D.R.O.P.S
Preliminary Design Review

October 20th, 2021 ASEN
4018-012 Team 8

Company Customer:
TB2 Aerospace

Faculty Advisor:
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Presentation Overview

1. Project Overview — Cody Watson, Nate Kuczun
2. Feasibility: *Alignment* — Alex Karas
3. Feasibility: *Connection* — Cody Watson
4. Feasibility: *Power* — Sid Arora, Daniel Mendoza
5. Feasibility: *Electronics & Data* — Josh Schmitz
6. Feasibility: *Conclusions* — Sid Arora
7. Future Work — Alex, Cody, Sid, Josh

Project Overview

Project Overview

Background:

Autonomous drone delivery systems are being developed and contracted for development by many different, large - scale organizations [1]

- *US Military* [2]
- *Amazon Prime Air*
- *UPS Flight Forward*
- *Wing*

Currently, **no standard exists** to allow **one cargo unit** to interface with a variety of different drone types and manufacturers

Motivation:

Effective: Current drone-to-pod attachment methods are non-standardized

Functionality: Current design solutions often hinder the overall performance of the drone's capabilities

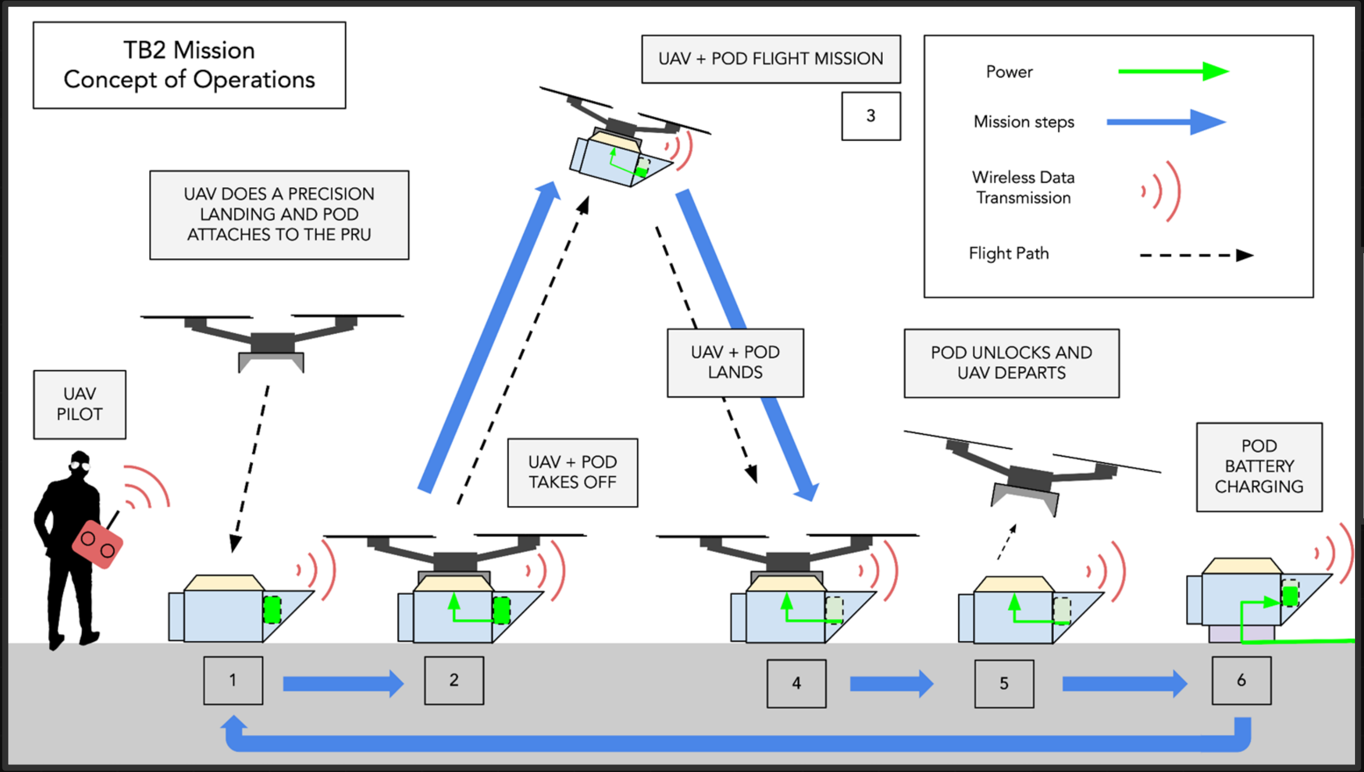
Safety: Current drone cargo delivery methods are often hazardous

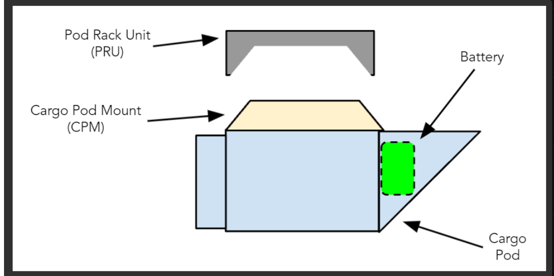
- *Straps/Bags*
- *Different Source Components*

Mission Statement

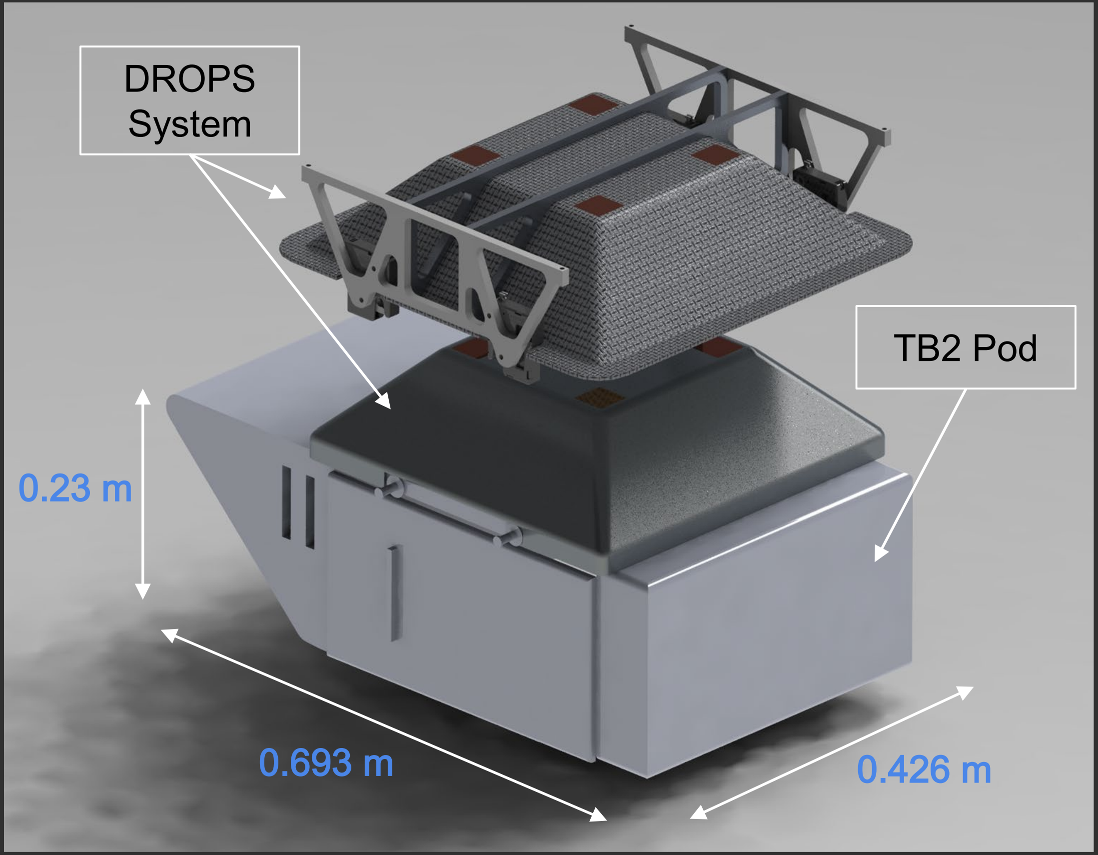
The Drone Recharging Operational Payload System **(DROPS)** aims to standardize autonomous cargo delivery units for both **military and commercial applications**. Development of a docking system will permit **mechanical and electrical connection between class 2 UAVs** and powered cargo units **while increasing functional range**.

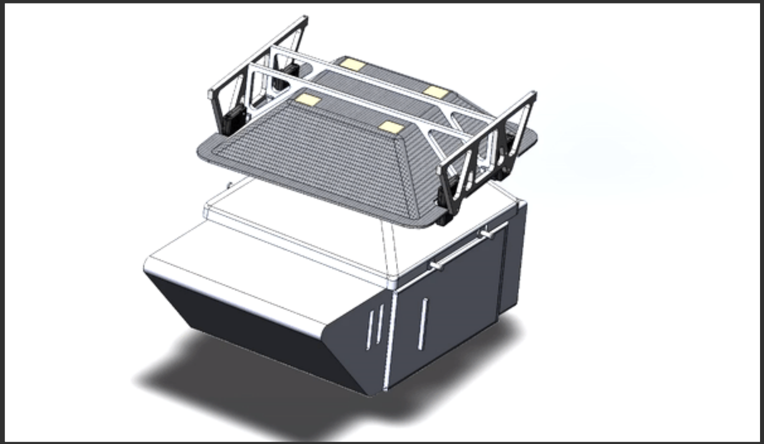
Mission CONOPS





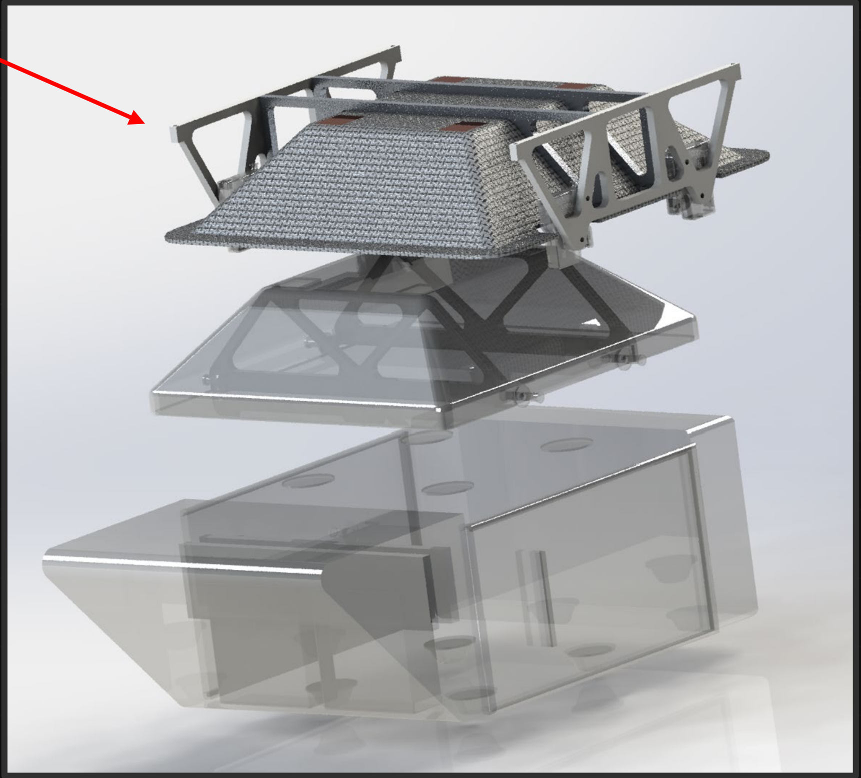
Baseline System Design





Pod Rack Unit (PRU) Design

Pod Rack Unit (PRU)

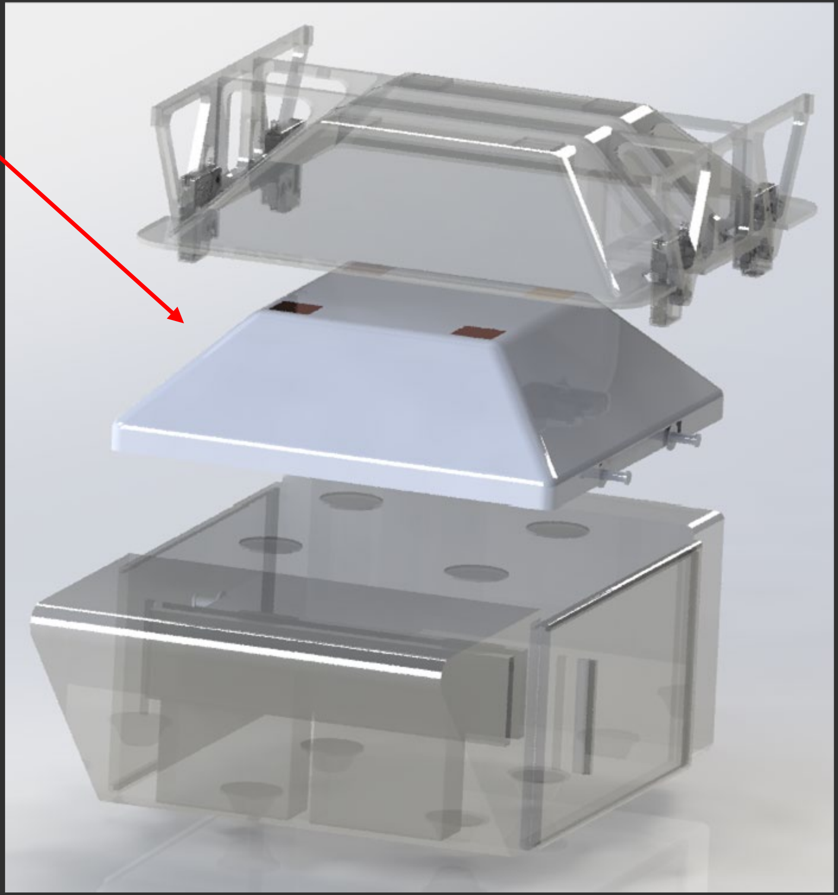


Key Features:

1. Interfaces with and is attached to a UAV via a bolted connection
2. Provides electrical connection from the CPM to the UAV via **electrical contacts**
3. Allows for alignment of the drone onto the CPM via the **slot slopes**
4. Maintains rotary latches to connect to the CPM latch points

Cargo Pod Mount (CPM) Design

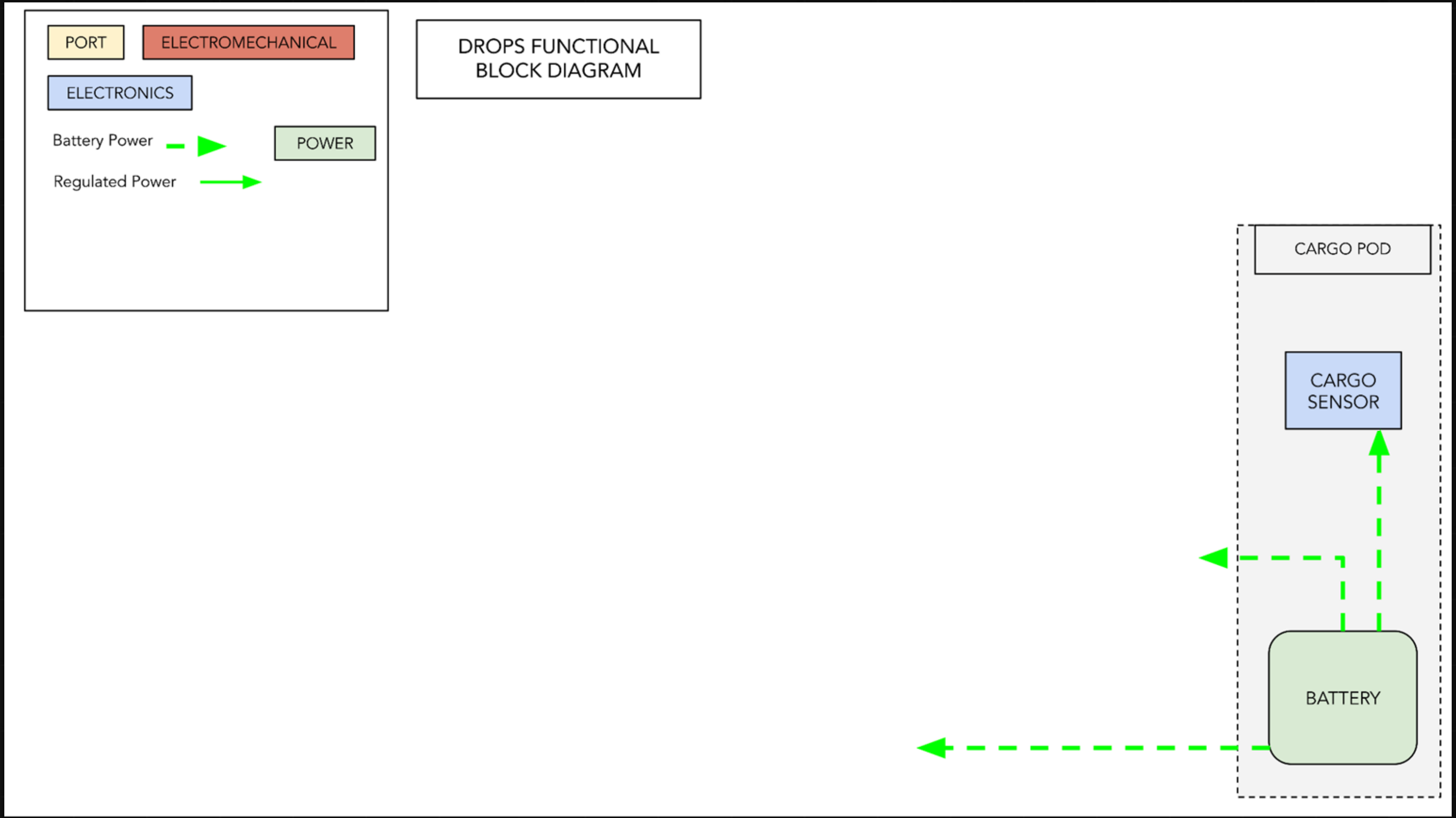
Cargo Pod Mount (CPM)



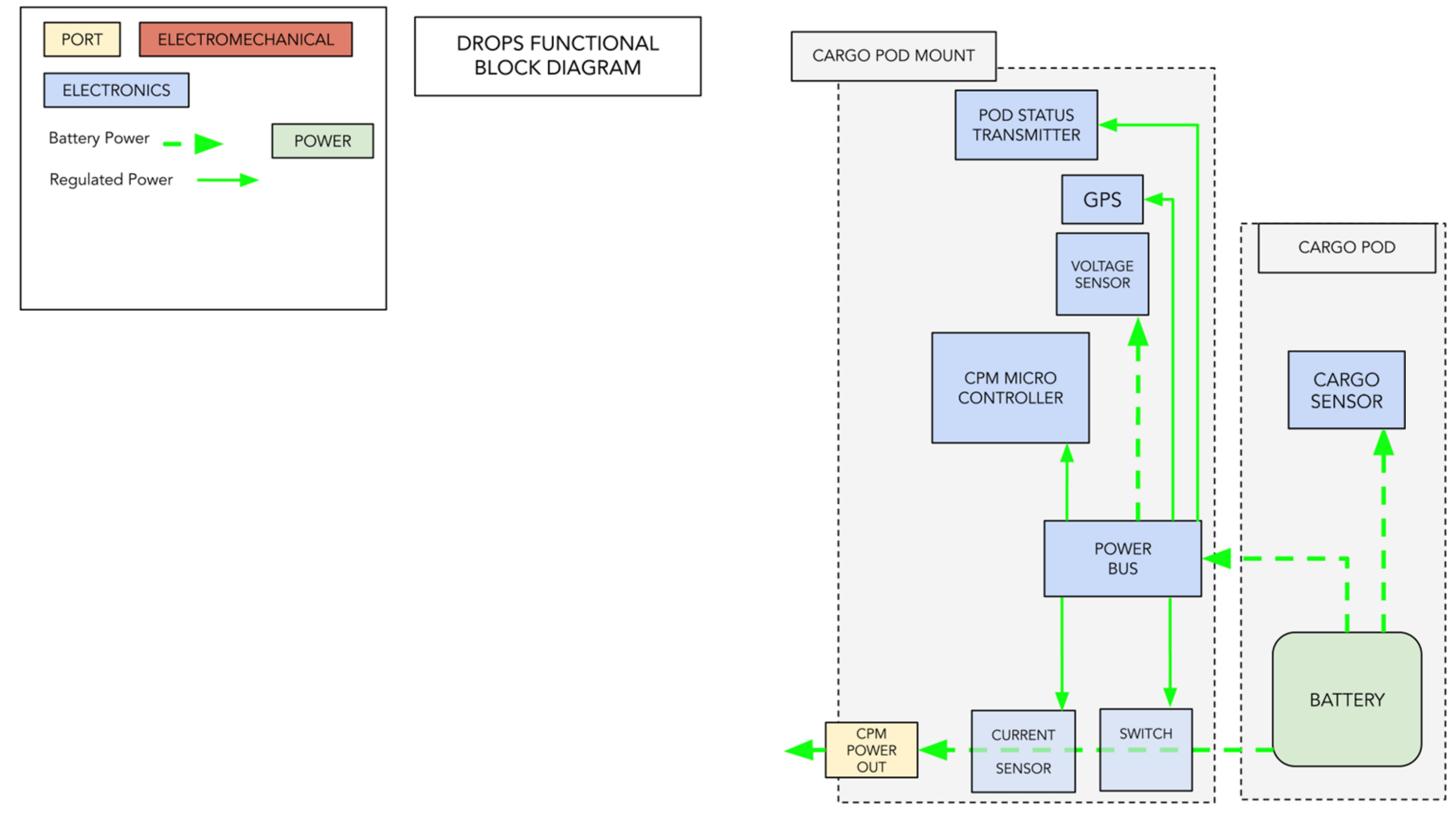
Key Features:

1. Interfaces with and is attached to a Pod via a bolted connection
2. Provides electrical connection from the Pod's batteries via metal contacts up to the UAV
3. Allows for alignment of the drone via the slot slopes
4. Houses data and communication components
5. Maintains latch points for the PRU to connect with

Functional Block Diagram

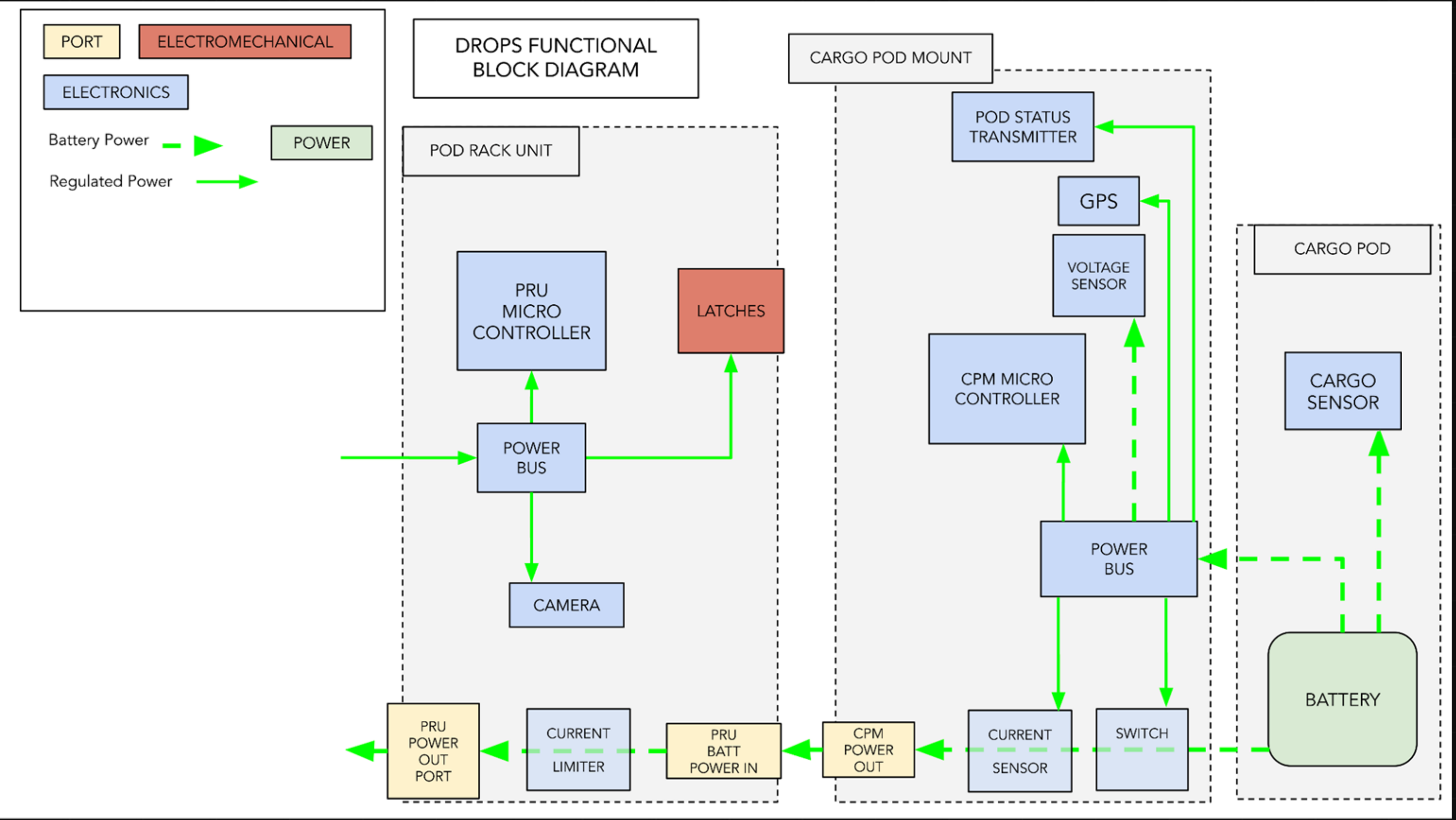


Functional Block Diagram

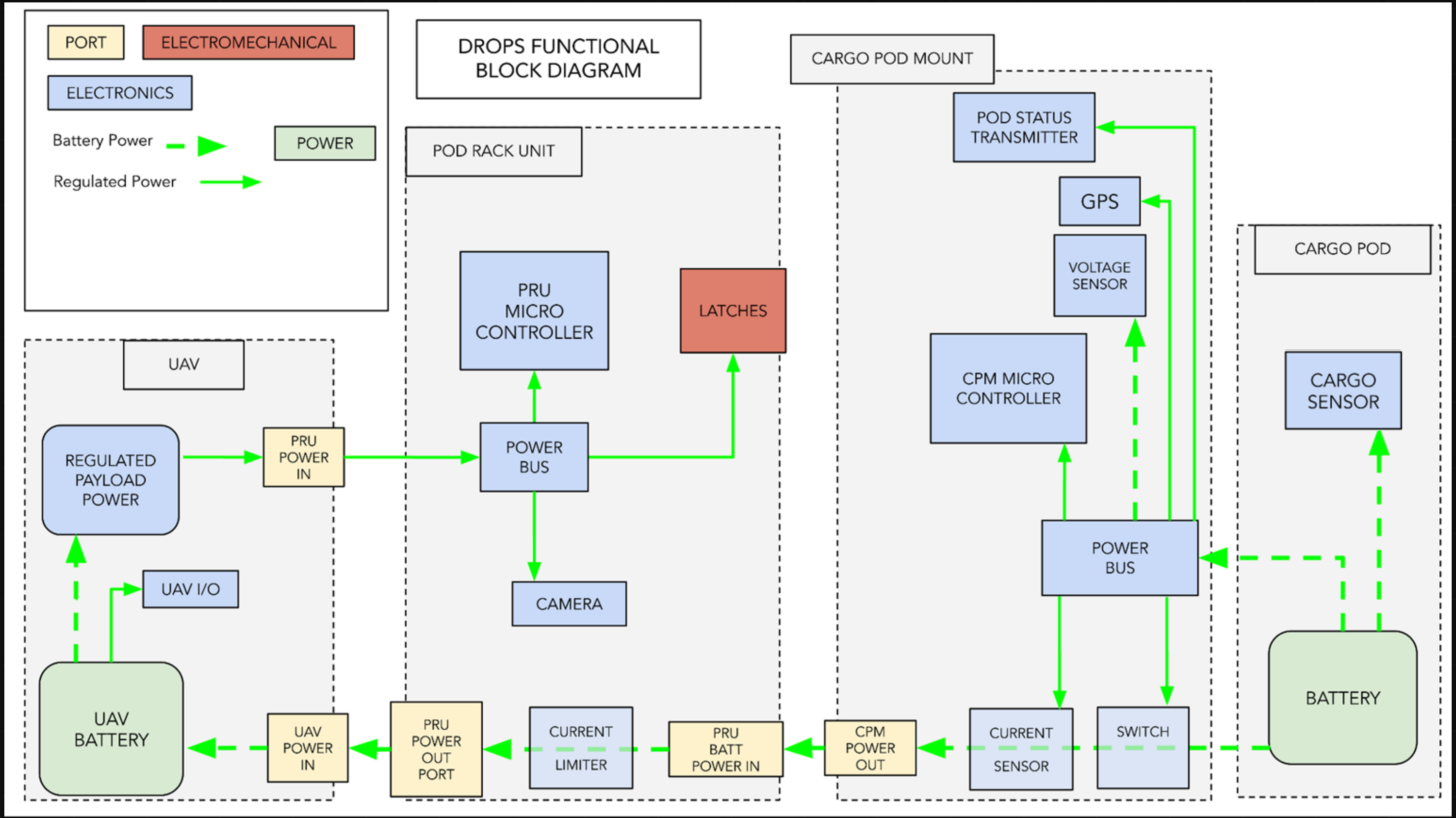


Overview

Functional Block Diagram

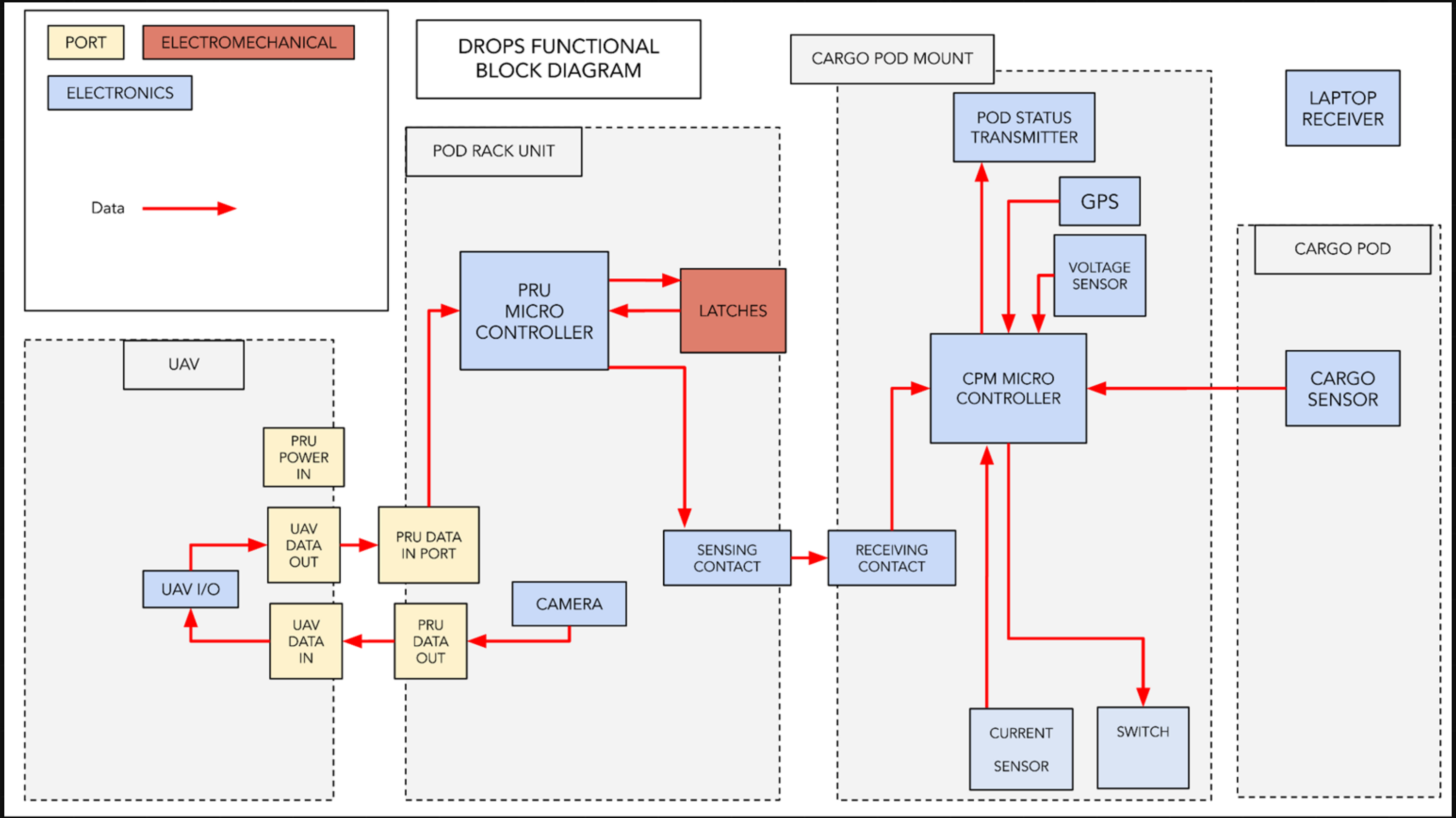


Functional Block Diagram

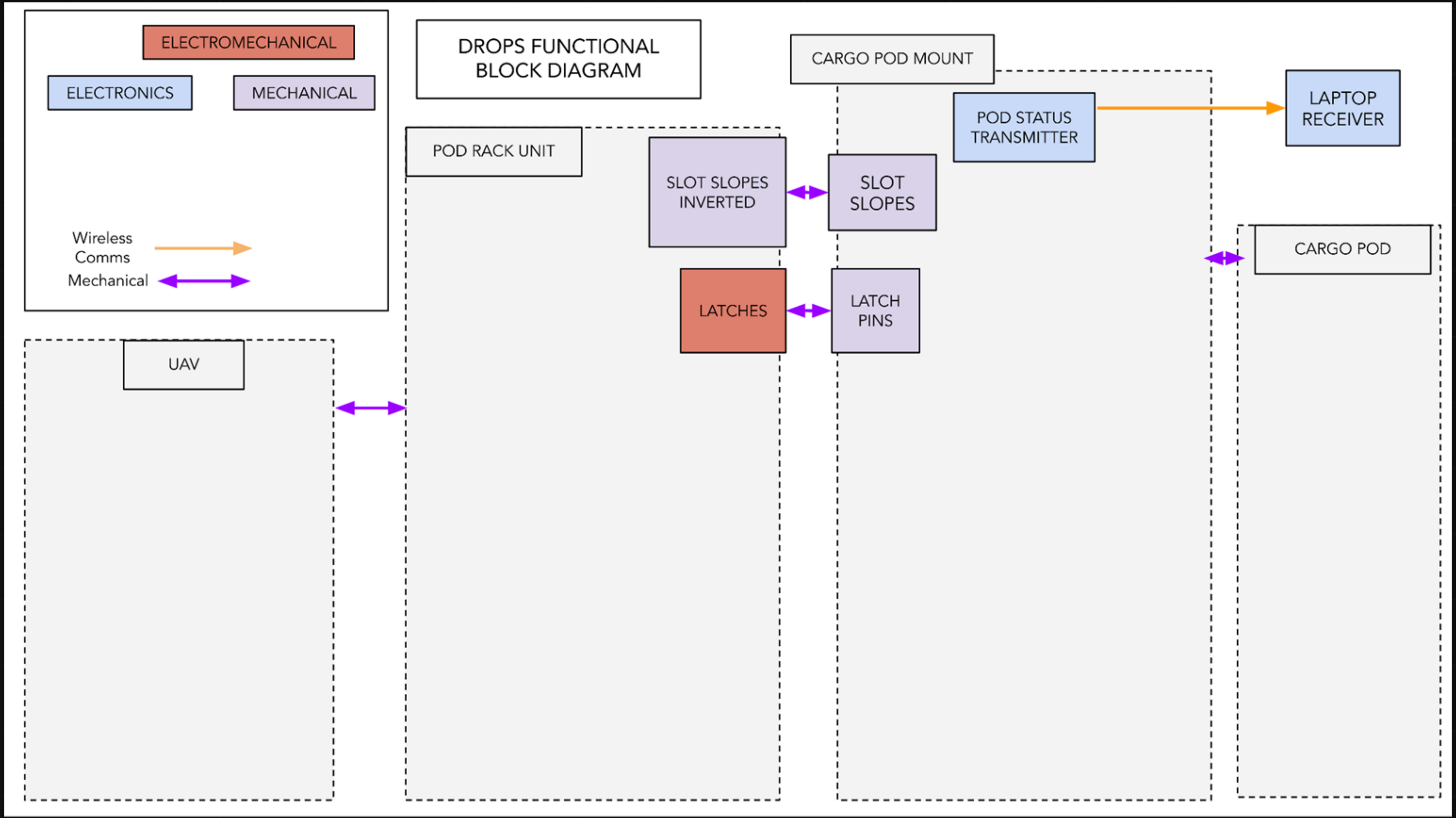


Overview

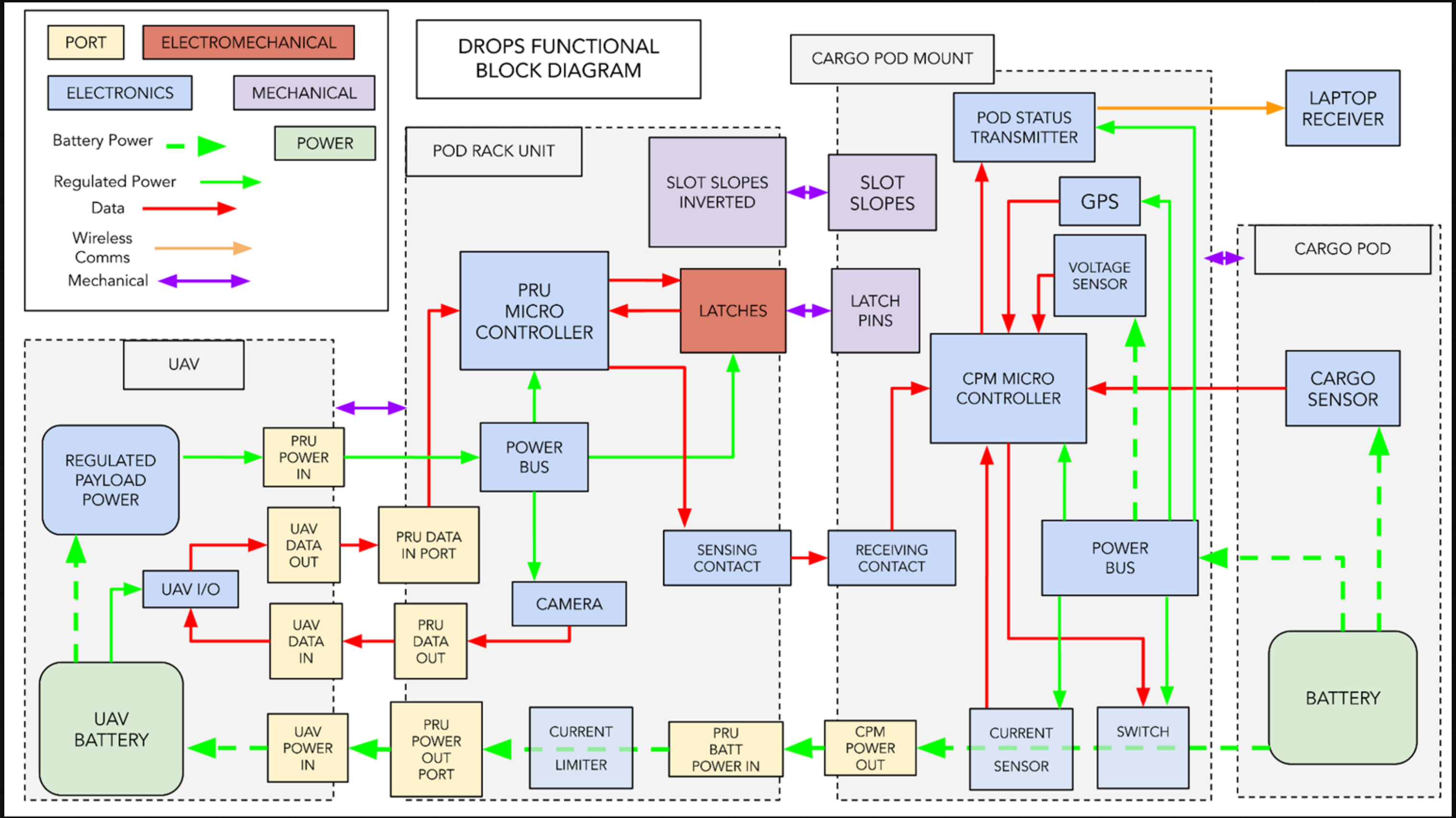
Functional Block Diagram



Functional Block Diagram

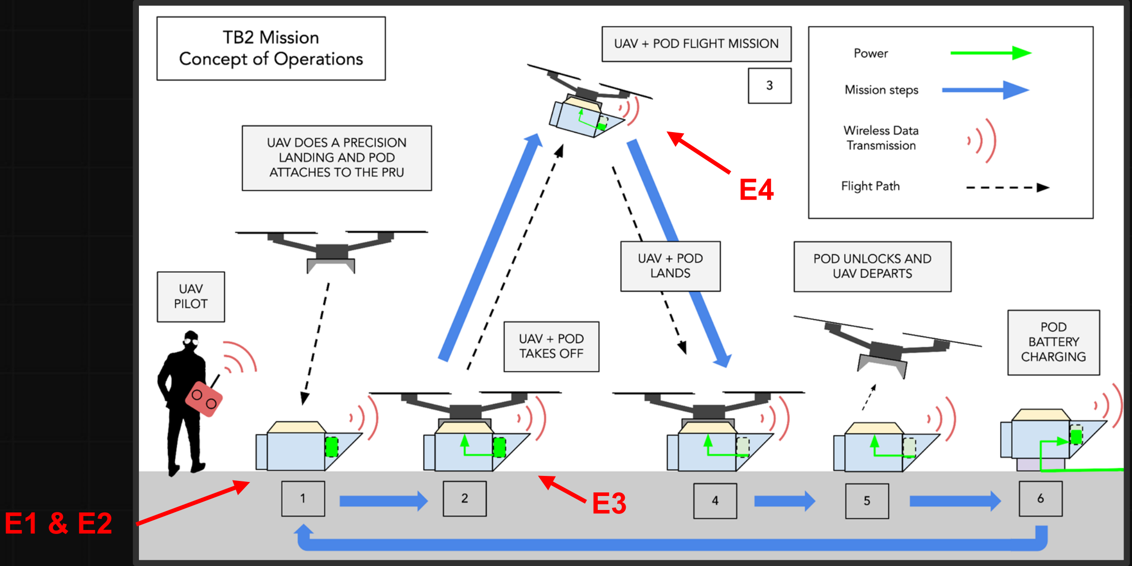


Functional Block Diagram



Design Feasibility

Critical Project Elements

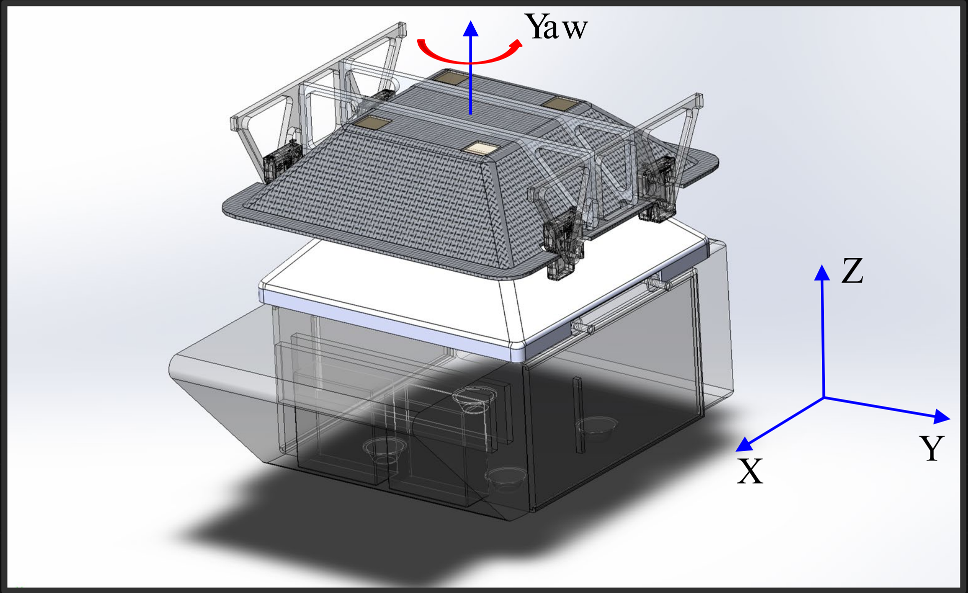


CPE	Description
E1	The UAV shall align itself with the Pod via the PRU
E2	The UAV shall connect to the Pod via the PRU
E3	There shall be power passthrough from the Pod through the PRU and into the UAV
E4	The status of the Cargo Pod shall be transferred to the operator

Design Feasibility:
Alignment

Critical Feasibility Element: Alignment

Label	Statement	CPE	Requirement	Feasible?
Alignment	The UAV-PRU system shall be able to consistently align to the CPM given a max centering offset of 0.1 m in the x-y plane and 20° yaw (z)	E1	FR 1	?



Feasibility: Slot Slopes Material Study

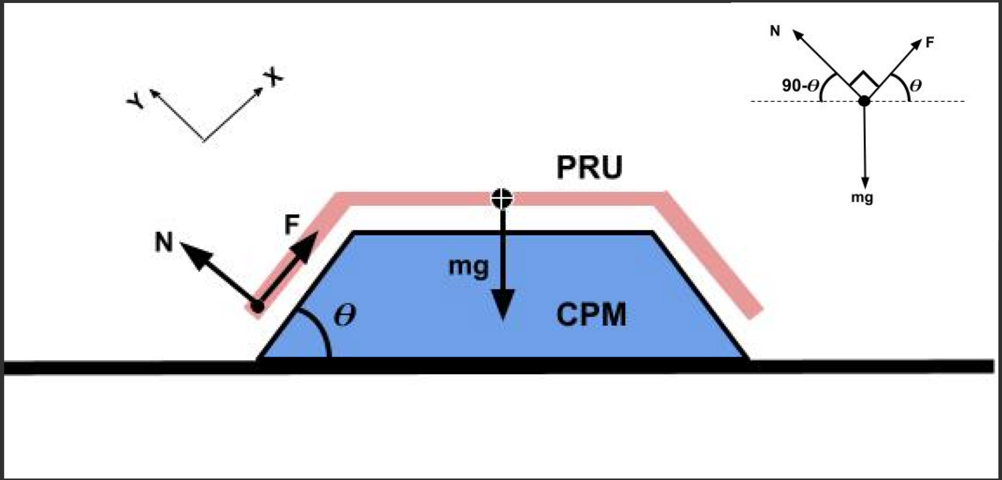
Determine: Minimum slot slope angle θ for weight of PRU to overcome static friction force to passively align itself

$$\Sigma F_y = N - mgcos(\theta) = ma_y$$
$$\Sigma F_x = f - mgsin(\theta) = ma_x$$

Assume:

1. Zero initial velocity
2. Acceleration only due to gravity

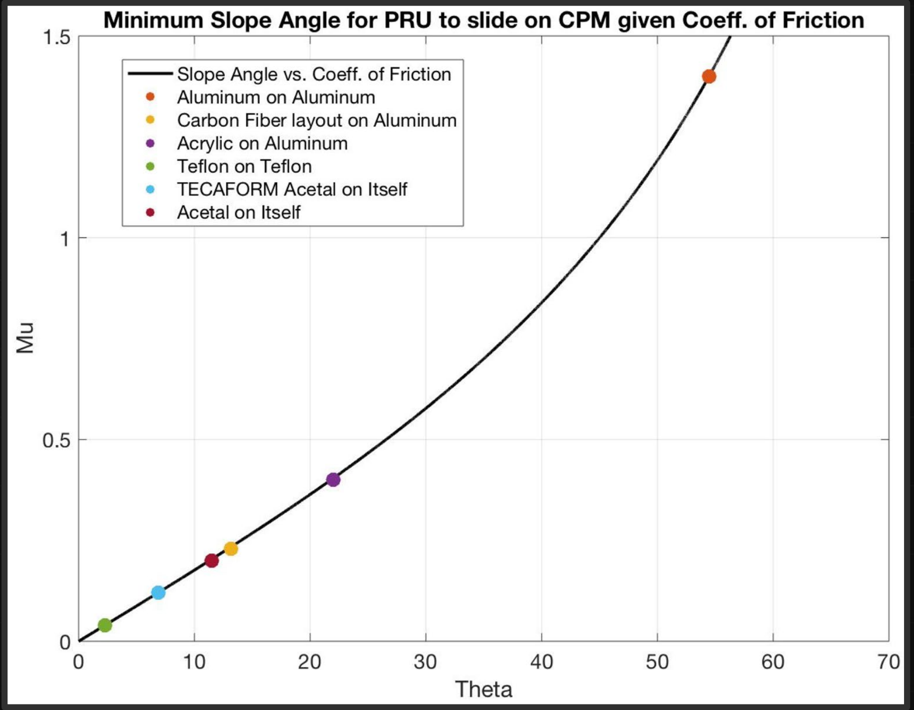
$$\Rightarrow \Sigma F_y = N - mgcos(\theta) = 0$$
$$\Rightarrow \Sigma F_x = f - mgsin(\theta) = 0$$
$$\Rightarrow N = mgcos(\theta)$$
$$\Rightarrow f = mgsin(\theta) = \mu N$$
$$\Rightarrow \mu mgcos(\theta) = mgsin(\theta)$$
$$\Rightarrow \boxed{\mu = tan(\theta)}$$



Feasibility: Slot Slopes Material Study

Potential Materials & Coatings

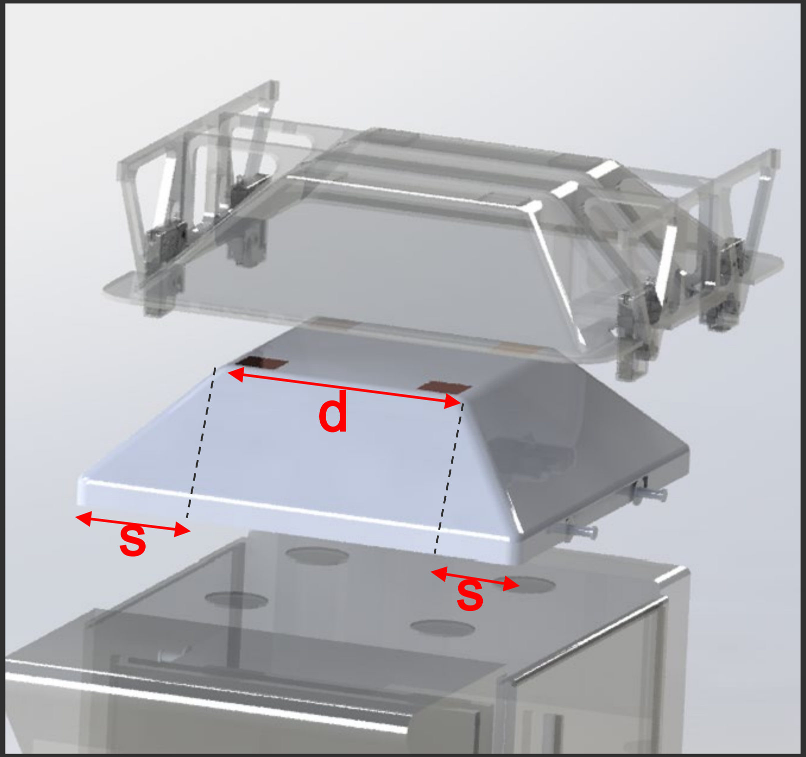
Material Name	Theta [deg.]	Coefficient of Friction, μ
Aluminum 6061 [3]	54.5	1.4 (on itself)
Carbon Fiber w/ Epoxy [4]	13.13	0.23 (on Aluminum)
Acrylic [5]	22	0.4 (on Aluminum)
Teflon [3]	2.3	0.04 (on itself)
TECAFORM Acetal [6]	6.89	0.12 (on itself)
Acetal [6]	11.5	0.2 (on itself)



Feasibility status: ***Confirmed***

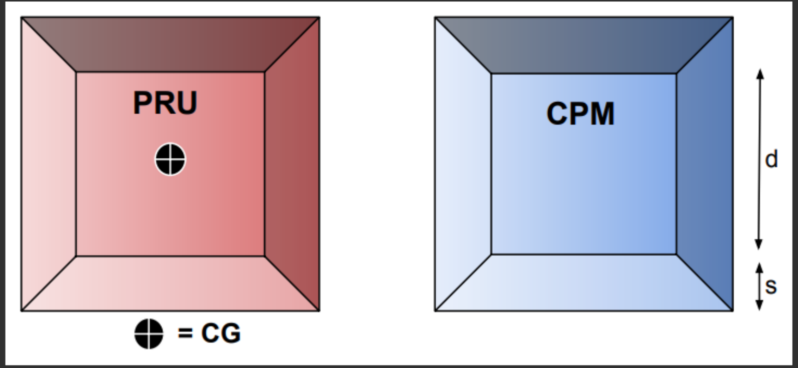
There exists a range of materials that can provide a coefficient of friction low enough such that the slope angle allows the PRU to passively align itself solely with its weight

CPM/PRU Slot Slope Surface Area Analysis



S: Horizontal length of slope
(Defines accuracy requirement)

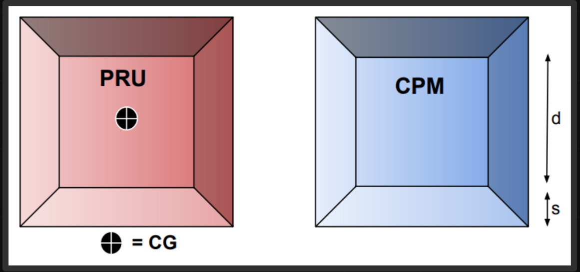
d: Length of top portion
(Defines stackability)



Top View

CPM/PRU Slot Slope Surface Area Analysis

PRU/CPM Definitions:



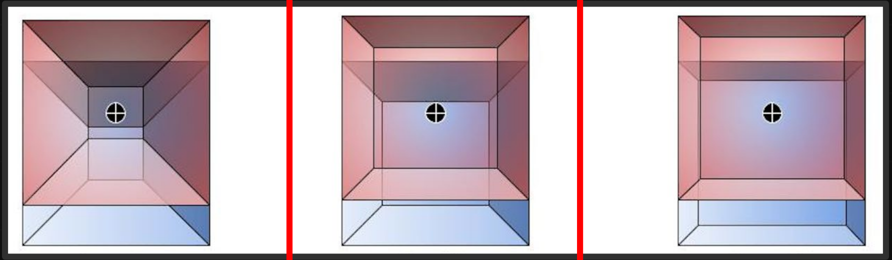
Top View

S: Horizontal length of slope
(Defines accuracy requirement)

d: Length of top portion
(Defines stackability)

Three Scenarios:

(A) (B) (C)



(A) S >> d/2

Pros: - Larger x - y tolerance

Cons: - CG over ledge
- Not stackable

(B) S = d/2

Pros: - Medium slope area
- CG over top unless unalignable

Cons: - Smaller S → harder to align

(C) S << d/2

Pros: - CG usually over top
- Stackable

Cons: - Small x-y landing tolerance

CPM/PRU Slot Slope Surface Area Analysis

CPM/PRU Slot Slope Surface Area Analysis

Assumptions/Constraints:

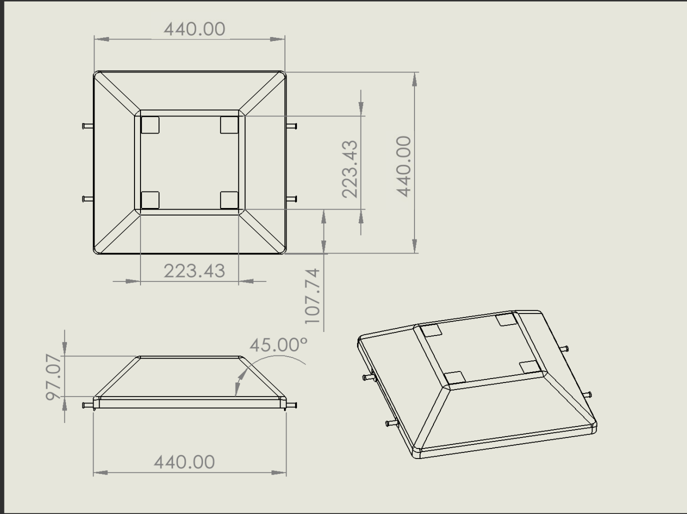
- UAV computer vision and lidar systems have position accuracy of < 10 cm [7]
- CPM width must exceed Pod width to accommodate connection latches
- This gives CPM width of 2S+D = 44 cm

Lateral allowable offset ***S*** **of +/ - 10.7 cm**

Given S = d/2 = 107 mm =

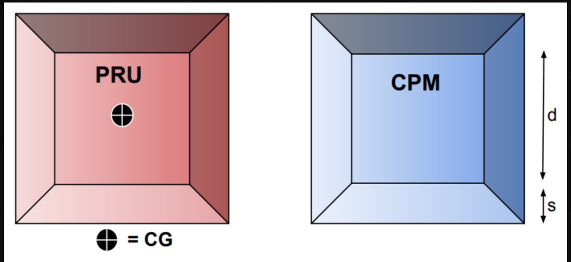
Allowable lateral offset
10.7 cm > 10 cm

Feasibility status: ***Confirmed***



CPM/PRU Slot Slope Surface Angle Analysis

PRU/CPM Definitions:

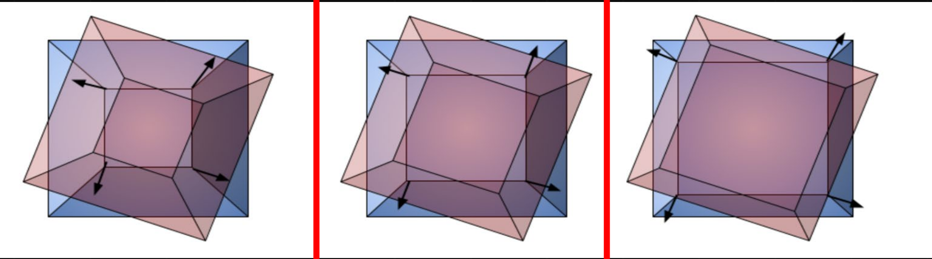


S: Horizontal length of slope
(Defines accuracy requirement)

d: Length of top portion
(Defines stackability)

Three Scenarios at 20 degrees yaw:

(A) (B) (C)



(A) S >> d/2

Pros:
- Larger x - y tolerance

Cons:
- Smaller torque arm
- Not stackable

(B) S = d/2

Pros:
- Larger torque arm distance
- All angles hit CPM corners
- Stackable

Cons:
- Smaller x - y tolerance

(C) S << d/2

Pros:
- Larger torque arm distance
- Very stackable

Cons:
- Smaller landing tolerance
- Not all angles hit CPM

Feasibility: Slot Slopes Offset Angle Study

Determine: Maximum heading offset Ψ for torque forces from CPU to PRU that can overcome static friction force to passively align itself

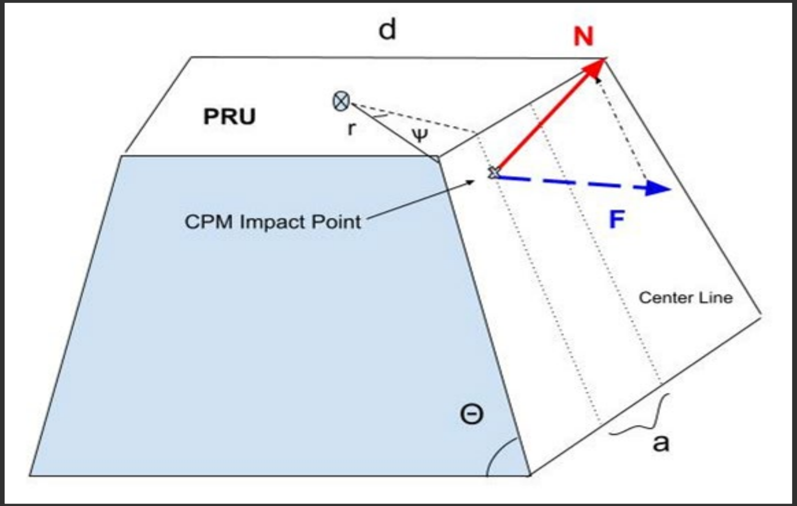
Assume:

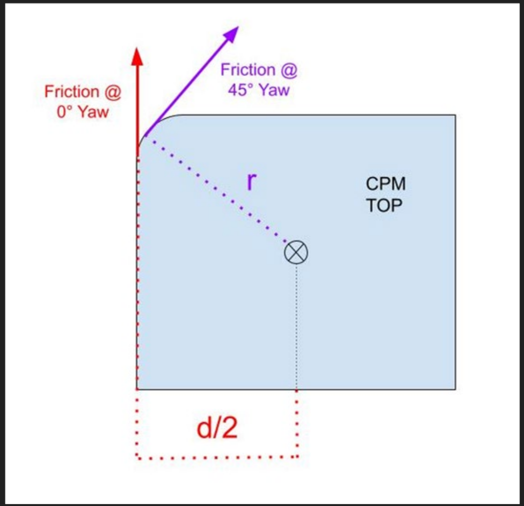
1. Zero initial velocity
2. Single point contact forces

$$T_{PRU} > T_{Friction}$$

$$F_{normal} * a > F_{friction} * (d/2 + (r - d/2)cos(2\psi))$$

$$N * sin(\theta) * a > \mu * N * (d/2 + (r - d/2)cos(2\psi))$$



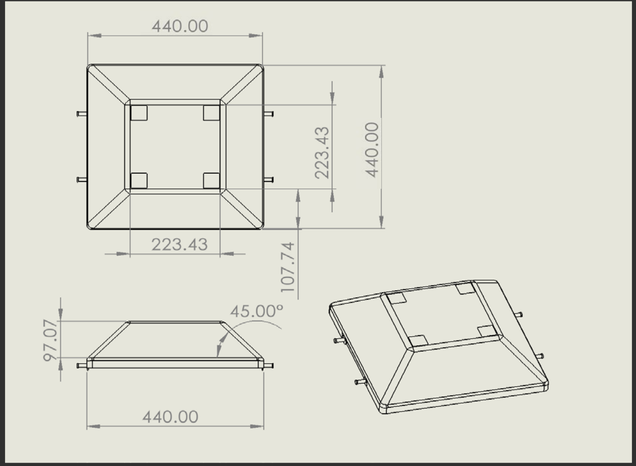


CPM/PRU Slot Slope Surface Angle Analysis

CPM/PRU Slot Slope Heading Offset Analysis

Assumptions/Constraints:

- Leveled descent (pitch/roll = 0°)
- UAV computer vision and compasses have a heading accuracy of < 1° [7]
- More human or weather error



Coefficient of Friction	Necessary Torque to Overcome	Max Heading Offset
0.6	54.80 Nm	+/- 8 degrees
0.4	33.07 Nm	+/- 15 degrees
0.2	26.46 Nm	+/- 22 degrees

Given S = d/2 = 107 mm,

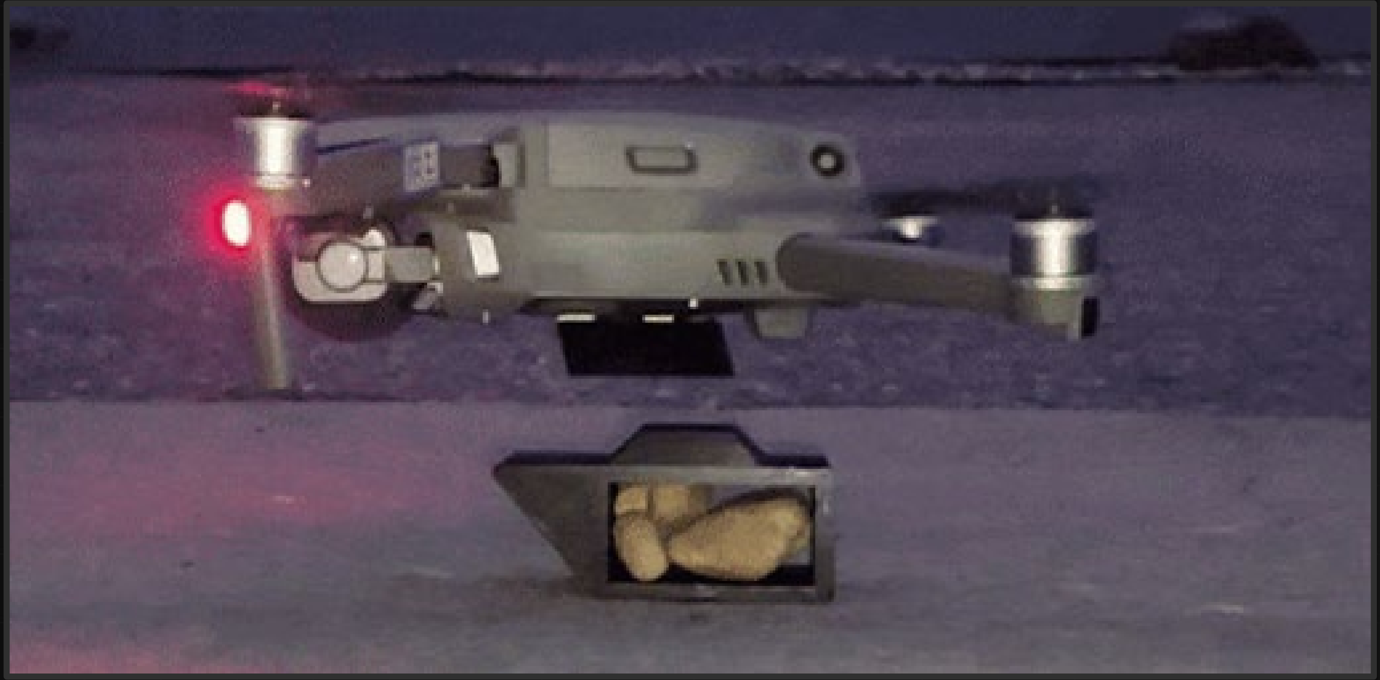
$\Theta = 45°$, AND $\mu \leq 0.2$

Allowable heading offset (Ψ)

$22° \geq 20$

Feasibility status: ***Confirmed***

Slot Slopes Concept Test



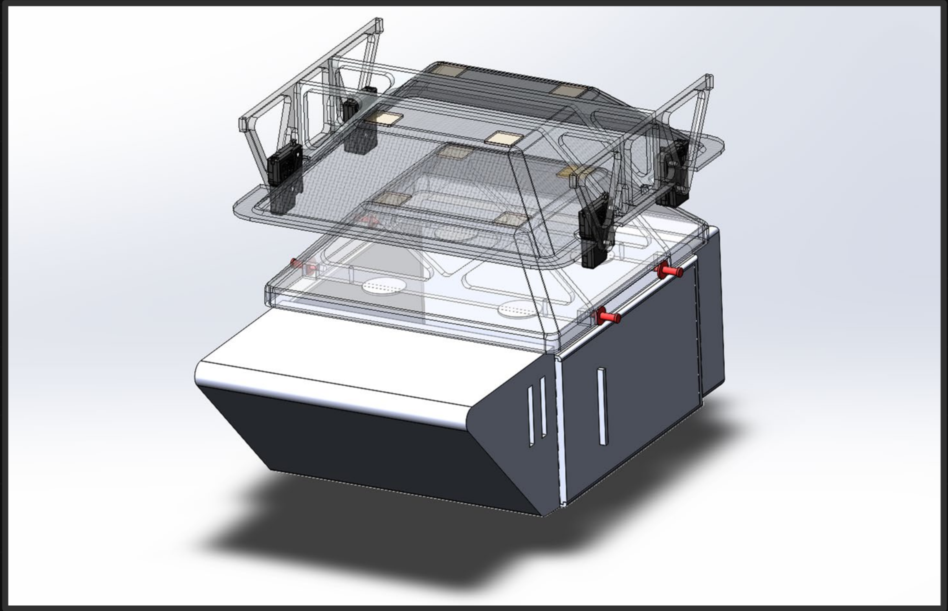
Proof of Concept Test (10/2/2021)	Manually piloted with computer vision position aid
2.86:1 Drone to Pod weight ratio	45° slope

Testing Characteristics

Design Feasibility:
Connection

Critical Feasibility Element: Connection

Label	Statement	CPE	Requirement	Feasible?
Connection	All connection components are capable of a safety factor equal or greater than 3 against structural failure in all phases of flight	E2	FR 2	?



Striker Bolts & Rotary Push - to - Close Latches

Feasibility model using the SouthCo R4EM9XX150 latch and associated R4-90-121-10 bolt [8, 9]

Rotary Push to Close Latches:

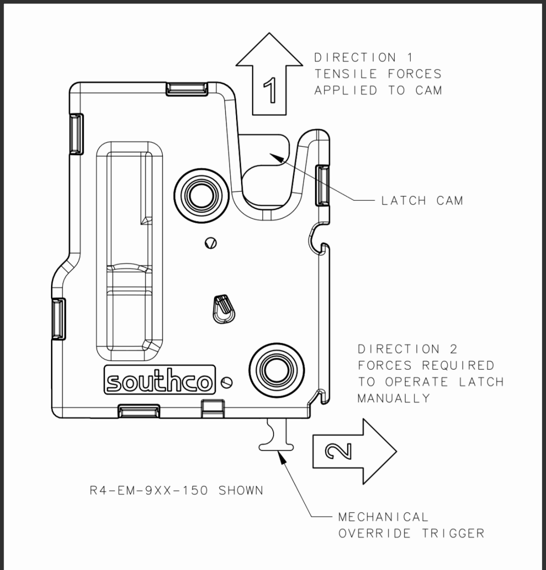
Attached to UAV (via PRU)

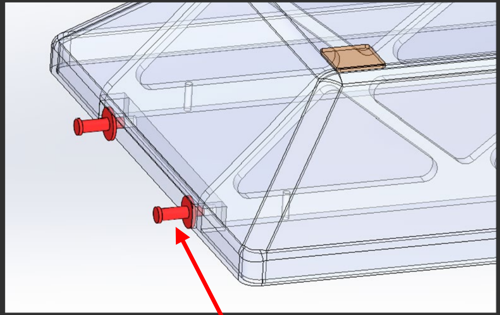
- Electrically actuated
- Very high load capabilities
- Simple, compact, and lightweight

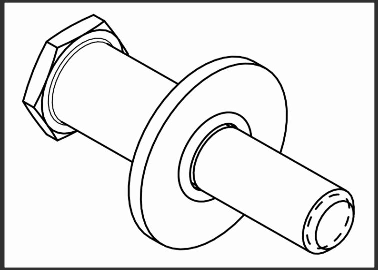
Striker bolts:

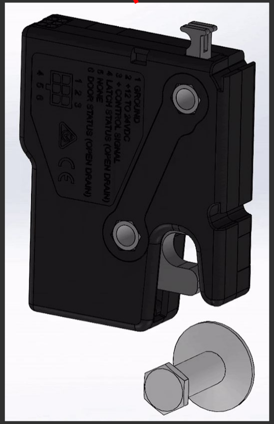
Attached to Pod (via CPM)

- Provides all-directional stability
- Many steel options (shear capable)
- Less weight compared to other methods









Hand Calculation: Latch Loading Capabilities

Key Assumptions:

1. $G_{Max} = 5$
2. W_{Pod} = 55 lbs = 255 N
3. $F_{max,\ allowable}$ = 5800 N
4. n = 4 (number of latches)
5. All force on Latches
6. Torque effect negligible

Feasibility:

Under 5G load, *FOS = 15.38*

Feasibility status: ***Confirmed***

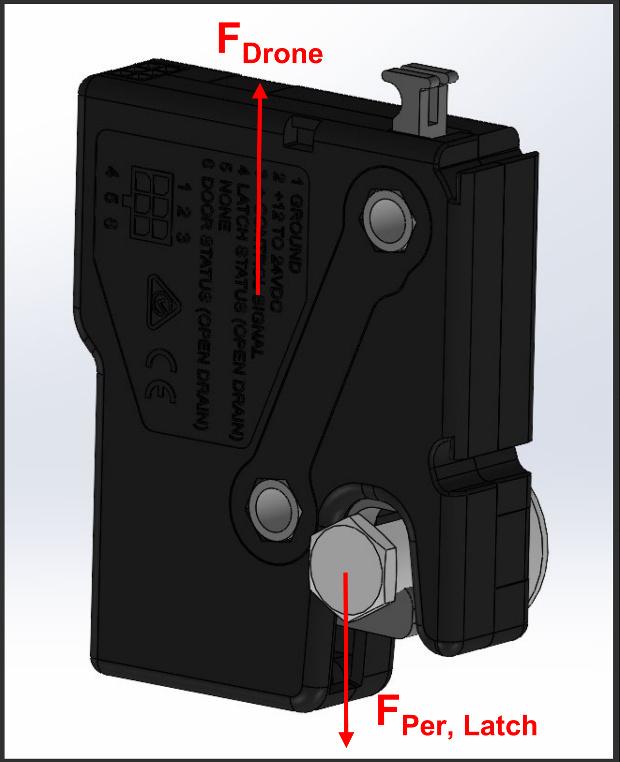
$$\Rightarrow F_{Per,Latch_{Max}} = \frac{W_{Pod} * (1 + G_{flight_{Max}})}{n}$$

$$\Rightarrow F_{Per,Latch_{Max}} = \frac{255N * (1+5)}{4}$$

$$\Rightarrow \boxed{F_{Per,Latch_{Max}} = 377N}$$

$$\ll F_{max,allowable} = 5800N$$

Max Latch Tensile Load	5800 N (1304 lbs)
Max Release Tensile Load	800N (180 lbs)
Average Mechanical Override Force	14.3 - 37.1N (3.21 - 8.34 lbs)



Hand Calculation: Minimum Shaft Diameter Required in Flight

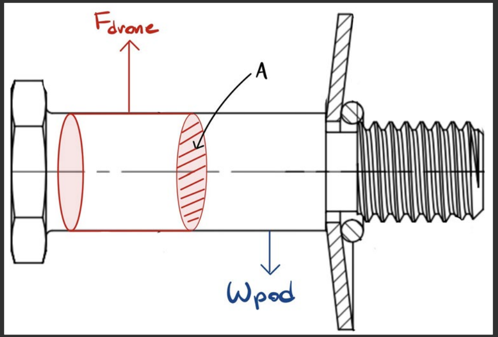
Key Assumptions:

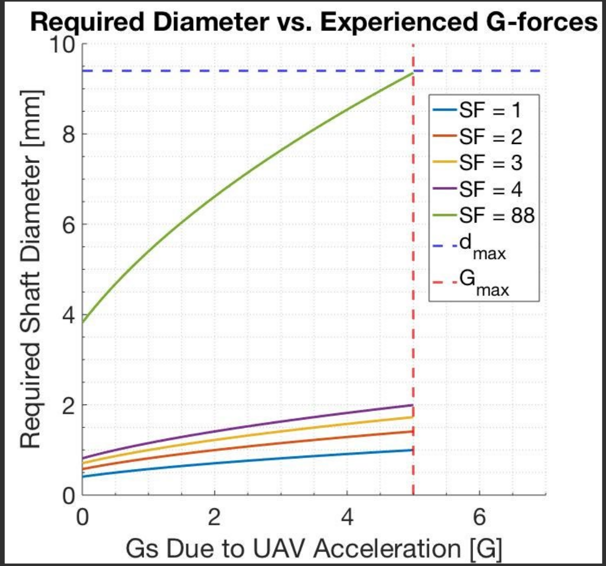
1. $G_{Max} = 5$
2. W_{Pod} = 55 lbs = 255 N
3. τ_{Max} = 470 MPa (4140 Cr-Mo Steel) [10]
4. n = 4 (number of latches)
5. All force transferred to striker bolts
6. Striker bolt mount can handle impulse
7. Latches in single shear
8. Torque effect negligible

Feasibility:

Under 5G load, *FOS = 88*

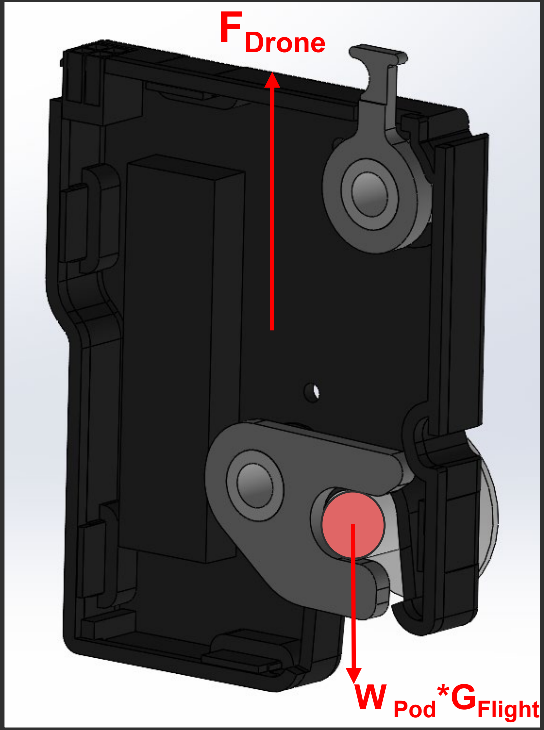
Feasibility status: ***Confirmed***





$$\Rightarrow d_{min} = \sqrt{\frac{4 * (W_{Pod} + W_{Pod} * G_{flight})}{n * \pi * \tau_{max}}}$$

$$\Rightarrow d = \sqrt{\frac{FOS * 4 * (W_{Pod} + W_{Pod} * G_{flight})}{n * \pi * \tau_{max}}}$$



Hand Calculation: Minimum Rod Diameter Required on Impact

Key Assumptions:

1. V_{Impact} = 0.7 m/s
2. W_{System} = 250 lbs = 1,112 N
3. τ_{Max} = 470 MPa (4140 Cr-Mo Steel)
4. n = 4 (number of latches)
5. All KE transferred to striker bolts
6. Striker bolt mount can handle impulse
7. Latches in single shear
8. Torque effect negligible

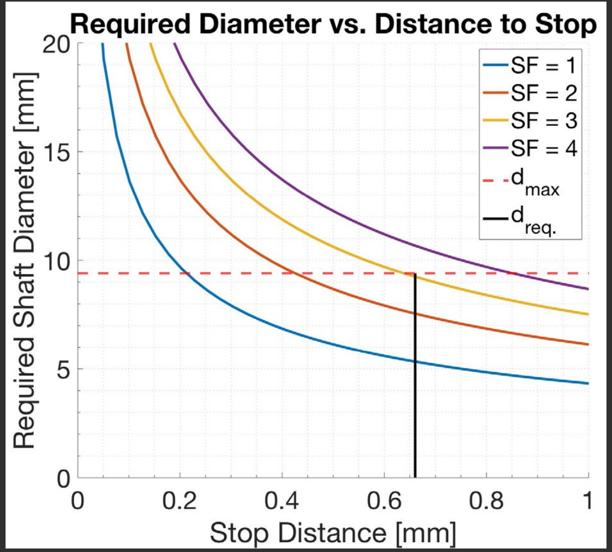
Feasibility:

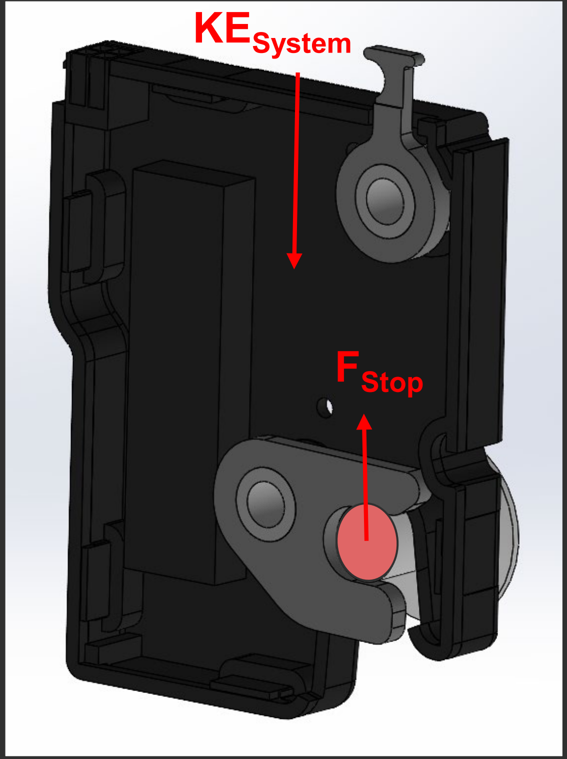
Very low impulse as d -> 0 mm

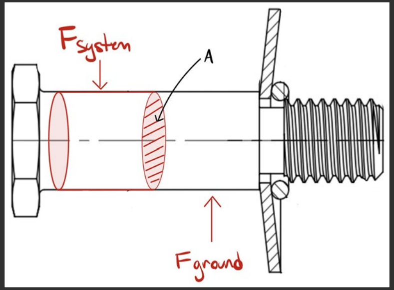
$d_{req.}$ for FOS of 3 ≥ 0.66 mm

Need some sort of damping to increase impulse

Feasibility status: ***Not yet confirmed!***







$$\Rightarrow d_{min} = \sqrt{\frac{2 * (W_{Pod} * V_{impact}^2)}{\pi * g * \Delta d * \tau_{max} * n}}$$

$$\Rightarrow d = \sqrt{\frac{FOS * 2 * (W_{Pod} * V_{impact}^2)}{\pi * g * \Delta d * \tau_{max} * n}}$$

Hand Calculation: Rubber Feet Dampers Distance to Stop

Feasibility model using the GMT RubberMetal- Technic REC-TRB1105 damper [11]

Key Assumptions:

1. $V_{Impact} = 0.7$ m/s
2. $W_{System} = 250$ lbs $= 1,112$ N
3. n = 4 (number of dampers)
4. All KE transferred to dampers

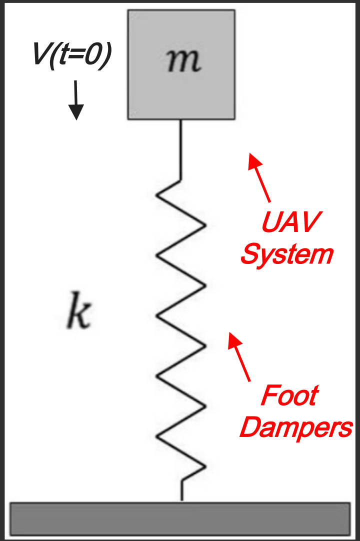
Feasibility:

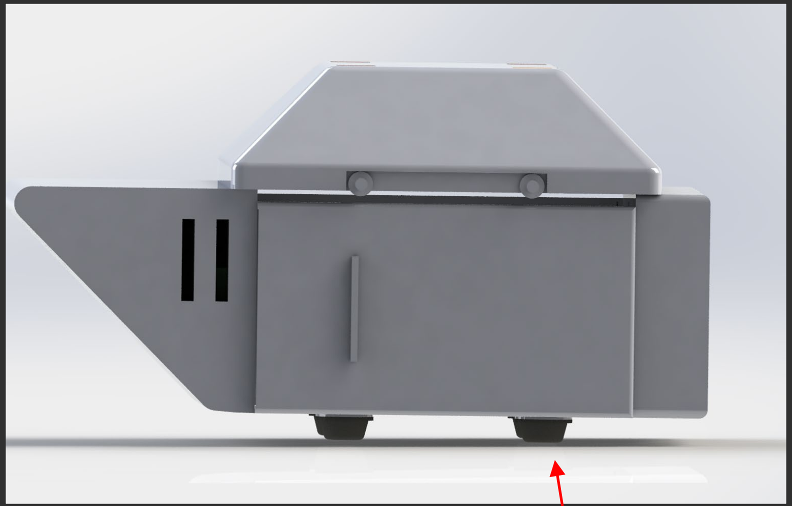
Assuming modeled

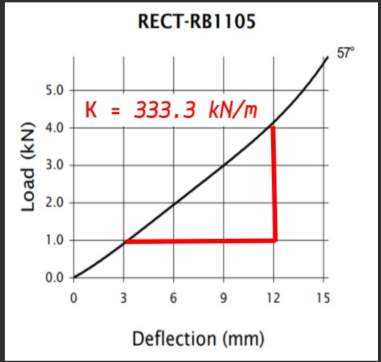
k = 333.3 kN/m

$d_{stop,\ new} = 6.46$ mm

What is the new FOS?







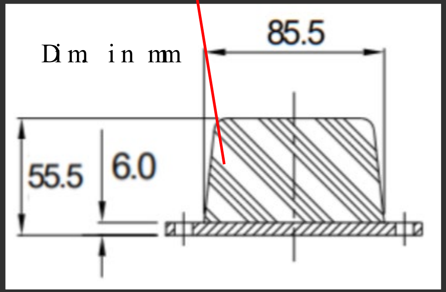
$$\Rightarrow KE = \frac{W_{Pod} * V_{impact}^2}{2 * g}$$

$$SE = KE = \frac{1}{2} * k * d^2$$

$$\Rightarrow SE = KE = \frac{n}{2} * k * d^2$$

$$\Rightarrow \frac{n}{2} * k * d^2 = \frac{W_{Pod} * V_{impact}^2}{2 * g}$$

$$\Rightarrow d = \sqrt{\frac{W_{Pod} * V_{impact}^2}{n * k * g}}$$



REC-TRB1105 Rubber Foot Damper

Hand Calculation: Rubber Feet Dampers Distance to Stop

Feasibility model using the GMT RubberMetal- Technic REC-TRB1105 damper [11]

Key Assumptions:

1. V_{Impact} = 0.7 m/s
2. W_{System} = 250 lbs = 1,112 N
3. n = 4 (number of dampers)
4. All KE transferred to dampers

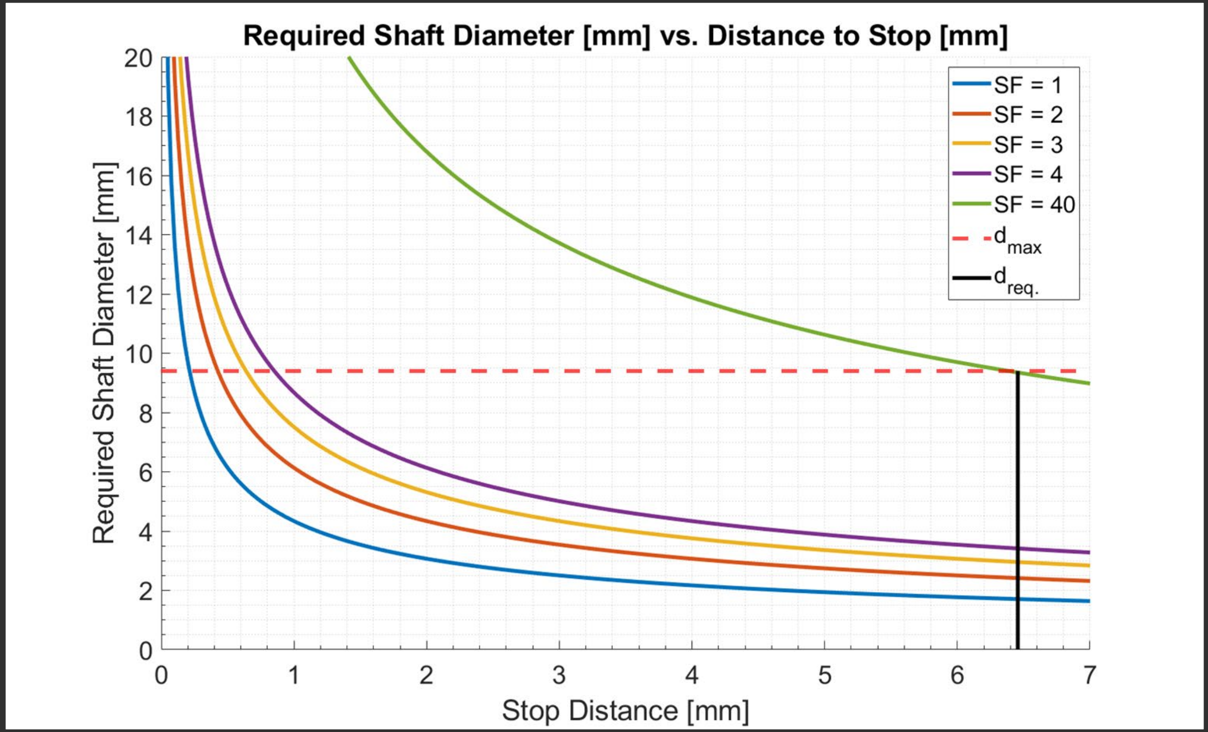
Feasibility:

Assuming modeled $d_{stop,\ new}$ = 6.46 mm

Assuming use of RECT-RB1105 damper

FOS = 40

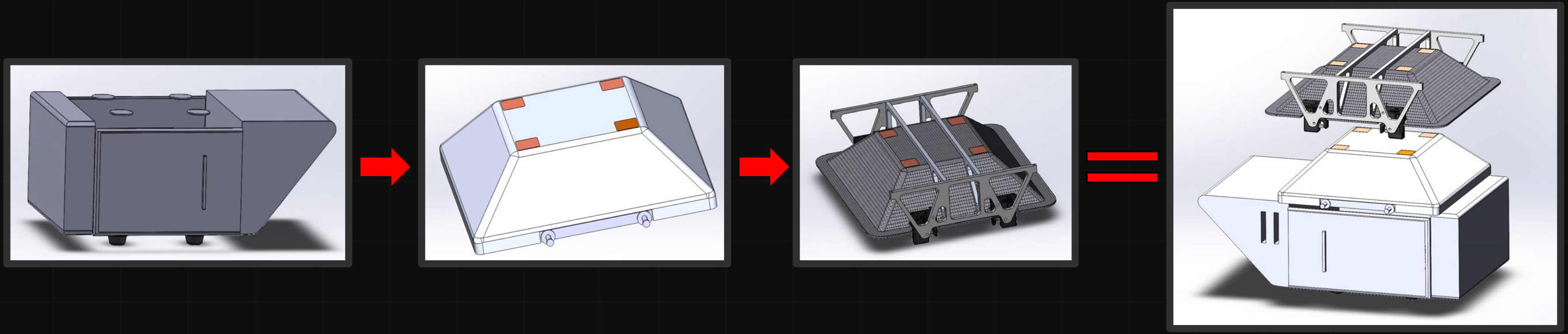
Feasibility status: ***Confirmed***



Design Feasibility:
Power

Critical Feasibility Element: Power & Charging

Label	Statement	CPE	Requirement	Feasible?
Power	Pod battery capacity shall be maximized given Pod size constraints as to provide the most available power to PRU outputs with less than 5% [12] total system path losses	E3	FR 4	?



Overall Power Requirements (High Power Path)

Justification of Feasibility:

- Pad battery selection rationale
  - Maximum capacity that fits in Pod nose
  - 3 min discharge rate
  - 12S common voltage for UAVs
- Maximizing high-power availability at PRU output (Ambiguous UAV charging requirements)
- Residential power grid recommends less than 3-5% total losses from breaker boxes to furthest outlets [13]
- Using power grid as efficient benchmark

Overall Power Efficiency Summary:

Batteries x2	Combined Voltage
Maxamp 16000mAh 6S [14]	44.4 Volts
Combined Current	**Combined Power Out**
320 Amps Nominal	~ 14.21 kW

Preliminary power loss modeling

Total power loses: ~ 359 W

Total percent loss: ~ **2.52%**

Feasibility status: *Confirmed*

Important Notes :

- *Main concern regarding **high-power transfer** feasibility from **Pod batteries to PRU** output*
- ***Not responsible** for high-power **PRU output to UAV** batteries (drone manufacturer)*
- ***Smaller power** connections (such as low amp sensors) **not a critical concern** at this stage*

Model Background (High Power Path)

Material Specs:

Wire/Connector Material	Copper
Wire Type	Stranded [15]
Wire Gauge	4 AWG
Resistivity @ 20 °C	1.68e-8 Ohmm [16]
Temperature Coefficient	0.00386 / °C [17]

General Equations:

$$R_0 = \rho(\frac{L}{A})$$

$$R_{wire} = R_0(1 + \alpha(T - T_0))$$

$$R_{conn} = \rho(\frac{1}{2rn} + \frac{1}{2r})$$

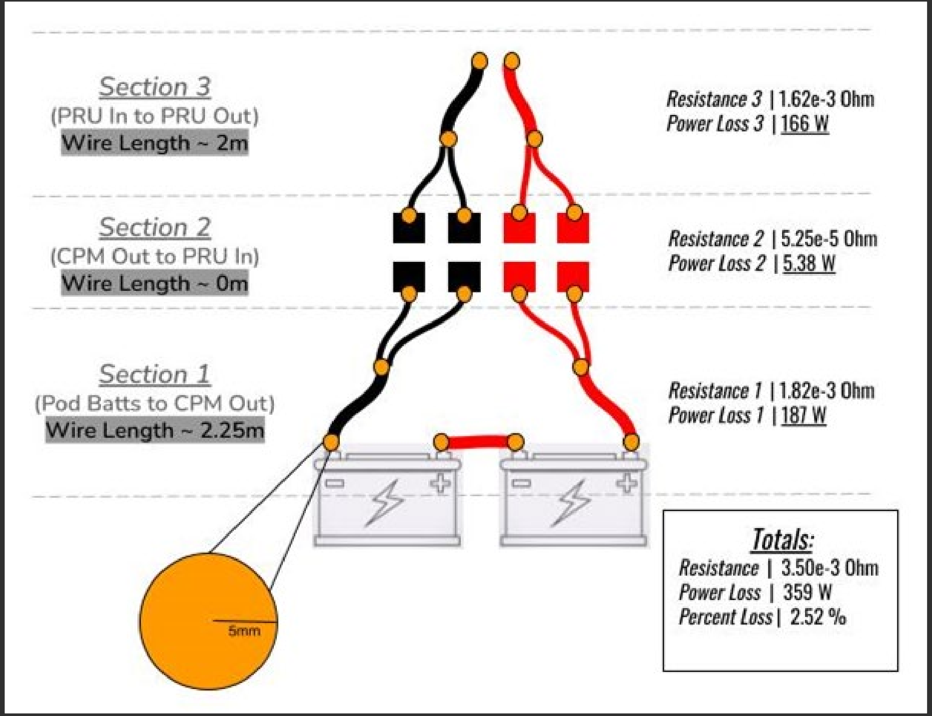
Model Limitations:

- Did not factor insulation types/braiding into wire resistance
- Neglecting voltage/current losses per section
  - Maximizing continuous power per step therefore maximizing resistance

Model Comparison:

Online Wire Resistance Table [18]	
Resistance (4 Gauge)	8.94e-4 Ohm/m
Power Loss	389 W
Online Wire Resistance Calculator [19]	
Resistance (4 Gauge)	8.31e-4 Ohm/m
Power Loss	362 W

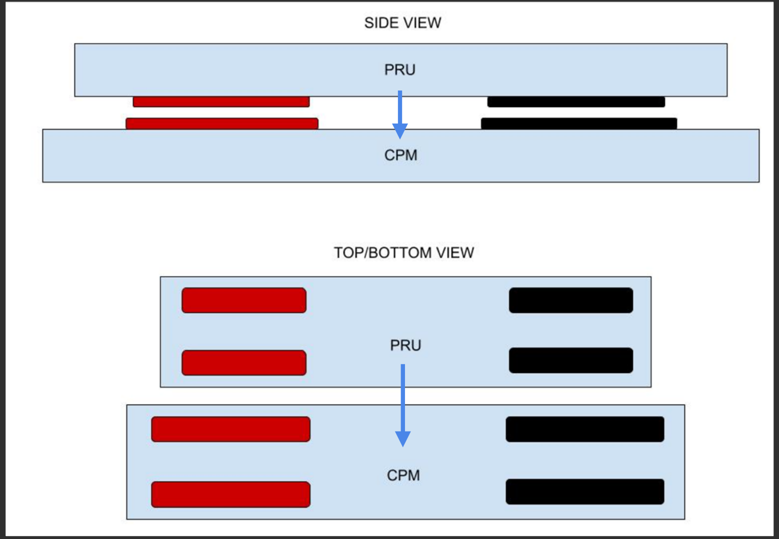
Modeling Diagram and Specs (High Power Path)



Est. Length of 4 - gauge Wire:	4.25 m
Est. Weight of Wires:	1.5 lbs
Large Connector Radius:	2 cm
Small Connector Radius:	5 mm
Number of Large Connectors:	4
Number of Small Connectors:	18
Est. Temperature:	25 °C

Feasibility: Power Passthrough Layout

Spring Loaded Pads - Custom Design



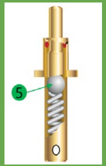
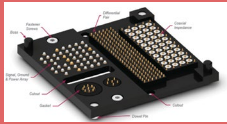
It is the most simple solution to:

1. Shorting risk
2. Power loss due to connection misalignment

How feasible is it to maintain/establish connection?

The pads are geometrically placed in such a way that they will physically connect as long as there is a CPM - PRU connection.

Feasibility: Power Contact Methods

Option	Pros	Cons	Example
Spring loaded pads	Superior connection quality	Manufacturing	
Fixed contact pads	Manufacturing simplicity	Risk of power interruptions due to manufacturing imperfections	
Smith Connectors	No manufacturing	Costs, waiting times, logistics	

Which One Is More Feasible?

- **Spring loaded pads**
- Custom team design

Why?

- Very Lenient Design Constraints In Terms Of:
  - Temperature
  - Needed contact area
  - Power Loss
- Avoids relying on external sources
- Reduces cost
- Does not interfere with POD alignment and connection

How Will Power be Transferred?

Spring-loaded custom design

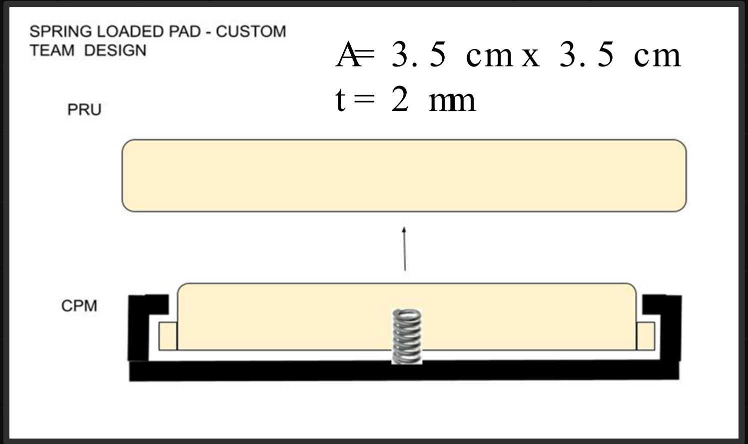
Why?

- Simple to manufacture
- No need to depend on external suppliers
- Power loss < 1 W
- Temperature change < 1 C

Feasibility status: ***Confirmed***

What is our design goal?

- Minimize power loss
  - Minimize Resistance
    - Maximize Area
    - Minimize Thickness



$$P = I * R^2$$

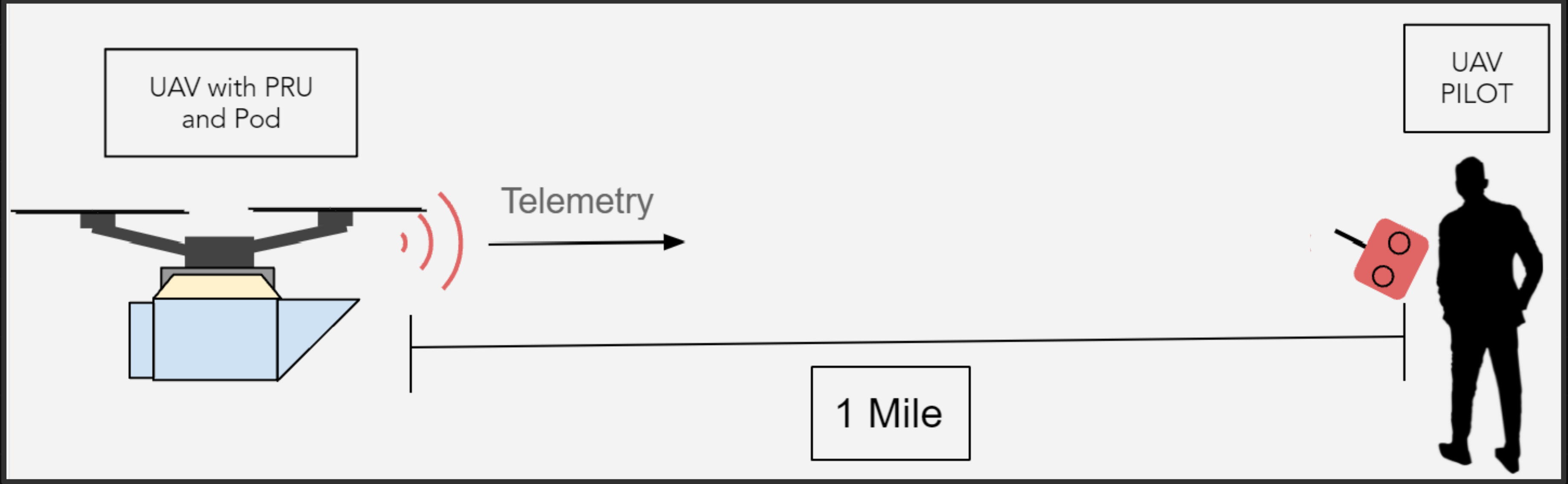
$$R = \rho * THICKNESS/AREA$$

$$\Delta T = P_{loss} * \frac{THICKNESS}{AREA * K}$$

Design Feasibility:
Electronics/Data

Critical Feasibility Element: Power & Charging

Label	Statement	CPE	Requirement	Feasible?
Data	The CPM is capable of transmitting critical Pod telemetry over a distance of one mile at 1 Hz with a resolution of 3m, 3A, 0.5 V	E4	FR 7	?



Link Budget - Component Data Output

The following data will be sampled and sent to the user at 1 Hz

Location	GPS Module
Cargo Status	Ultrasonic Distance Sensor
Battery Health	Current Sensor & Voltage Divider to ADC
Connection Status	Continuity Test via Arduino Due

Link Budget - Component Data Output

Data outputs will be sampled at the following rates:

Component	Max Sample Rate	Bits per Sample
GPS (via UART)	5Hz	656
Cargo Bay Sensor (ADC)	1MHz	32
Voltage Sensor (ADC)	1MHz	12
Current Sensor (ADC)	1MHz	12
Connection Sensor (ADC)	1MHz	12
Total	N/A	724

Link Budget - Baud Rate Capabilities

Baud Rate: The rate at which data can be transferred through a communication channel

Total bits per message	724 bits (Baud)
Maximum Baud rate of Arduino	115200 Baud [20]
Maximum Baud rate of Radio	921600 Baud [21]

Since the max baud rates for both the Arduino Due and Xbee 3 are greater than the bits per message, our design is feasible

Feasibility status: ***Confirmed***

CPM Microcontroller Selection

The Arduino Due has a clock speed of 84 MHz [20] and the following pins available for use which is more than what is required to manage our data streams

	Required Pins	Available Pins	Feasible
Serial Pins	2	12	Yes
Analog Pins	4	54	Yes

Resolution Feasibility

12-bit ADC from the Arduino Due: 4096 voltage levels

Voltage Range from Due pins: 0 - 3.3 V

$$Resolution = \Delta V = \frac{V_{max} - V_{min}}{2^n}$$

$$Resolution = \frac{3.3 - 0\ V}{2^{12}} = 0.00805\ \frac{V}{bin}$$

Resolution Feasibility

In order to calculate the resolution, we need to multiply the resolution from the previous slide with the data sheet spec

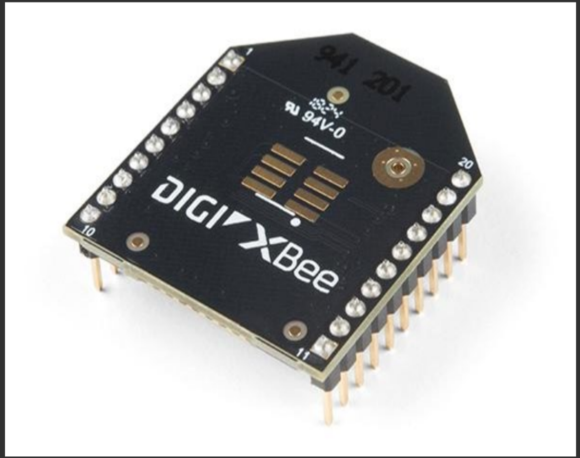
Component	Number of Bins	Range Measured	Resolution	Desired Resolution	Feasible
Current Sensor	4096	0-400 A	0.0977 A	3 A	Yes
Voltage	4096	38 - 50.4 V	0.00303 V	0.5 V	Yes

Component	Position Uncertainty	Reported Precision	Desired Resolution	Feasible
GPS	2.5 m	0.001 degrees (lat & long)	3 m	Yes

XBee Pro 3 Feasibility

DataSheet Specifications [21]

- Range: 2 miles
- Power Consumption: 135 mA @ 3.3 V
- Frequency: 2.4 GHz
- Data Rate: 250 Kbps



	Required	XBee 3 Capability	Feasible?
Range	1 mile	2 miles	Yes
Data Rate	724 bps	250 Kbps (Default)	Yes

Design Feasibility:
Conclusions

Feasibility: Conclusions

Label	Statement	CPE	Requirement	Feasible?
Alignment	The UAV-PRU system is capable of aligning to the CPM within max centering offset of 0.1 m in x-y plane and 20° yaw (z)	E1	FR 1	Yes
Connection	All connection components are capable of a safety factor equal or greater than 3 against structural failure in all phases of flight	E2	FR 2	Yes
Power	Pod battery capacity shall be maximized given Pod size constraints as to provide the most available power to PRU outputs with less than 5% total system path losses	E3	FR 4	Yes
Data	The CPM is capable of transmitting critical Pod telemetry over a distance of one mile at 1 Hz with a resolution of 3 m, 3 A, 0.5 V	E4	FR 7	Yes

Feasibility: Quick Finances (Thus Far)

Conn/Align Subsystem	$0
Data Subsystem	$10
Power Subsystem	$1140
Pod Total	$1150

Conn/Align Subsystem	$950
Data Subsystem	$395
Power Subsystem	$85
CPM Total	$1430

Conn/Align Subsystem	$1050
Data Subsystem	$100
Power Subsystem	$55
PRU Total	$1,205

Conn/Align Subsystem	$2000
Data Subsystem	$505
Power Subsystem	$1280
Margin	20%
Project Total	**$4542**

Takeaway: DROPS has a projected cost below the baseline budget of $5000 with *multiple potential funding opportunities* from external sources (TB2, L3 Harris, Glenair) in case of future alterations

Future Work

Future Work

Alignment:

1. Iterate on geometry to ensure no latch interference during alignment
2. Downselect materials for CPM and PRU slopes

Connection:

1. Downselect materials for the Pod to ensure striker bolt connection feasible
2. Downselect materials for the feet dampers
3. Ensure rotary latches are able to be remotely controlled

Power/Charging:

1. Contact pad materials/coating and spring design finalization
2. Ground to Pod induction finalization (mag. field, shield, Pod material)
3. Custom wire specs: braiding, Y junction, jackets (For Glenair)

Electronics/Data:

1. Look into custom PCB board manufacturing
2. Design housing for electrical components inside CPM
3. More detailed work into wiring and power distribution

Acknowledgements

Presentation Review	-	Emma Markovich
Connection	-	Dr. Alireza Doostan
Data/Electronics	-	Dr. Nicholas Rainville
Advisor	-	Dr. Jade Morton
Data Downlink	-	Bobby Hodgkinson
Sustenance	-	Domino’s & Cosmos Pizza

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[21] https://www.sparkfun.com/products/15127

Thank You!

Questions?

Backup Slide Links

Mission CONOPS

Functional Requirement

All Feasibility Requirements

Feasibility: Connection

Feasibility: Alignment

Feasibility: Power and Charging

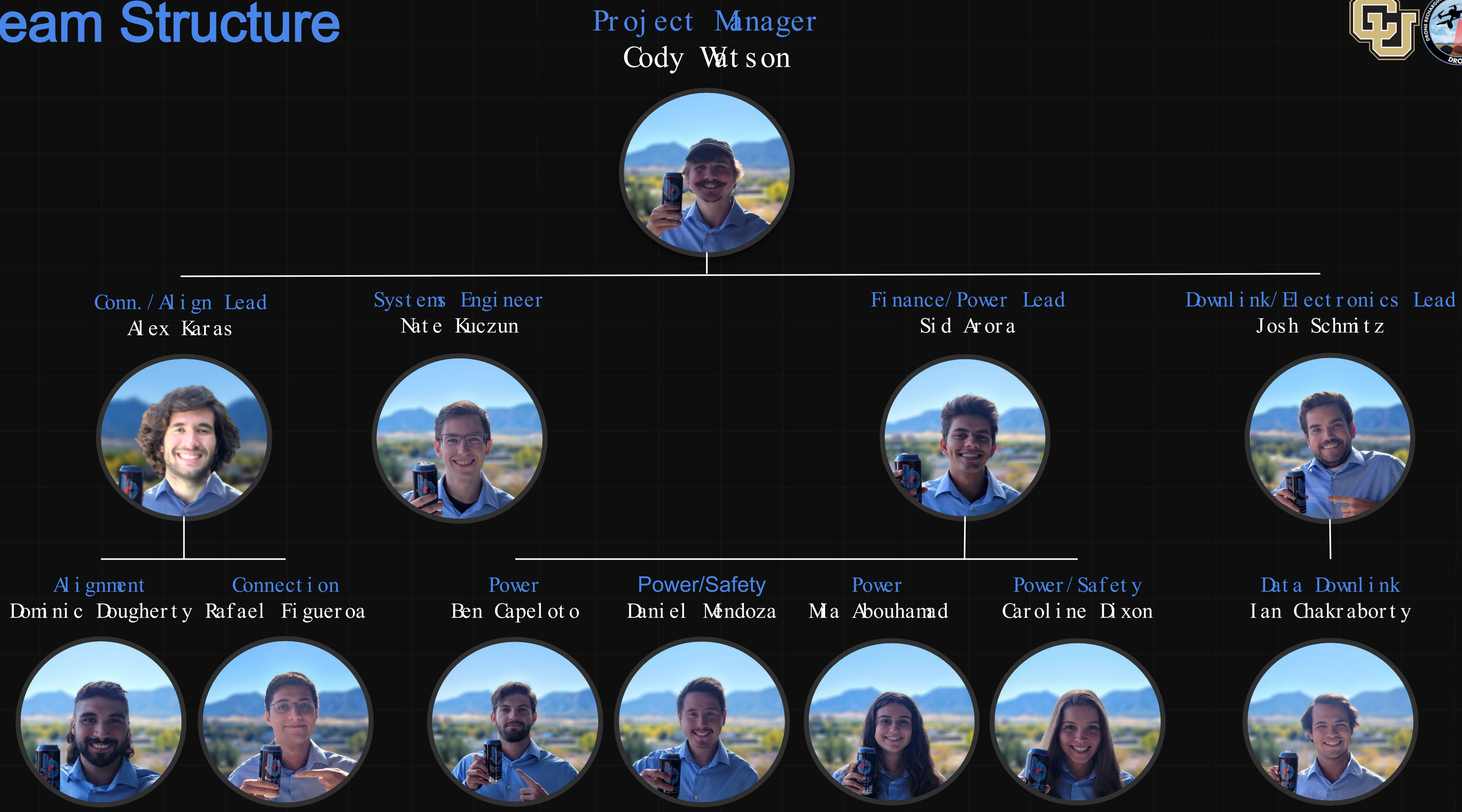
Feasibility: Data Downlink

Battery Choices

Feasibility: Pod Charging

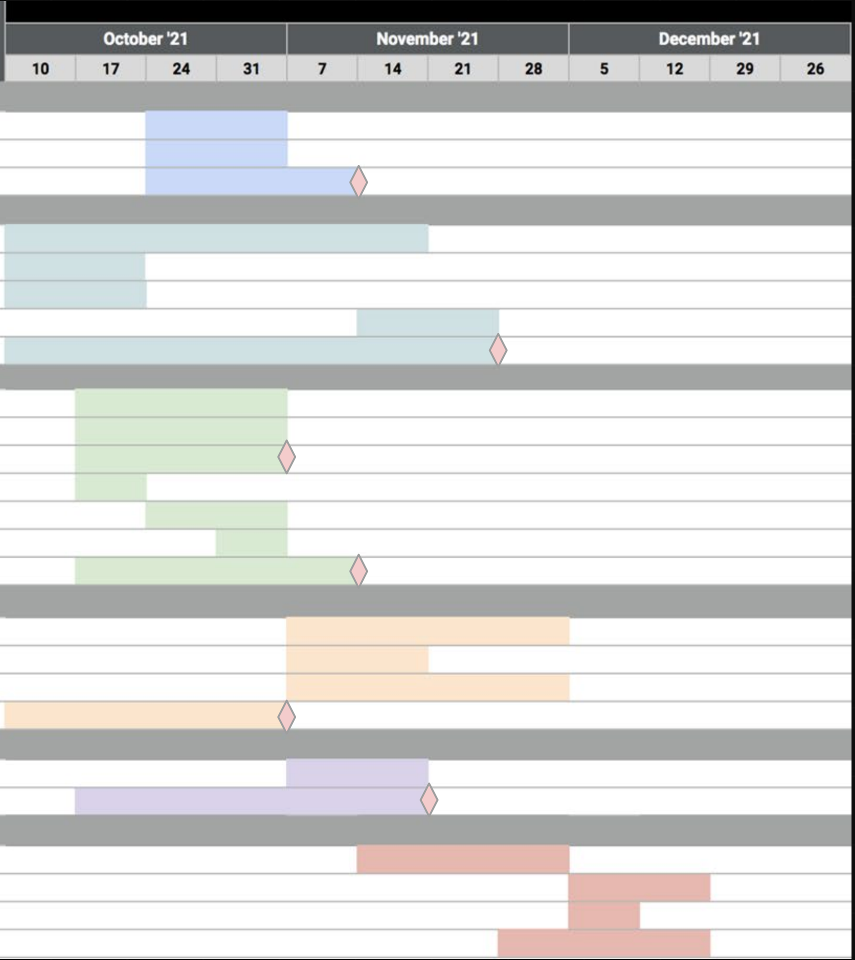
Backup Slides:
Team Structure/Schedule

Team Structure



Scheduling Gantt Chart

	TASK TITLE	START DATE	DUE DATE	POC
1	**Connection**			
1.0	Downselect materials for Pod	10/24/21	10/31/21	Cody
1.1	Downselect materials for feet dampers	10/24/21	10/31/21	Cody
1.2	Full component selection (connection)	10/24/21	11/7/21	Alex
2	**Alignment**			
2.1	Refine PRU/CPM geometry	10/11/21	11/15/21	Caroline
2.2	Downselect materials for CPM slopes	10/12/21	10/20/21	Dom
2.3	Downselect materials for PRU slopes	10/12/21	10/20/21	Dom
2.4	Rotary latch test for remote operation	11/15/21	11/22/21	Nate
2.4	PRU and CPM full CAD complete	10/11/21	11/27/21	Nate
3	**Power and Charging**			
3.1	Finalize contact pad materials	10/18/21	11/5/21	Rafael
3.2	Finalize contact pad coating	10/18/21	11/5/21	Rafael
3.3	Finalize spring design	10/18/21	11/5/21	Mia
3.4	Determine GTP mag field	10/11/21	10/24/21	Ben
3.5	Determine GTP charging shield	10/24/21	10/31/21	Ben
3.6	Downselect pod bottom material for GTP charging	10/31/21	11/5/21	Ben
3.7	Finalize custom harnessing specs	10/18/21	11/12/21	Sid
4	**Electronics and Data**			
4.1	Custom PCB design	11/5/21	11/28/21	Dom
4.2	Housing design for CPM electronics	11/5/21	11/15/21	Ian
4.3	Finalize power distribution	11/5/21	11/28/21	Josh
4.4	Finalize component selection	10/11/21	11/5/21	Sid
5	**Testing**			
5.1	Test Procedures	11/1/21	11/19/21	Caroline
5.2	Facilities scheduling	10/15/21	11/19/21	Dan
6	**Deliverables**			
6.1	CDR Presentation Slides	11/12/21	11/29/21	ALL
6.2	Peer Reviews	12/5/21	12/12/21	ALL
6.3	CDR Presentation	11/29/21	12/3/21	ALL
6.4	Fall Final Report	11/30/21	12/13/21	ALL

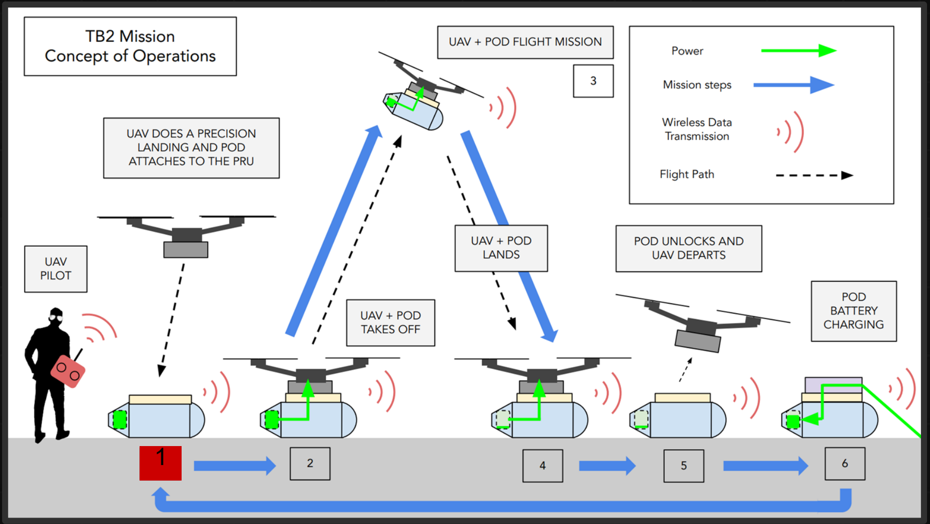


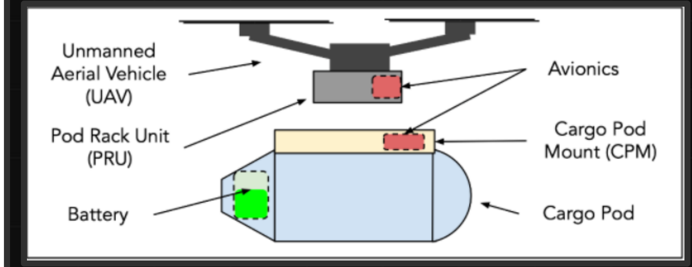
Backup Slides Links

Backup Slides:
Overview

Backup Slides Links

Mission CONOPS: Step 1



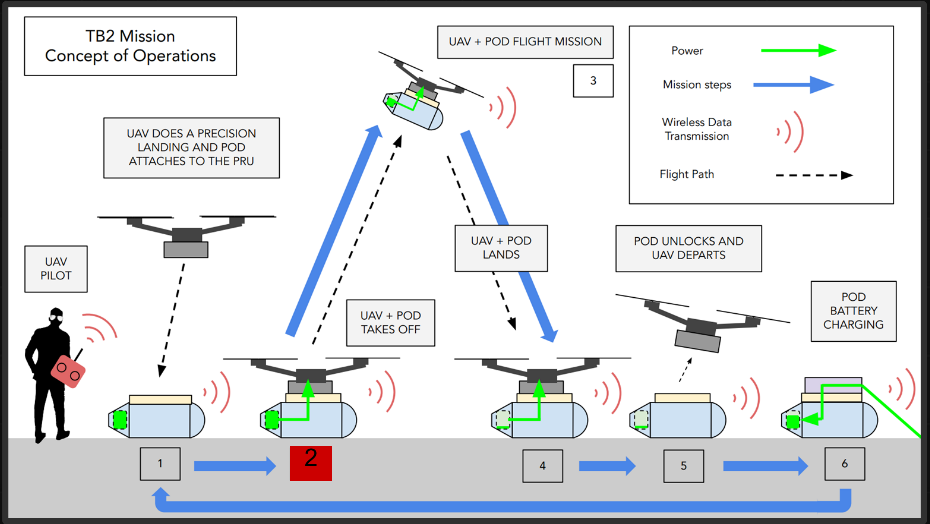


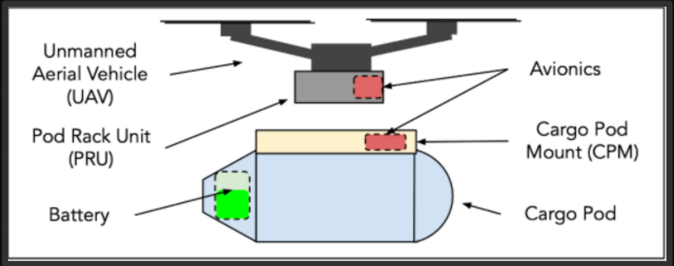
Functional Requirement	*Requirement Description*
FR 1	The UAV shall align itself with the Pod via the PRU
FR 6	There shall be regulated power to operate the PRU mechanisms

Requirement Group
Connection and Alignment
Power and Charging
Data Downlink
Design Constraints

Backup Slides Links

Mission CONOPS: Step 2





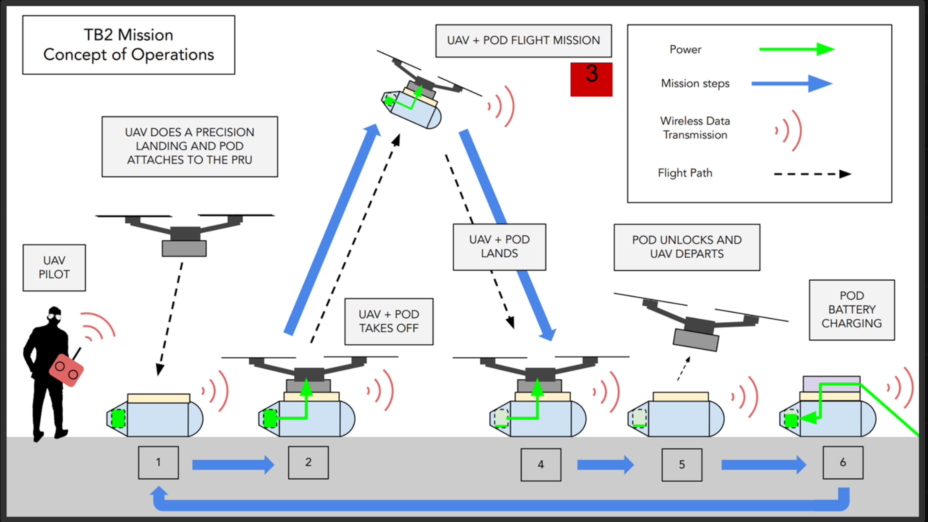
Functional Requirement	*Requirement Description*
FR 1	The UAV shall align itself with the Pod via the PRU
FR 2	The UAV shall connect to the Pod via the PRU
FR 4	There shall be power passthrough from the Pod through the PRU and into the UAV
FR 6	There shall be regulated power to operate the PRU mechanisms

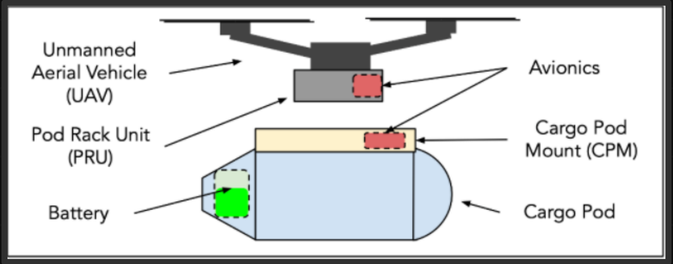
Requirement Group
Connection and Alignment
Power and Charging
Data Downlink
Design Constraints

Backup Slides Links

Overview

Mission CONOPS: Step 3





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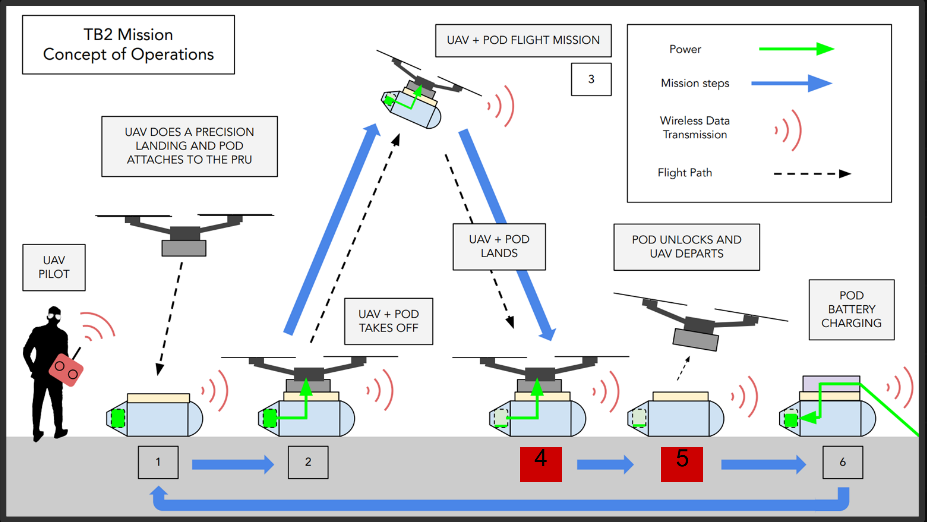
FR 6	There shall be regulated power to operate the PRU mechanisms
FR 7	There shall be data transfer between the Cargo Pod Mount and the operator
FR 8	There shall be a GPS unit within the Pod

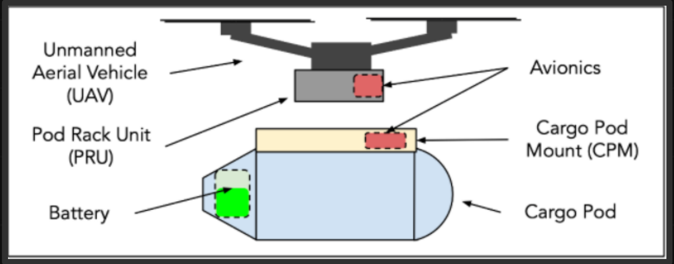
Requirement Group
Connection and Alignment
Power and Charging
Data Downlink
Design Constraints

Backup Slides Links

Overview

Mission CONOPS: Step 4 & 5





Functional Requirement	*Requirement Description*
FR 1	The UAV shall align itself with the Pod via the PRU
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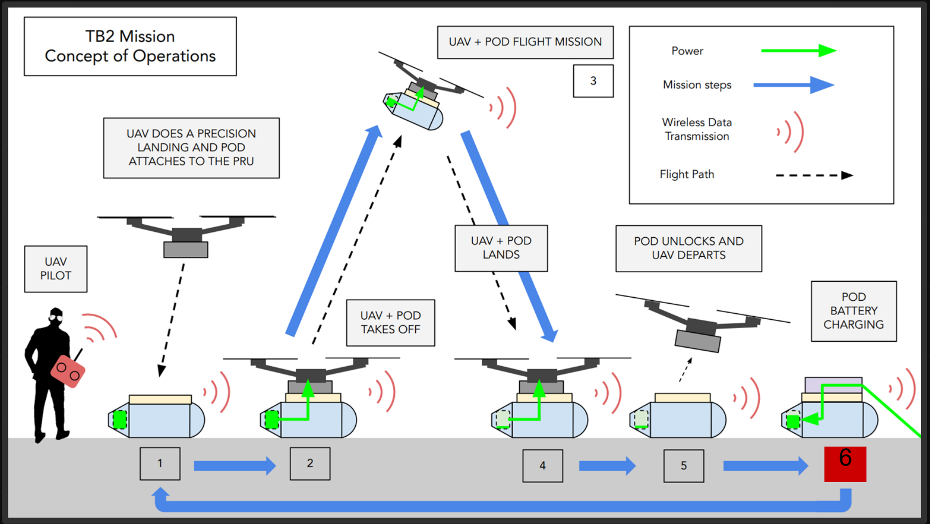
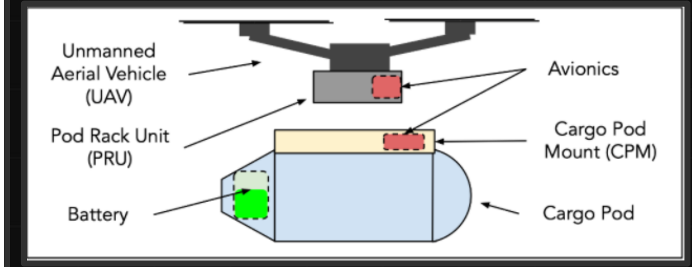
FR 6	There shall be regulated power to operate the PRU mechanisms
FR 7	There shall be data transfer between the Cargo Pod Mount and the operator
FR 8	There shall be a GPS unit within the Pod
FR 10	The design of the PRU shall allow for the UAV to takeoff and land with or without the PRU being connected to Pod

Requirement Group
Connection and Alignment
Power and Charging
Data Downlink
Design Constraints

Mission CONOPS: Step 6





Functional Requirement	*Requirement Description*
FR 1	The UAV shall align itself with the Pod via the PRU
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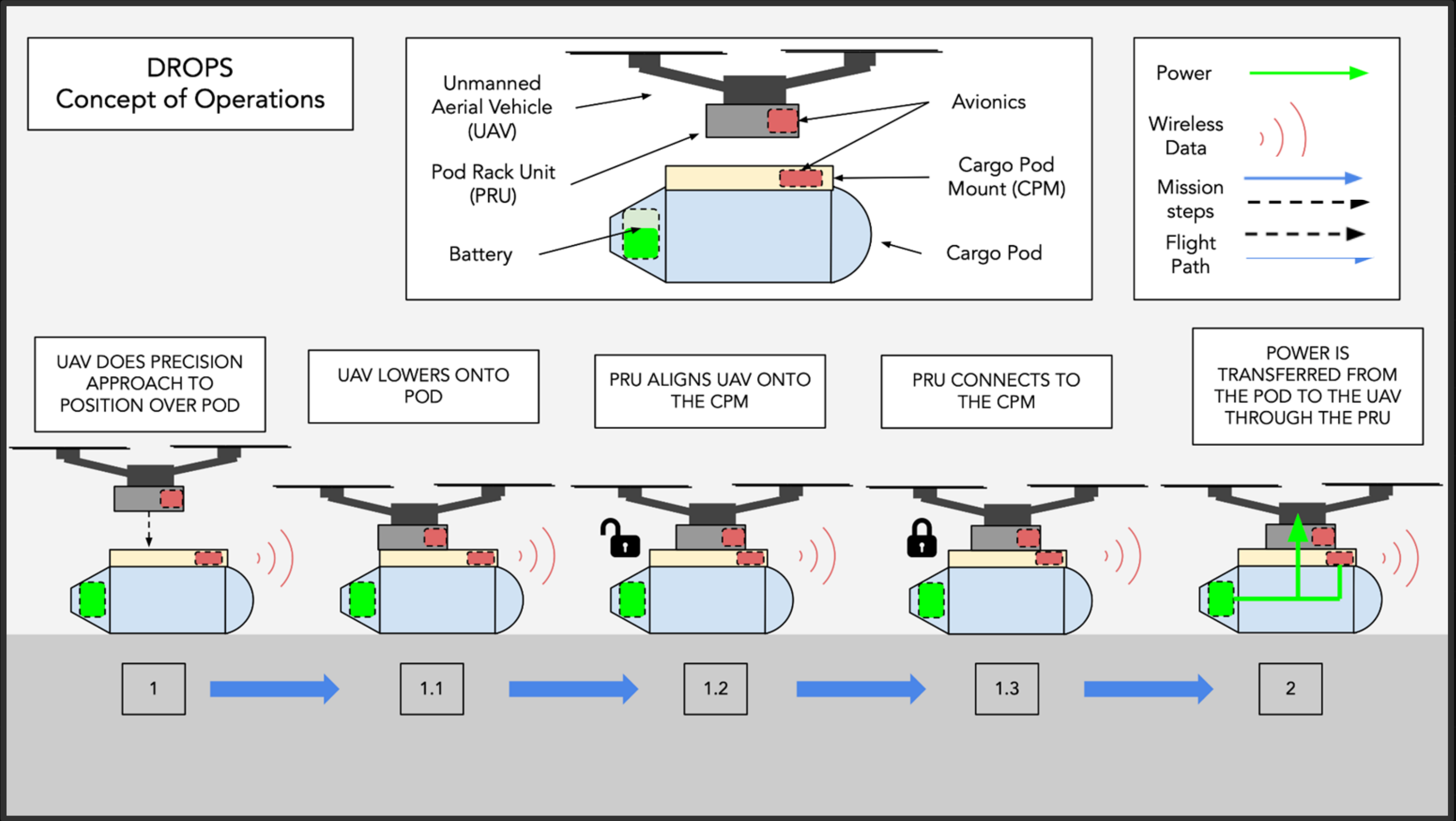
FR 3	The UAV shall disconnect from the Pod via the PRU
FR 4	There shall be power passthrough from the Pod through the PRU and into the UAV
FR 5	There shall be power passthrough between an external power source and the Pod through some TBD external transmission path
FR 6	There shall be regulated power to operate the PRU mechanisms
FR 7	There shall be data transfer between the Cargo Pod Mount and the operator
FR 8	There shall be a GPS unit within the Pod
FR 9	PRU interface shall be designed to enable stackable Pod units
FR 10	The design of the PRU shall allow for the UAV to takeoff and land with or without the PRU being connected to Pod

Requirement Group
Connection and Alignment
Power and Charging
Data Downlink
Design Constraints

Backup Slides Links

Overview

Connection and Alignment CONOPS



Backup Slides Links

Functional Requirements

Functional Requirement	*Requirement Description*
FR 1	The UAV shall align itself with the Pod via the PRU
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Requirement Group
Connection and Alignment
Power and Charging
Data Downlink
Design Constraints

Backup Slides Links

Critical Feasibility Elements

Label	Statement	CPE	Requirement
Alignment	The UAV-PRU system is capable of aligning to the CPM within max centering offset of 10 cm in x-y plane and 20° yaw (z)	E1	FR 1
Connection	All connection components are capable of a safety factor equal or greater than 3 against structural failure in all phases of flight	E2	FR 2
Power	Pod battery capacity shall be maximized given Pod size constraints as to provide the most available power to PRU outputs with less than 5% total system path losses	E3	FR 4
Data	The CPM is capable of transmitting critical Pod telemetry at least a mile range at 1 Hz with a resolution of 3m, 3A, 0.5 V	E4	FR 7

Backup Slides Links

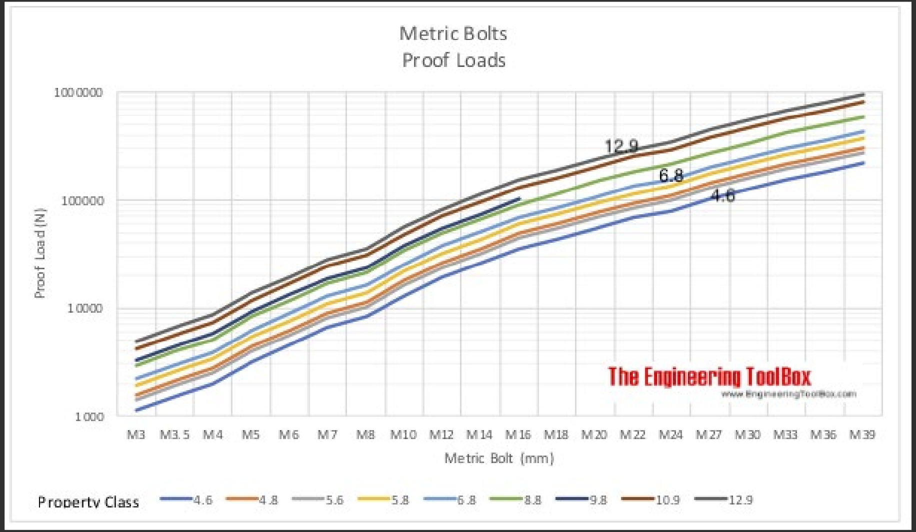
Backup Slides: Connection

Connection Decision Matrix

Connection Decision Matrix							
Categories	Familiarity	Cost	Estimated Weight	Avaibility	Integrability	Max Allowable Distance to Function	Total
Weight	0.05	0.1	0.15	0.2	0.2	0.3	
Solenoid Operated Locks	3	3	3	3	2	2.5	2.65
Servo Operated Turnstile	2	3	3	2	2.5	2.5	2.5
Rock Climbing Cam	1	3	3	3	1	2	2.2
J hooks	3	3	3	2	1	2	2.1
Paneling Clips	2	2	2	1	2	3	2.1

Backup Slides Links

Forces on the Screws



Metric Bolts - Coarse Threads

Minimum Ultimate Tensile Load

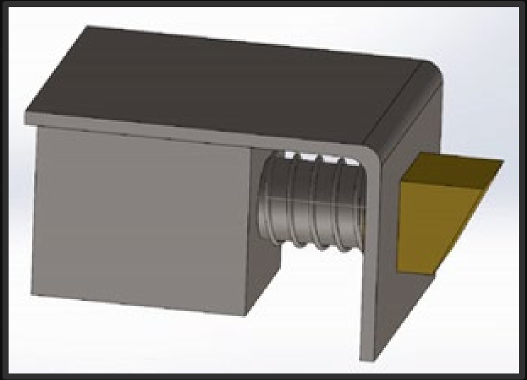
Thread d (mm)	Pitch P (mm) (in)	Nominal Stress Area $A_{s,nom}$ (mm^2) (in2)	Property Class								
			4.6	4.8	5.6	5.8	6.8	8.8	9.8	10.9	12.9
			Minimum Ultimate Tensile Load - $F_{m,min}$ (N) (kgf, lbf)								
M3	0.50	5.03	2010	2110	2510	2620	3020	4020	4530	5230	6140
M3.5	0.60	6.78	2710	2850	3390	3530	4070	5420	6100	7050	8270
M4	0.70	8.78	3510	3690	4390	4570	5270	7020	7900	9130	10700
M5	0.80	14.2	5680	5960	7100	7380	8520	11350	12800	14800	17300
M6	1.00	20.1	8040	8440	10000	10400	12100	16100	18100	20900	24500
M7	1.00	28.9	11600	12100	14400	15000	17300	23100	26000	30100	35300
M8	1.25	36.6	14600	15400	18300	19000	22000	29200	32900	38100	44600
M10	1.50	58.0	23200	24400	29000	30200	34800	46400	52200	60300	70800
M12	1.75	84.3	33700	35400	42200	43800	50600	67400[d)]	75200	87700	103000
M14	2.00	115	46000	48300	57500	59800	69000	92000[d)]	104000	120000	140000
M16	2.00	157	62800	65900	78500	81600	94000	125000[d)]	141000	163000	192000
M18	2.50	192	76800	80600	96000	99800	115000	159000		200000	234000
M20	2.50	245	98000	103000	122000	127000	147000	203000		250000	299000
M22	2.50	303	121000	127000	152000	158000	182000	252000		315000	370000
M24	3.00	353	141000	148000	176000	184000	212000	293000		367000	431000
M27	3.00	459	184000	193000	230000	239000	275000	381000		477000	560000
M30	3.50	561	224000	236000	280000	292000	337000	466000		583000	684000
M33	3.50	694	278000	292000	347000	361000	416000	576000		722000	847000
M36	4.00	817	327000	343000	408000	425000	490000	678000		850000	997000
M39	4.00	976	390000	410000	488000	508000	586000	810000		1020000	1200000

Backup Slides Links

Connection Update: Solenoid → R4 EM Solution

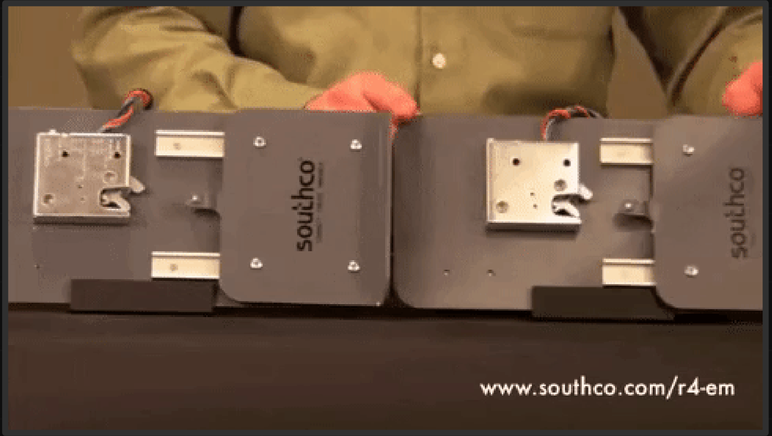
Solenoid Operator Locks:

- Simplistic Design from Trades
- Increased Risk On Takeoff and Landing
- Less Power Draw
- PRU Support Size Increased



R4 EM Electronic Rotary Latches:

- Latching/Connection Sensor
- Striker Bolt Instead of Slots
- SouthCo Partnership & CAD
- Simpler Mounting Ability

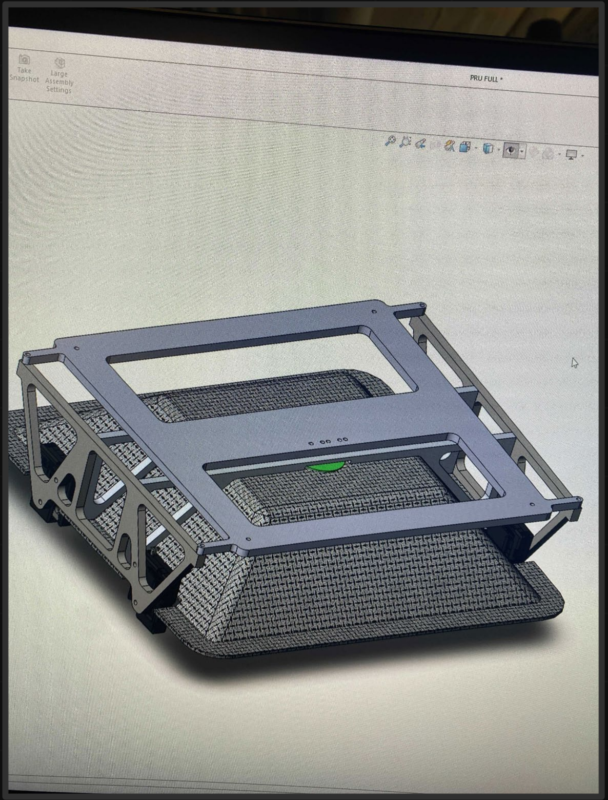


Backup Slides Links

PRU/UAV Mounting

Working with 2 UAV Companies to Interface With

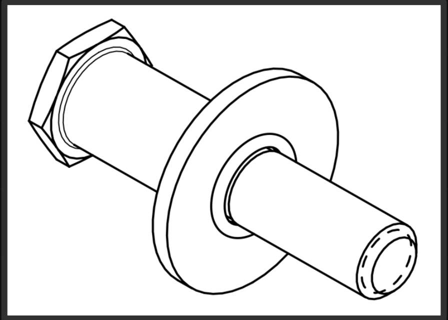
- Volanci and Periscope
- Still awaiting NDA to be approved and obtain access to CAD models, similar to Pod Mounting decisions, DROPS will continue to be agnostic but allow for simple bolted design.



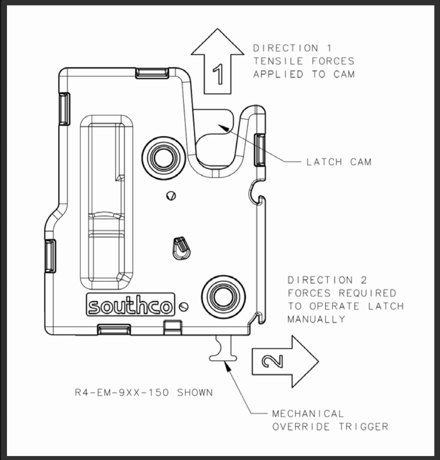
Backup Slides Links

Striker Bolts & Rotary Push - to - Close Latches Limitations

Properties	Annealed 4140 Cr-Mo Steel
τ_{Max}	470 MPa
E	190 GPa



Max Latch Tensile Load (Direction 1)	5800 N (1304 lbs)
Max Release Tensile Load (Direction 1)	800N (180 lbs)
Average Mechanical Override Force (Direction 2)	14.3-37.1N (3.21-8.34 lbs)



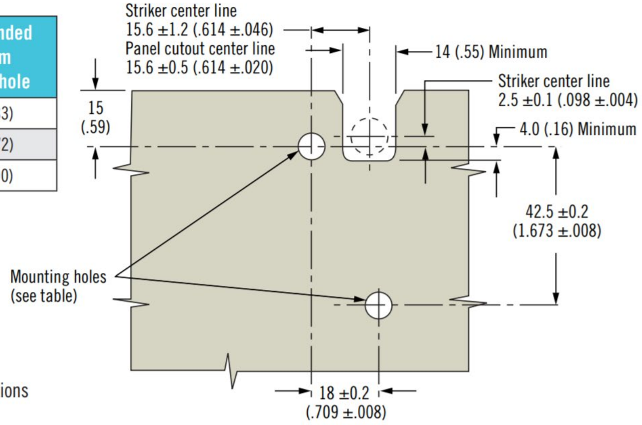
Backup Slides Links

Feasibility: Mounting of Connection Latches

Installation

Panel Preparation

Base Mounting Style	Recommended minimum mounting hole
1/4-20 thread	Ø 7.2 (.283)
M6 thread	Ø 6.9 (.272)
Thru hole	Ø 7.6 (.300)



Operation

See page 34 for operating instructions

Accessories

Striker Bolt or Cast Striker

See page 35

Cable Mounting Kit

See page 35

Backup Slides Links

Hand Calculation: Latch Loading Capabilities

Key Assumptions:

1. G_{Max} = 5 (cite reasoning)
2. W_{Pod} = 55 lbs = 255 N
3. $F_{max,\ allowable}$ = 5800 N
4. n = 4 (number of latches)
5. All force transferred to Latches
6. Torque effect negligible

Feasibility:

Under 5G load, *FOS = 15.38*

Feasibility status: Confirmed

Max Latch Tensile Load (Direction 1)	5800 N (1304 lbs)
Max Release Tensile Load (Direction 1)	800N (180 lbs)
Average Mechanical Override Force (Direction 2)	14.3 - 37.1N (3.21 - 8.34 lbs)

$$F_{All,Latch} = W_{Pod} + W_{Pod} * G_{flight}$$

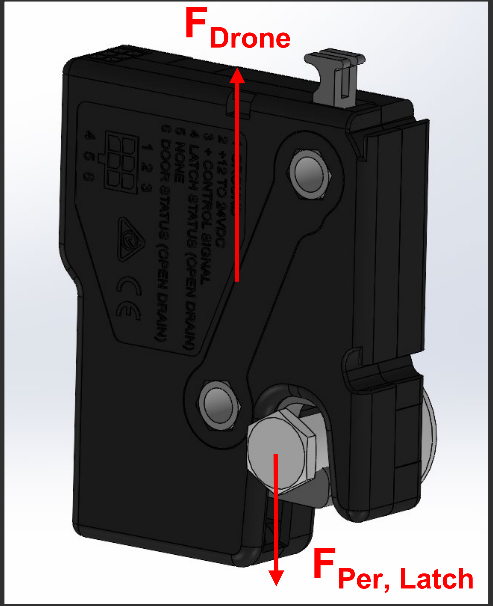
$$\Rightarrow F_{Per,Latch} = \frac{W_{Pod} + W_{Pod} * G_{flight}}{n}$$

$$\Rightarrow F_{Per,Latch} = \frac{W_{Pod} * (1 + G_{flight})}{n}$$

$$\Rightarrow F_{Per,Latch_{Max}} = \frac{W_{Pod} * (1 + G_{flight_{Max}})}{n}$$

$$\Rightarrow F_{Per,Latch_{Max}} = \frac{255N * (1 + 5)}{4}$$

$$\Rightarrow \boxed{F_{Per,Latch_{Max}} = 377N \ll F_{max,allowable} = 5800N}$$



Backup Slides Links

Hand Calculation: Minimum Shaft Diameter Required in Flight

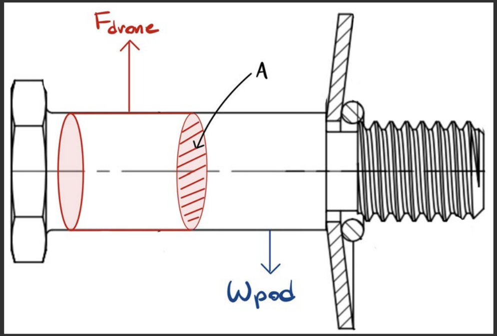
Key Assumptions:

1. $G_{Max} = 5$ (cite reasoning)
2. W_{Pod} = 55 lbs = 255 N
3. τ_{Max} = 470 MPa (4140 Cr-Mo Steel) (cite
4. n = 4 (number of latches)
5. All force transferred to striker bolts
6. Striker bolt mount can handle impulse
7. Latches in single shear
8. Torque effect negligible

Feasibility:

Under 5G load, *FOS = 88*

Feasibility status: ***Confirmed***



$$\Rightarrow \boxed{m_{Pod} = \frac{W_{Pod}}{g}}$$

$$F = m_{Pod} * g + m_{Pod} * a_{Drone}$$

$$\Rightarrow F = \frac{W_{Pod}}{g} * g + \frac{W_{Pod}}{g} * a_{Drone}$$

$$\Rightarrow F = W_{Pod} + W_{Pod} * \frac{a_{Drone}}{g}$$

$$\Rightarrow \boxed{F = W_{Pod} + W_{Pod} * G_{flight}}$$

$$\tau = \frac{F}{A}$$

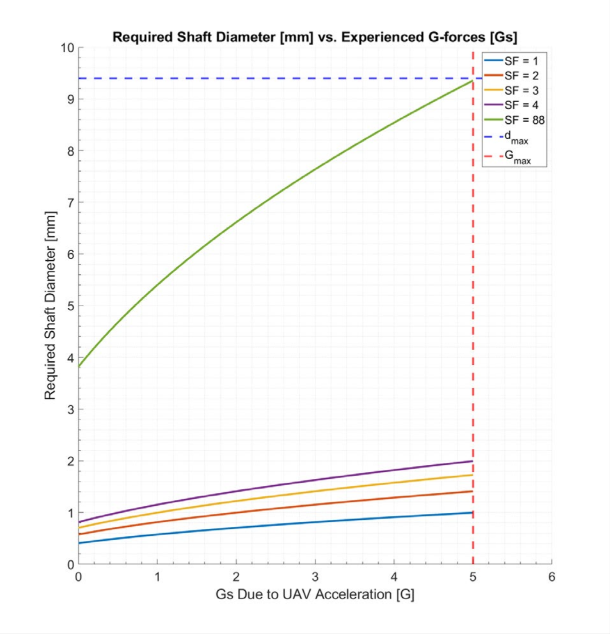
$$\Rightarrow \tau = \frac{F}{A * n}$$

$$\Rightarrow \tau = \frac{W_{Pod} + W_{Pod} * G_{flight}}{n * (pi/4)d^2}$$

$$\Rightarrow d = \sqrt{\frac{4 * (W_{Pod} + W_{Pod} * G_{flight})}{n * \pi * \tau}}$$

$$\Rightarrow d_{min} = \sqrt{\frac{4 * (W_{Pod} + W_{Pod} * G_{flight})}{n * \pi * \tau_{max}}}$$

$$\Rightarrow \boxed{d = \sqrt{\frac{FOS * 4 * (W_{Pod} + W_{Pod} * G_{flight})}{n * \pi * \tau_{max}}}}$$



Backup Slides Links

Hand Calculation: Minimum Rod Diameter Required on Impact

Key Assumptions:

1. V_{Impact} = 0.7 m/s
2. W_{System} = 250 lbs = 1,112 N
3. τ_{Max} = 470 MPa (4140 Cr-Mo Steel)
4. n = 4 (number of latches)
5. All KE transferred to striker bolts
6. Striker bolt mount can handle impulse
7. Latches in single shear
8. Torque effect negligible

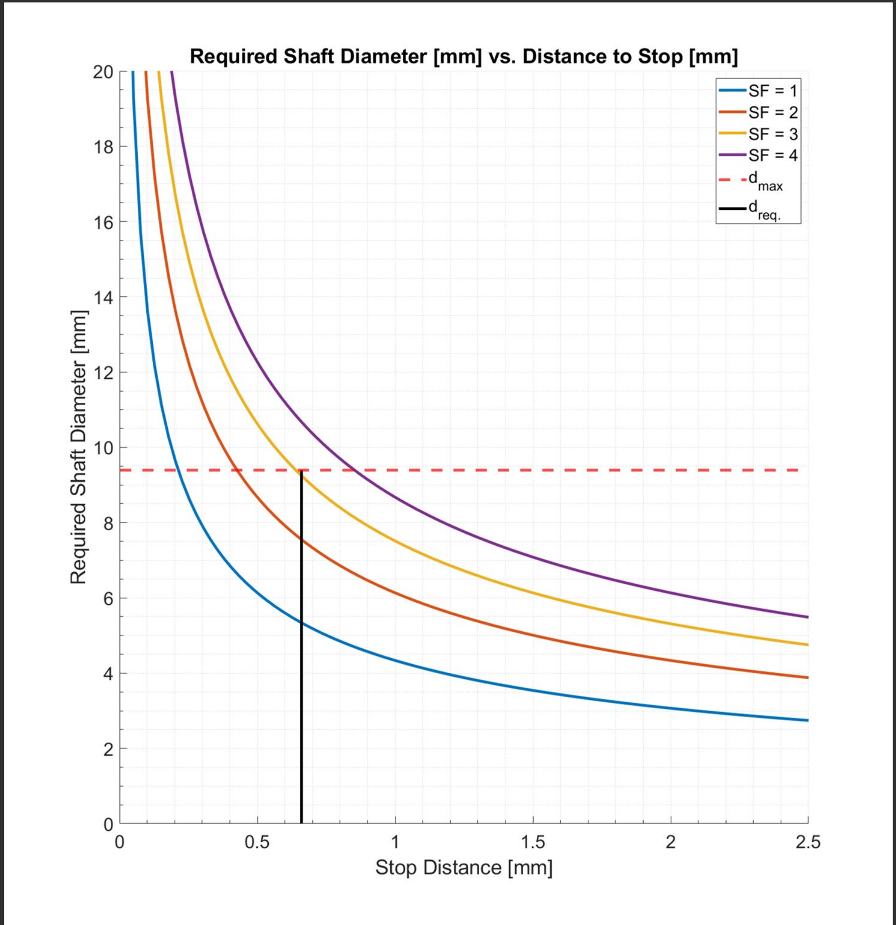
Feasibility:

Very low impulse as d -> 0 mm

$d_{req.}$ for FOS of 3 ≥0.66 mm

Need some sort of damping to increase impulse

Feasibility status: Not yet confirmed!



$$W_{Pod} = m_{Pod} * g$$

$$\Rightarrow \boxed{m_{Pod} = \frac{W_{Pod}}{g}}$$

$$KE = \frac{1}{2} * m * V_{impact}^2$$

$$\Rightarrow \boxed{KE = \frac{W_{Pod} * V_{impact}^2}{2 * g}}$$

$$Work = F * \Delta d = \Delta KE$$

$$\Rightarrow \boxed{F = \frac{W_{Pod} * V_{impact}^2}{2 * g * \Delta d}}$$

$$\tau = \frac{F}{A}$$

$$\Rightarrow \tau = \frac{F}{A * n}$$

$$\Rightarrow A = \frac{F}{\tau * n}$$

$$\Rightarrow \boxed{A = \frac{W_{Pod} * V_{impact}^2}{2 * g * \Delta d * \tau * n}}$$

$$\frac{\pi}{4} * d^2 = \frac{W_{Pod} * V_{impact}^2}{2 * g * \Delta d * \tau * n}$$

$$\Rightarrow d = \sqrt{\frac{2 * (W_{Pod} * V_{impact}^2)}{\pi * g * \Delta d * \tau * n}}$$

$$\Rightarrow d_{min} = \sqrt{\frac{2 * (W_{Pod} * V_{impact}^2)}{\pi * g * \Delta d * \tau_{max} * n}}$$

$$\Rightarrow \boxed{d = \sqrt{\frac{FOS * 2 * (W_{Pod} * V_{impact}^2)}{\pi * g * \Delta d * \tau_{max} * n}}}$$

Backup Slides Links

Hand Calculation: Rubber Feet Dampers Distance to Stop

Feasibility model using the GMT Rubber-Metal- Technic REC-TRB1105 damper

Key Assumptions:

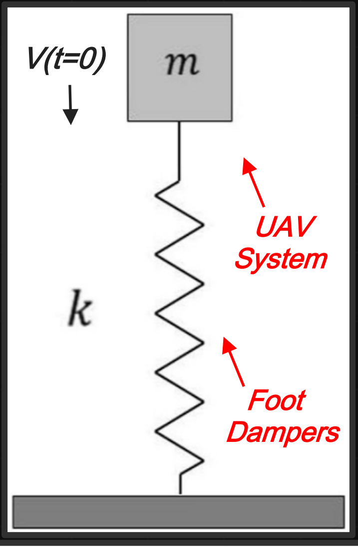
1. V_{Impact} = 0.7 m/s
2. W_{System} = 250 lbs = 1,112 N
3. n = 4 (number of dampers)
4. All KE transferred to dampers

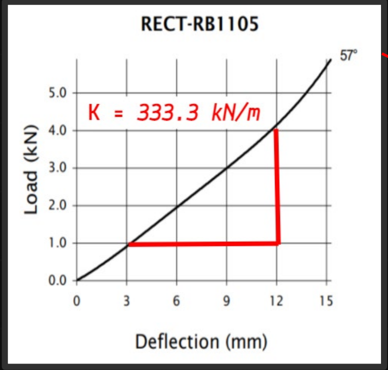
Feasibility:

Assuming modeled $k = 333.3$ kN/m

$d_{stop,\ new} = 6.46$ mm

What is the new FOS?





$$W_{Pod} = m_{Pod} * g$$

$$\Rightarrow \boxed{m_{Pod} = \frac{W_{Pod}}{g}}$$

$$KE = \frac{1}{2} * m * V_{impact}^2$$

$$\Rightarrow \boxed{KE = \frac{W_{Pod} * V_{impact}^2}{2 * g}}$$

$$SE = KE = \frac{1}{2} * k * d^2$$

$$\Rightarrow SE = KE = \frac{n}{2} * k * d^2$$

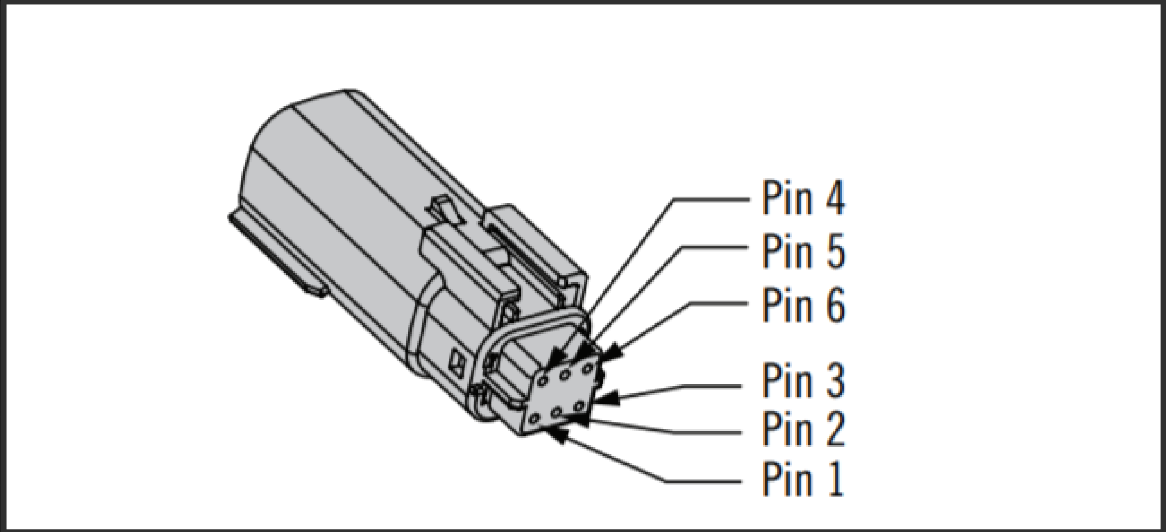
$$\Rightarrow \frac{n}{2} * k * d^2 = \frac{W_{Pod} * V_{impact}^2}{2 * g}$$

$$\Rightarrow \boxed{d = \sqrt{\frac{W_{Pod} * V_{impact}^2}{n * k * g}}}$$

Backup Slides Links

Feasibility: R4 - EM Connection Status

- Ability to confirm successful connection
- Ability to transfer power to system reliably



Backup Slides Links

Backup Slides:
Alignment

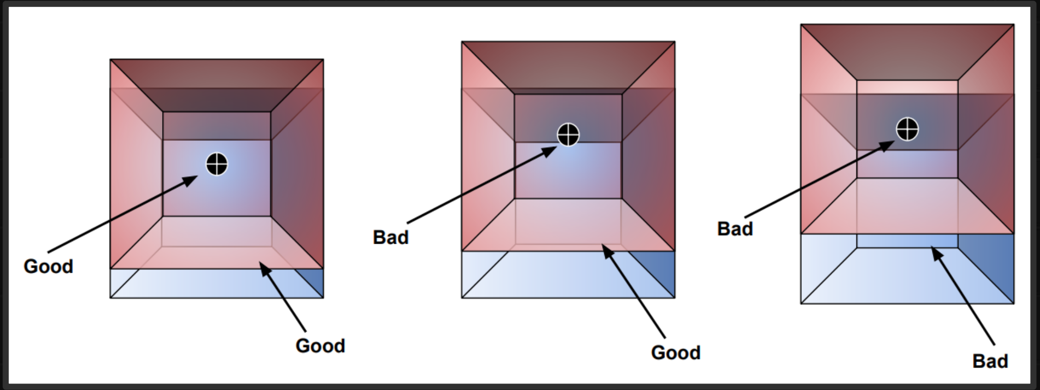
Alignment Decision Matrix

Alignment Decision Matrix

Categories	Familiarity	Cost	Estimated Weight	Avaibility	Integrability	Max Allowable Distance to Function	Total
Weight	0.05	0.1	0.15	0.2	0.2	0.3	
Camera/Visual Feedback	2	3	3	3	1	3	2.55
Slot Slopes	3	3	3	2	3	2	2.5
Vice-Style Wedge Grips	3	3	2	2	2	3	2.45
Conic Spikes	3	3	3	2	3	1	2.2
Electromagnet Orientation	2	2	2	3	1	2	2
Suction/Venturi	1	2	1	3	1	2	1.8

Backup Slides Links

Top of Platform Geometry



(1) (2) (3)

Alignment Cases

Backup Slides Links

Feasibility: Additional Feedback Alignment

Visual Alignment System

- QR/APRIL Tags on CPM Flat Surface with Down-facing camera on PRU
- Sending visual data to UAV manufacturer for initial centering OR Planck Ace System

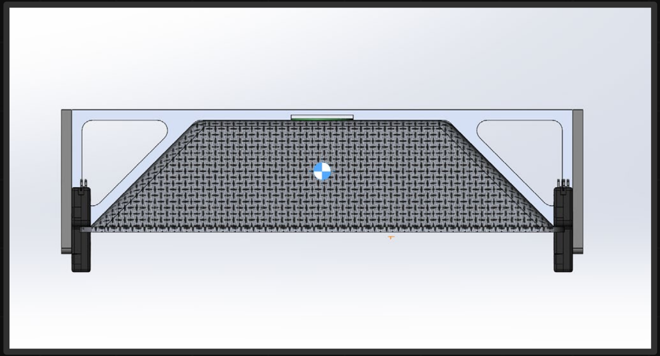
Important:

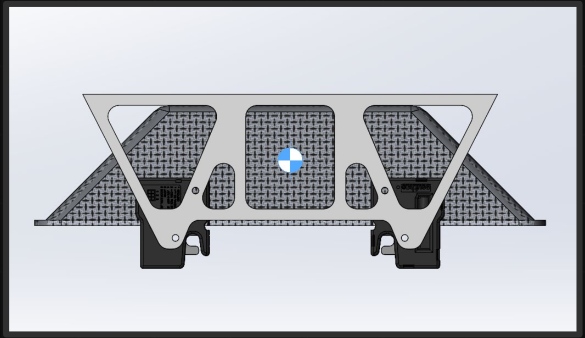
This system will not be fully implemented in this year's requirements; however will be designated space and power placeholders.

Backup Slides Links

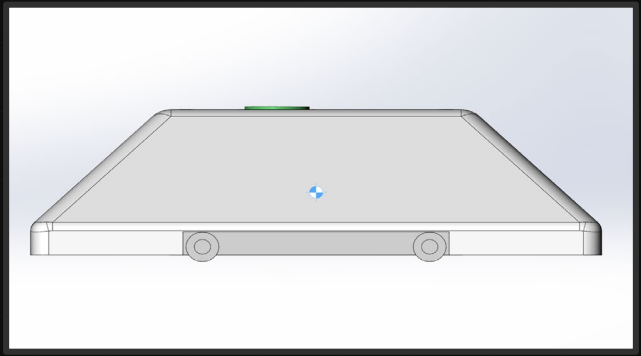
CG Feasibility: External Structures

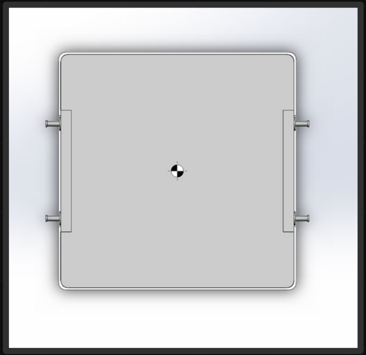
Pod Rack Unit:





Cargo Pod Mount:

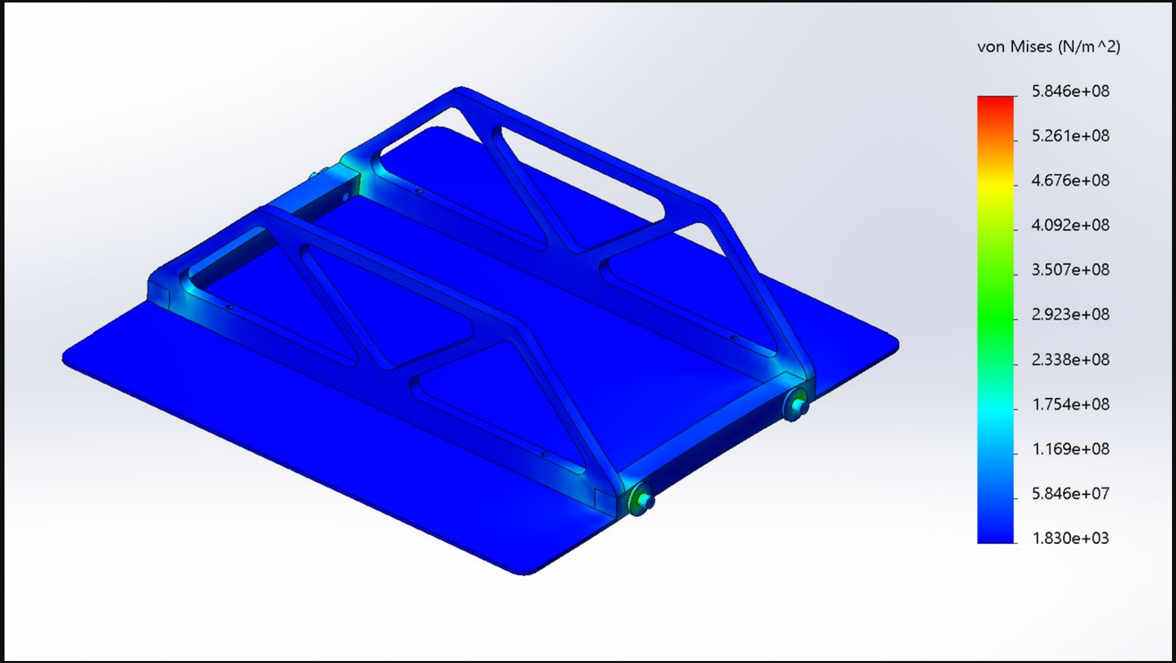




Backup Slides Links

FEM Analysis

FEM Analysis on CPM capability to withstand the load of striker bolts



Yield strength 4140 Steel - 470MPa = 4.7*10^(8) N/m^2

Max 3.51 * 10^(8) N/m^2

Load = 10.5 kN per striker bolt

Weight Feasibility

Pod Rack Unit:

Physical Structure	1.67 Kg
Conn/Align Subsystem	1.80 Kg
Data Subsystem	0.15 Kg
Power Subsystem	1.0 Kg
PRU Total	4.62 Kg

Cargo Pod Mount:

Physical Structure	0.67 Kg
Conn/Align Subsystem	2.33 Kg
Data Subsystem	0.70Kg
Power Subsystem	0.85 Kg
CPM Total	4.55 Kg

Backup Slides Links

Backup Slides:
Power and Charging

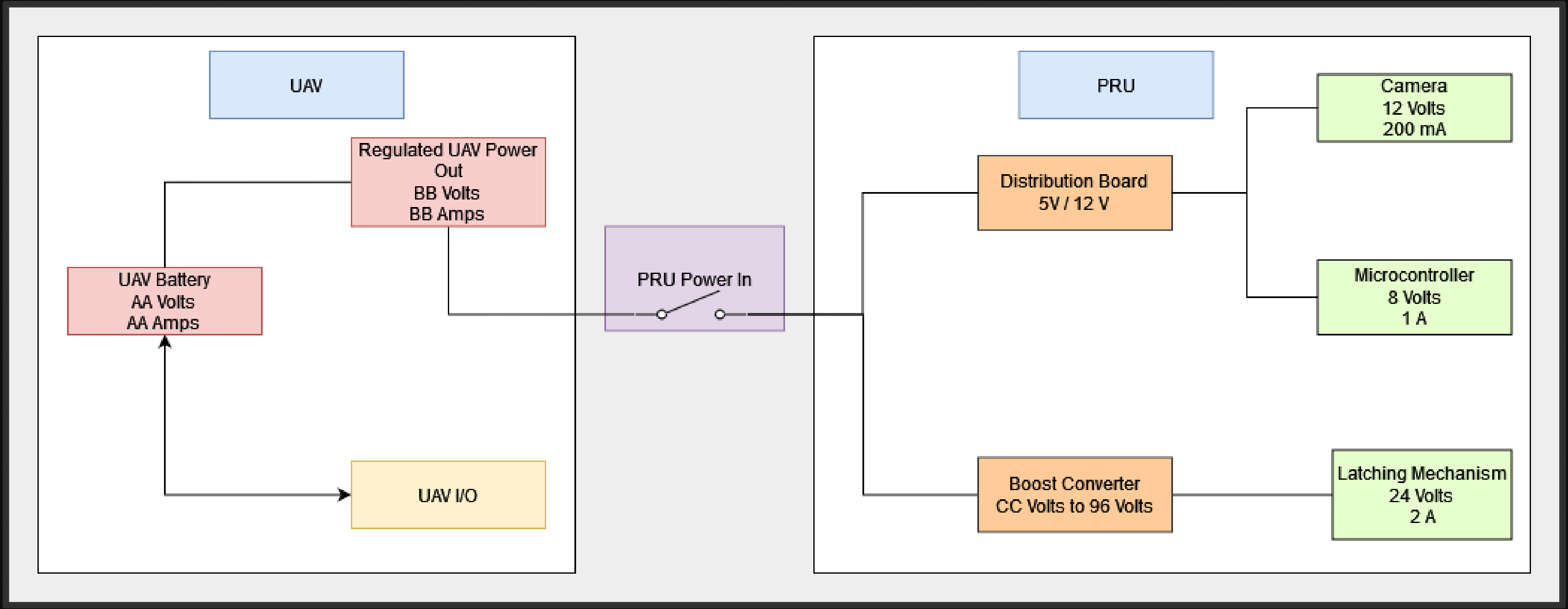
Backup Slides Links

Feasibility: Pod Battery Charging

Ground to Pod Charging Decision Matrix								
Categories	Availability	Integratability	Operator Involvement	Pod Design Impact	Cost	How Robust against explosion/fire/ elements	Power Transfer Efficiency	Total
Weight	0.05	0.1	0.15	0.15	0.15	0.2	0.2	
Wireless Induction Pad Charging	2	3	3	3	2	3	1	2.4
Contact Charging	2	3	2	2	1	2	3	2.15
Physical Power Cable	3	3	1	1	3	1	3	2
Grounded hooks	1	1	2	2	1	1	3	1.7

Backup Slides Links

How will the PRU systems be powered?



Total Power Draw: 58.4 Watts

Full subsystem verification impeded by NDAs

Backup Slides Links

Backup Slides:
Data Downlink

Power Consumption Analysis

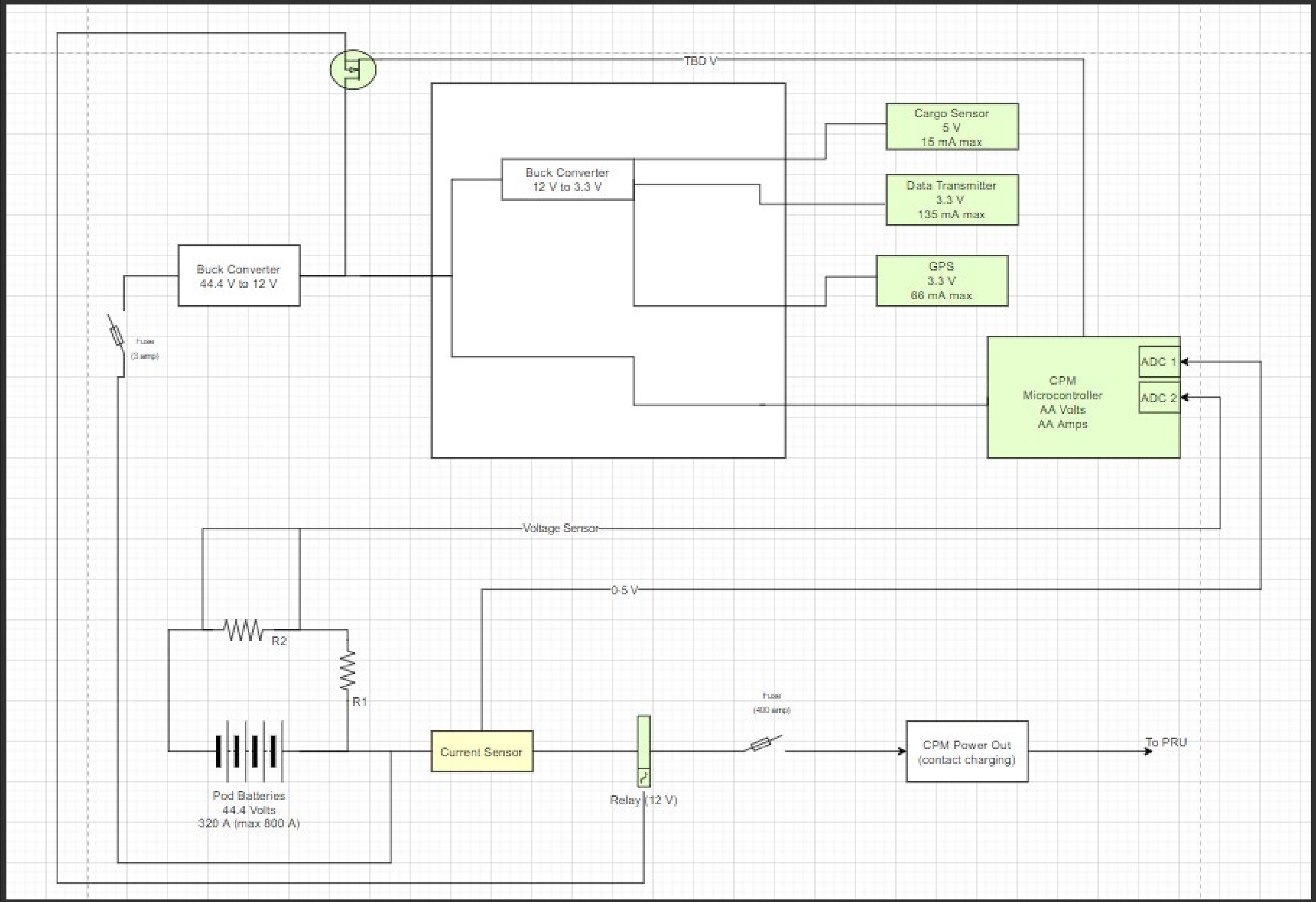
- The data downlink subsystem will be powered by the Pod’s internal batteries
- The GPS, sonar, and radio module will be powered by a 3.3V line that will be provided by a buck converted line from the battery
- The Arduino Due will be powered by a 12V line that will be provided by a second buck converted line from the battery

Power Consumption of Components- CPM

Component	Operating Voltage	Max Current Draw	Max Power Consumption
XBee 3 Pro	3.3 V	135 mA	0.4455 W
NEO-6M GPS Module	3.6 V	45 mA	0.162 W
HC-SR04 Sonar Sensor	5 V	15 mA	0.075 W
Microcontroller	7-12 V	200 mA	0.03812 W
Current Sensor	12 V	< 5 mA	0.060 W
Total		400 mA	0.7266W

Backup Slides Links

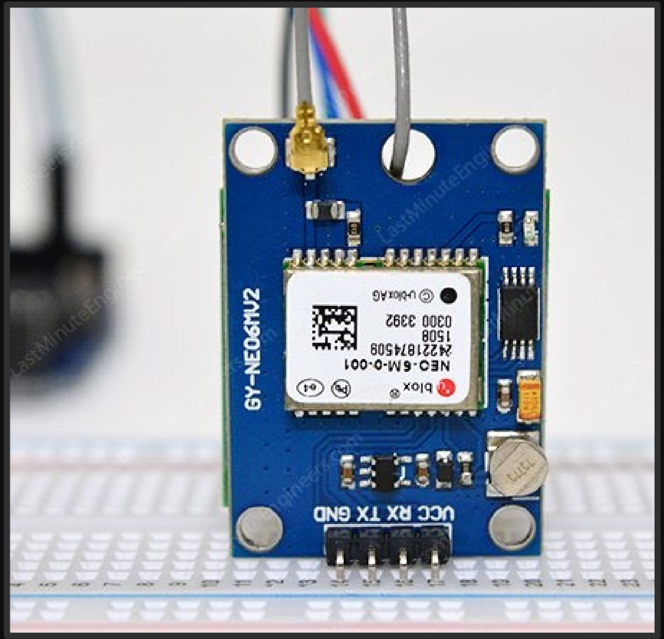
Circuit Diagram - CPM



Backup Slides Links

GPS Selection

- We are required to provide the location of the Pod and this will be accomplished by using a NEO-6M GPS module
    - Update rate of location: 1 HZ (5 Hz max)
    - Horizontal Accuracy: 2.5m
    - Time-To-First-Fix (TTFF): under 1s
    - Operating Voltage: 2.7-3.6V @ 45mA



Backup Slides Links

Data Sheet NEO6 GPS

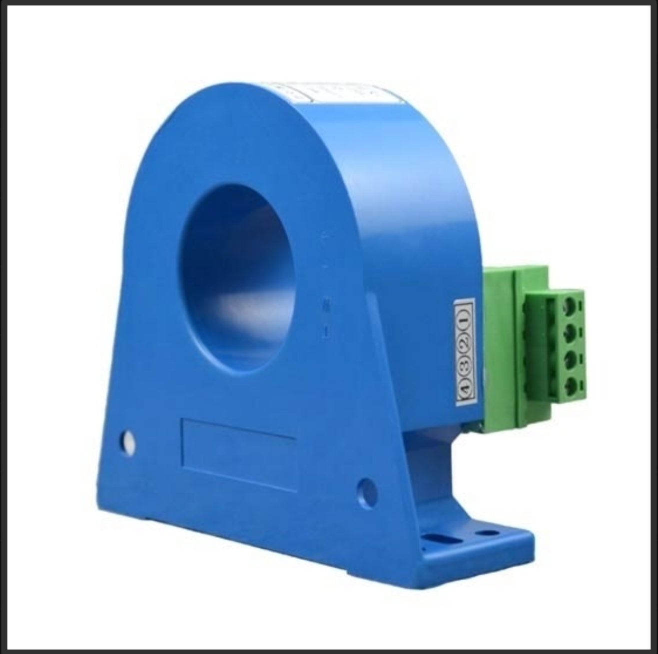
Here are complete specifications:

Receiver Type	50 channels, GPS L1(1575.42Mhz)
Horizontal Position Accuracy	2.5m
Navigation Update Rate	1HZ (5Hz maximum)
Capture Time	Cool start: 27sHot start: 1s
Navigation Sensitivity	-161dBm
Communication Protocol	NMEA, UBX Binary, RTCM
Serial Baud Rate	4800-230400 (default 9600)
Operating Temperature	-40°C ~ 85°C
Operating Voltage	2.7V ~ 3.6V
Operating Current	45mA
TXD/RXD Impedance	510Ω

Backup Slides Links

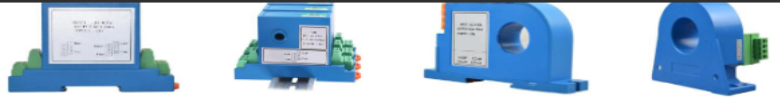
Current Sensor Selection

- It is required to know the operating voltage and current of the battery at any given time.
- The current will be measured with an ATO Current Sensor
  - Current Measuring Range:0 - 400A DC
  - Output Signal: 0 - 5V DC
  - Power Supply: 12V DC
- The voltage will be measured by creating a voltage divider that can be sent to the arduino ADC



Backup Slides Links

Data Sheet Current Sensor



Model	ATO-CURTS-DJIA	ATO-CURTS-DJIB	ATO-CURTS-DJIC	ATO-CURTS-DJID
Measuring range	AC 0-10A	AC 0-150A	AC 0-400A	AC 0-800A
Output signal	4-20mA, 0-20mA, 1-5V, 0-5V	4-20mA, 0-20mA, 1-5V, 0-5V	4-20mA, 0-20mA, 1-5V, 0-5V	4-20mA, 0-20mA, 1-5V, 0-5V
Power supply	DC 24V, DC 12V, AC 220V	DC 24V, DC 12V, AC 220V, AC 110V	DC 24V, DC 12V, AC 220V, AC 110V	DC 24V, DC 12V, AC 220V, AC 110V
Accuracy	0.5%F.S.	0.5%F.S.	0.5%F.S.	0.5%F.S.
Isolation voltage	3KV/50Hz/1min	3KV/50Hz/1min	3KV/50Hz/1min	3KV/50Hz/1min
Offset voltage	≤10mV	≤10mV	≤10mV	≤10mV
Temperature drift	≤100PPM/℃	≤100PPM/℃	≤100PPM/℃	≤100PPM/℃
Frequency bandwidth	20~50KHz	20~50KHz	20~50KHz	20~50KHz
Current consumption	<5mA	<5mA	<5mA	<5mA
Load capacity	Voltage output: 5mA, current output: 6V	Voltage output: 5mA, current output: 6V	Voltage output: 5mA, current output: 6V	Voltage output: 5mA, current output: 6V
Response time	Photoelectric isolation: ≤15μs, modulation and demodulation: < 150ms	<250ms	<250ms	<250ms
Overload capacity	10 times nominal input	30 times nominal input	30 times nominal input	30 times nominal input
Work temperature	-10~+70℃	-10~+70℃	-10~+70℃	-10~+70℃
Hole diameter	No hole	4mm, 8mm, 12mm, 15mm	22mm	35mm, 45mm, 55mm, 72mm
Installation	DIN rail and screw fixation	DIN rail and screw fixation	DIN rail and screw fixation	DIN rail and screw fixation

Cargo Bay Sensor Selection

- We are required to determine whether or not the cargo bay has an item in it and will accomplish this by using a Sparkfun SEN - 15569 ultrasonic distance sensor
  - Range Distance: 2 - 4m
  - Measuring Angle: 15 °
  - Operating Voltage: 5V @ 15mA

Backup Slides Links

Data Sheet Cargo Sensor

Wire connecting direct as following:

- 5V Supply
- Trigger Pulse Input
- Echo Pulse Output
- 0V Ground

Electric Parameter

Working Voltage	DC 5 V
Working Current	15mA
Working Frequency	40Hz
Max Range	4m
Min Range	2cm
MeasuringAngle	15 degree
Trigger Input Signal	10uS TTL pulse
Echo Output Signal	Input TTL lever signal and the range in proportion
Dimension	45*20*15mm

Backup Slides Links

Data Sheet Arduino Due

Tech specs

MICROCONTROLLER	AT91SAM3X8E
OPERATING VOLTAGE	3.3V
INPUT VOLTAGE (RECOMMENDED)	7-12V
INPUT VOLTAGE (LIMITS)	6-16V
DIGITAL I/O PINS	54 (of which 12 provide PWM output)
ANALOG INPUT PINS	12
ANALOG OUTPUT PINS	2 (DAC)
TOTAL DC OUTPUT CURRENT ON ALL I/O LINES	130 mA
DC CURRENT FOR 3.3V PIN	800 mA
DC CURRENT FOR 5V PIN	800 mA
FLASH MEMORY	512 KB all available for the user applications
SRAM	96 KB (two banks: 64KB and 32KB)
CLOCK SPEED	84 MHz
LENGTH	101.52 mm
WIDTH	53.3 mm
WEIGHT	36 g

Backup Slides Links

Datasheet XBee 3 Pro

Performance specifications

The following table describes the performance specifications for the devices.

Specification	XBee 3	XBee 3-PRO
Indoor/urban range	Up to 60 m (200 ft)	Up to 90 m (300 ft)
Outdoor RF line-of-sight range	Up to 1200 m (4000 ft)	Up to 3200 m (2 mi)
RF Transmit power output (maximum)	6.3 mW (+8 dBm)	79 mW (+19 dBm)
BLE power output	6.3 mW (+8 dBm)	6.3 mW (+8 dBm)
RF data rate	250,000 b/s	
Receiver sensitivity	-103 dBm	

Note Range figure estimates are based on free-air terrain with limited sources of interference. Actual range will vary based on transmitting power, orientation of transmitter and receiver, height of transmitting antenna, height of receiving antenna, weather conditions, interference sources in the area, and terrain between receiver and transmitter, including indoor and outdoor structures such as walls, trees, buildings, hills, and mountains.

Power requirements

The following table describes the power requirements for the XBee 3 RF Module.

Specification	XBee 3	XBee 3-PRO
Adjustable power	Yes	
Supply voltage	2.1 - 3.6 V	
Operating current (transmit, typical)	40 mA @ +3.3 V, +8 dBm	135 mA @ +3.3 V, +19 dBm
Operating current (receive, typical)	17 mA	
Power-down current, typical	2 μA @ 25° C	

Backup Slides Links

Datasheet Relay

KILOVAC LEV200 Series Contactor With 1 Form X Contacts Rated 500+ Amps, 12-900Vdc

Product Facts

- Designed to be the lowest cost sealed contactor in the industry with its current rating (500+A carry, 2000A interrupt at 320Vdc)
- Available with bottom or side mounting — not position sensitive
- Optional auxiliary contact for easy monitoring of power contact position
- Hermetically sealed — intrinsically safe, operates in explosive/harsh environments with no oxidation or contamination of coils or contacts, including long periods of non-operation
- Typical applications include battery switching and backup, DC voltage power control, circuit protection and safety
- Versatile coil/power connections
- Designed and built in accordance to AIAG QS9000
- RoHS compliant

Coil Data (Valid Over Temperature Range) [4]				
Nominal Voltage	12Vdc	24Vdc	48Vdc	72Vdc
Pickup Voltage (Will Operate)	9.0Vdc	19.0Vdc	38.0Vdc	57.0Vdc
Voltage (Max.)	15Vdc	30Vdc	60Vdc	90Vdc
Dropout Voltage	0.75 - 2.0Vdc	1.0 - 5.0Vdc	2.0 - 7.0Vdc	3.0 - 12.0Vdc
Coil Resistance @ 25° (Typ.)	11 ohms	40 ohms	145 ohms	357 ohms

Ordering Information

Typical Part Number ▶ LEV200 A 4 N A A

Series:
LEV200 = 500+ Amp, 12-900Vdc Contactor

Contact Form:
A = Normally Open
H = Normally Open with Aux. Contacts. (Option "H" requires option "A" in Coil Wire Length and option "N" in Coil Terminal Connector.)
Note: Other auxiliary contact forms available. Consult factory.

Coil Voltage:
4 = 12Vdc 5 = 24Vdc B = 28Vdc

Performance Data

Contact Arrangement, Power Contacts — 1 Form X (SPST-NO-DM)

Rated Operating Voltage — 12 - 900 VDC

Continuous (Carry) Current, Typical — 500 A @ 65°C, 400 mcm conductors
Consult TE for required conductors for higher (500+ A) currents

Make/Break Current at Various Voltages [1] — See graph next page

Break Current at 320VDC [1] — 2,000 A, 1 cycle [3]

Contact Resistance, Typ. (@200A) — 0.2 mohms

Load Life — See graph next page

Mechanical Life — 1 million cycles

Contact Arrangement, Auxiliary Contacts — 1 Form A (SPST-NO)

Aux. Contact Current, Max. — 2A @ 30VDC / 3A @ 125VAC

Aux. Contact Current, Min. — 100mA @ 8V

Aux. Contact Resistance, Max. — 0.417 ohms @ 30VDC / .150 ohms @ 125VAC

Operate Time @ 25°C —
Close (includes bounce), Typ. — 25 ms
Bounce (after close only), Max. — 7 ms
Release (includes arcing), Max @ 2000A — 12 ms

Dielectric Withstanding Voltage — 2,200 Vrms @ sea level (leakage <1mA)

Insulation Resistance @ 500VDC — 100 megohms [2]

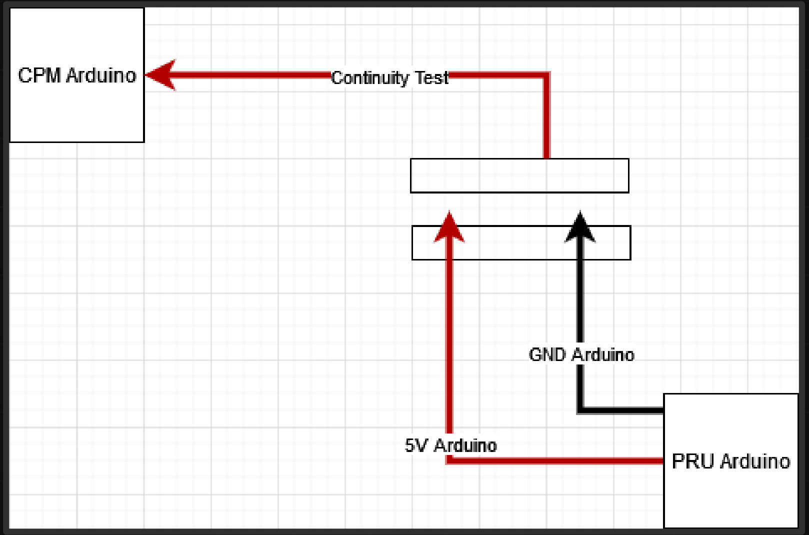
Shock, 11ms 1/2 Sine, Peak, Operating — 20 G

Vibration, Sine, 80-2000Hz.,

Backup Slides Links

Connection Sensor Selection

- It is required to know when the PRU is connected to the CPM and this we be accomplished by using a relay to send a small electrical signal to an arduino
- This is incorporated into the electrical rotary latches



Backup Slides Links

Link Budget - Arduino Pin Allocation

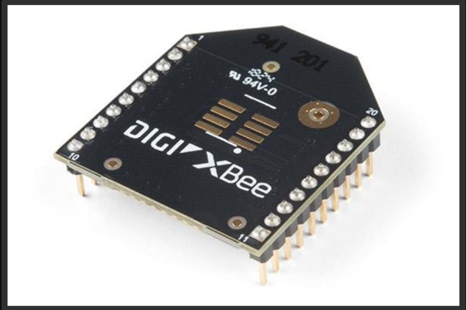
Data will be transmitted via UART communication to the radio

Component	Max Sample Rate	Arduino Pin(s) Used
GPS (via UART)	5Hz	0,1 (Serial 0 pins)
Cargo Bay Sensor (ADC)	1MHz	A0 (Analog 0)
Voltage Sensor (ADC)	1MHz	A1 (Analog 0)
Current Sensor (ADC)	1MHz	A2 (Analog 0)
Connection Sensor (ADC)	1MHz	A3 (Analog 0)
XBee Radio (via UART)	N/A	18,19 (Serial 1 pins)

Feasibility: Electronics/Data - CPM

Justification of XBee Pro 3:

- RF Module selection rationale
  - Doesn’t rely on a 3rd party signal
  - Significantly cheaper to maintain a continuous data stream
  - Capable of meeting FR 7 requirements with a reasonable margin

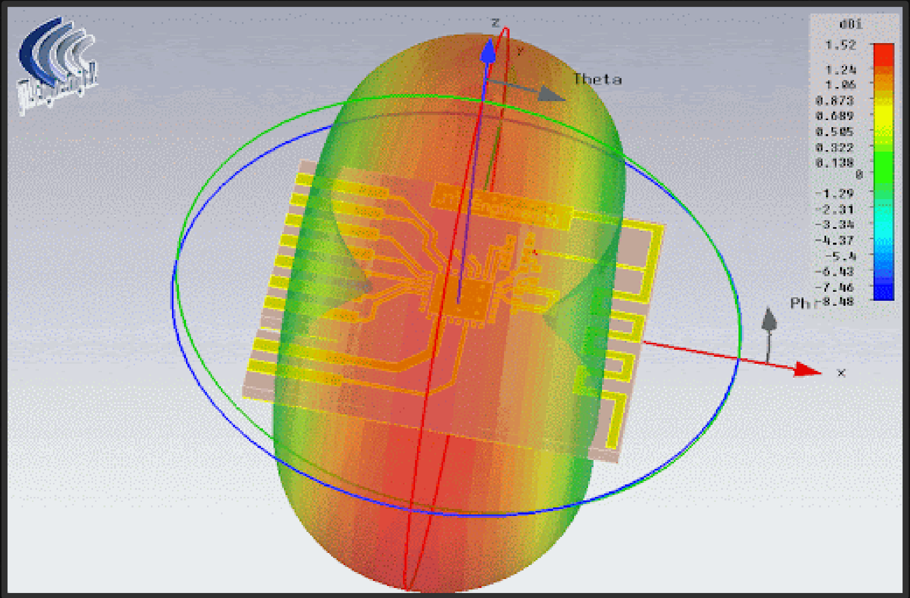


Backup Slides Links

PCB Antenna Analysis

Requirement: The user should be able to receive the data regardless of where they are oriented relative to the CPM

The radiation pattern of a PCB antenna is omnidirectional which makes our design feasible



Feasibility status: *Confirmed*

Backup Slides Links

Backup Slides:
Battery Choices

Common Commercial Drone Battery Specifications

Lithium-polymer batteries:

Manufacturer 1 (per battery):

7S, 22 Ah, 40C battery -> 569.8Wh available

Manufacturer 2 (per battery):

12S, 16 Ah, 20C battery -> 710.4Wh available

Similar battery voltages and capacities should be used to provide sufficient power.

While military-approved batteries would be ideal, there seems to be almost no standard LiPo battery available with military approval.

Specifications of Batteries TB2 Could Acquire

Manufacturer	Type	V_{min} - V_{max}	V_{nom}	Weight	Volume	Capacity	Discharge Rate
Maxamps - 12s	LiPo	36-50.4 V	44.4 V	3.972 kg	1821.6 cm^3	16Ah	20C
Maxamps - 6s	LiPo	18-25.2 V	22.2 V	1.992 kg	910.8 cm^3	16 Ah	20C
Maxamps - 7s	LiPo	21-29.4 V	25.9 V	2.950 kg	1314.4 cm^3	22 Ah	40C
Bren Tronics	Li-Ion	24-33.0 V	28.8 V	1.4 kg	19.523 cm^3	9.9 Ah	1.01 C
EaglePicher	Li-Ion	2.5-4.1 V	4.1 V	810g	867.66 cm^3	17 Ah	117.6 C

Backup Slides Links

Considered Battery Efficiencies

Manufacturer	Type	Total Energy	Energy Density	Specific Energy	Max Continuous Discharge
Maxamps - 12s	LiPo	710.4Wh	Wh/kg	0.389Wh/cm^3	320A
Maxamps - 6s	LiPo	355.2Wh	Wh/kg	0.389Wh/cm^3	320A
Maxamps - 7s	LiPo	569.8Wh	193.15Wh/kg	0.433Wh/cm^3	880A
Bren Tronics	Li-Ion	285.12Wh	203.65Wh/kg	0.328Wh/cm^3	2000 A
EaglePicher	Li-Ion	69.7Wh	80Wh/kg	0.213Wh/cm^3	10A

Backup Slides Links

Battery Charge Times

Manufacturer	Total Energy	Charging Rating	Max Charge Power
Maxamps - 12s	710.4Wh	5C	3552 W
Maxamps - 7s	569.8Wh	5C	2849 W

Discharge Rates

Battery	Total Energy	Discharge Rating	Max Power	% of C rating
Maxamps - 12s	710.4Wh	20C	14208 W	25%
Maxamps - 6s	355.2Wh	20C	7104 W	25%
Maxamps - 7s	569.8Wh	40C	22792 W	15.6%
Bren Tronics	285.12Wh	1.1C	316.799 W	1121%
EaglePicher	69.7Wh	117.6C	8196.72 W	43.3%

Backup Slides Links

Available Battery Housing Volume in Pod

Length = 40.6 cm, Height = 21.0cm, Depth = 7.633cm

Battery	Length (cm)	Height (cm)	Depth (cm)	Redesign Required?
Maxamps - 12s	13.8	13.2	100	Yes
Maxamps - 6s	13.8	13.2	5.0	No
Maxamps - 7s	15.8	14.1	5.9	No
Eaglepicher	22.91588	14.9324	0.98044	No

Cost and Connection Availability

Battery	Cost	Connection Availability
Maxamps - 6s	Free OR 1139.98	Readily available, 6S is a very common LiPo type
Maxamps - 7s	Free OR 899.99	Very small, 7S is a very rare LiPo type
Eaglepicher	>7000 total, maybe later	From supplier

Backup Slides Links

Feasibility: Pod Battery Charging

Requirements:

Fr 5: There Shall Be Power Passthrough Between An External Power Source And The Pod Through Some Tbd External Transmission Path

Pr 5.1: The Pod Shall Have An Unregulated Power Passthrough To A Power Distribution System To Allow For Charging Of The Internal Batteries.

Pr 5.2: The Pod Shall Have A Regulated Power Passthrough To A Power Distribution System To Allow For Charging Of The Internal Batteries.

Backup Slides:
Charging Pod Batteries

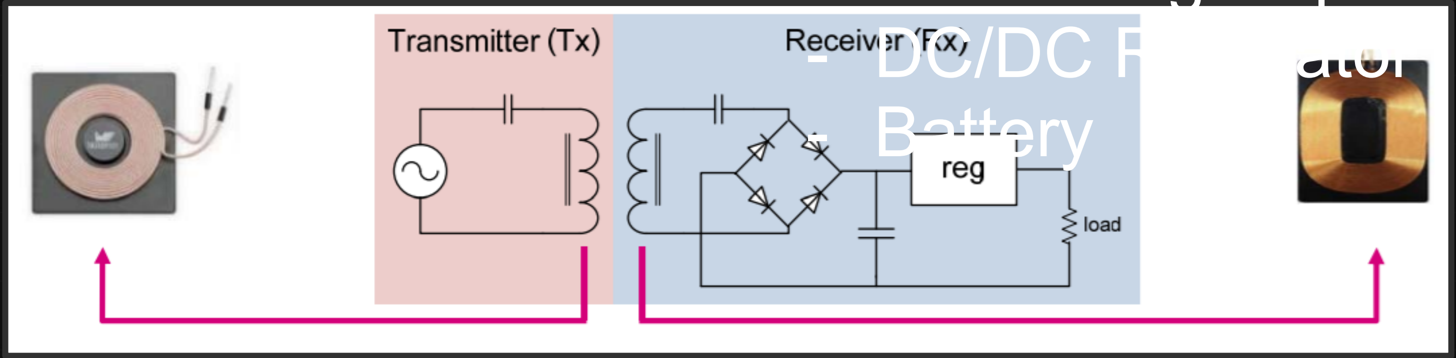
Induction Charging Principles

Transmitter

- Power source
- LC Bridge
- Transmitter coil
- Shielding

Receiver

- Receiver Coil
- Shielding
- Rectifier
- Smoothing Capacitor
- DC/DC R[illegible]ator
- Battery



What chargers are available, what are their specs?

ONBOARD CHARGERS	OC-110	OC-210	OC-251	OC-262-ST	OC-262-WP	OC-301
Battery Compatibility	LiPO, LiIon, SLA LiFePO4,NMH,NCAD	LiPO, LiIon, SLA LiFePO4,NMH,NCAD	LiPO, LiIon, SLA LiFePO4,NMH,NCAD	LiPO, LiIon, SLA LiFePO4,NMH,NCAD	LiPO, LiIon, SLA LiFePO4,NMH,NCAD	LiPO, LiIon, SLA LiFePO4,NMH,NCAD
Max Charging Current (A)	5	10	12	12	12	30
Max Charging Power (W)	90	125	250	300	300	300
Voltage (V)	7.92 - 30.1	12.03 - 36	8.0 - 58.4	8.0 - 58.4	8.0 - 58.4	8.0 - 58.4
Weight (w/ inclosure) (g)	101	162	293	580	630	540
Cooling Method	Active	Active	Active	Passive	Passive	Active
Length (mm)	66.65	80.63	100	105.5	105.5	118
Width (mm)	75	108.85	138	145.5	145.5	181.4
Height (mm)	35	36.3	42	33.5	43.5	52.5

Backup Slides Links

Feasibility: Pod Battery Charging

INDUCTION CHARGING FEASIBILITY

- Can induction charging provide the necessary power?
- What physical constraints do the transmitter and receiver coils have?
- How will the material between the transmitter and receiver affect power?
- Will the induction system create heating that affects the Pod?
- Will the induction system interfere with other instruments in the Pod/CPM?
- How will the weight of the components affect the Pod and UAV?
- How will mounting the receiver system affect the structural integrity of the POD?

Backup Slides Links

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Backup Slides Links

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Backup Slides Links

Induction Charging Assumptions

Battery

- Max Capacity: 22,000 mAh (22Ah) - *MaxAmps 7S*
- Max Voltage: 44.4 Volts - *MaxAmps 12S*

Rationale

- Largest Capacity and Voltage from available batteries
- Will provide upper bound estimates

Backup Slides Links

Induction Charging: Power

Key Assumptions

1. V_{Batt} = 44.4 V
2. C_{Batt} = 22,000 mAh (22Ah)
3. Charging at max charger current
4. Simplified Time to Charge

Feasibility:

Time to charge is not requirement but preferred faster

Charger voltage range must include V_{Max}

Analysis

$$V_{Charger_{Min}} \leq V_{Batt} \leq V_{Charger_{Max}}$$

$$T = Time\ to\ Charge$$

$$T = \frac{C_{Batt}}{I_{Charger}}\ Hours$$

Backup Slides Links

Induction Charging: Power

ONBOARD CHARGERS	OC-110	OC-210	OC-251	OC-262-ST	OC-262-WP	OC-301
Voltage (V)	7.92 - 30.1	12.03 - 36	8.0 - 58.4	8.0 - 58.4	8.0 - 58.4	8.0 - 58.4
Max Charging Current (A)	5	10	12	12	12	30
Time To Charge (Hours)	4.4	2.2	1.83	1.83	1.83	0.73

Feasibility:

Feasible!

Rest of analysis done with 0C -251

Backup Slides Links

Induction Charging: Power

ONBOARD CHARGERS	Battery Comp.	Max Charging Current (A)	Max Charging Power (W)	Max Voltage (V)	Weight (g)	Cooling Method	Length (mm)	Width (mm)	Height (mm)
OC-251	LiPO, LiIon, SLA LiFePO4,NMH,NiCAD	12	250	58.4	293	Active	100	138	42

Feasibility:

Feasible!

Rest of analysis done with 0C - 251

Backup Slides Links

Feasibility: Pod Battery Charging

INDUCTION CHARGING FEASIBILITY

- Can induction charging provide the necessary power?
- What physical constraints do the transmitter and receiver coils have?
- How will the material between the transmitter and receiver affect power?
- Will the induction system create heating that affects the Pod?
- Will the induction system interfere with other instruments in the Pod/CPM?
- How will the weight of the components affect the Pod and UAV?
- How will mounting the receiver system affect the structural integrity of the POD?

Backup Slides Links

Induction Charging: Field strength through Pod

Key Assumptions

1. Transmitter and receiver designed for free space
2. Magnetic Flux Density linearly proportional to permeability
3. Material between transmitter and receiver separation 0.4 cm max
4. Transmitter and receiver provide full power within 0.4 cm (Wibotic)

Feasibility:

Relative Permeability must be 1+/-0.05 for field to remain 95% effective

Analysis

Magnetic Flux Density of field between transmitter and receiver determines charging strength

B = Magnetic Flux Density (H^2/m)
μ = Permeability (H/m)
$\mu_0 = 4\pi \times 10^{-7}$ (H/m)
M = Field Strength (H)

$$B = \mu \cdot M$$

Relative Permeability $= \mu / \mu_0$

Backup Slides Links

Induction Charging: Field strength through Pod

Key Assumptions

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3. Material between transmitter and receiver separation 0.4 cm max
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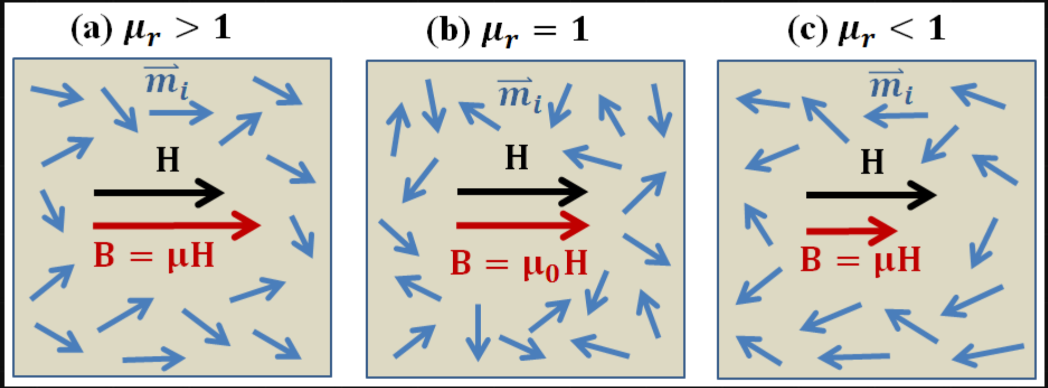
Feasibility:

Relative Permeability must be 1+/-0.05 for field to remain 95% effective

Analysis



Relative permeability close to 1 allows for field to pass through

Backup Slides Links

Induction Charging: Field strength through Pod

Analysis :

- Receiver may be designed as an exterior component on the Pod allowing fields to travel through free space
- Transmitter/Receiver commonly built in ABS Plastic housings that allow for strong field

Feasibility:

If designed as an external component or material of Pod has correct permeability

Feasible!

Common Materials

Medium	Relative Permeability (μ_0)
Air	1.00000037
Aluminum	1.000022
Copper	0.999834
Stainless Steel	1.003 - 7

Backup Slides Links

Feasibility: Pod Battery Charging

INDUCTION CHARGING FEASIBILITY

- Can induction charging provide the necessary power?
- What physical constraints do the transmitter and receiver coils have?
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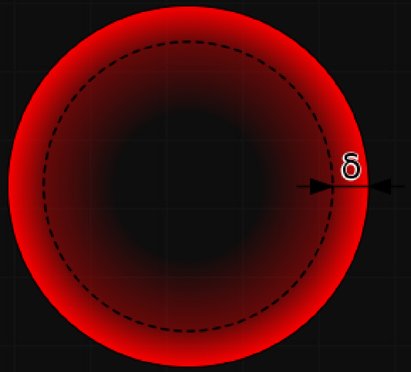
- How will the weight of the components affect the Pod and UAV?
- How will mounting the receiver system affect the structural integrity of the POD?

Induction Charging: Material Heating

Key Assumptions

1. Only eddy current loss heating
2. Frequency of magnetic field approximately 6 MHz
3. Skin effect equation used for penetration depth
4. Simplified induced current



Analysis

Induced eddy current causes heating in materials

Skin effect measures distribution of density of current below surface

Density concentrated near surface increases effective resistance

Higher resistance creates more heat

Backup Slides Links

Induction Charging: Material Heating

Key Assumptions

1. Only eddy current loss heating
2. Frequency of magnetic field approximately 6 MHz
3. Skin effect equation used for penetration depth
4. Simplified induced current

Feasibility:

With extreme frequencies of induction system resistivity must be very high to avoid heating

Analysis

I = Induced Current (A)
I_0 = Surface Current (A)
z = distance below surface (m)
δ = penetration depth (m)
ρ = resistivity (Ω m)
μ = Permeability (H/m)
F = frequency (Hz)

$$I = I_0 e^{\frac{-z}{\delta}}$$

$$\delta = \sqrt{\frac{\rho}{\pi \mu f}}$$

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Induction Charging: Material Heating

Key Assumptions

1. Only eddy current loss heating
2. Frequency of magnetic field approximately 6 MHz
3. Skin effect equation used for penetration depth
4. Simplified induced current

Feasibility:

Material must match permeability and resistivity requirements, impossible with metals

Must be polycarbonate, acrylic, or ceramic but...

Feasible!

Common Materials

Medium	Resistivity (ρ)
Air	1e15
Rubber	1e13
Aluminum	2.65e-8
Stainless Steel	6.9e-7

Backup Slides Links

Feasibility: Pod Battery Charging

INDUCTION CHARGING FEASIBILITY

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- How will the weight of the components affect the Pod and UAV?
- How will mounting the receiver system affect the structural integrity of the POD?

Backup Slides Links

Induction Charging: Shielding

Key Assumptions

1. Pod consists of free space between receiver and components
2. Thin layer of material can be placed between receiver and free space

Feasibility:

Magnetic Flux Density must be 0.005% of free space density at transmitter coil to not affect components

Analysis

Magnetic Flux Density of field from induction

B = Magnetic Flux Density (H^2/m)
μ = Permeability (H/m)
$\mu_0 = 4\pi \times 10^{-7}$ (H/m)
N = number of turns in the wire (constant)
a = coil radium (constant)
x = distance from wire (displacement)
I = current

$$B = \mu \cdot M$$

$$B = \frac{\mu N I a^2}{2(x^2 + a^2)^{\frac{3}{2}}}$$

Relative Permeability = μ / μ_0

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Induction Charging: Shielding

Analysis :

1. Commercial solutions have built in shielding or smart transmitters that scale field
2. Many materials made for shielding have permeability in excess of what is required
3. Distance from transmitter will not matter with sufficient shielding

Feasibility:

Using commercial or manufactured shielding

Feasible!

Common Materials

Medium	Relative Permeability (μ_0)
Air	1.00000037
Ferrite	16-640
Permalloy	100,000
Metglass	1,000,000

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Feasibility: Pod Battery Charging

INDUCTION CHARGING FEASIBILITY

- Can induction charging provide the necessary power?
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- How will mounting the receiver system affect the structural integrity of the POD?

Induction Charging: Weight

Key Assumptions

- Only receiver coil and and onboard charger integrated into pods
- Mounting mechanisms will be small screws
- Connections will be made with short wires
- UAV lifting capacity 22-55 lbs

Feasibility:

512 grams = 1.12877 lbs
5.13% of lifting capacity
Not ideal but ...

Feasible!

Weight Analysis

Component	Weight (g)
Charger	293
Receiver	69
Mounting Screws	~50
Connection Wires	~100
TOTAL	512

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