Advancing Undergraduate Space Research with a Standardized CubeSat Bus

CubeSat Workshop 2025

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April 24, 2025

Problem Statement

- Cubesats are expensive

Problem Statement

- Cubesats are expensive
- Cubesats are custom

“Modularity” We Are Used to Seeing

Even with “standard” components, integration with payload components turn the satellite into one-off, custom builds → Takes too long

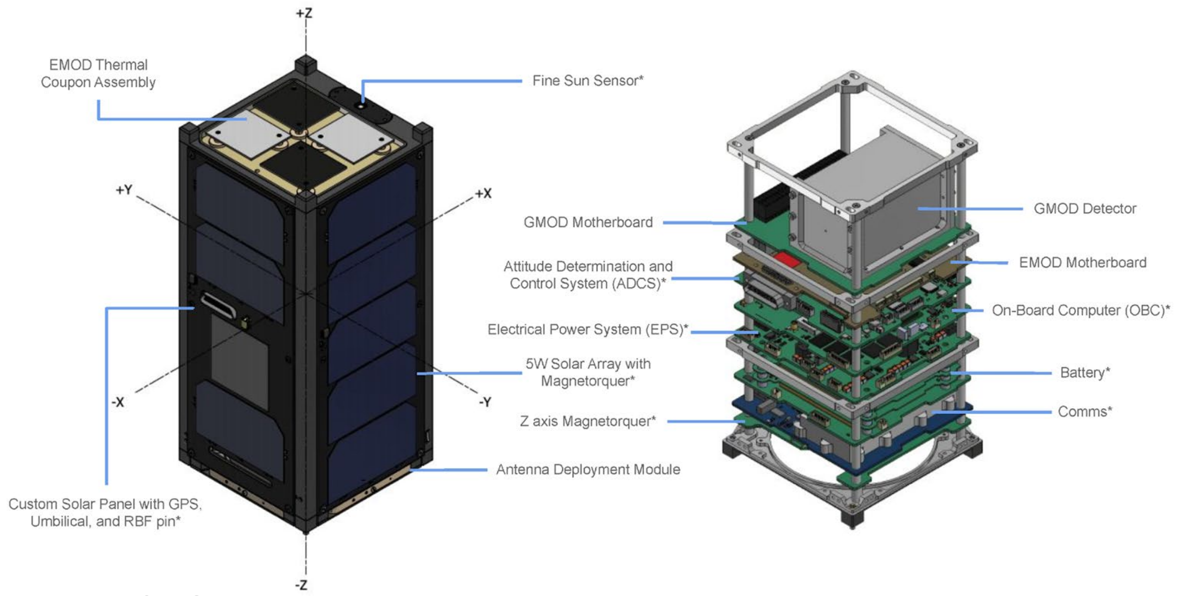
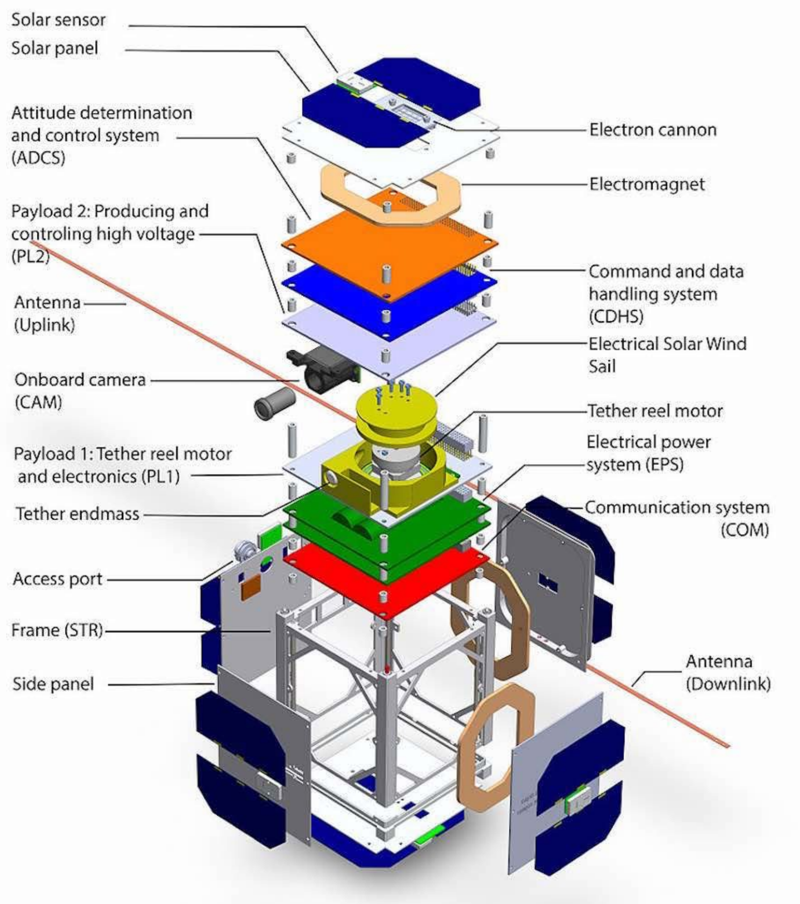


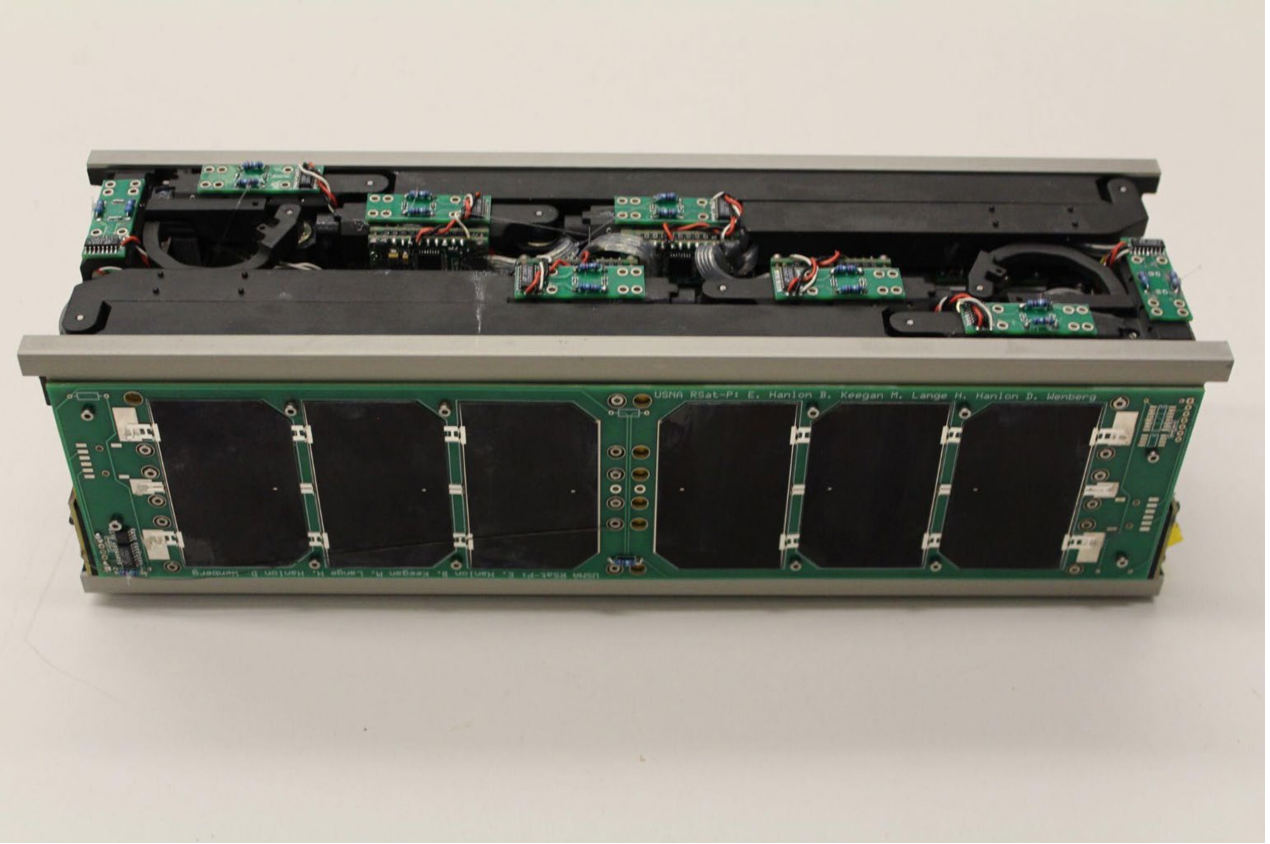
Illustration of EIRSAT-1



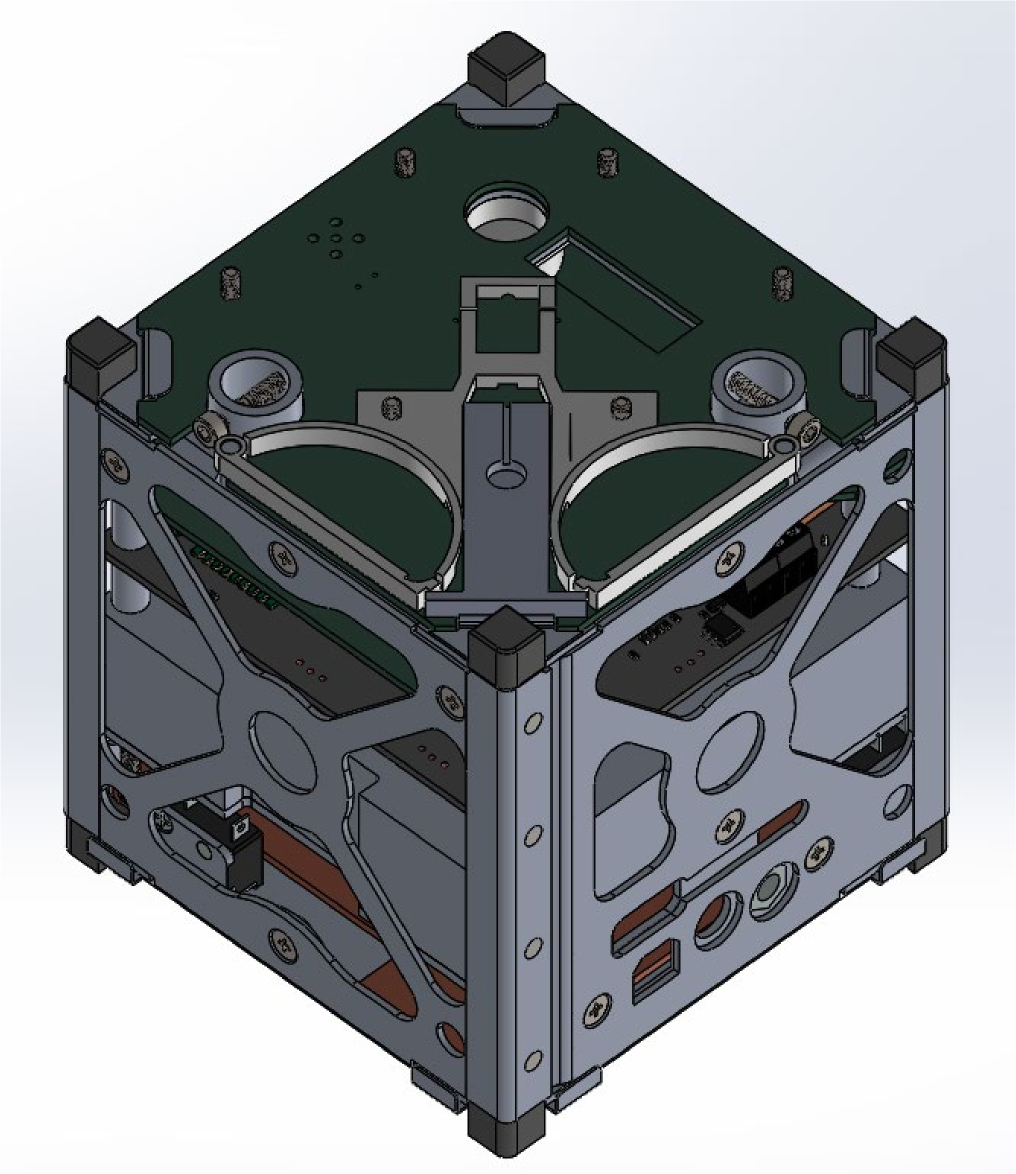
The structure of cubesat ESTCube-1

Problem Statement

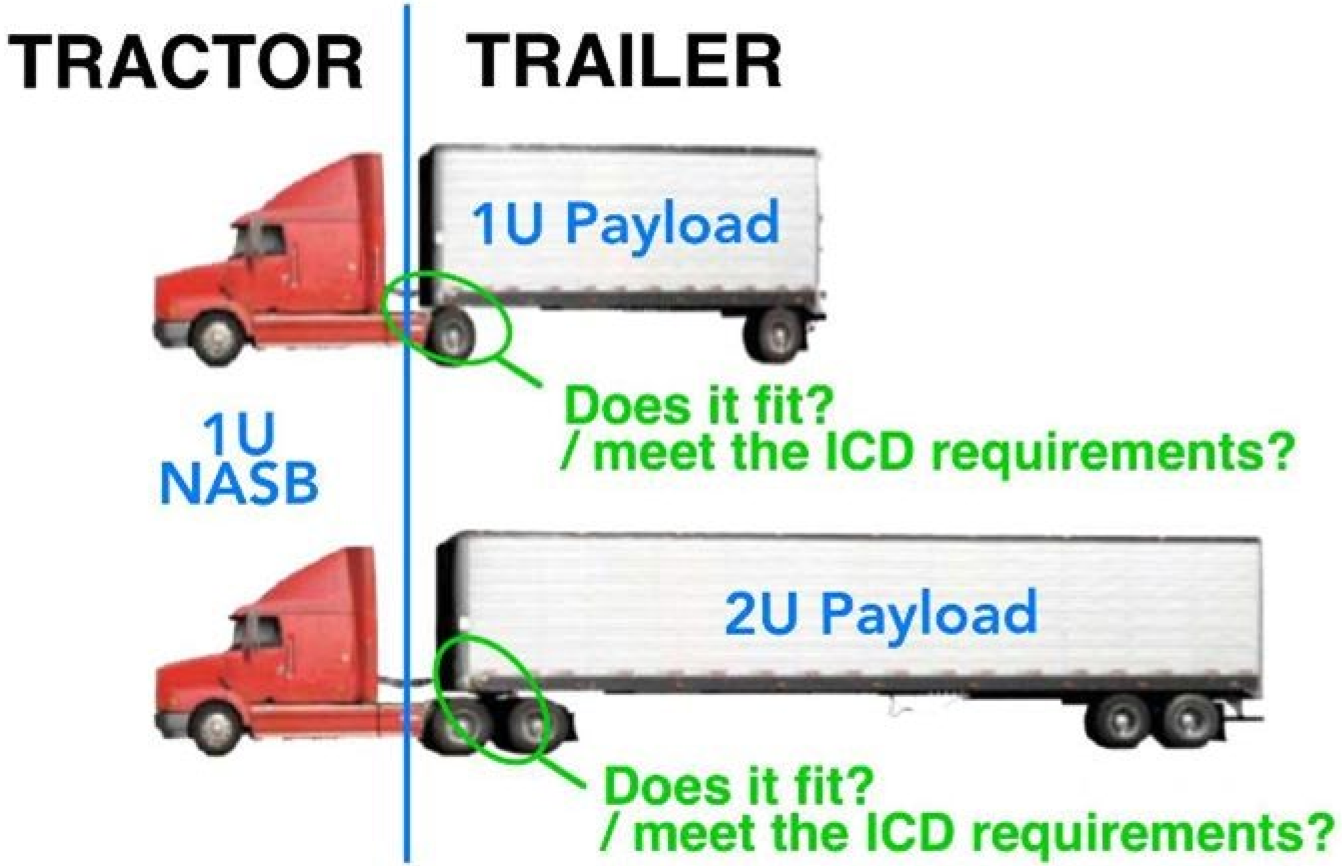
- Cubesats are expensive
- Cubesats are custom
- Cubesats are hard!

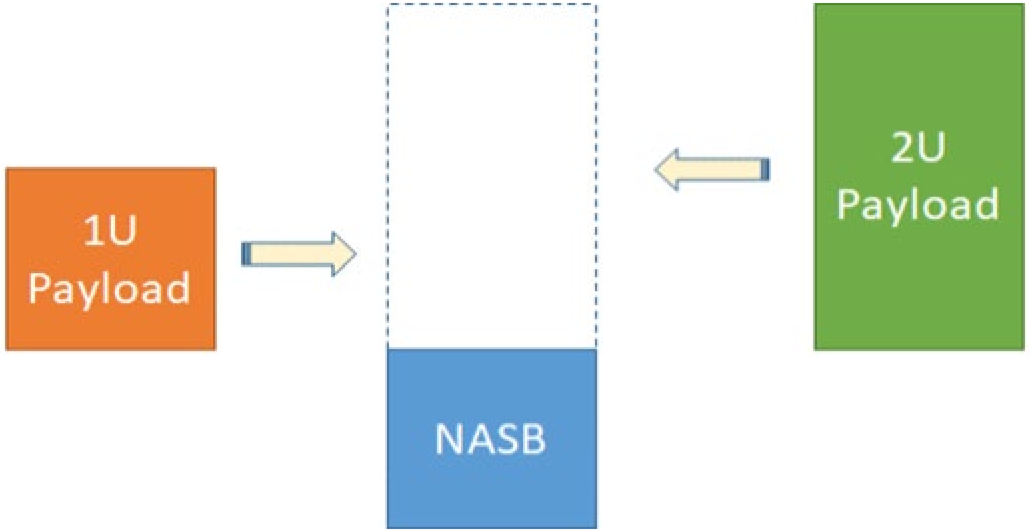


NASB

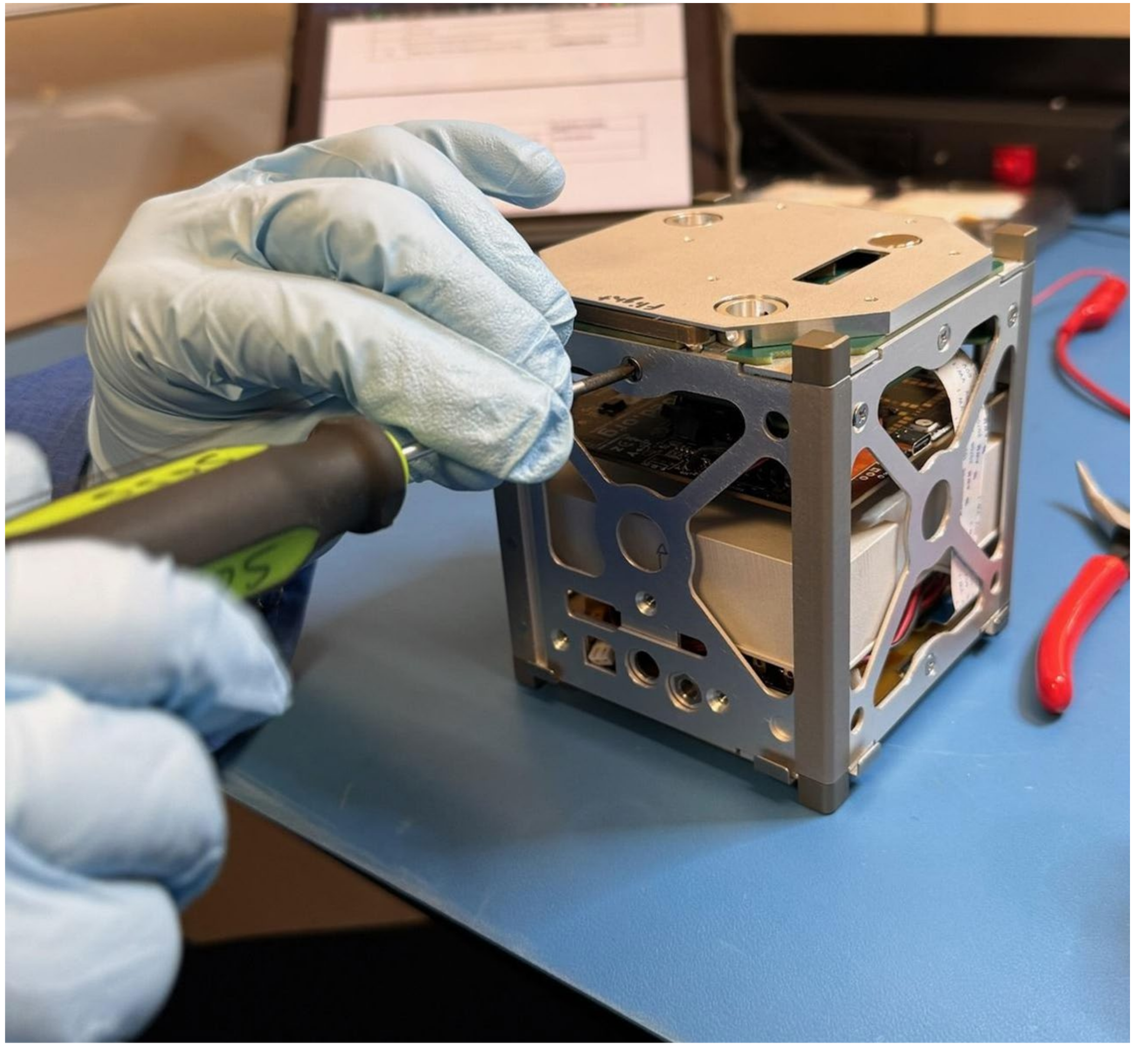


Naval Academy Standard Bus (NASB) Tractor-Trailer Design



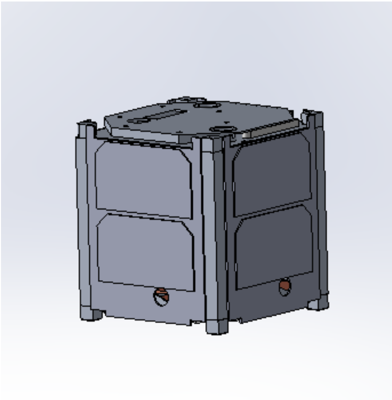


General 1U Standard Bus



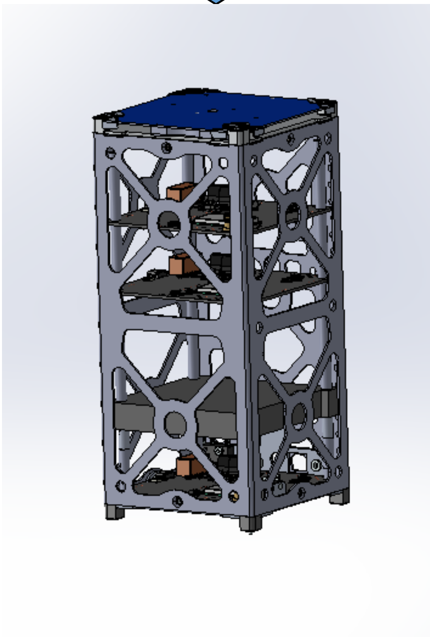
Combined 3U CubeSat

1U
Bus



+

2U
Payload



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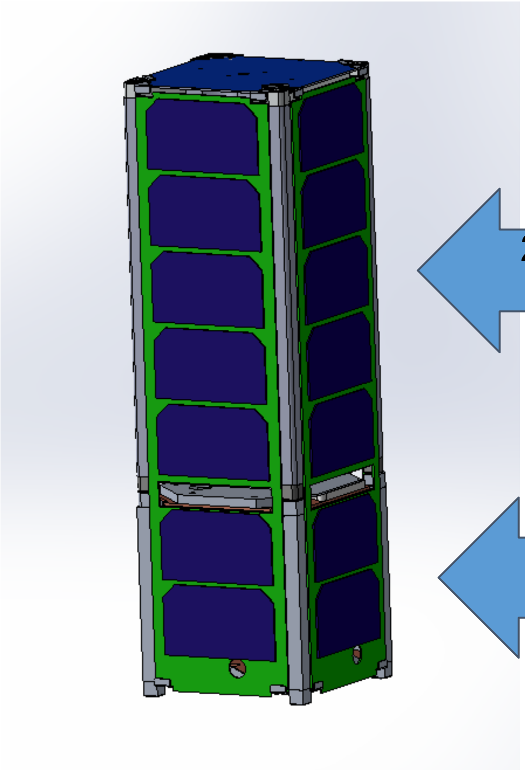
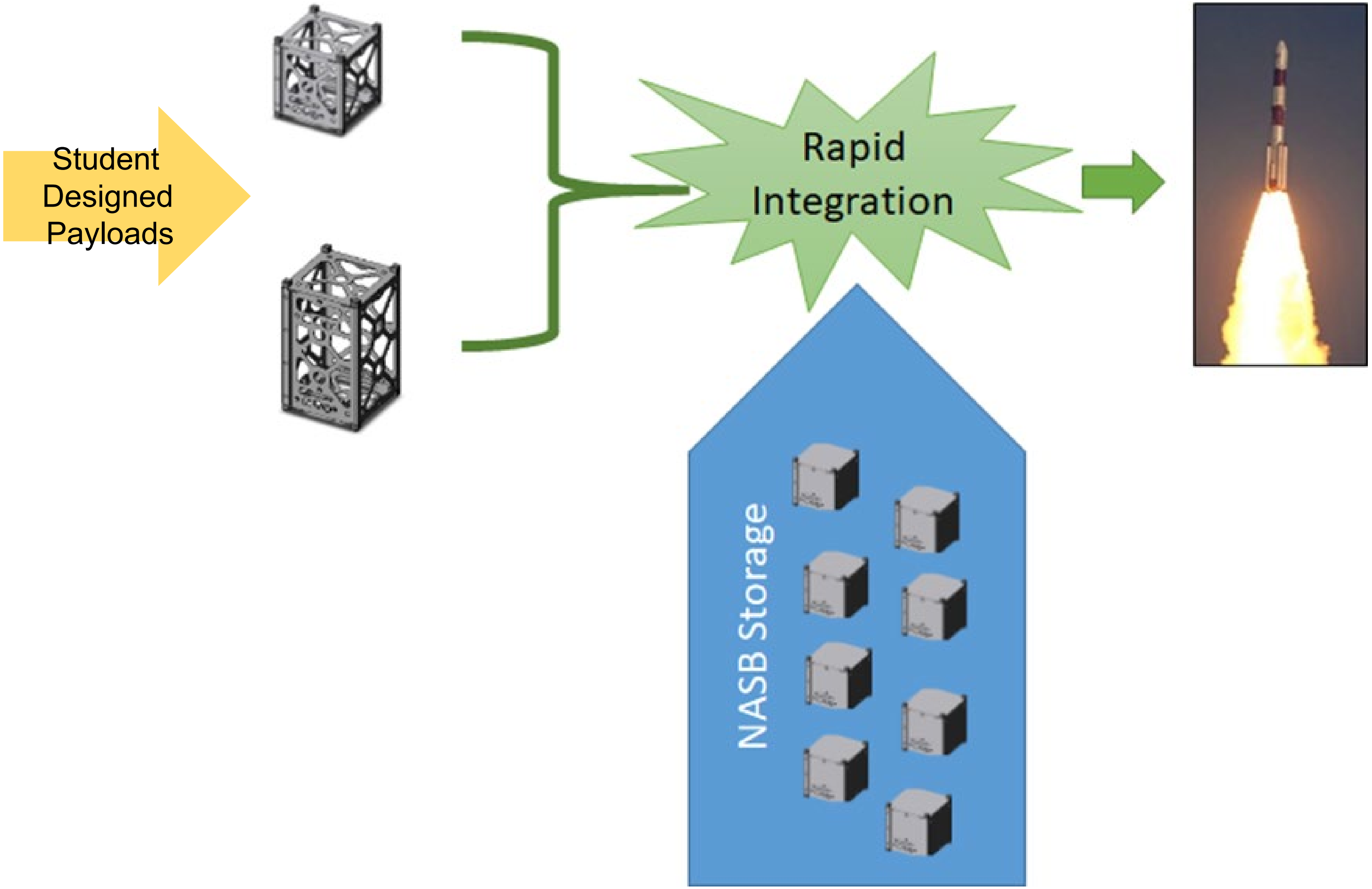


2U Payload Module

1U NASB

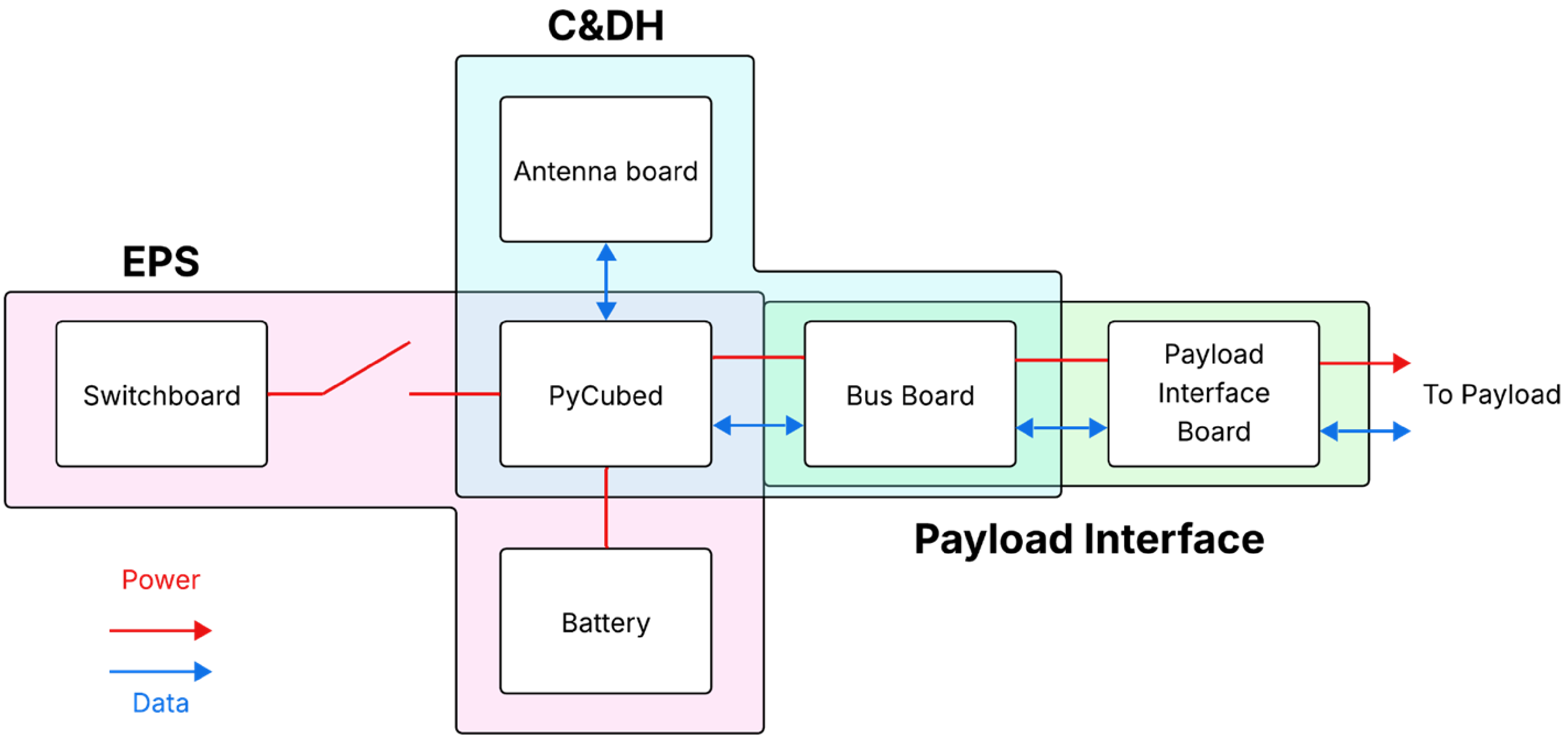
Parallel development of NASB and Payload



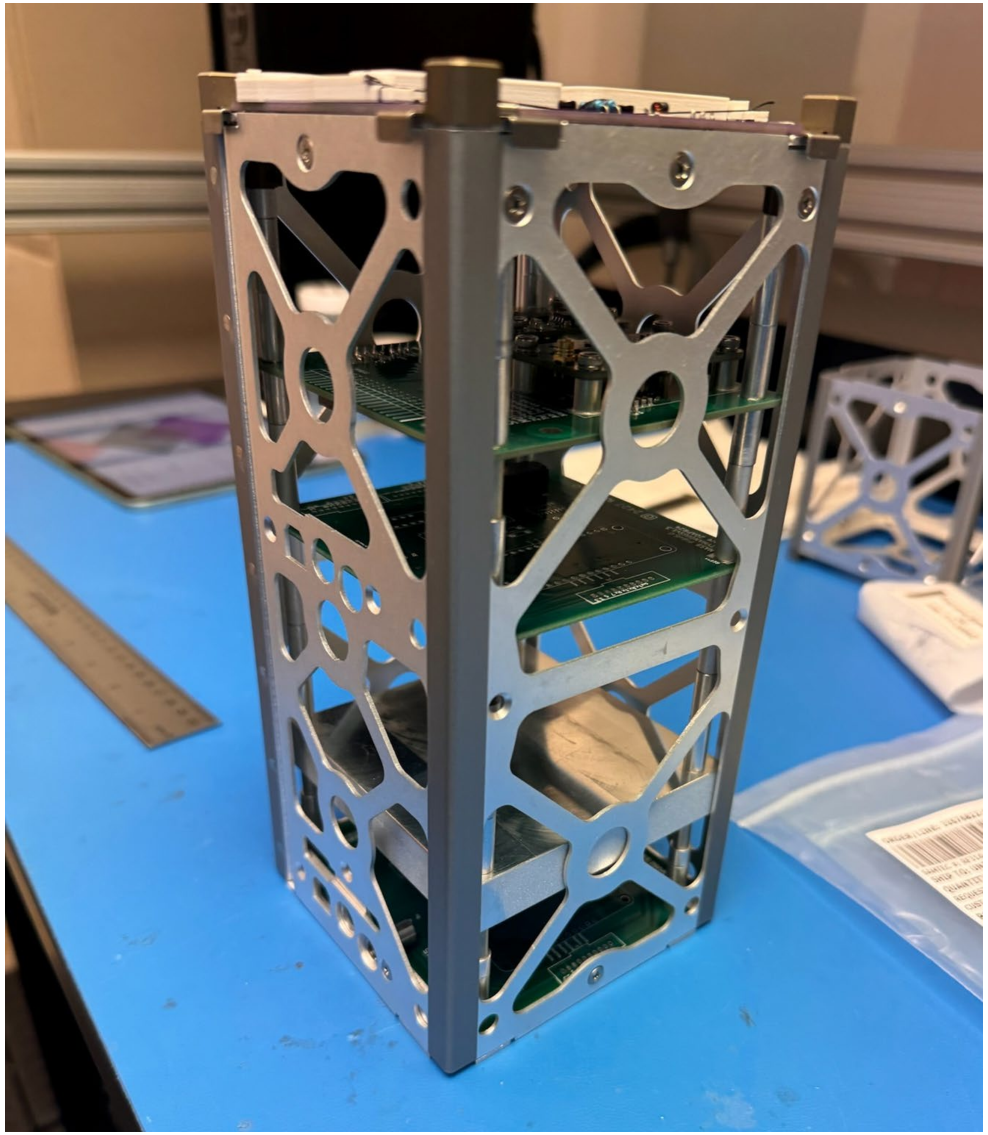
Completed satellites launched whenever opportunity given

- Successful payload developed, OR
- NASB on its own

Bus Block Diagram



Payload Module (PM)

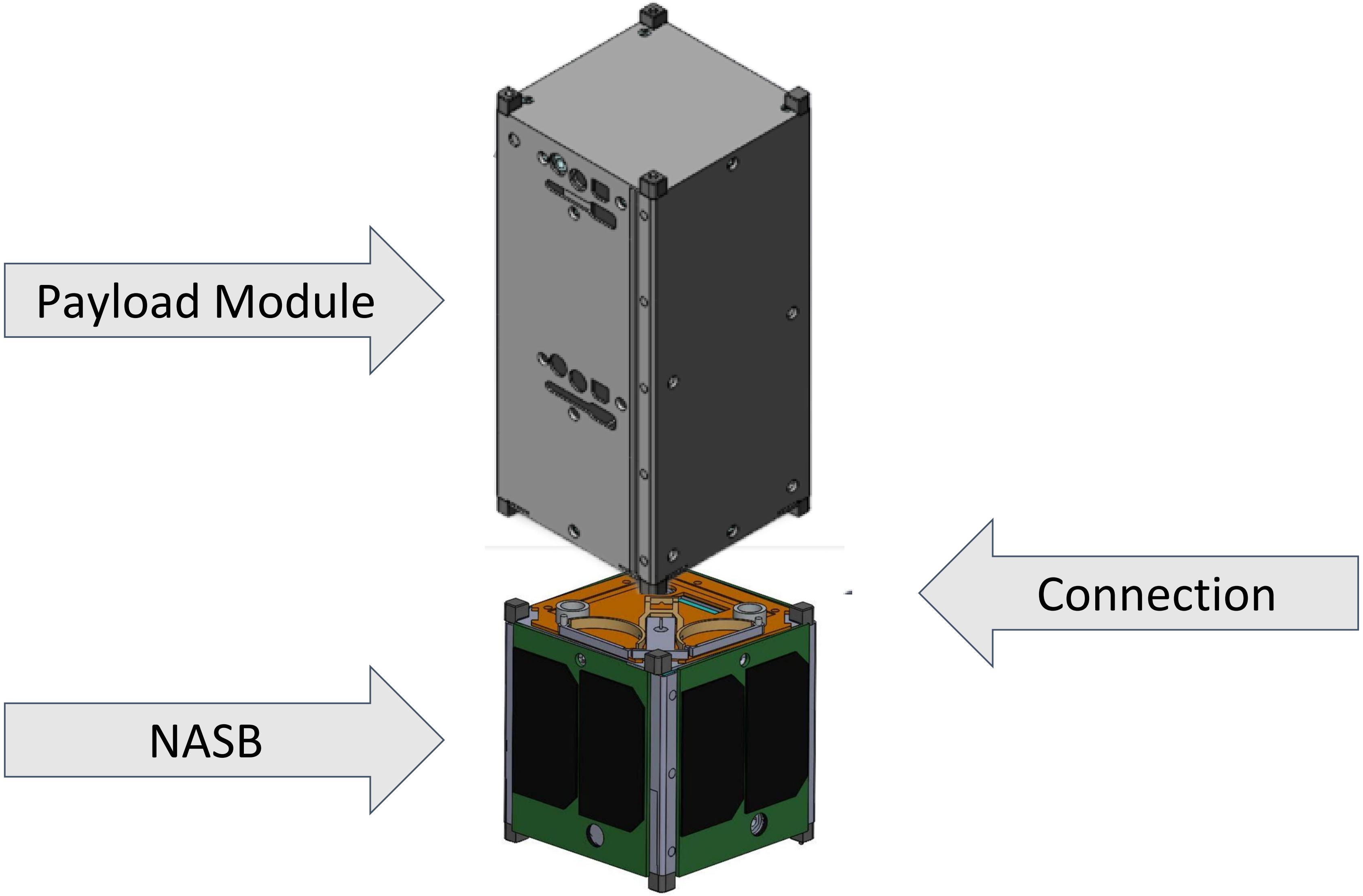


Interface Control Document

- Dimension requirements
- Mass and mass properties requirements
- Integration/adaptor requirements
- Electrical interface requirements

Mechanical Interface

Combined 3U CubeSat



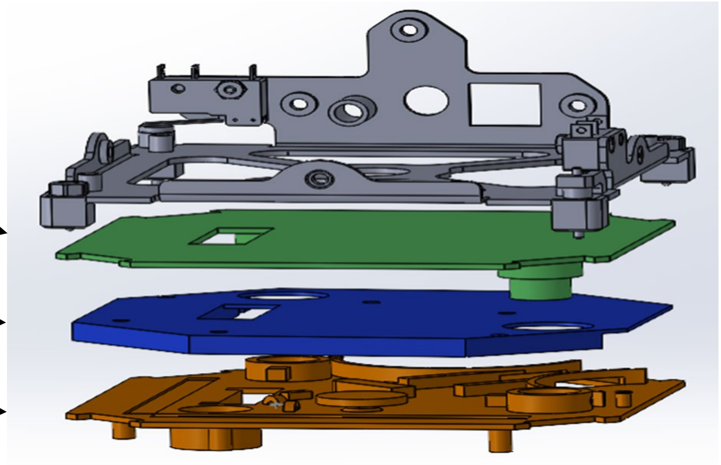
Mechanical Connection from Payload Module to NASB

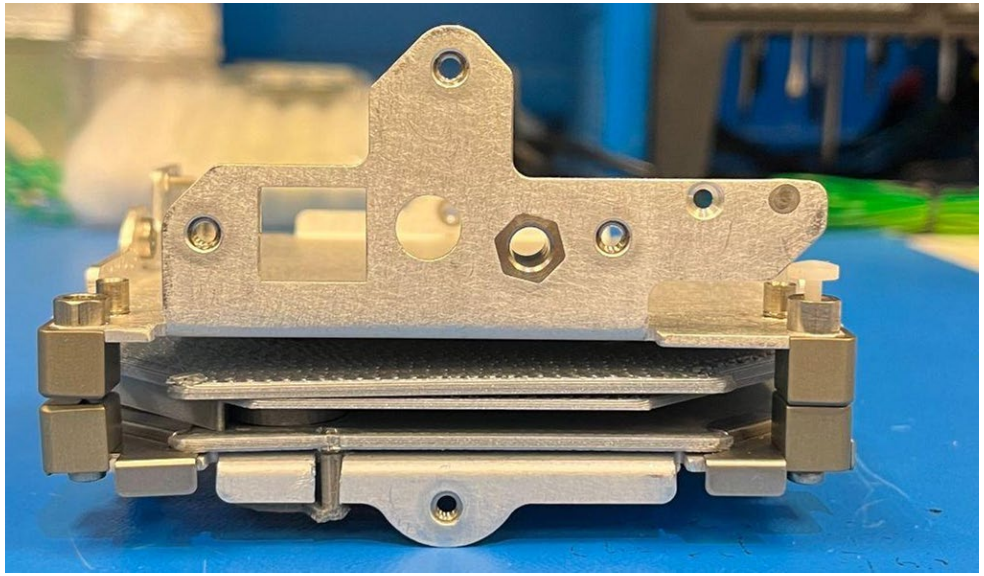
Payload Module

Payload Baseplate
Payload connection

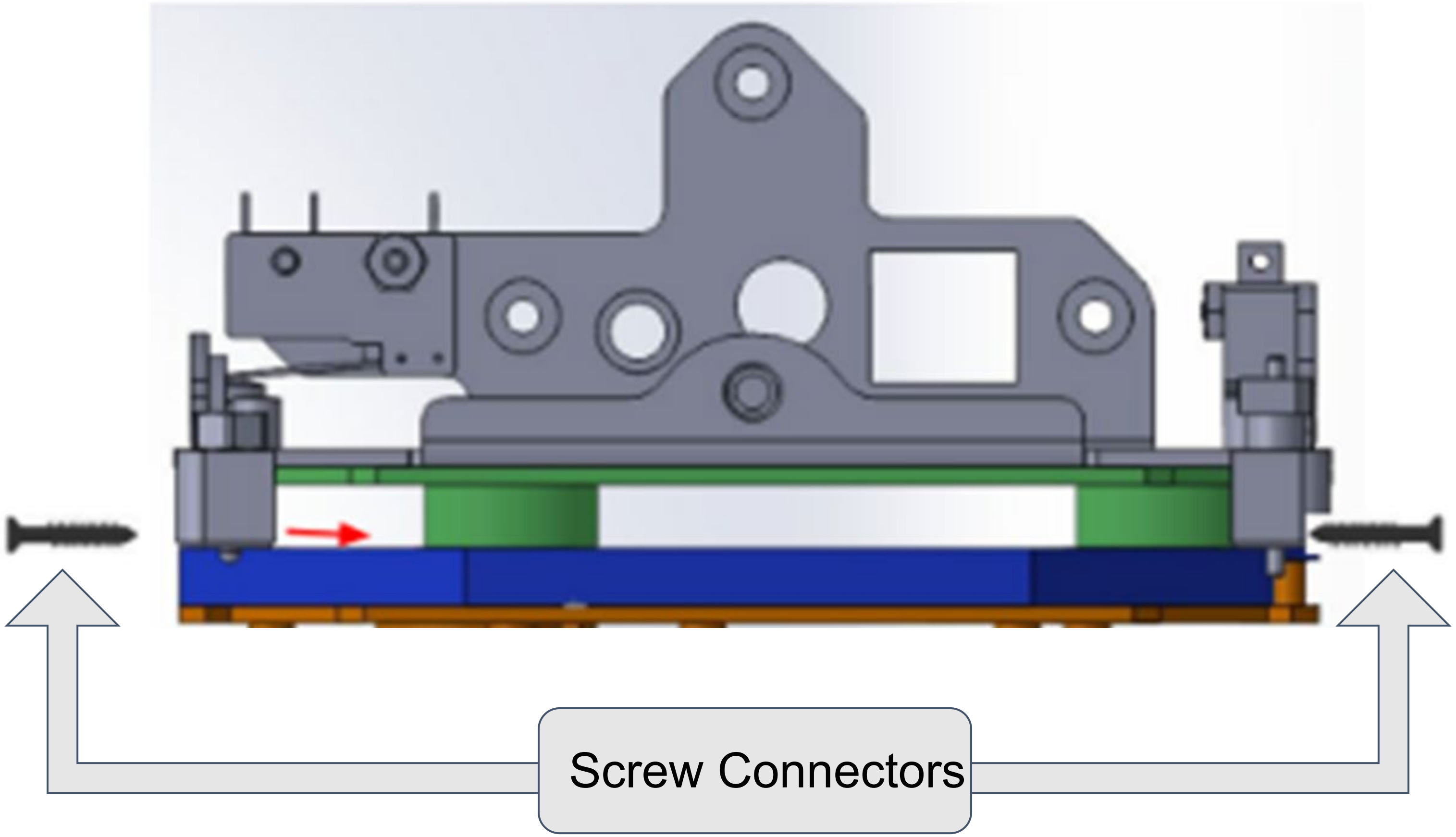
NASB

Antenna Board
Cover
Antenna Board

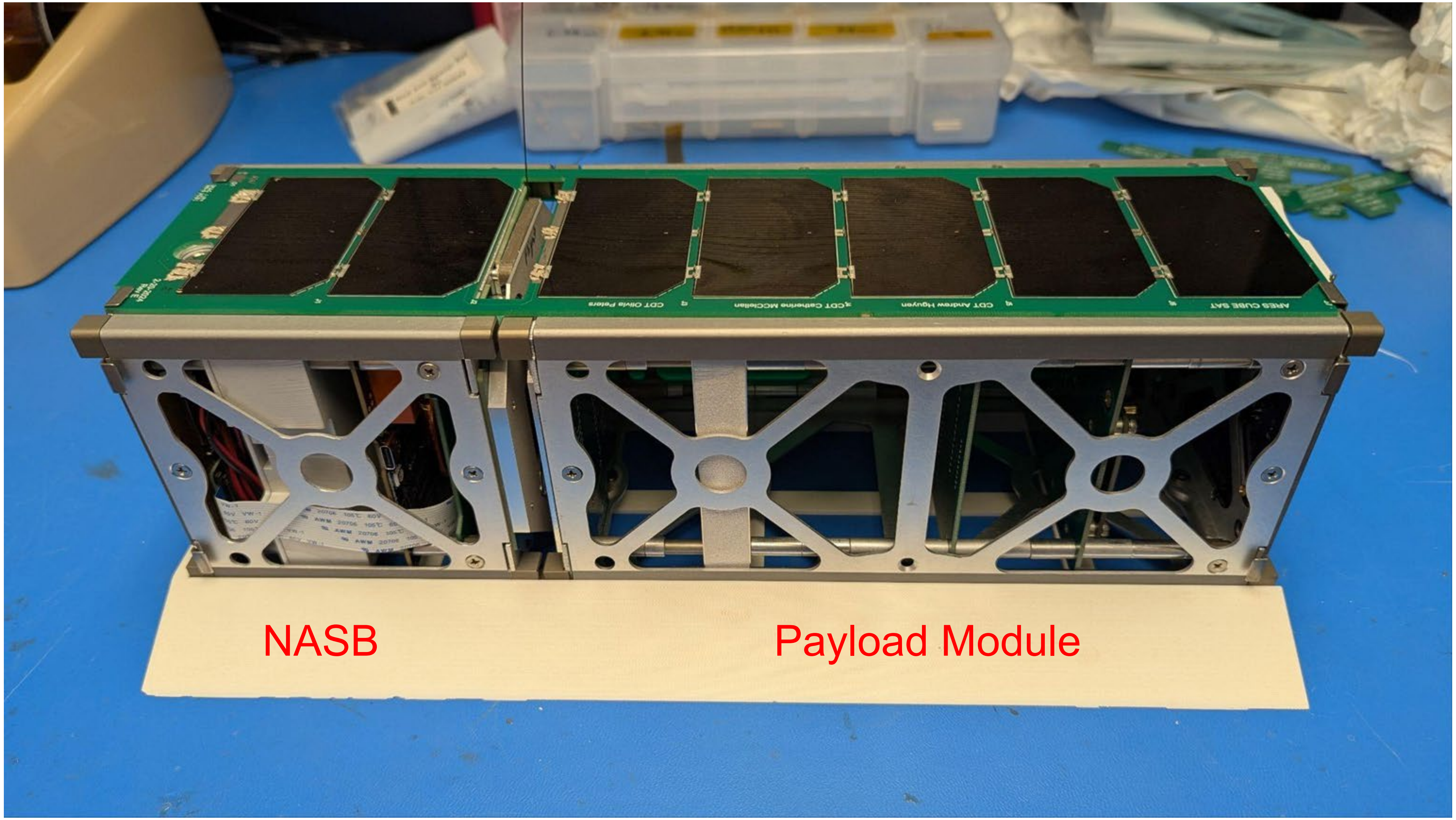


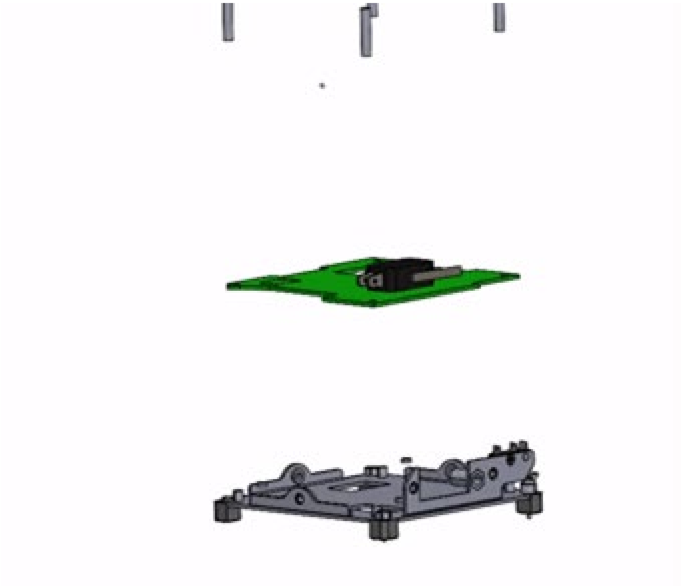


Structural Attachment of PM to NASB



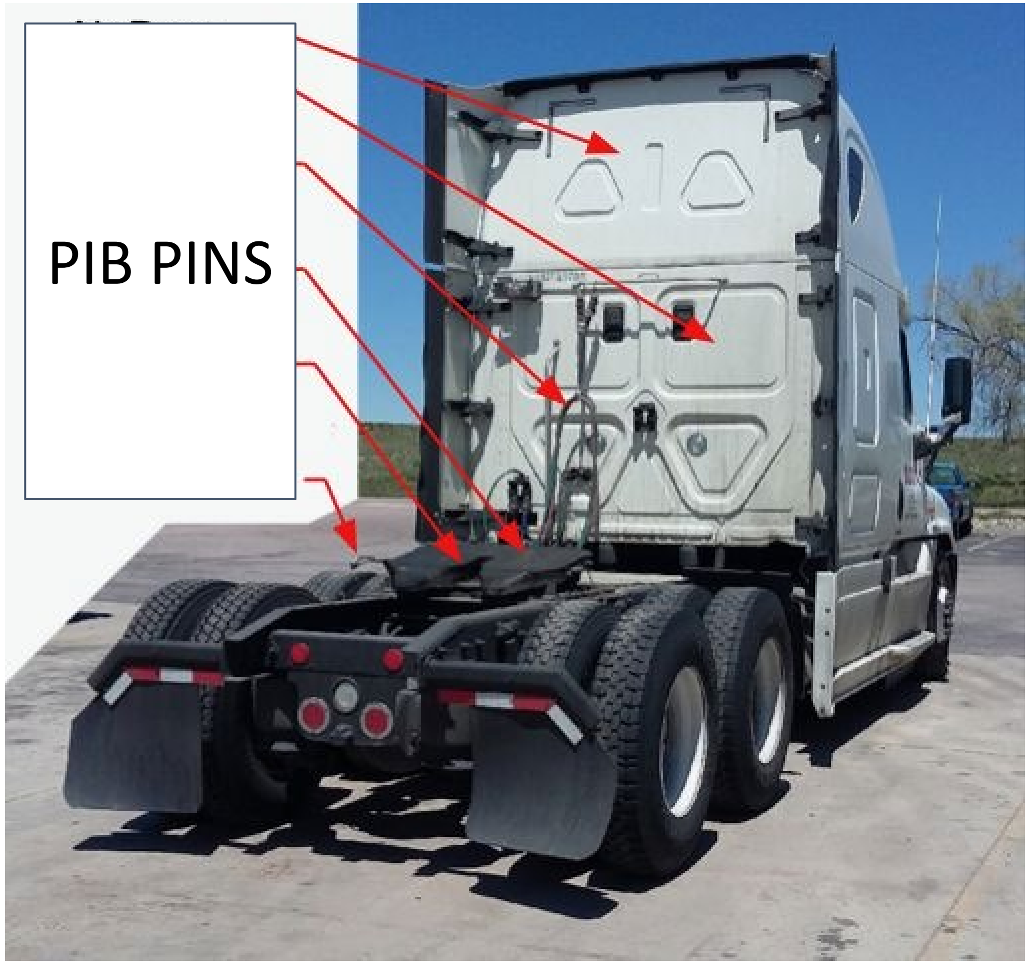
Combined 3U CubeSat

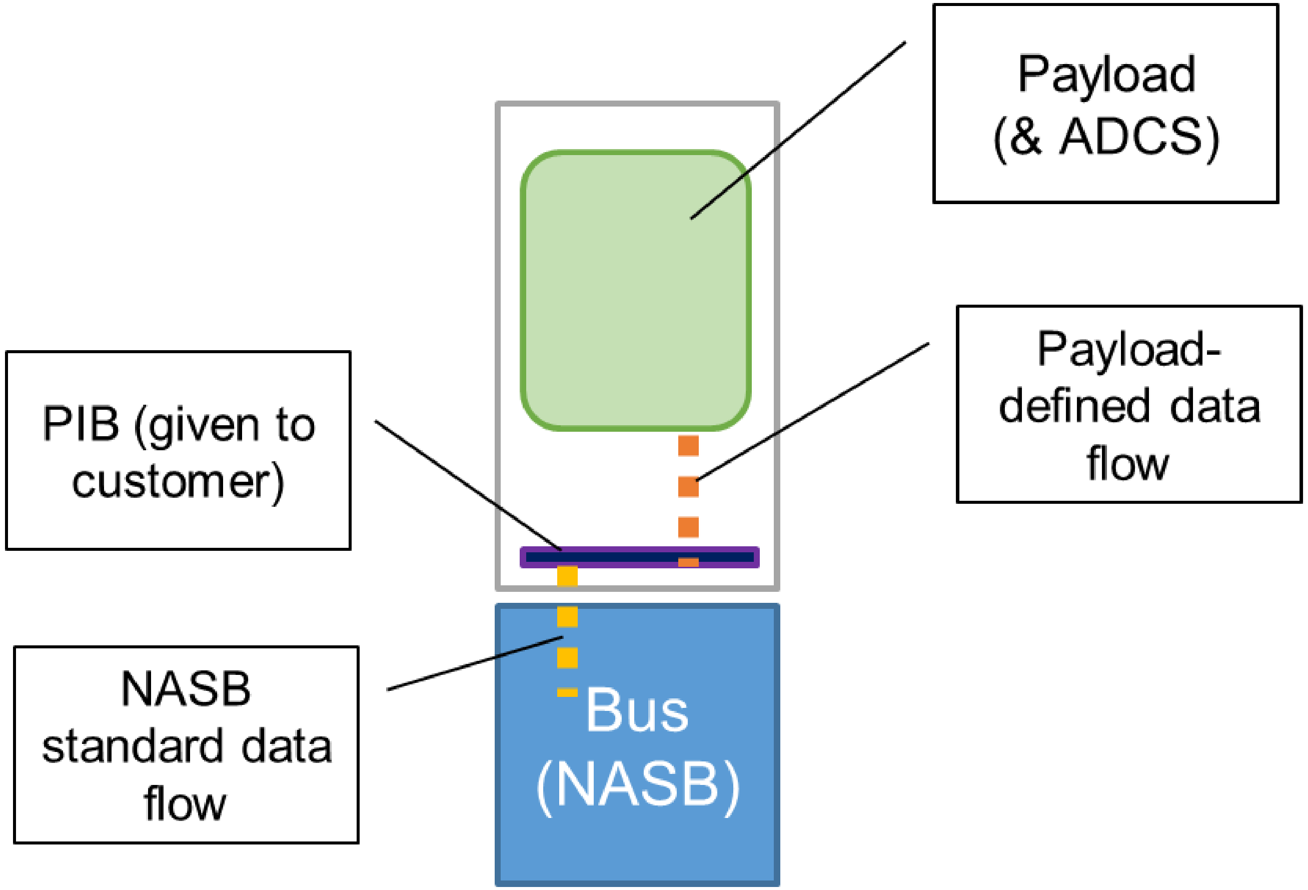




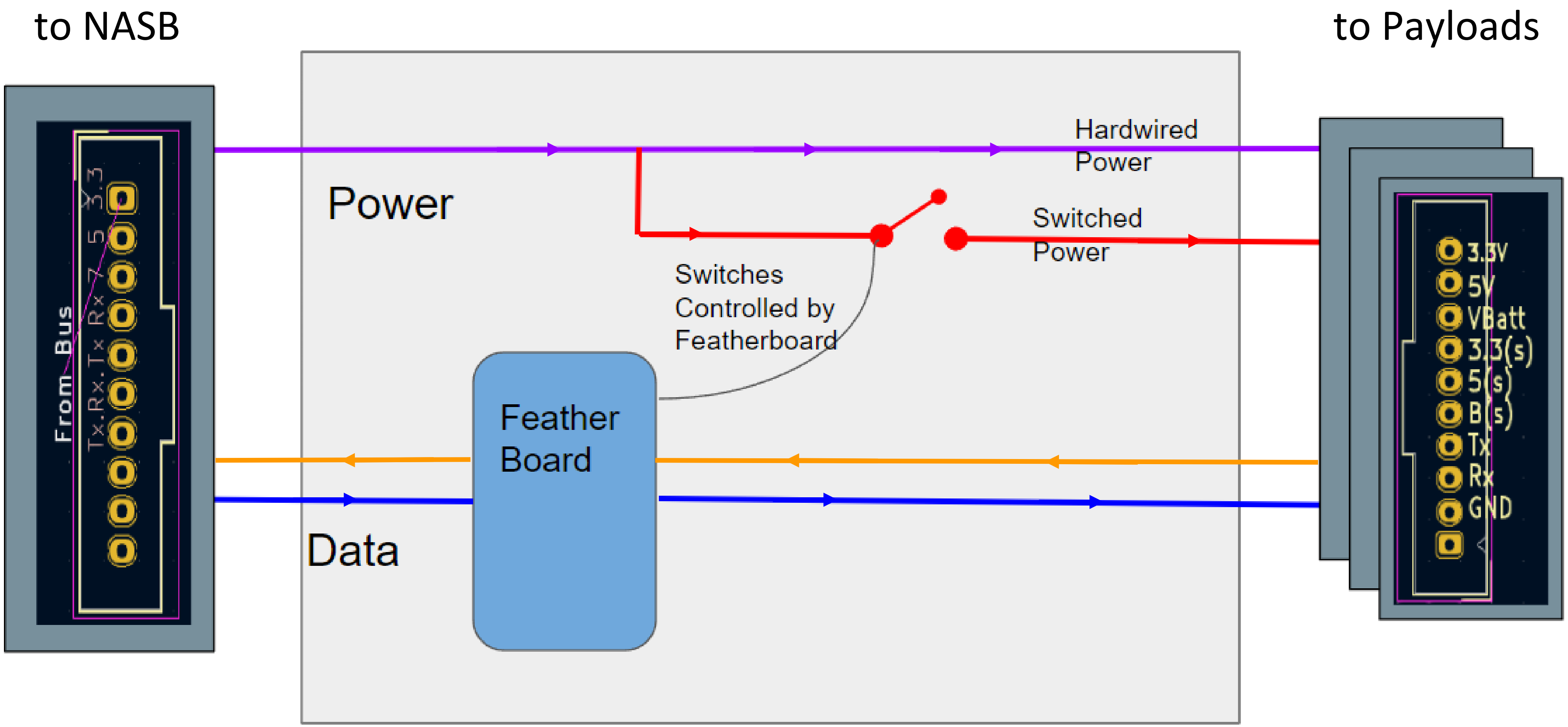
Electrical Interface

Payload Interface Board (PIB)





PIB Block Diagram

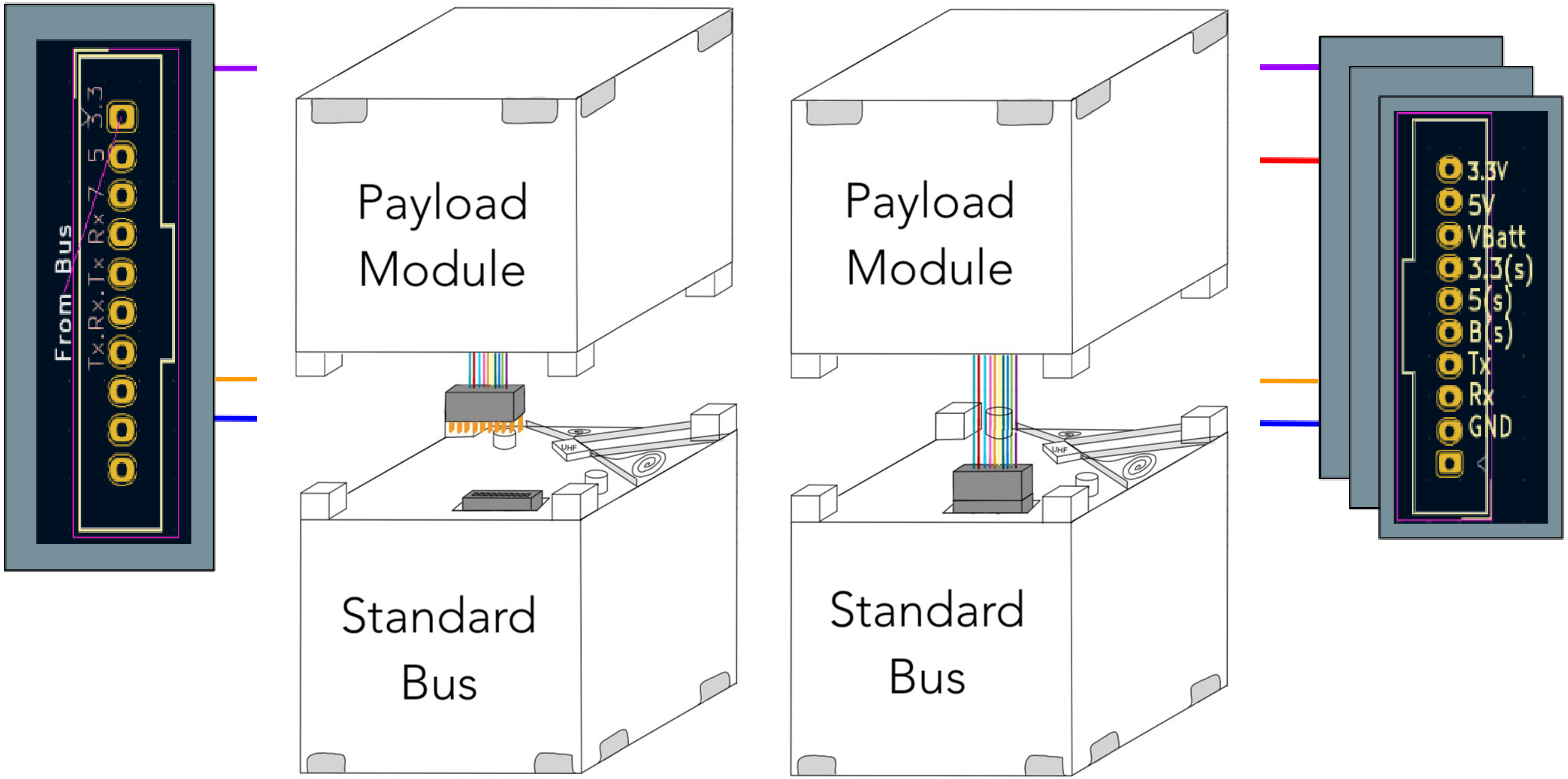


PIB Block Diagram

to NASB

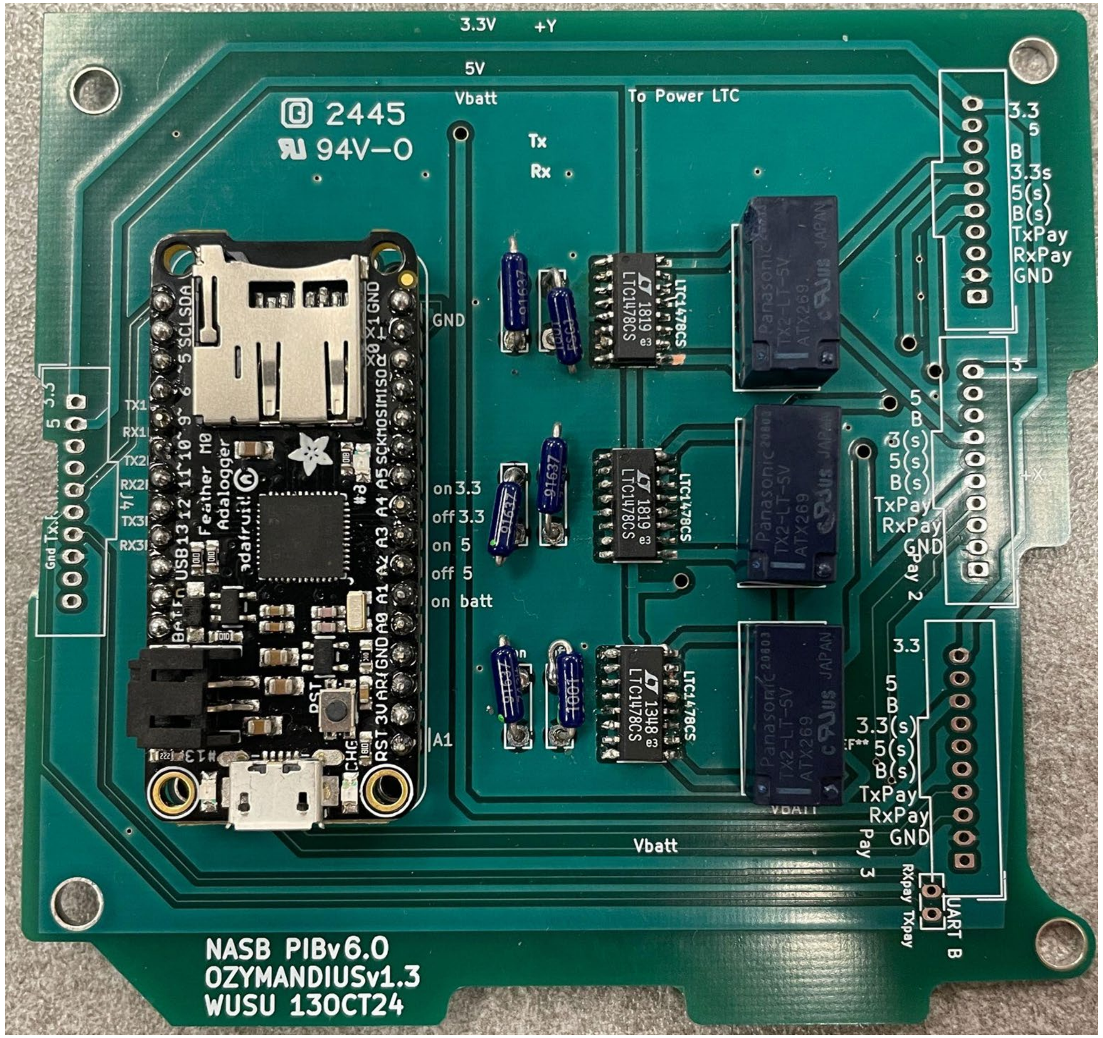
Electrical Connection

to Payloads



PIB Design

Bus

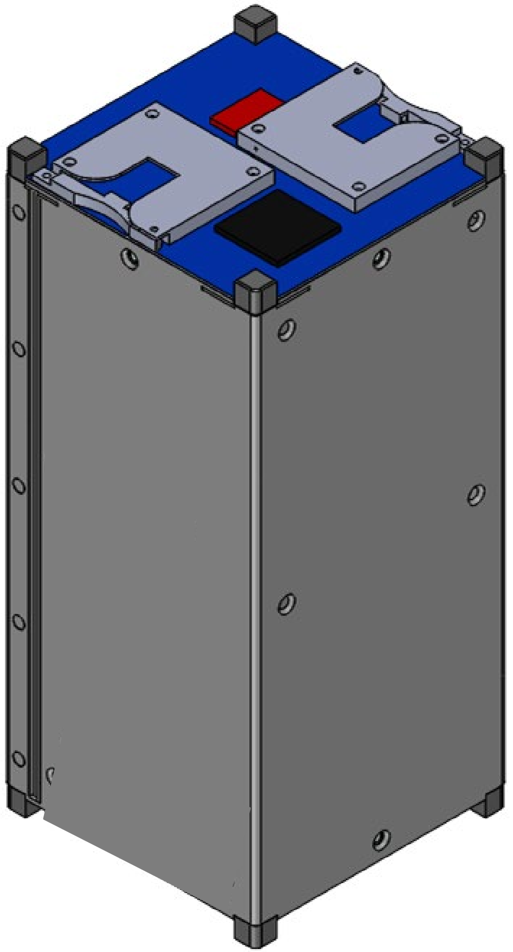


Payloads

On-orbit Demonstration: USNA-16 Mission

USNA-16 Mission

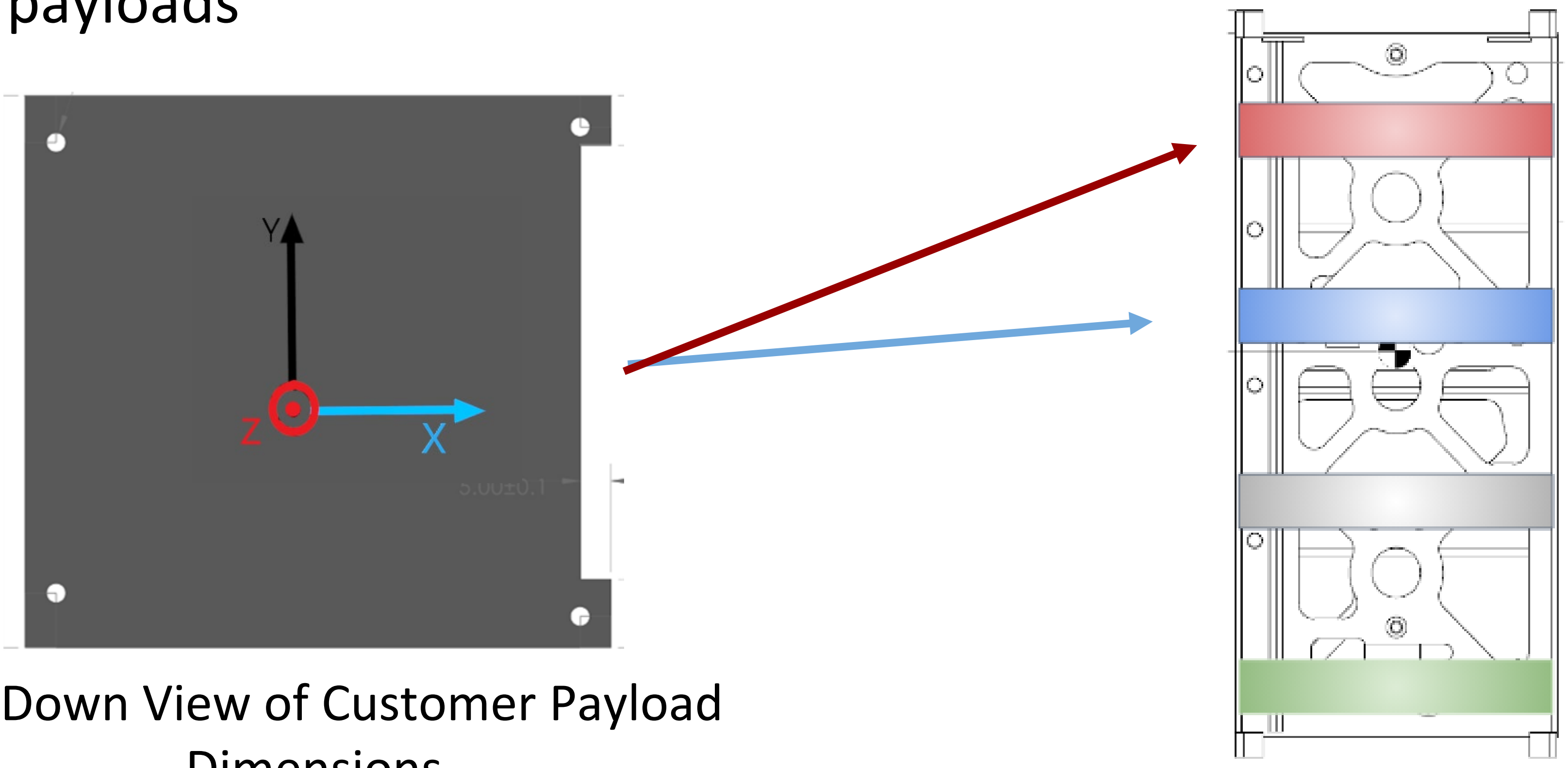
- Mass CubeSat: 3.5kg
- Power generation:
  - 5.5 W BOL -> 5.2 W EOL (3U)
- Mission orbit: 500 km 60°inclination
- Mission life: 2 years
- Holds 2 Payloads
  - University of Maryland
  - U.S. Air Force Academy



Full 2U Payload Module

Payload Mechanical Specifications

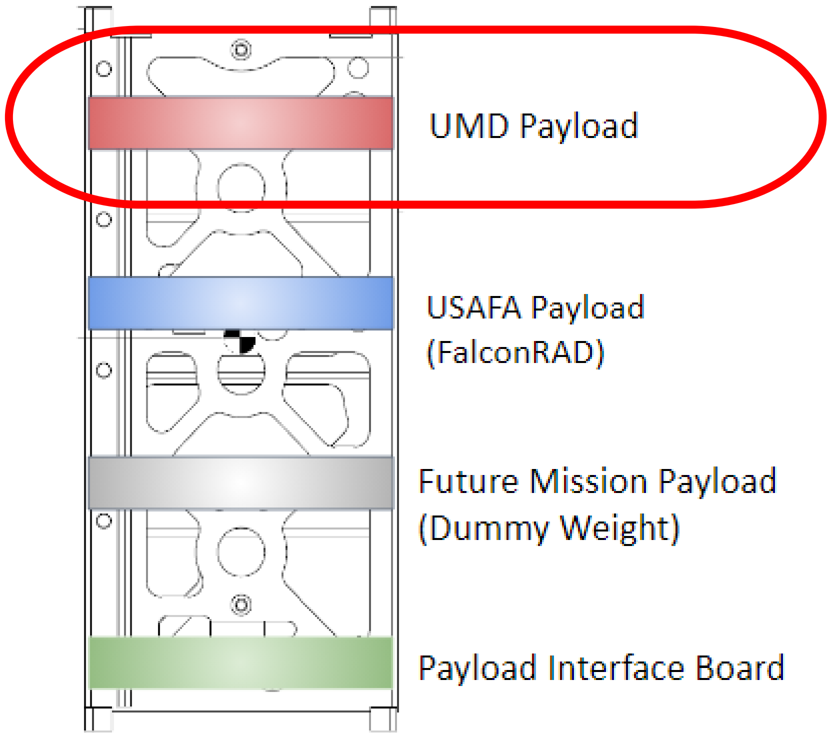
- 90 x 96 x 40mm
  - PCB hole alignment to meet Pumpkin standard for integration
  - 0.4U allotted to each customer
- Cut out on +X face to allow for frictionless wire connection between PIB and payloads



Top Down View of Customer Payload Dimensions

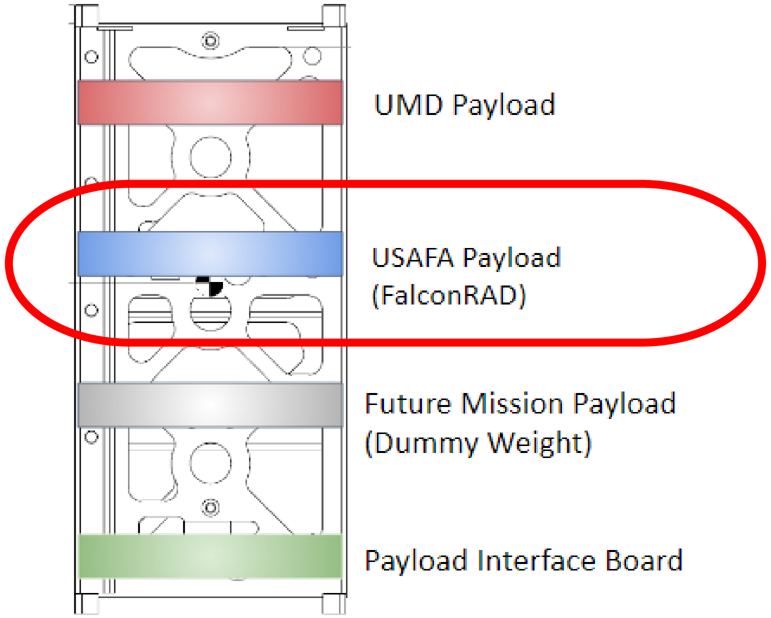
University of Maryland Payload

- An antenna to transmit to their ground station via UHF transmission
- PCB and Antenna Deployment System (ADS)
- Will operate their own antenna
  - USNA Bus will provide power

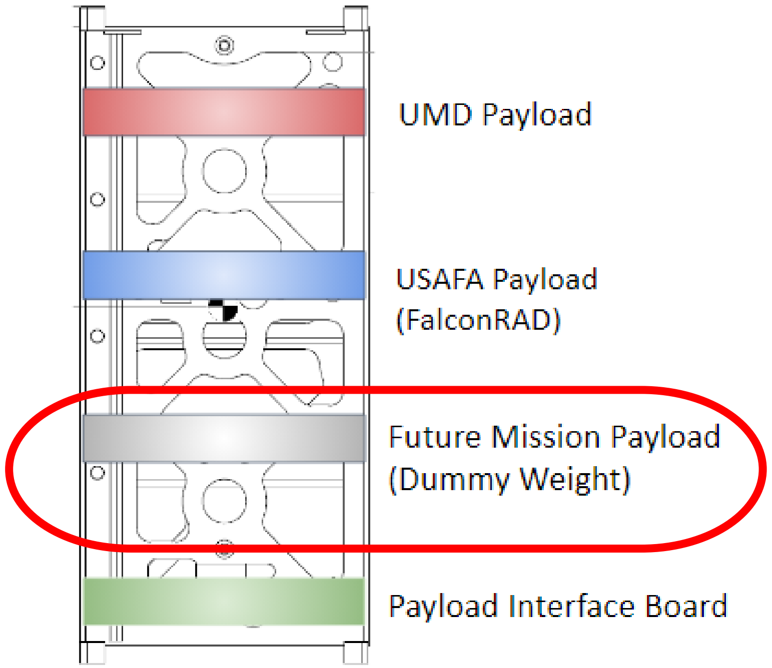


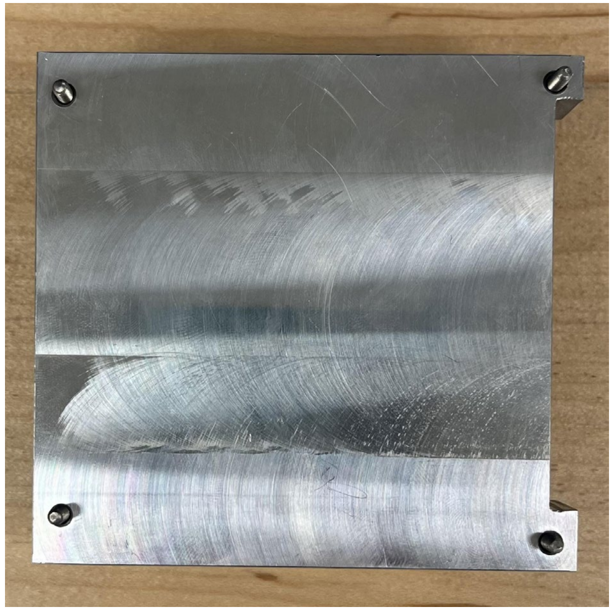
United States Air Force Academy Payload

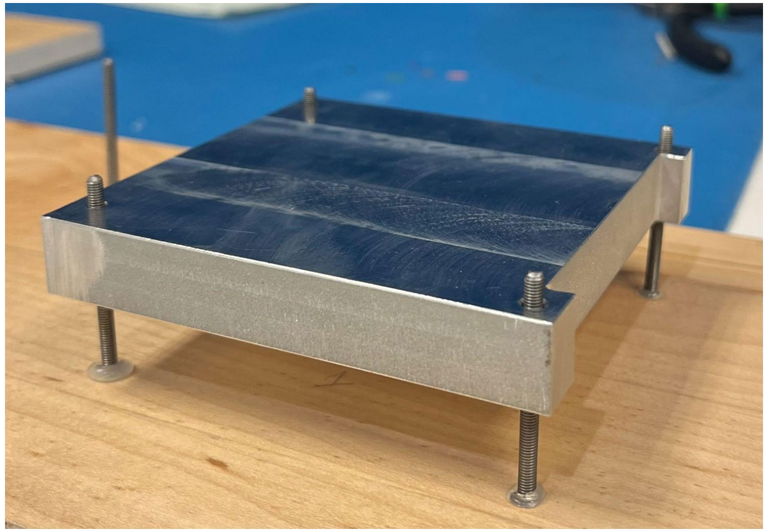
- Dosimeter to measure radiation
- Data collection in South Atlantic Anomaly
  - Higher radiation
  - Causes spacecraft malfunctions
  - Potentially due to tilt of Earth’s magnetic field and currents produced by movement of outer core



Dummy Weight







Team Goals

Provides Midshipmen and students opportunity to

- Assemble Fully Functional Satellites
- Go through entire Mission Design Process
- Aids in the learning process for satellite creation and operation

Team Adaptations

- Team Turnover
  - Project has “opened” to Brigade of Midshipman
  - Moving from “firsties” as designers and builders to “firsties” as project managers

Future Design Changes

- Standardizing connectors within bus
- Shape changes and routing holes for better fit
- Designing for better power efficiency

NASB Design Document

Revision Notes

Referenced the 2023 NASB Capstone Team's Design Document, Power, Link, and Data Budgets

Rev number	Rev date	Revised by	Notes
0	10/18/2023	NASB C&DH TEAM AY2024	Initial release
1	11/21/2023	NASB C&DH TEAM AY2024	Updated budgets, tests, schedule, plans
2	04/24/2024	NASB C&DH TEAM AY2024	Updated boards and information with final designs
3	04/29/2024	NASB C&DH TEAM AY2024	Rearranged and Removed and Added Sections
4	7/9/2024	Jake Van Spanje	Combined with Structures Design Doc

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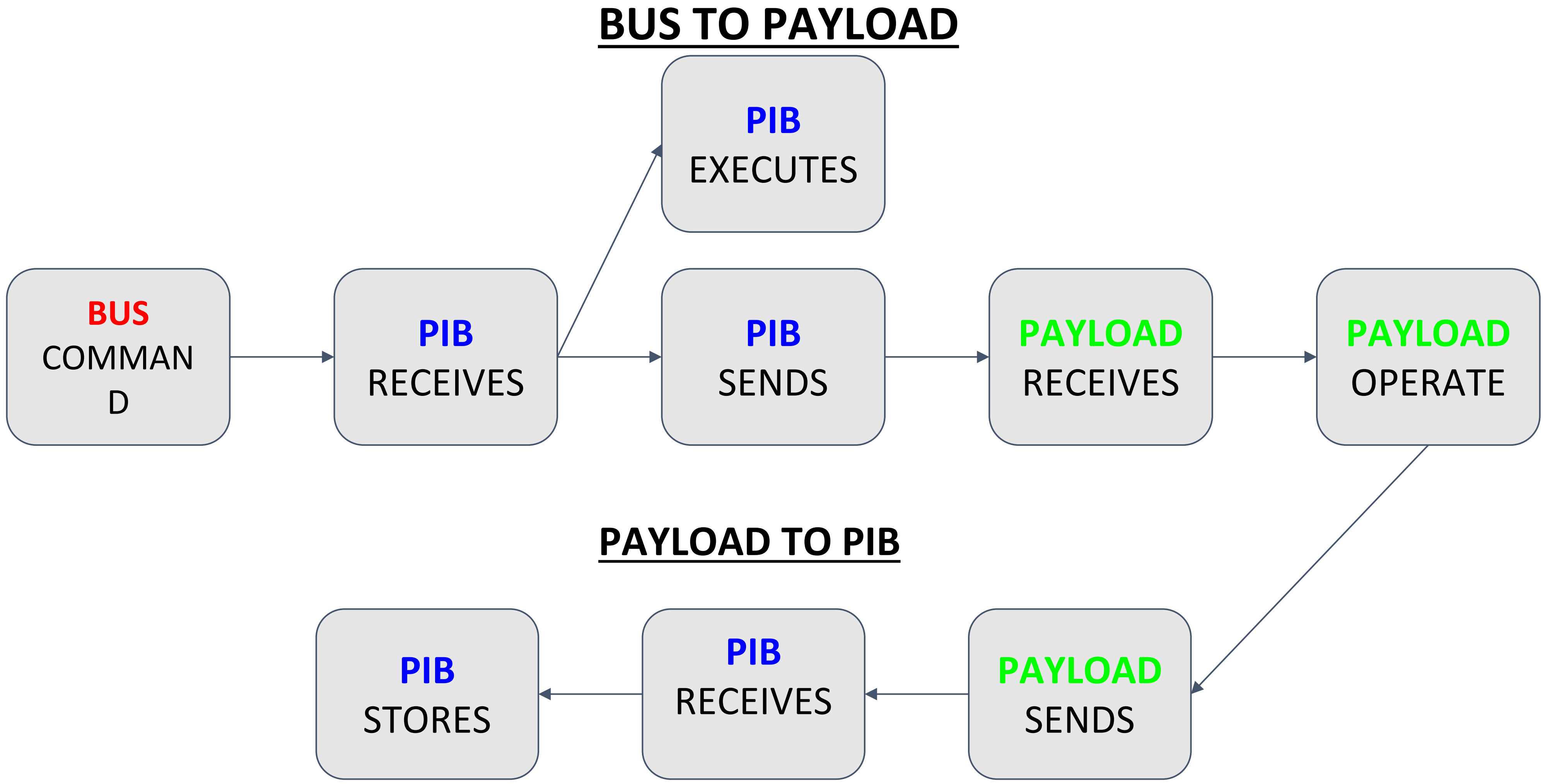
Thank you.
Questions?

PIB Software



CM Calculation

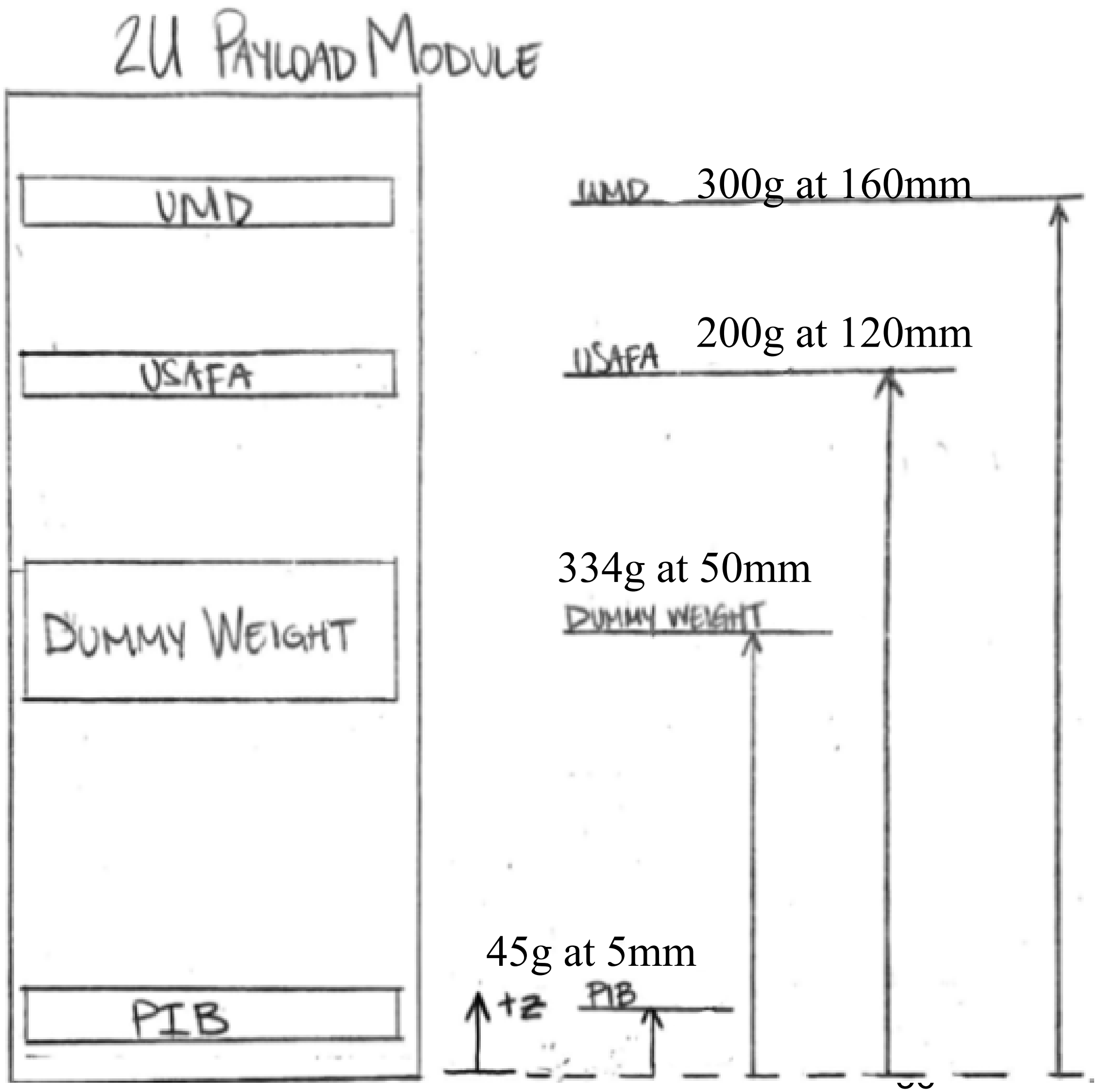
Tolerance: +/- 40mm from geometric center (100mm)

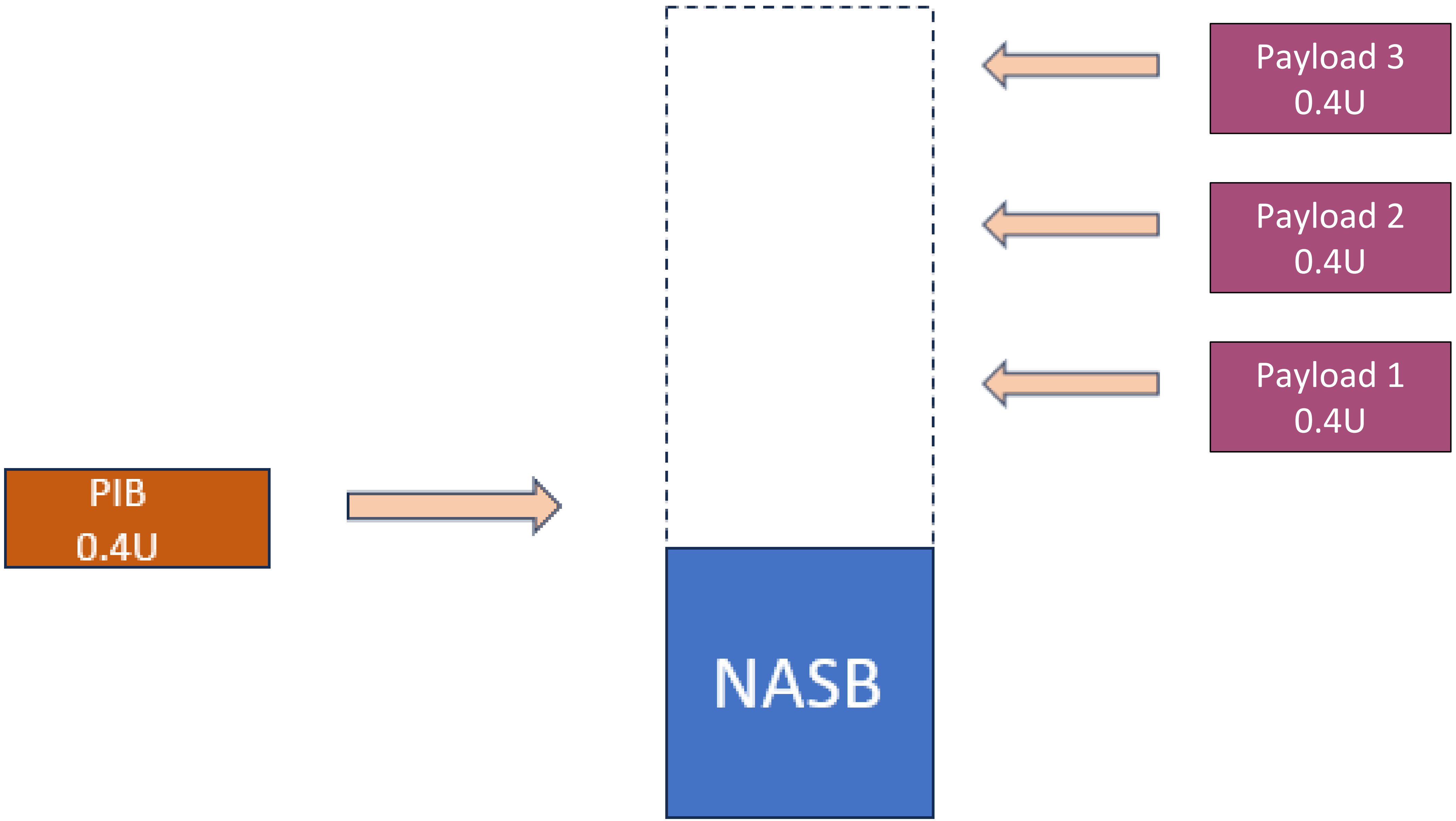
$$CM = \frac{\Sigma m_i Z_i}{\Sigma m_i}$$

$$CM = \frac{[43g*5mm]+[334g*50mm]+[200g*120mm]+[300g*160mm]}{[43+334+200+300]g}$$

$$\boxed{CM = 101.4mm}$$

[60 < 101.4 < 140] mm ✓




Payload 3
0.4U
Payload 2
0.4U
Payload 1
0.4U
PIB
0.4U
NASB

	MON	TUE	WED	THU	FRI
1 - 0755-0845		FP384		FP384	PE402
2 - 0855-0945	EA461	FP384	EA461	FP384	EA461
3 - 0955-1045	HH216		HH216	EA405	HH216
4 - 1055-1145	EA405		EA405	EA405	
Lunch - 1145-1320					
5 - 1330-1420	EA469	EA467	EA469	EA467	EA469
6 - 1430-1520	EA469	EA467	EA469	EA467	

The Payload Interface Board Software Commands

BUS TO PAYLOAD

"C:" - ID for commands to PAYLOAD from GROUND

"I:" - ID for commands to PIB to control power from GROUND

"A:" - ID for commands from GROUND to PIB requesting message file to be downlinked

"F:" - ID for commands from GROUND to PIB requesting data file to be downlinked

"$G" - ID for timecode sent to PIB from the BUS GPS

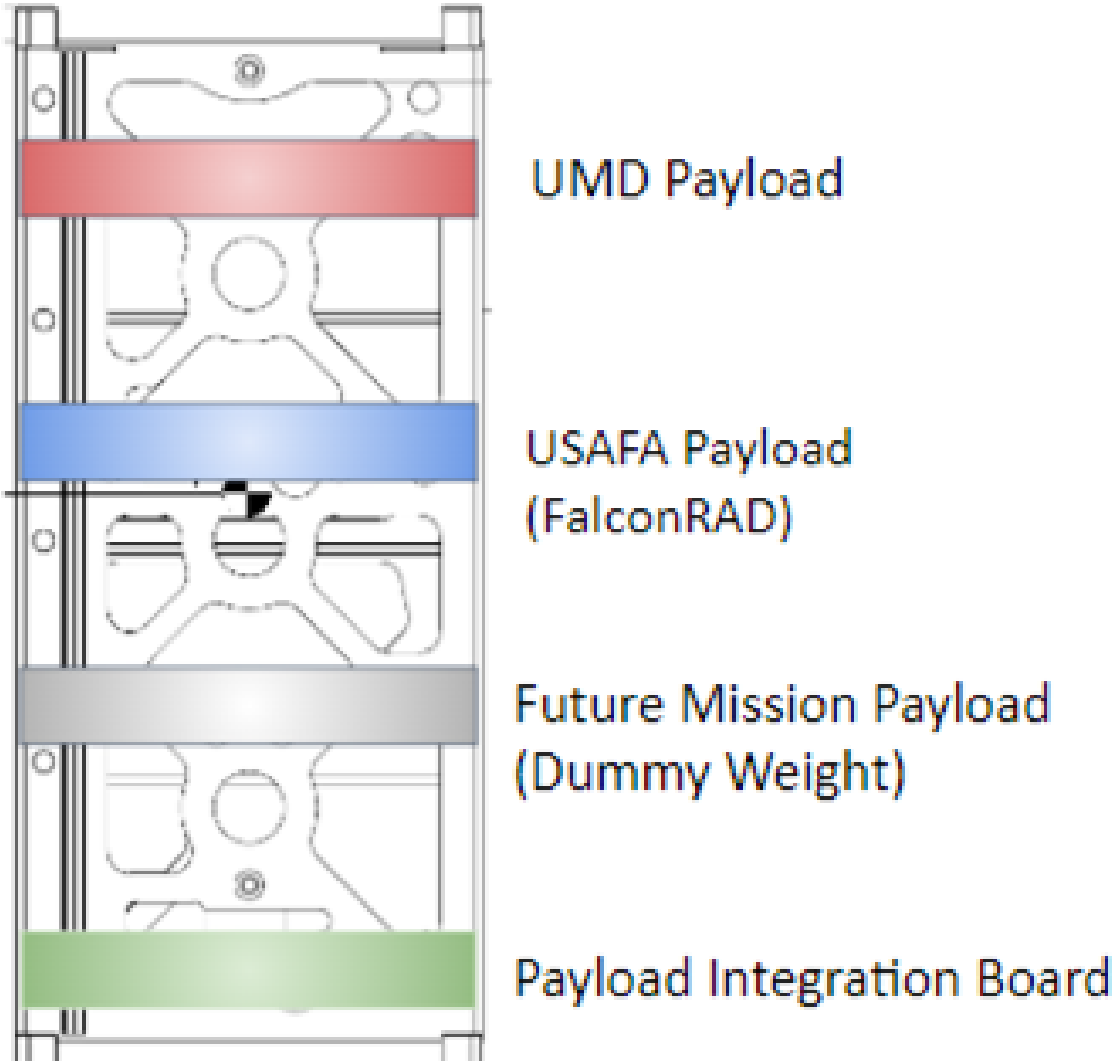
PAYLOAD TO PIB

"D:" - ID for data sent from PAYLOAD to PIB

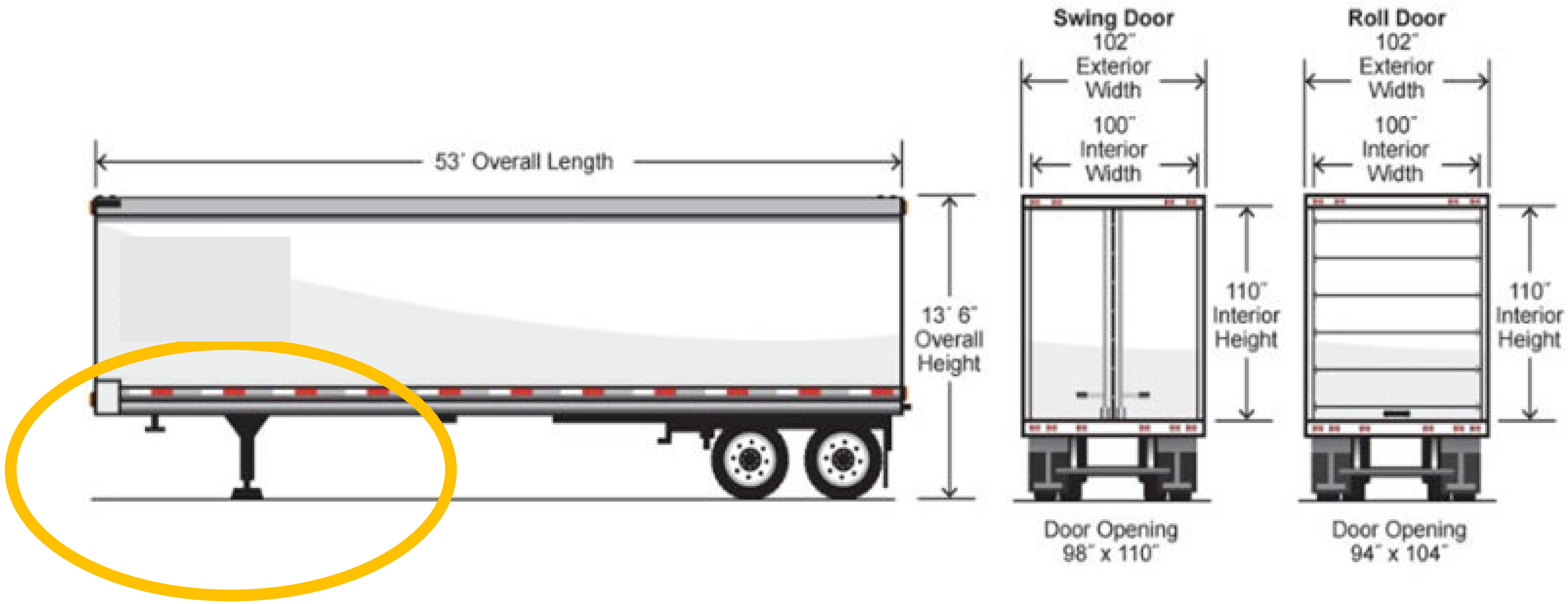
"M:" - ID for messages sent from PAYLOAD to PIB

USNA-16 Payload Module

- 2U (100x100x200mm)
  - Housing external customer payloads
  - United States Air Force Academy (USAFA)
  - University of Maryland (UMD)
  - Enough space for a third customer
- Connection to standardized bus
  - Modular connection
  - Quick and easy to replicate



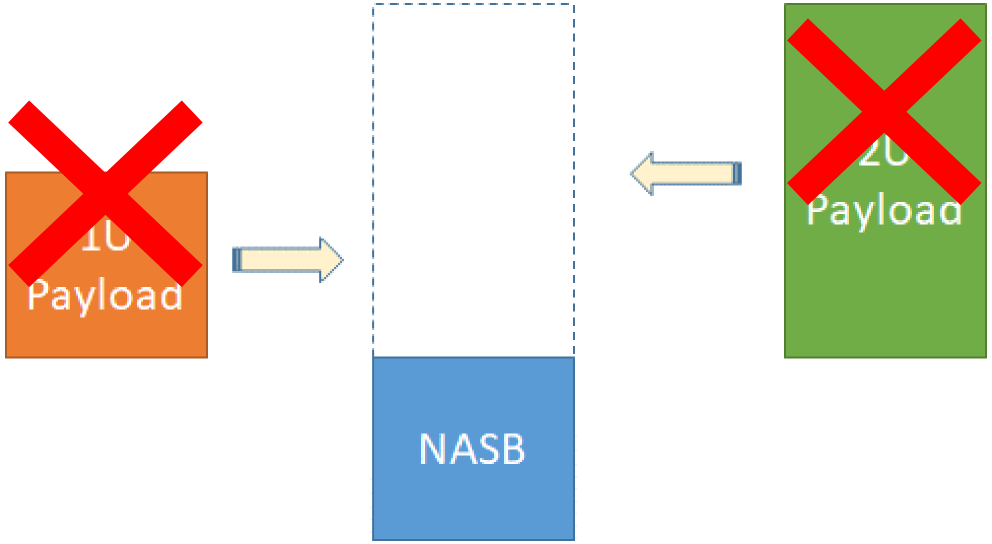
"If it fits" → Meet ICD



- Dimension requirements
- Mass and mass properties requirements
- Integration/adaptor requirements

Bus is standalone satellite

- Can be launch on own, can perform satellite communication mission



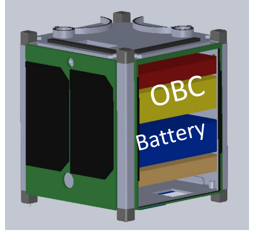
Full Standalone Satellite

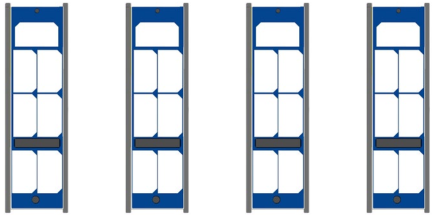
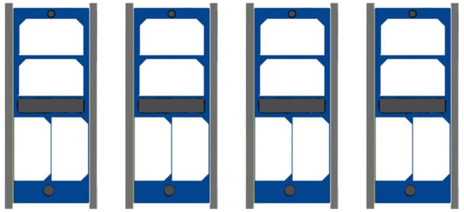
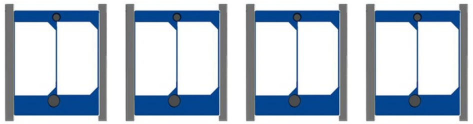
Link Budget Summary

S-Band SX1280 Transmitter
To downlink information from payloads

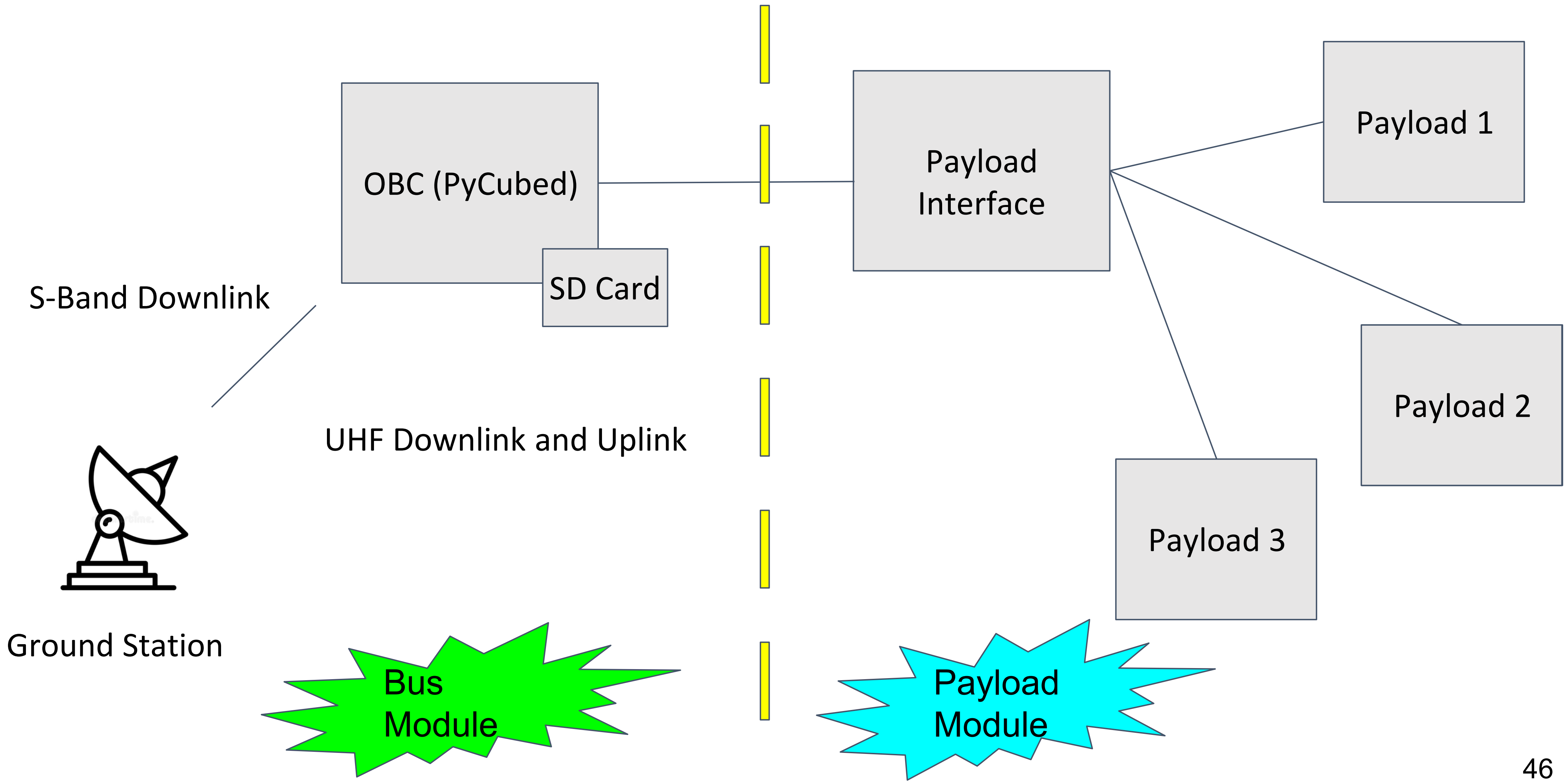
Transmitter Power	0.5W
Transmitter Antenna Gain	0.5 dBi
Downlink Frequency	2.4 GHz
Eb / No Margin	**4.0 - 11.5 dB for elevations over 20°**
Data Rate	**76.1 kbps**
Maximum downlink (accounting for losses and data overhead)	**1.0 MB per day**

Power Generation



Average Orbital Power Generated for Each Configuration		
Panel Configuration	**Beginning of Life**	**End of Life** *(2 year mission life)*
3U 	5.5 W	5.19 W
2U 	3.1 W	2.97 W
1U 	1.56 W	1.48 W

C&DH - Data Flow Overview

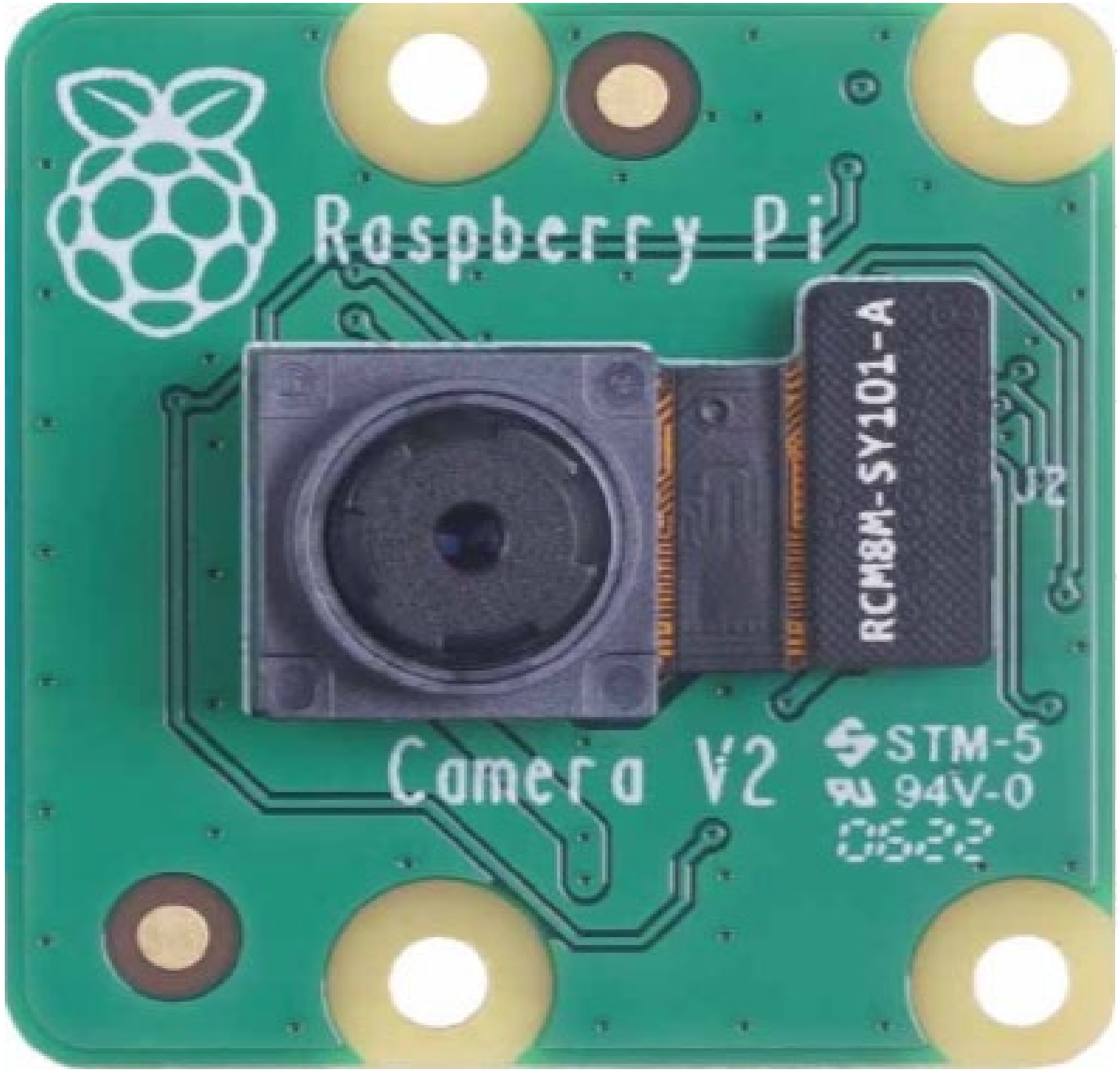


Conclusion

This design accomplishes the desired level of modularity, significantly reducing the time required for spacecraft development.

- All key functionalities made available to the payload with simply a physical and electrical connection
- variety of future projects to be successfully integrated
  - Flexible solar panel options
  - Pre-designed ADCS systems
  - Different payload size options
- Drastically shortened design phase
- Pre-constructed, shelf-stored NASB
- Rapid integration when following ICD

Camera



Raspberry Pi Camera Module 2

- Sony IMX219 8-megapixel sensor
- Capabilities: high-definition video, as well as stills photographs
- Supports: 1080p30, 720p60 and VGA90 video modes, as well as still capture
- Carries an 8 megapixel Sony IMX219 image sensor
- Dimensions: 120mm x75mm x23mm
- Weight: (32g)
- Max Operating Temp: 105º C
- attaches via a 15cm ribbon cable to the CSI port on the Raspberry Pi

PMAC - Hysteresis Strips (damping)

Hy Mu 80 (permalloy)

- Dimensions: 5.0” (length) x 0.2”(width) x 0.02” (depth)
- Material Form: Strip
- Material: 80% Nickel-Iron alloy
- Plating/Coating: Ni-Cu-Ni (Nickel)
- Magnetic feature: highly permeable
- Weight: negligible

Thermal Analysis - 250K Average Temperature

Short description of factors considered and assumptions made

1U Thermal Analysis | USNA NASB | EA469 – Capstone Project

Q: A USNA $1000 cm^3$ CubeSat in a circular, LEO @ 400 Km altitude generates power using Spectrolabs UTJ solar cells in daylight & Lithium-ion batteries in eclipse.

On average, the CubeSat generates 1.56 W of power per orbit.

The absorptivity of the solar cells with account for the majority of the CubeSat surface is 0.8 & their emissivity is 0.9.

Use: Solar flux of $1366\ W/m^2$, solar albedo ~30% of solar flux

Earth IR ~$237\ W/m^2$, $\sigma = 5.67 \times 10^{-8}\ W/K^4 m^2$

98% of power generated is generated heat.

Thermal Analysis - 250K Average Temperature

Plans for temperature control

S: $A_{in} = 0.01\,m^2$, $A_{out} = 0.06\,m^2$ 2179.7 sec / 0.60547 hr ~ eclipse

3312.4 sec / 0.92011 hr ~ daylight ~ 0.60312 % of orbit

Daylight: Q_{gen}, Q_{sun}, Q_{albedo}, Q_{IR}

Eclipse: Q_{gen}, Q_{IR}

$$Q_{gen} = 0.98\,(1.56\,W) \Rightarrow 1.53\,W$$

$$Q_{sun} = \alpha S A_{in} = (0.8)(1366\,W/m^2)(0.01\,m^2) \rightarrow 10.928\,W$$

$$Q_{albedo} = 0.3\,(Q_{sun}) \rightarrow 3.2784\,W$$

$$Q_{IR} = \alpha(IR)A_{in} = (0.8)(237\,W/m^2)(0.01\,m^2) \rightarrow 1.896\,W$$

$$\Sigma Q_{in} = \Sigma Q_{out} = \varepsilon A_{out} \sigma T^4 \Rightarrow T = [\Sigma Q_{ins} / \varepsilon A_{out} \sigma]^{1/4}$$

$$T_{day} = [(1.53 + 10.928 + 3.2784 + 1.896\,W)/(0.9)(0.06)(5.67\times10^{-8})]^{1/4}$$

$$\boxed{T_{day} = 275.48\,K}$$

$$T_{eclipse} = [(1.53 + 1.896\,W)/(0.9)(0.06)(5.67\times10^{-8})]^{1/4}$$

$$\boxed{T_{eclipse} = 183\,K}$$

$\boxed{T_{avg} = 250\,K}$ ⇒ duty cycle calculation!

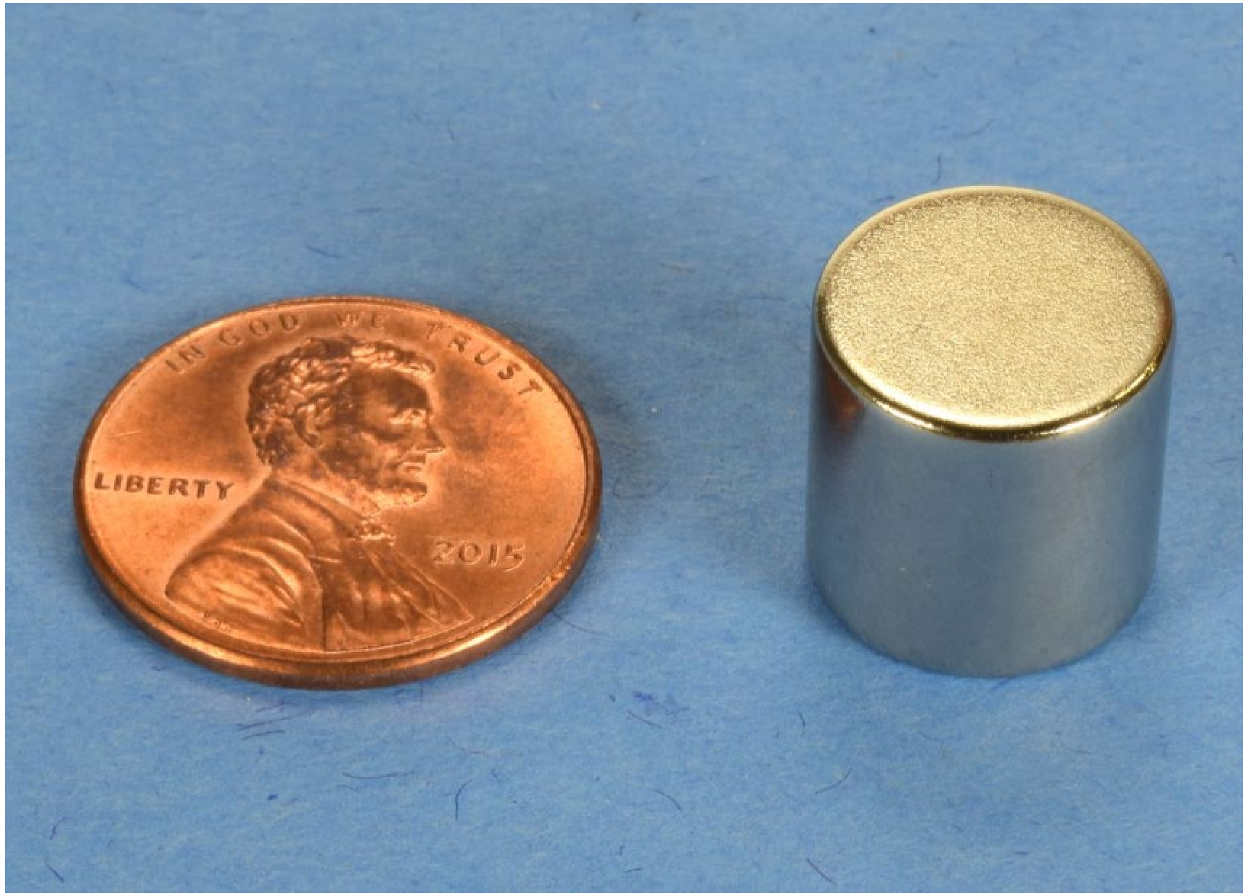
Cost Budget

Component/Item	Item Price ($)
UTJ Solar Cells	2200.00
All Printed Circuit Boards	100.00
Solar Panels	100.00
DC-DC Buck Converter 6~14V to 5V/8A	8.50
Raspberry Pi Zero 2W	15.00
8:1 Serial Port Expander	19.99
CaribouLite SDR	138.00
20 AWG Teflon Coated Wire	13.98
LiPo Batteries	52.72
GPS Antenna	13.62
Bar Magnet	2.32
Solar Panel Step-Up Converter	9.11
1U Fully Solid Pumpkin Structure	1215.00
Cover Plate Assembly	495.00
Base Plate Assembly	690.00

Component/Item	Item Price ($)
Raspberry Pi Camera Module V2	29.95
Diode for Solar Panels	2.80
Solar Panel Boost Converer 3.6-18V to 24V no pin	3.11
C to C extension cable	10.88
USB to C extension cable	13.98
Antenna Splitter	9.30
Patch Antenna	21.19
316 M3 1 meter Through Rods	51.28
Bar Magnet	3.98
Hymu80 (Hysteresis Strips)	600.00
Camera Cable	3.95
Board Connector (Plug)	0.52
Board Connector (Receptacle)	0.44
Solar Panel Connector (Plug)	1.05
Solar Panel Connector (Receptacle)	1.17
MOLEX Crimper for 24-30AWG	410.13

TOTAL	6234.30

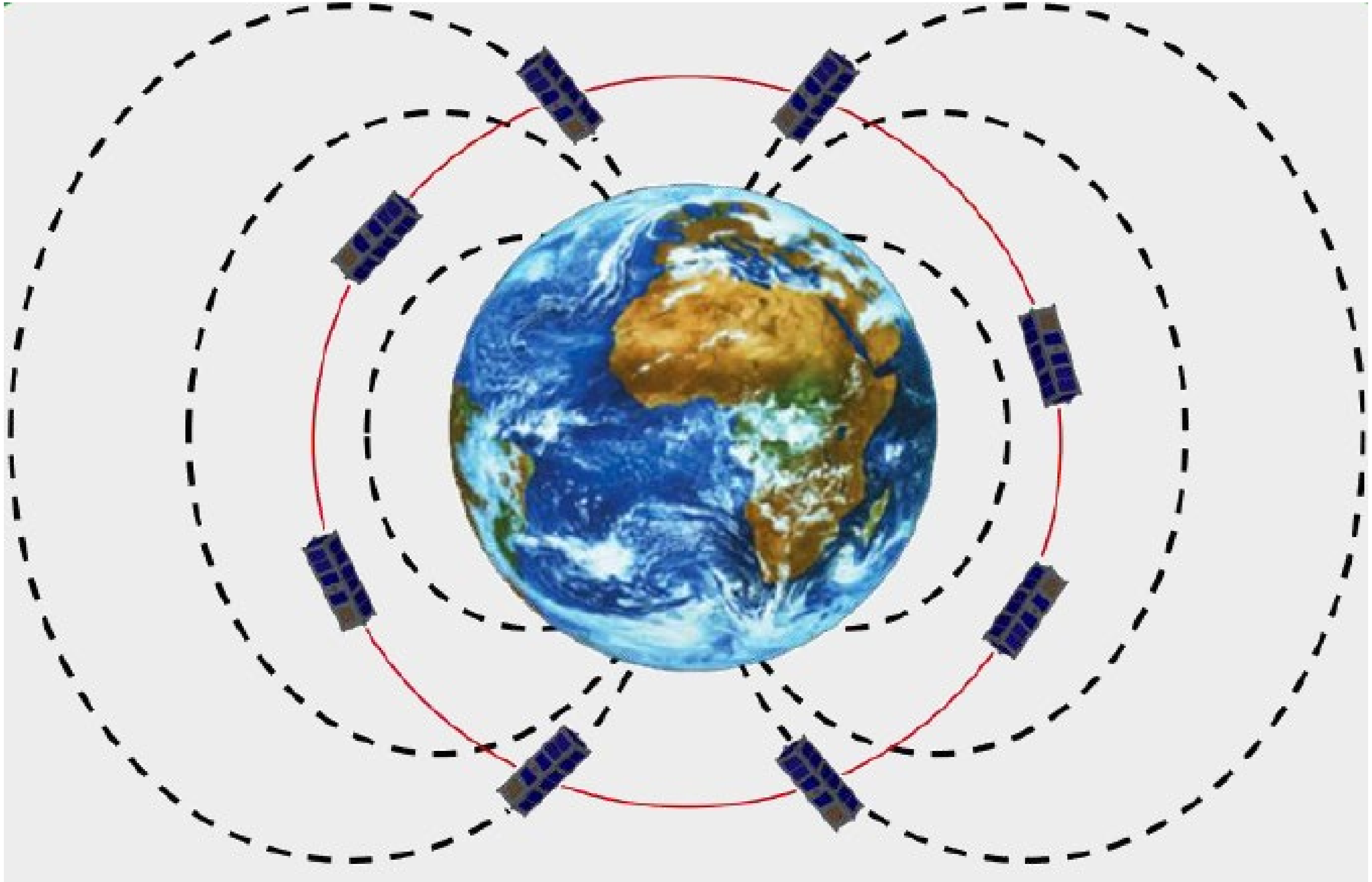
PMAC - Bar Magnet (tracking)



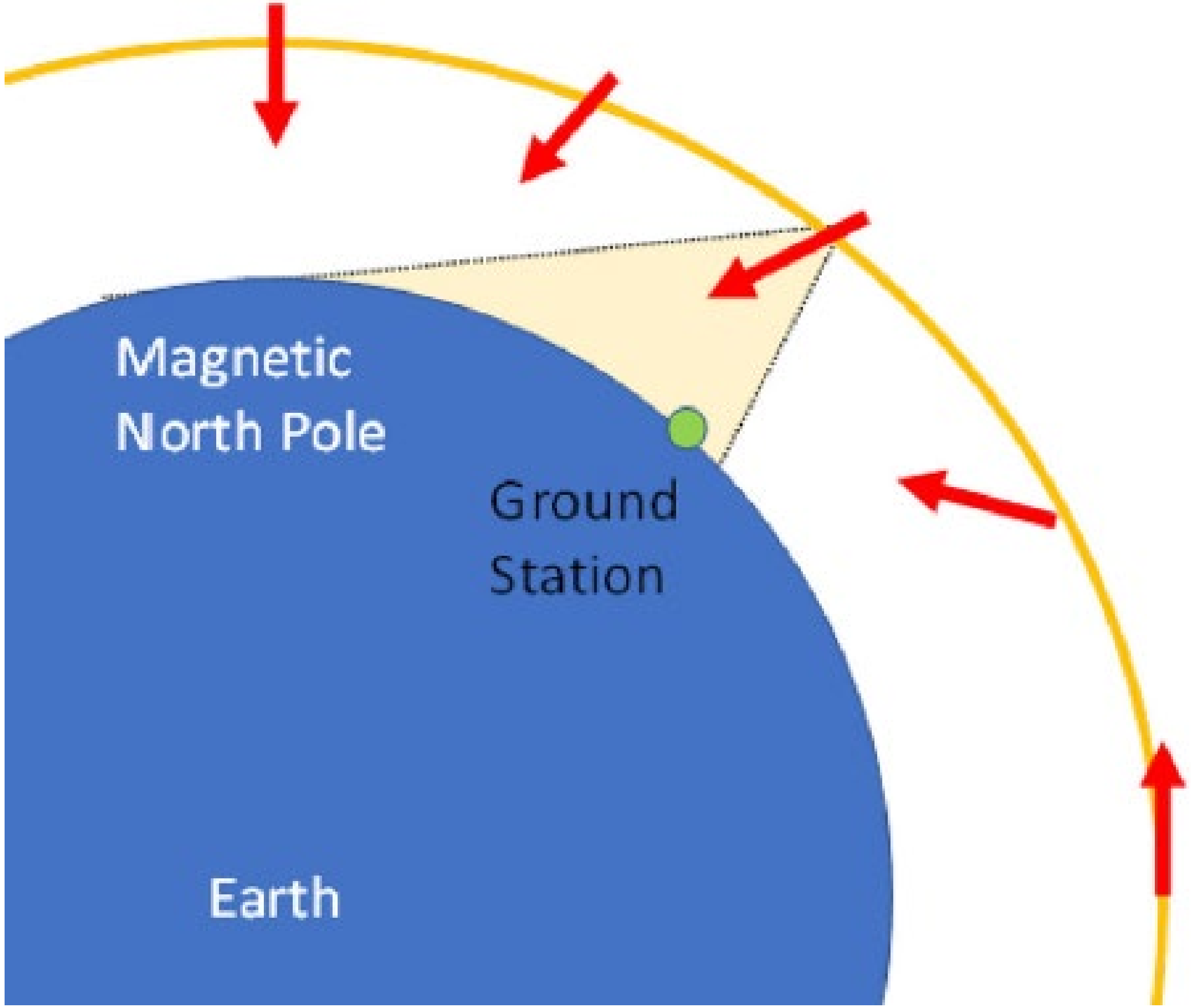
D88-N52

- Dimensions: 1/2" dia. x 1/2" thick
- Material: NdFeB, Grade N52
- Plating/Coating: Ni-Cu-Ni (Nickel)
- Magnetization Direction: Axial (Poles on Flat Ends)
- Weight: 0.426 oz. (12.1 g)
- Pull Force, Case 1: 18.08 lbs
- Pull Force, Case 2: 20.38 lbs
- Surface Field: 6619 Gauss
- Max Operating Temp: 176ºF (80ºC)
- Brmax: 14,800 Gauss
- BHmax: 52 MGOe

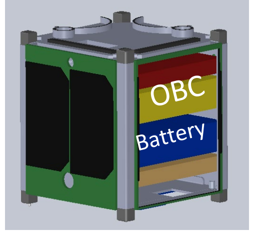
Antenna Pointing



Antenna Pointing



Standard Bus Power Consumption



Bus Power Consumption		
	Measured	**Power Consumed in Normal Mode**
PyCubed	0.098 W	0.10 W
RPi	1.23 W	0.12 W
(Worst Case) Radio UHF	3.38 W	0.035 W
Total Bus Power Consumed:		0.25 W
Power Available		1.48 W
Total Margin		83 %