inclination of the surface is zero degrees.
  - Air resistance is negligible.
  - Motor efficiency is 65%



Motor Torque Model

$f = F_{req} = F_a + F_r$

$F_a = ma$

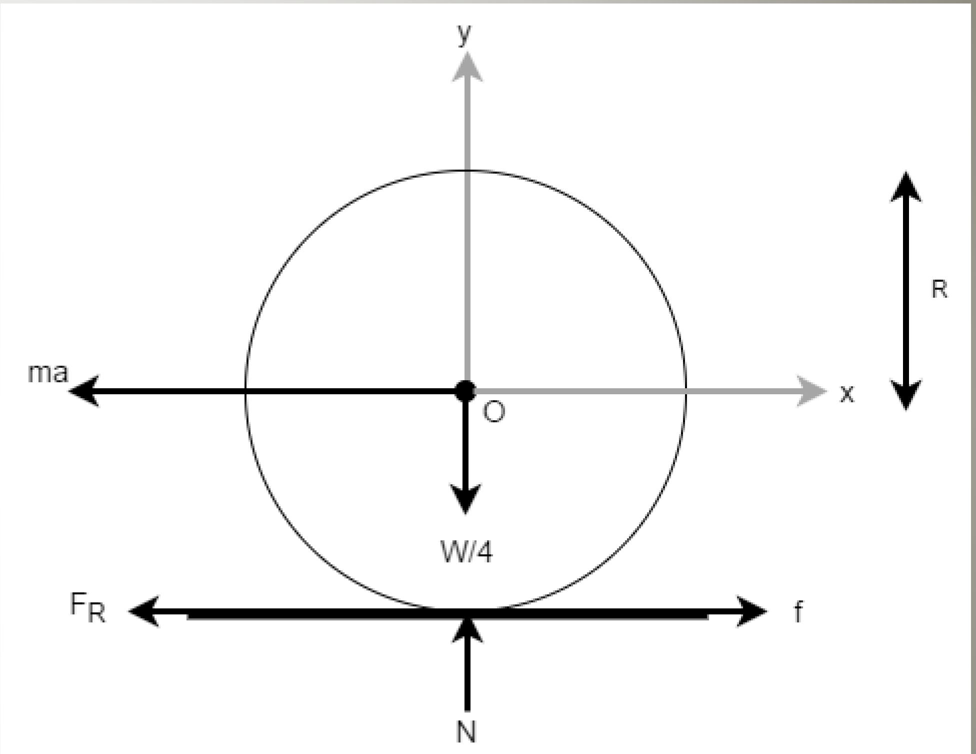
$F_r = \left(\frac{W}{4}\right) C_{rr}$ (C_{rr} is the coefficient of rolling resistance)

$F_a = m\left(\frac{v}{t}\right)$

$F_{req} = m\left(\frac{v}{t}\right) + \left(\frac{mg}{4}\right) C_r$

$T_{req} = \left(\frac{100}{e}\right) F_{req} R$ (T_{req}= required torque, e = efficiency)

$$T_{req} = \left\{m\left(\frac{v}{t}\right) + \left(\frac{mg}{4}\right) C_r\right\}\left(\frac{100}{e}\right) R$$



F_r = rolling resistance

N = normal force

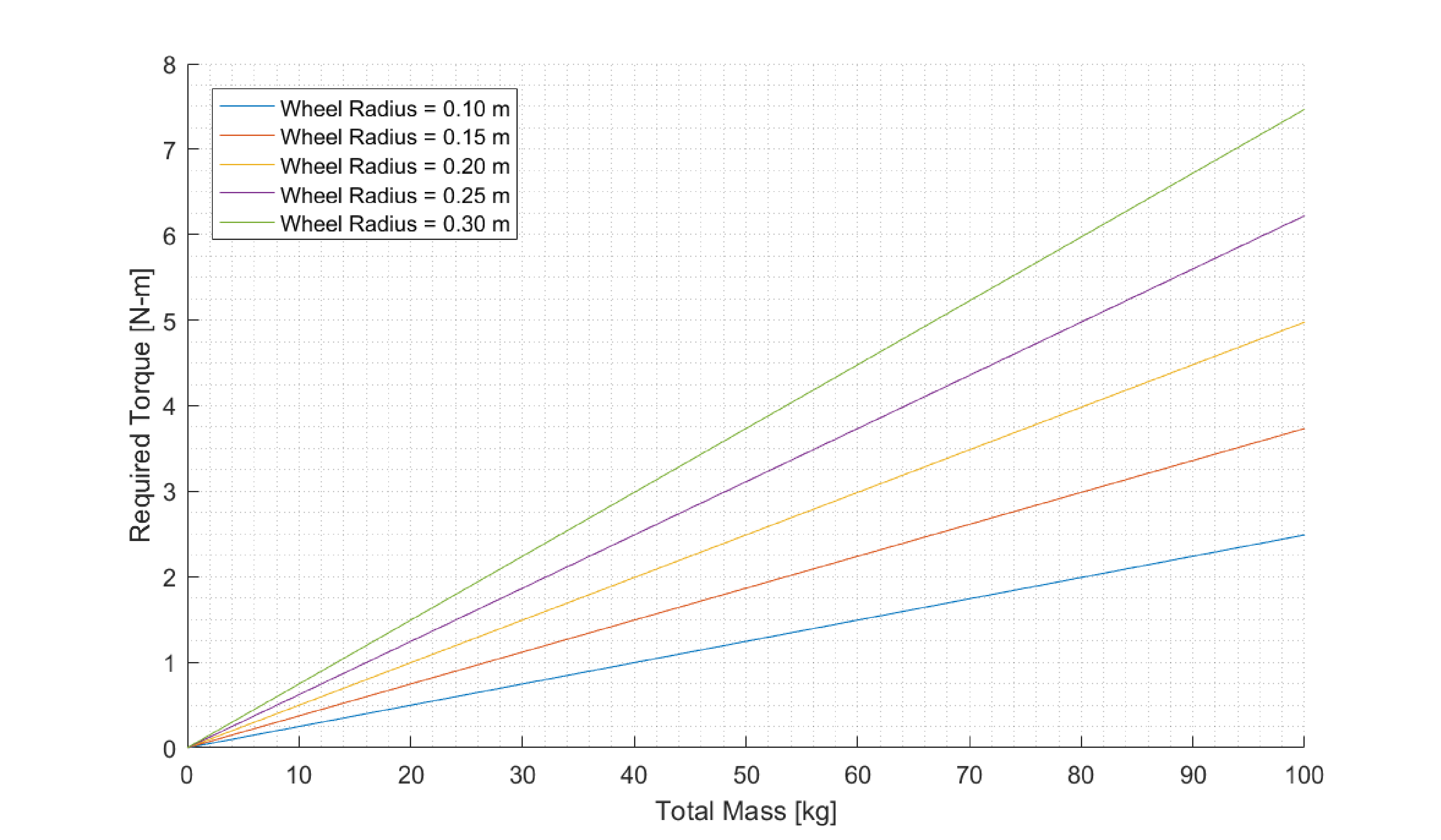
W = weight

R = radius

F_a = acceleration force

f = frictional force

Motor Torque Model Results



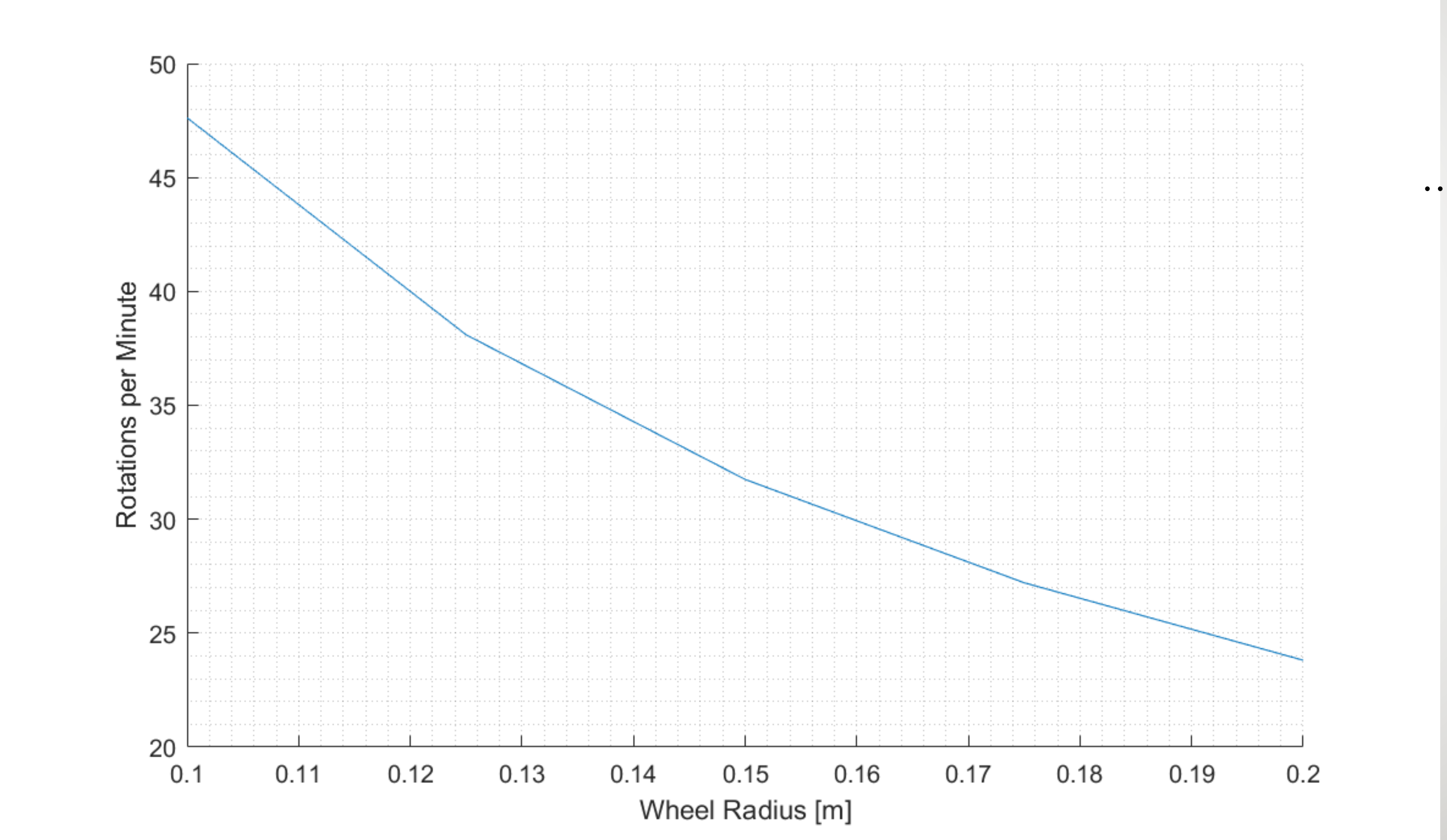
Required torque for each wheel motor for various radii versus the total mass of the CHIMERA system.

Motor Torque Feasibility

- Current System Parameters
  - Mass = 100 kg (based on SolidWorks model)
  - Wheel Diameter = 10 inches (0.127 m).
  - Assume motor efficiency = 65%.
  - Maximum velocity of MRS = 0.5 m/s
  - Time to accelerate to maximum speed = 1 s
  - Result: Motor torque must be greater than or equal to 3.16 Nm and the motor must rotate at least 37.5 RPMs.
- The motor shown in the figure on the right provides 3.73 Nm of torque at 60 RPMs
- Feasible

High Torque DC Servo Motor 60RPM With UART/12C/PPM Drive

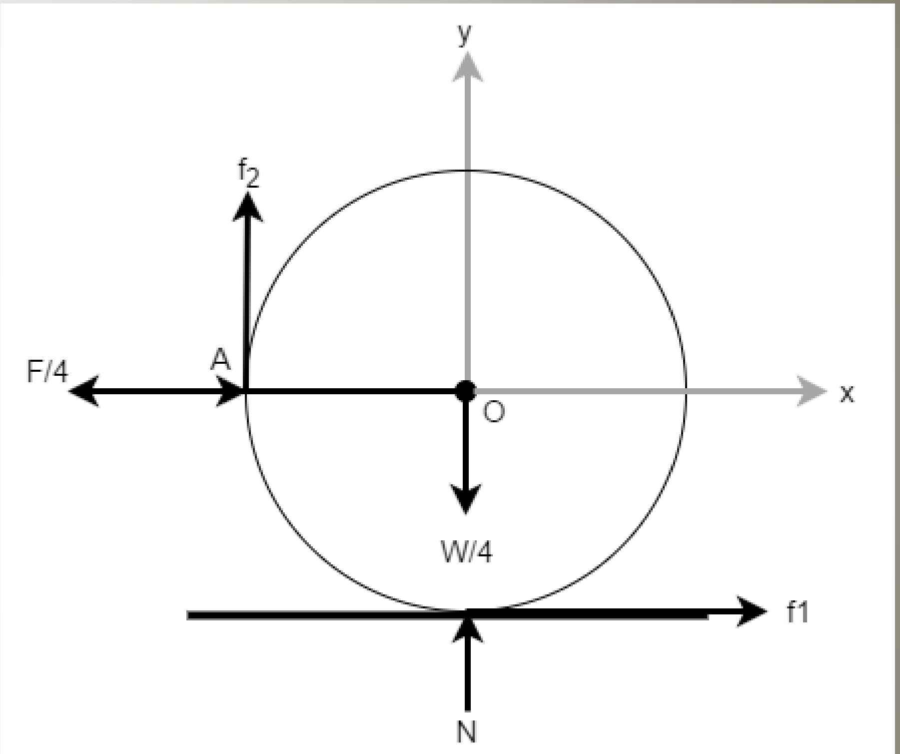
Wheel RPM Model



…

Wheel Locking Force Model

- Assumptions:
  - The mass of the MRS is evening distributed amongst the four wheels.
  - The impact force of the CDS landing on the platform acts on all four wheels equally.
  - Rubber-concrete contact between wheel and ground
  - Rubber-rubber contact between wheel and brake



Project Overview | Autonomous Landing | Docking and Securing | Wheel Locking | Charging | Communication | Conclusion

Wheel Locking Force Model

$$\sum F_x = 0 = A - \frac{F}{4} + f_1 \qquad A = \frac{F}{4} - f_1 \qquad f_{2,max} = \mu_{s,2}A$$

$$f_{1,max} = \mu_{s,2}N$$

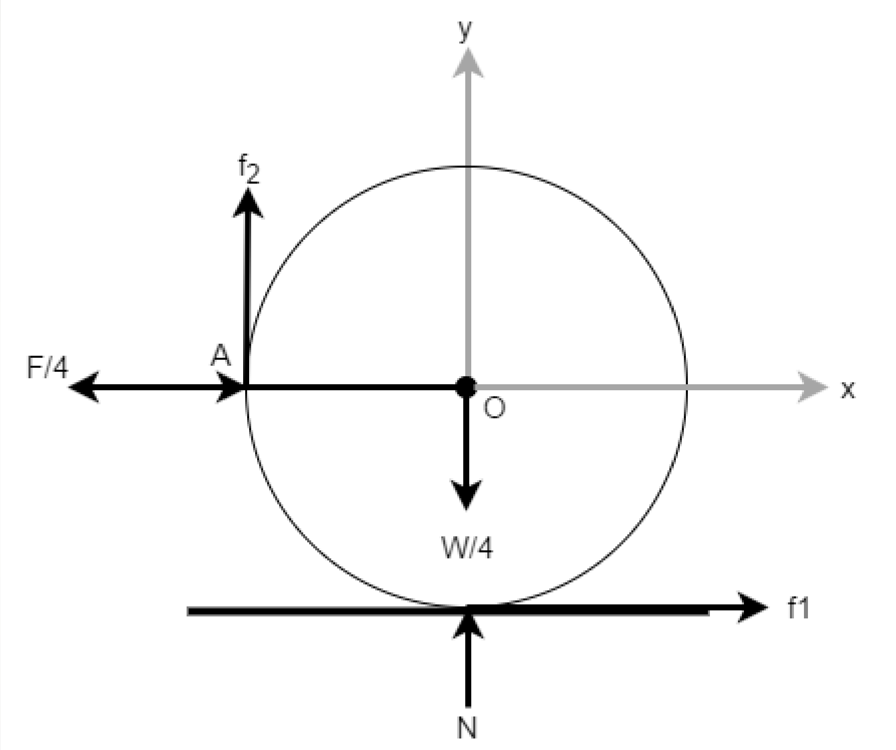
$$\sum F_y = 0 = N - \frac{W}{4} - f_2 \qquad N = \frac{W}{4} + f_2$$

$$\sum M_O = 0 = f_1R - f_2R \qquad f_1 = f_2$$

$$\mu_{s,2}A = \mu_{s,1}N \rightarrow N = \mu_{s,2}A/\mu_{s,1}$$

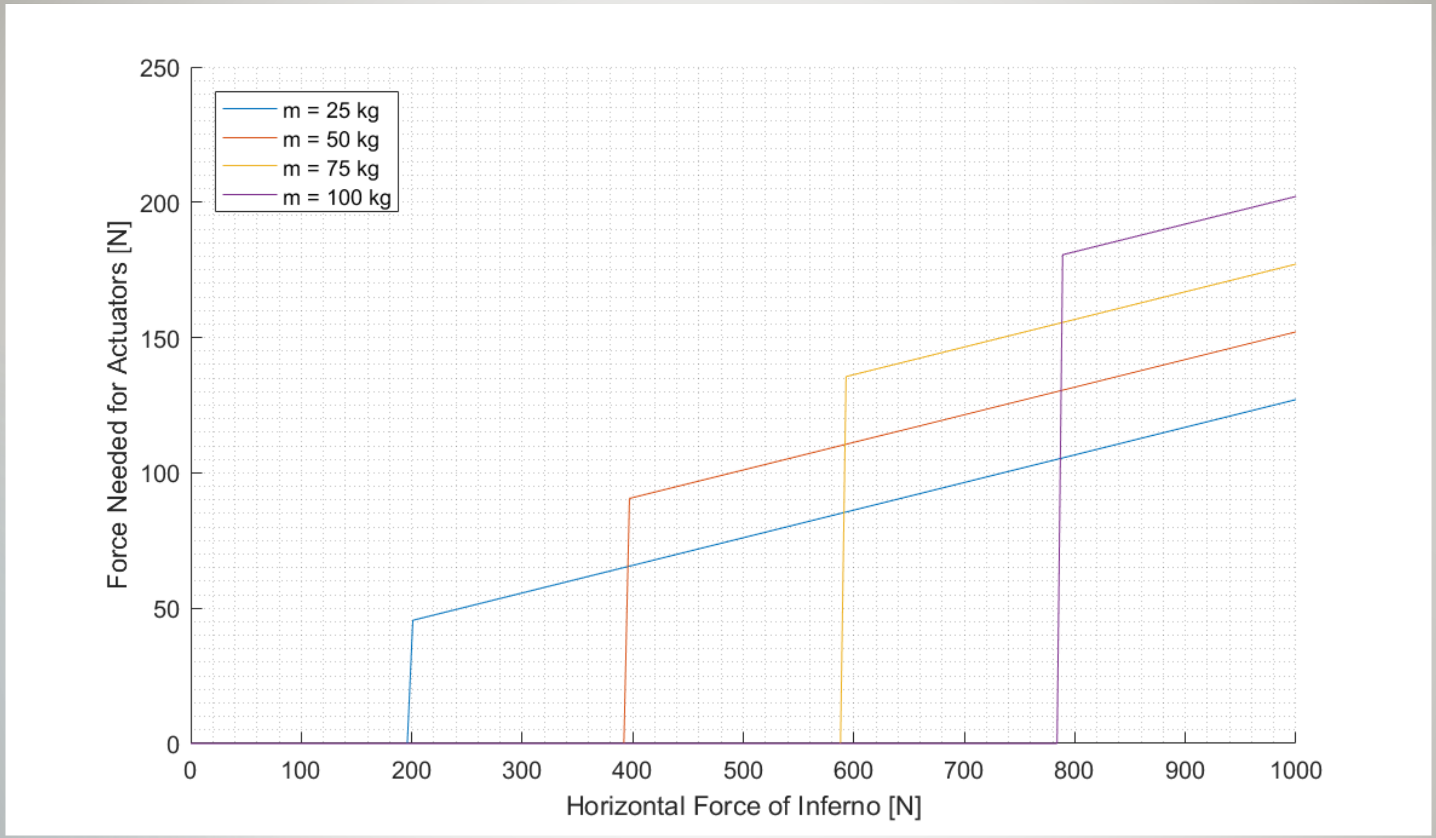
$$\frac{\mu_{s,2}A}{\mu_{s,1}} = \frac{W}{4} + \frac{F}{4} - A \rightarrow A\left(\frac{\mu_{s,2}}{\mu_{s,1}} + 1\right) = W + \frac{F}{4},$$

$$A = \frac{\frac{W+F}{4}}{\frac{\mu_{s,2}}{\mu_{s,1}} + 1}$$



Project Overview | Autonomous Landing | Docking and Securing | Wheel Locking | Charging | Communication | Conclusion

Wheel Locking Force Model



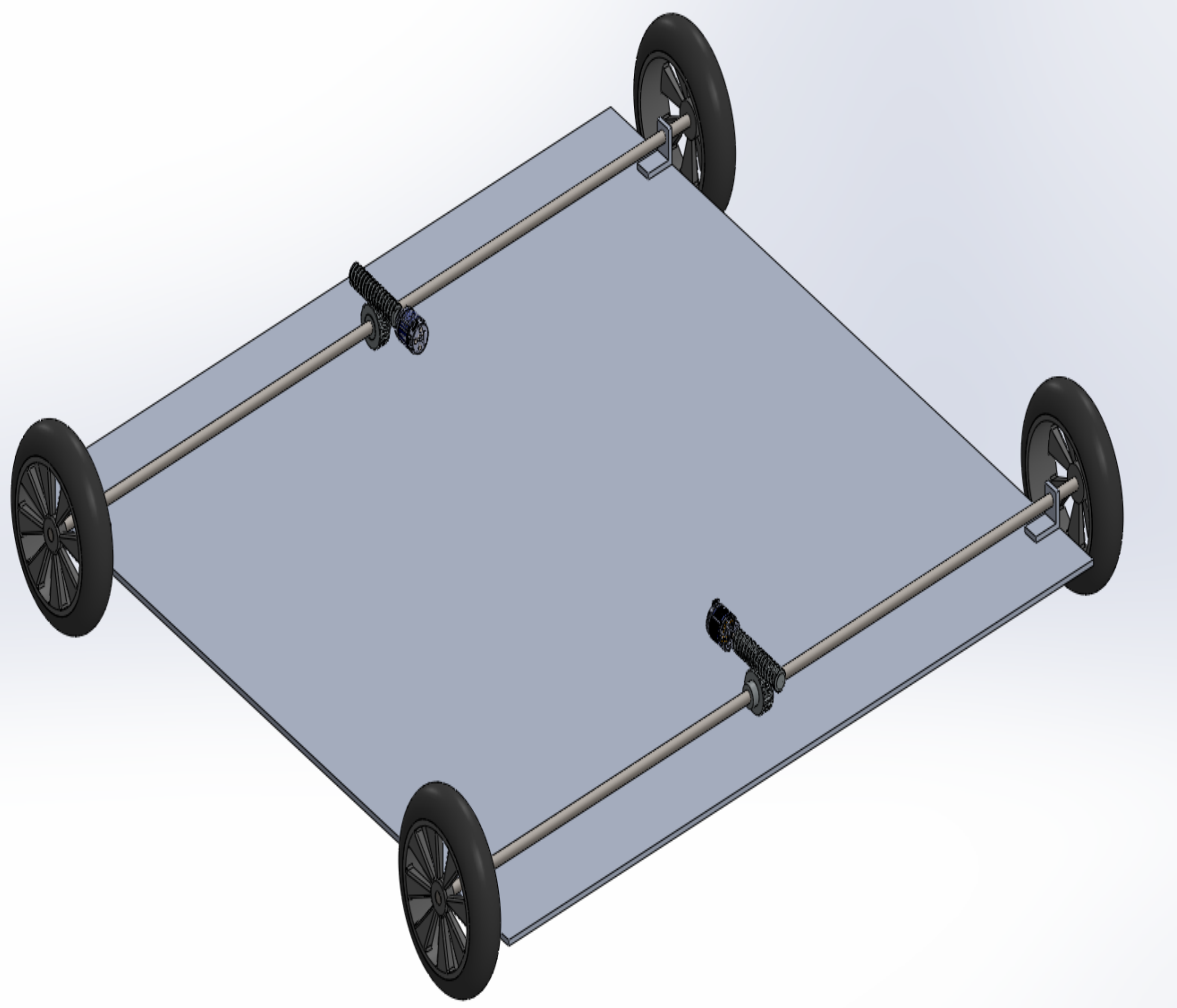
The force needed to be applied to keep the system static versus the horizontal impact force of the CDS.

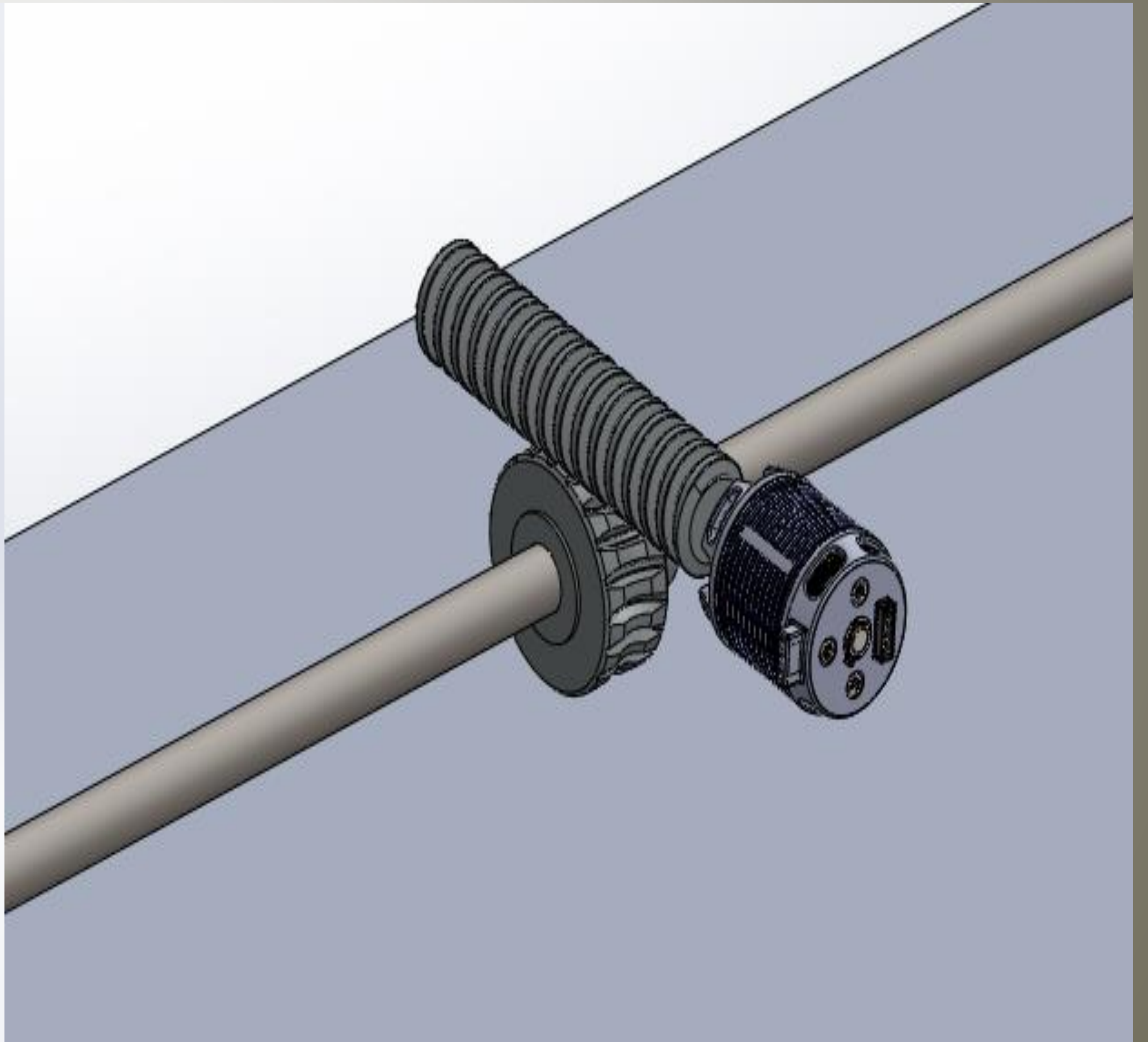
Wheel Locking Feasibility

- Worst case scenario:
  - The mass of the MRS system is 100 kg (SolidWorks).
  - Impact force:
    - CDS mass: 3.04 kg
    - Maximum speed: 13.8 m/s
    - Impact time = 0.05 s
    - CDS hits the MRS horizontally.
    - Impact force = m(v/t) = 839 N
  - The required force from the actuators is 185 N.
- This $30 linear actuator can provide 100 N to 2500 N of force.
- Feasible.

80mm 3inch Stroke 24V 10mm/s 980N 220LBS Linear Actuator Electric Nursing Bed TOAUTO-A2-24-80-T4

Drive and WLS

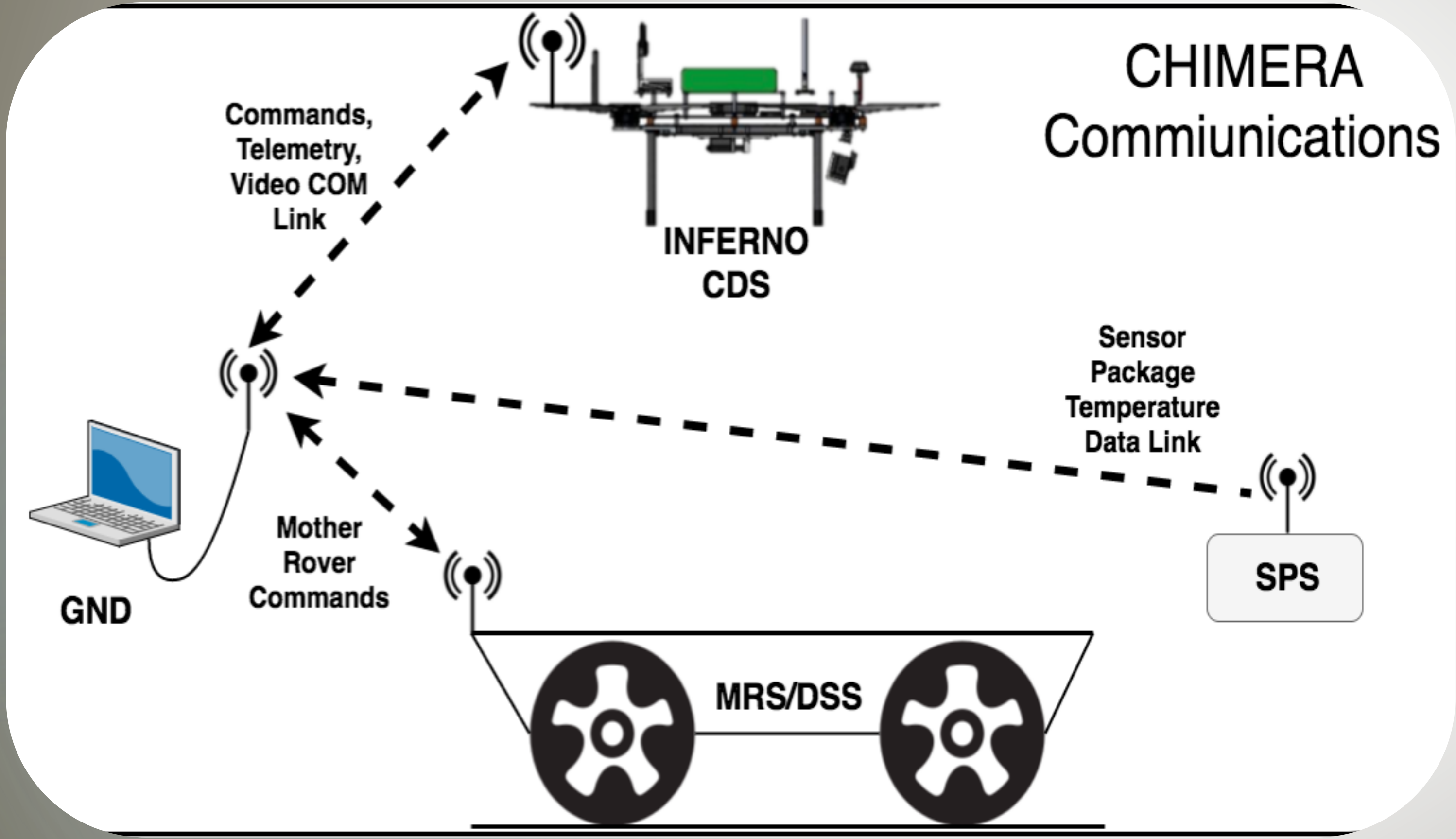




Communication Overview

Requirement	Description
FR 5.0	The COM shall wirelessly transmit data at a minimum horizontal range of 200 meters at 915 MHz.
FR 6.0	The COM shall wirelessly receive data at a minimum horizontal range of 500 meters 915 MHz.
FR 7.0	The COM shall wirelessly receive SPS data at a minimum horizontal distance of 700 meters at 900 MHz.
FR 8.0	The COM shall wirelessly receive video at a maximum horizontal range of 700 meters at 5.8 GHz.

Communication Assumptions



Assumptions
Primary Loss: Free Space Path Loss with no environmental interference (Rain/Snow)
All distances are open space with elevated ground station to avoid Fresnel affect
Min. Design Margin = 6 dB
Average temperature for July in Colorado is reference temperature (303 K)
Possible max distance analyzed for feasibility

Communication Methodology Backup Slide

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]:

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

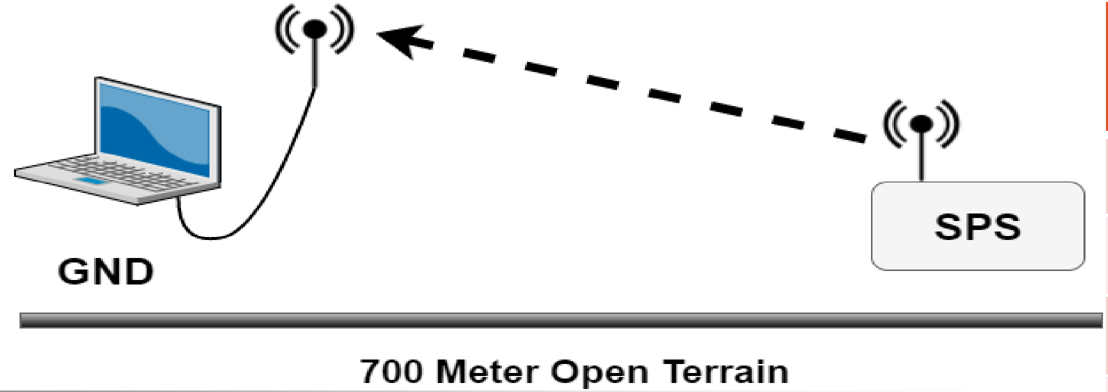
Link Margin [dB]: $\left(\frac{P_r}{N_0}\right) - \left(\frac{P_r}{N_0}\right)_{min}$

- Values for above calculations obtained from data sheets and literature

Reference: The spreadsheet and math was updated from INFERNO JPL Senior Project

Link Margin Analysis

- Link Margin for Sensor Package System Data Transmission

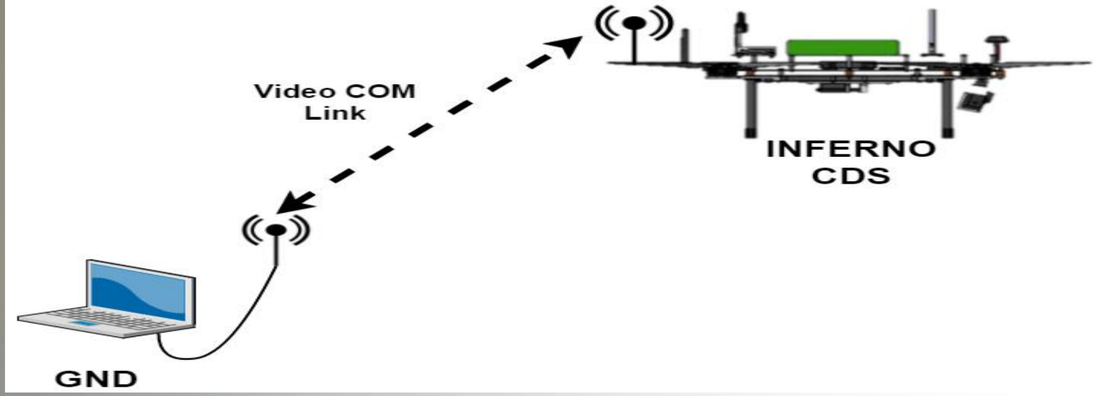


- Xbee transmitter and receiver
- 915 MHz at Data Rate of 9600 bps
- Max: 700 meter distance

Xbee-Pro 900 HP (900 MHz)	Transmitter (SPS)	Receiver (GND)
Power Transmitted	-6 dBW	-6 dBW
Gain Transmit	1 dBi	N/A
Gain Received	N/A	.1225 dBi
Space Loss	-88 dB	-88 dB
Additional Error (Line Loss)	-.5 dB	-.5 dB
Power Received (Actual)	-105 dB	-105 dB
Power Received (Minimum)	-142 dB	-142 dB
Link Margin	**37 dB**	**37 dB**

Link Margin Analysis

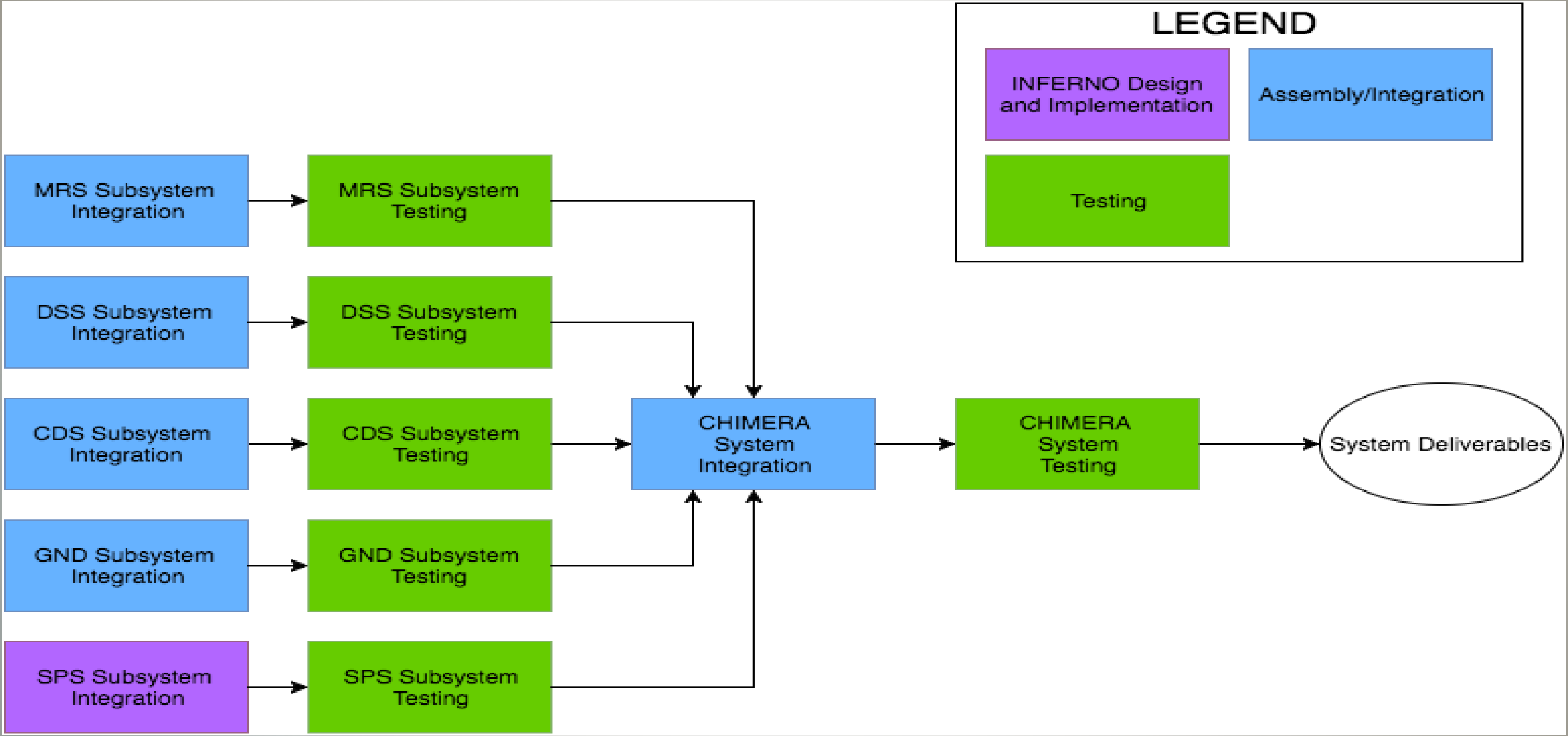
- Link Margin for INFERNO Child Drone System Data Transmission



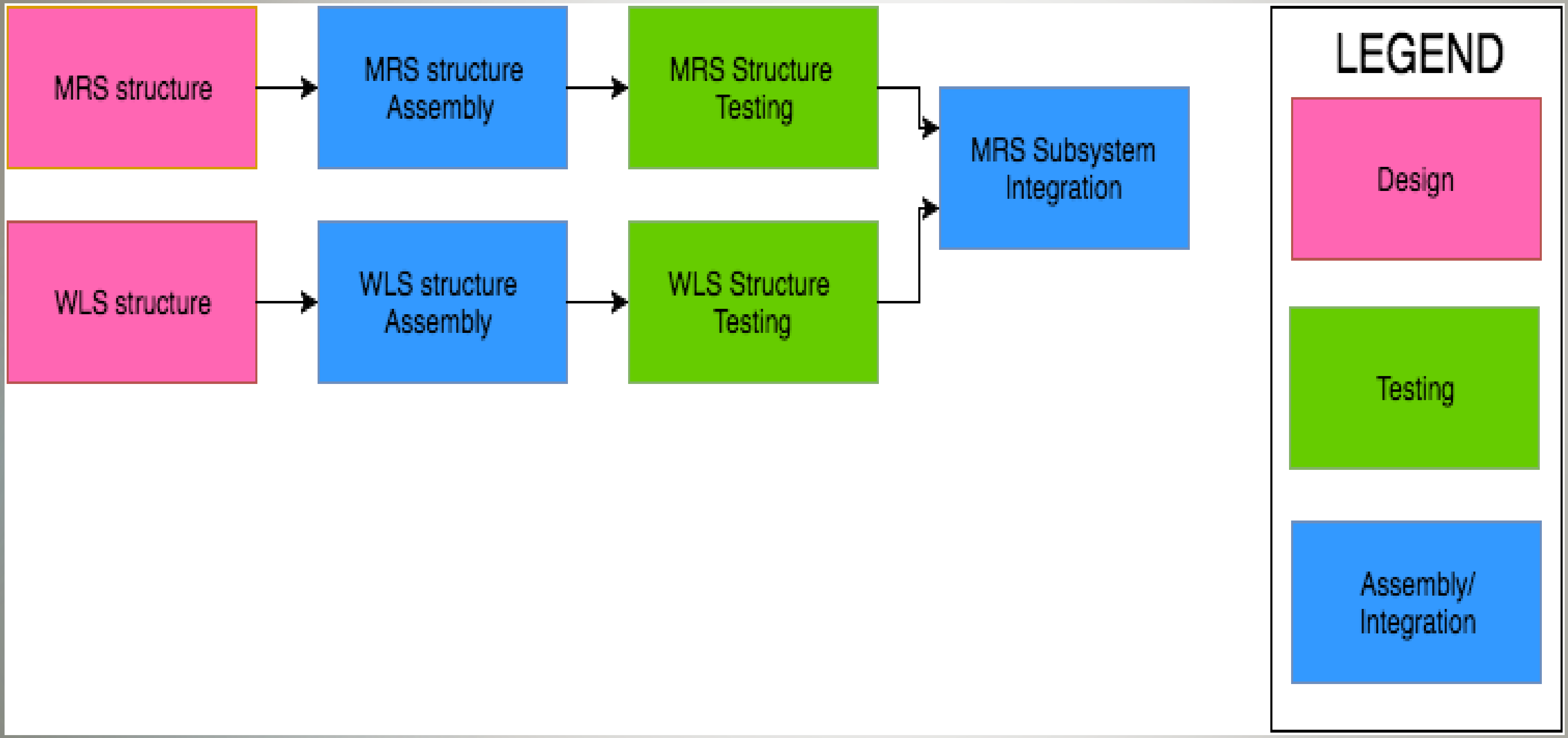
- 3DR Transmitter and Receiver
- 915 MHz at Data Rate of 250 kbps
- Max: 700 meter distance
- *NOTE: Same system will be used for GND to MRS across distance of 500 meters.*

3DR (915 MHz)	Transmitter (GND & CDS)	Receiver (GND & CDS)
Power Transmitted	-10 dbW	-10 dbW
Gain Transmit	1 dBi	1 dBi
Gain Received	.125 dBi	.125 dBi
Space Loss	-89 dB	-89 dB
Additional Error (Line Loss)	-.5 dB	-.5 dB
Power Received (Actual)	-109	-109
Power Received (Minimum)	-128 dB	-128 dB
Link Margin	**19 dB**	**19 dB**

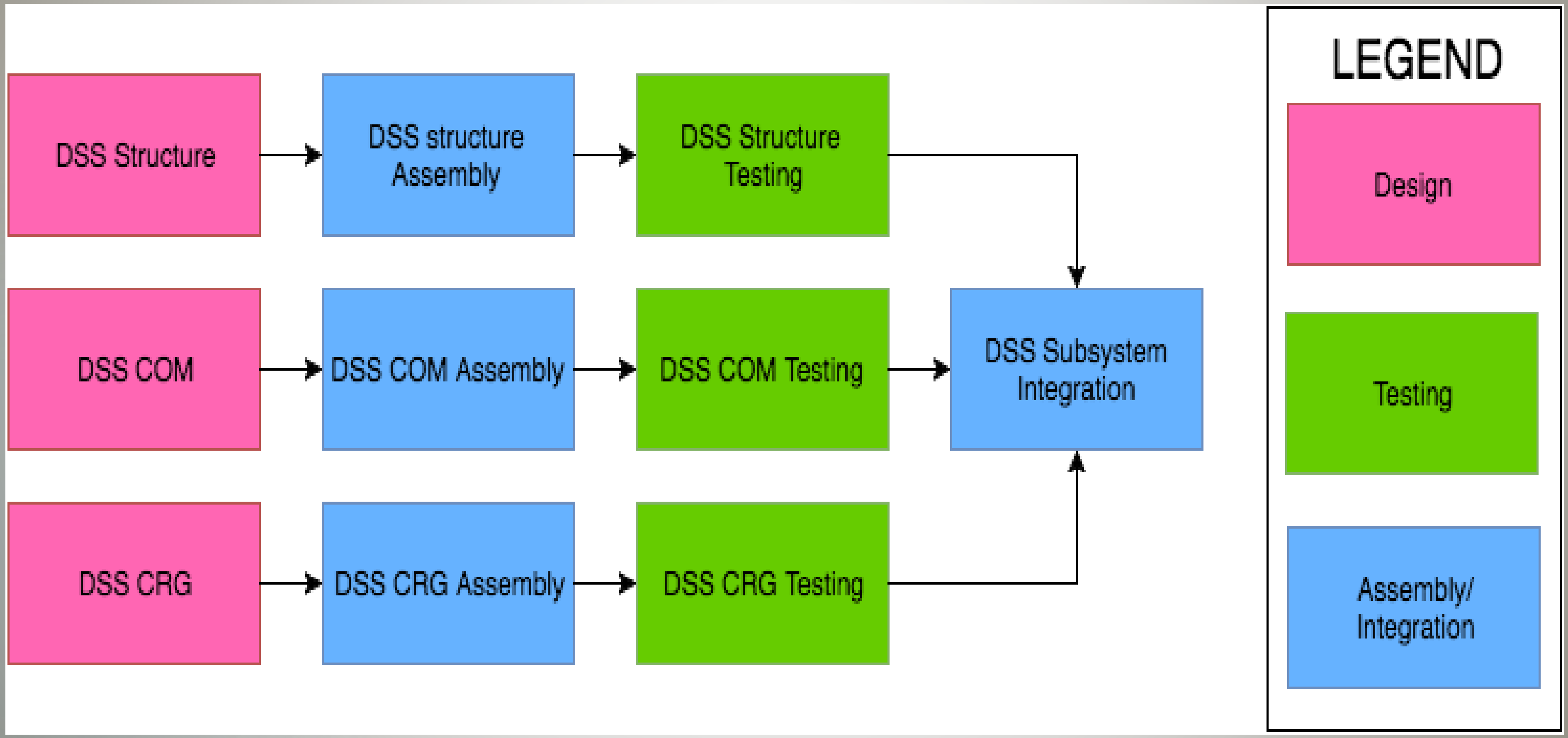
AI&T Diagrams



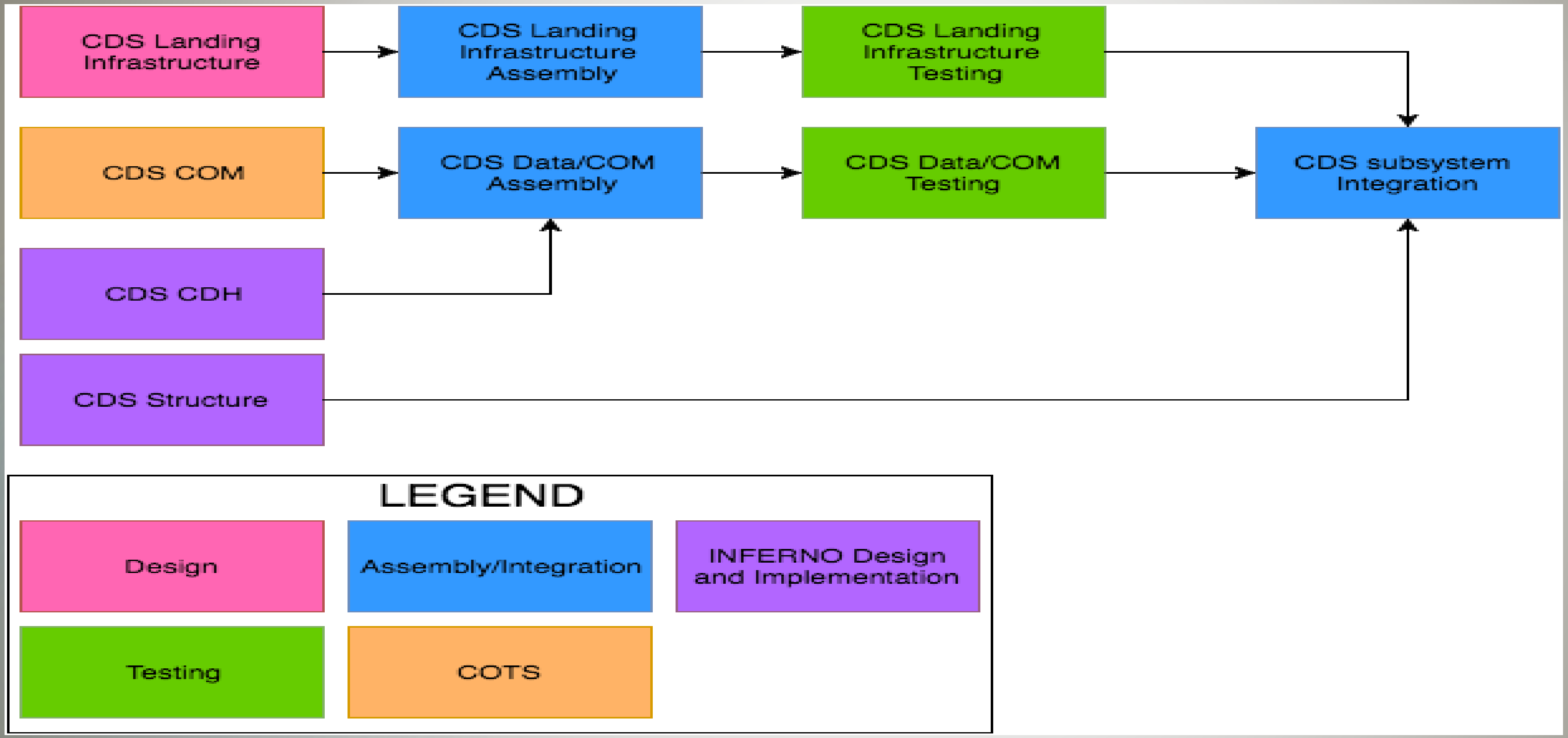
MRS AI&T Diagram



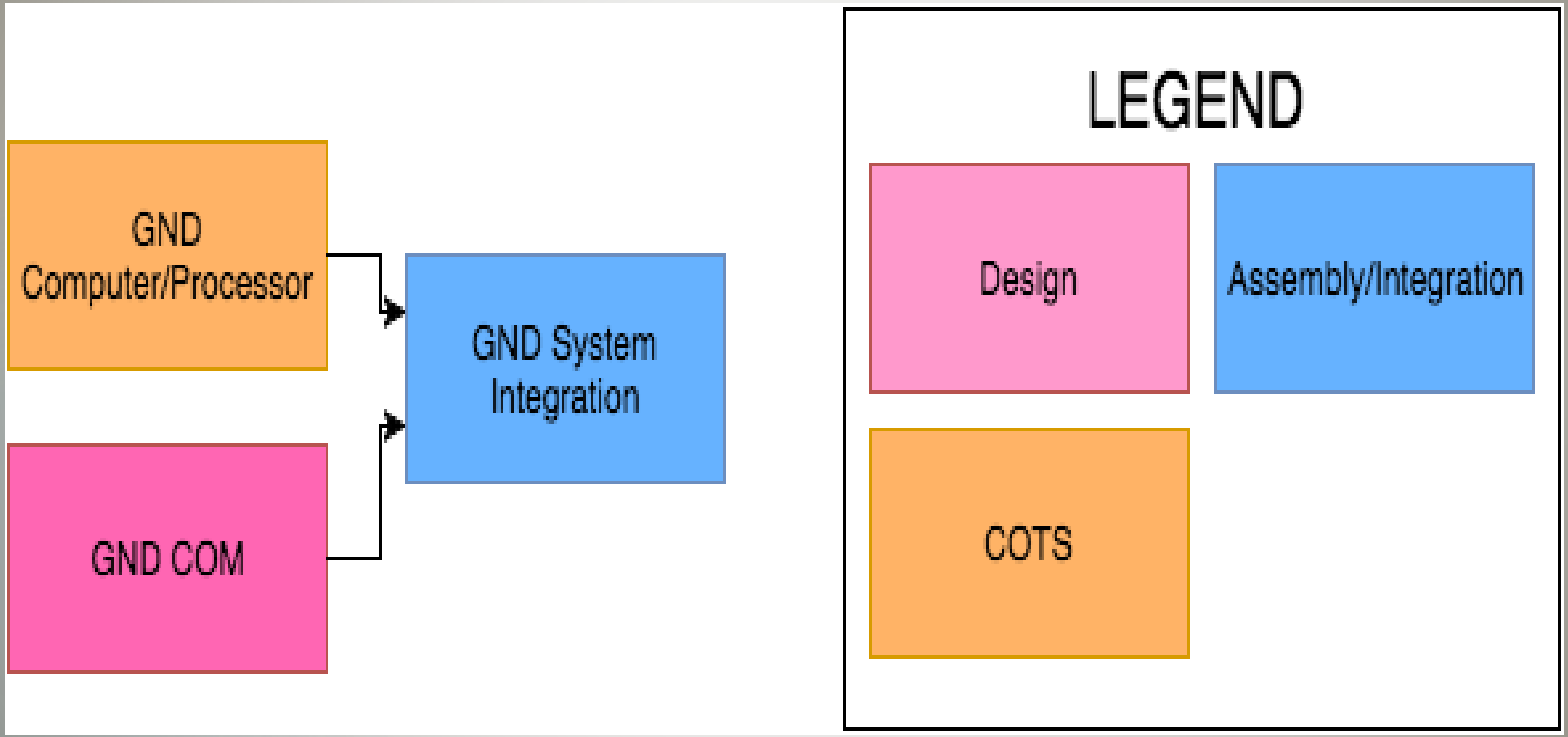
DSS AI&T Diagram



CDS AI&T Diagram



GND AI&T Diagram



Budget: MRS Manufacturing

Manufacturing- Mother Rover System					
Part Name	Description	Unit Cost	Quantity	Discounts	Total Cost
4ft x 8ft .032 thick 3003 Aluminum Sheet	MRS Bed Material	$ 74.00	1	0%	$ 74.00
Cold Finish Aluminum Bare Rectangle 2024 T351, 2 feet	MRS Bed Struts	$ 11.00	1	0%	$ 11.00
ATR Wheel and Shaft Set Pair 8mm bore - 10 inch Traction Lug	Pairs of Wheels	$ 95.00	2	0%	$ 190.00
Multistar High Capacity 4S 10000mAh Multi-Rotor Lipo Pack	Battery	$ 59.00	3	0%	$ 177.00
High Torque DC Servo Motor 60RPM With UART/12C/PPM Drive	Motor	$ 59.00	2	0%	$ 118.00
Stepper Mounting Bracket	Motor Mounting Bracket	$ 6.00	4	0%	$ 24.00
DX2E 2Ch DSMR Surface Radio w/SR310	Remote Control Transmitter	$ 60.00	1	0%	$ 60.00
SR310 DSMR 3-Channel Sport Receiver	Remote Control Receiver	$ 45.00	1	0%	$ 45.00
Raspberry Pi Model 2	Data Handling Computer	$ 46.00	1	0%	$ 46.00
Xbee PRO-900HP, Part Number: 602-1301-ND	Communication to GND	$ 39.00	1	0%	$ 39.00
3DR Radio Set	Communication to CDS	$ 100.00	1	0%	$ 100.00
900MHz Duck Antenna RP-SMA	Communcation to GND	$ 8.00	1	0%	$ 8.00
–	Miscellaneous Communication Hardware	$ 100.00	1	0%	$ 100.00
–	Miscellaneous Hardware and Electronics	$ 100.00	1	0%	$ 100.00
				Mother Rover System Total	$ 1,092.00

Budget: CDS Upgrades

Upgrades: Child Drone System					
Part Name	**Description**	**Unit Cost**	**Quantity**	**Discounts**	**Total Cost**
1215 Carbon Steel, Rod, 1" Diameter, 1' Length	Magnetic Inserts for CDS Securement	$ 10.00	1	0%	$ 10.00
E-CAM50IMX6 - 5MP MIPI iMX6 Camera Board	Autonomous Landing Imaging System	$ 69.00	1	0%	$ 69.00
Hummingboard- Gate	Autonomous Landing Onboard Computer	$ 83.00	1	0%	$ 83.00
Xbee PRO-900HP, Part Number: 602-1301-ND	CDS to GND Antenna	$ 39.00	1	0%	$ 39.00
Super-Conductive 101 Copper, Rectangular Bar, 1/16" x 1", 4' Length	Conductive Panels for Autonomous Charge	$ 28.00	2	0%	$ 56.00
White Delrin ® Acetal Resin Rectangular Bar, 3/4" Thick x 1-1/2" Width	Mounting for Conductive Panels	$ 13.00	2	0%	$ 26.00
Type 316 Stainless Steel Socket Head Cap Screw, 4-40 Thread, 7/8" Length, packs of 25	Securement of Conductive Panels	$ 12.00	2	0%	$ 24.00
Raspberry Pi Model 2	Data Handling Computer for Image Recognition System	$ 46.00	1	0%	$ 46.00
–	Miscellaneous Hardware and Electrical Components	$ 100.00	1	0%	$ 100.00
				Child Drone System Upgrades Total	**$ 453.00**

Budget: DSS Manufacturing

Manufacturing- Docking and Securement System					
Part Name	**Description**	**Unit Cost**	**Quantity**	**Discounts**	**Total Cost**
Multipurpose 6061 Aluminum, 1/4" Thick, 12" x 48"	Bed Fabrication Material	$ 83.00	2	0%	$ 166.00
General Purpose Low-Carbon Steel, Sheet, .075" Thick, 24" x 48"	Magnetic panels for securement of CDS	$ 76.00	2	0%	$ 152.00
Super-Conductive 101 Copper, Rectangular Bar, 1/16" x 1", 4' Length	Panels for CDS Autonomous Charging	$ 28.00	2	0%	$ 56.00
White Delrin ® Acetal Resin Rectangular Bar, 3/4" Thick x 1-1/2" Width	Mounting for CRG Panels	$ 13.00	2	0%	$ 26.00
OpenGrab EPM v3	Magnet	$ 54.00	3	0%	$ 162.00
DC 12V 0.07A 3.5RPM High Torque Gear Box Electric Motor 37mm	Motor	$ 13.00	4	0%	$ 52.00
Actobotics 48T Aluminum Hub Gear (0.5")	Motor Gear	$ 13.00	4	0%	$ 52.00
70 Tooth Timing Belt	Gear Track	$ 3.00	10	0%	$ 30.00
Multistar High Capacity 4S 10000mAh Multi-Rotor Lipo Pack	DSS Battery	$ 59.00	2	0%	$ 118.00
Multistar High Capacity 4S 10000mAh Multi-Rotor Lipo Pack	CRG Battery	$ 59.00	2	0%	$ 118.00
–	Miscellaneous Hardware and Electrical	$ 150.00	1	0%	$ 150.00
				Docking and Securement System Total	**$ 1,082.00**

Budget: GND & WLS Manufacturing

Manufacturing- Ground Station					
Part Name	Description	Unit Cost	Quantity	Discounts	Total Cost
900 MHz 5dBi Rubber Duck Antenna	Communication to SP	$ 23.00	1	0%	$ 23.00
–	Miscellaneous Software/Interfacing	$ 50.00	1	0%	$ 50.00
–	Miscellaneous Hardware/Electronics	$ 100.00	1	0%	$ 100.00
				Ground Station Total	$ 173.00

Manufacturing- Wheel Locking System					
Part Name	Description	Unit Cost	Quantity	Discounts	Total Cost
Boston Gear D1418KRH Worm Gear, 14.5 Degree Pressure Angle, 0.750" Bore, 10 Pitch, 1.25 PD, RH	Worm Gear	$ 43.00	2	0%	$ 86.00
Actobotics 48T Aluminum Hub Gear (0.5")	Motor Gear	$ 13.00	2	0%	$ 26.00
–	Miscellaneous Hardware	$ 100.00	1	0%	$ 100.00
				Wheel Locking System Total	$ 212.00

Budget: Administrative & Testing

Replacements: Child Drone System					
Part Name	Description	Unit Cost	Quantity	Discounts	Total Cost
Gemfan T-Type CF Prop 13x5.5	Propellers (pair)	$14.00	2	0.00%	$28.00
Lumenier 30A ESC	Elec. Speed Controllers	$25.00	1	0.00%	$25.00
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	7	0.00%	$35.00
				Testing Total	$106.00

Testing and Safety					
Part Name	Description	Unit Cost	Quantity	Discounts	Total Cost
CO2 Fire Extinguisher	Electrical Fire Extinguisher	$ 150.00	1	0%	$ 150.00
Bushnell Velocity Speed Gun	Speedometer for MRS testing	$ 90.00	1	0%	$ 90.00
				Testing Total	$ 240.00

Administrative				
Description	Unit Cost	Quantity	Discounts	Total Cost
Printing	$ 160.00	1	0%	$ 160.00
			Adminstrative Total	$ 160.00

What is a Chimera?

Offspring of Typhon (giant, last son of Gaia) and Echidna (She-Viper).

Head of a lion, body (and head) of a goat, and snake tail.

Defeated by Bellerophon with the help of Pegasus.