Dream Big PDR

Emerging Technology for manufacturing & entrepreneurship of Student payloads

CHARM-Sat

(Control of Hardware Attitude using Reliable Magnetorquers) 🍀 ✨

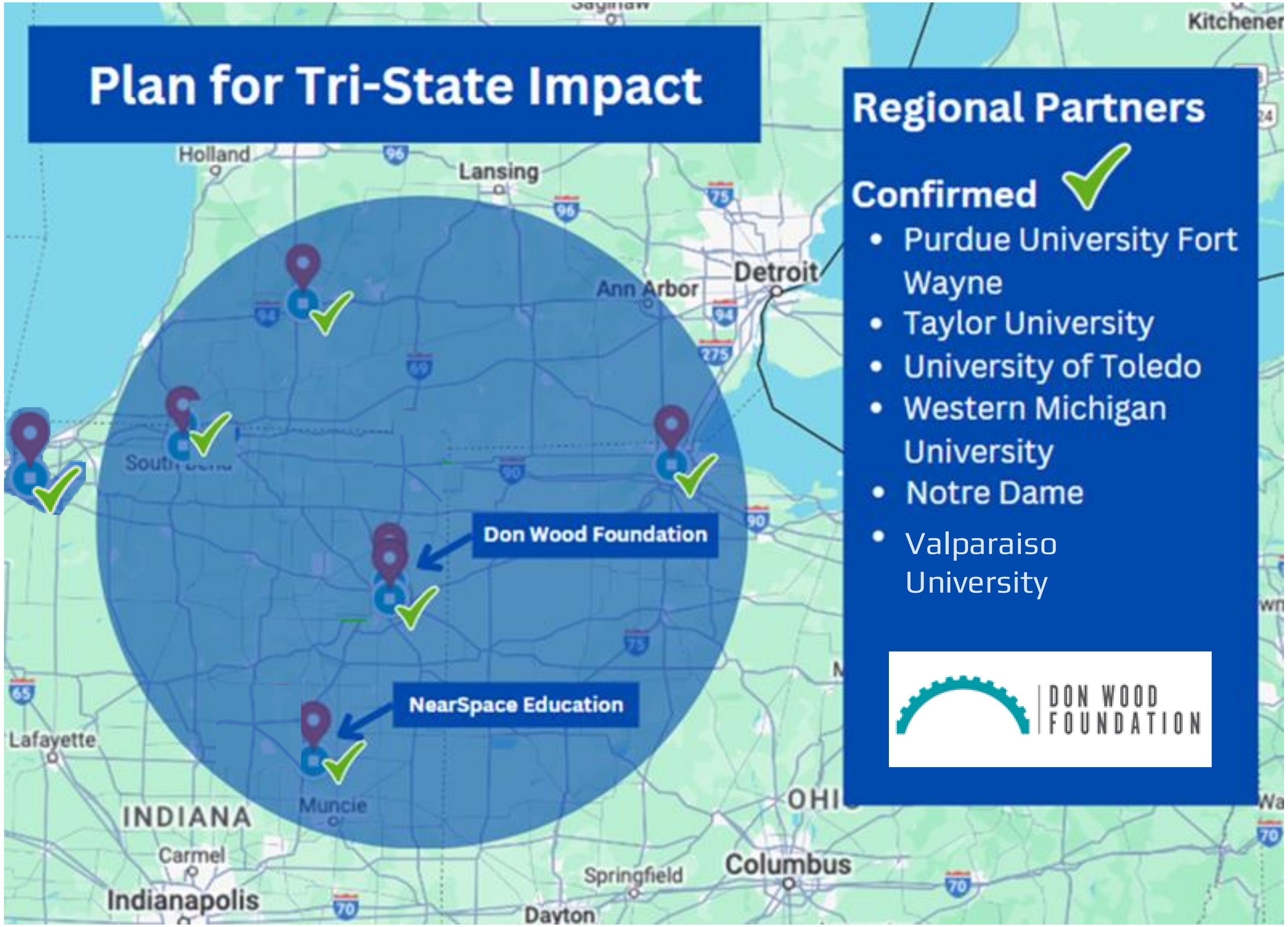
University of Notre Dame

IrishSat

Agenda

- Introductions
- Project Overview
- Outreach Plan/results
- Objectives of Team Mission
- Schedule
- Payload specifications
  - CAD
  - System block diagram
  - Firmware Op
  - Power
  - Test
  - BOM
  - Risk
- Deliverables for CDR meeting at Dec 2024
- Questions and Feedback

Project Overview



Project Dream Big

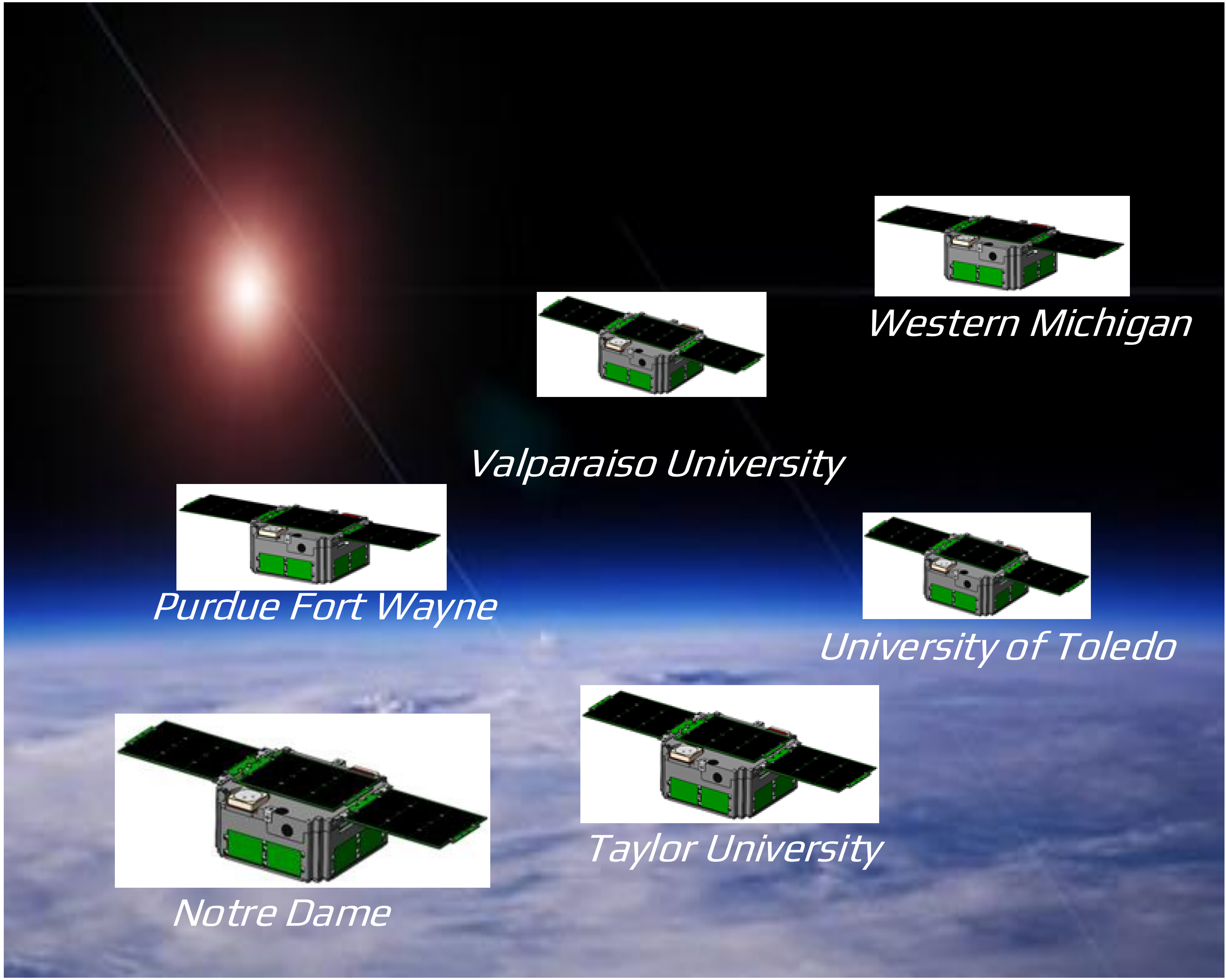
Phase 1

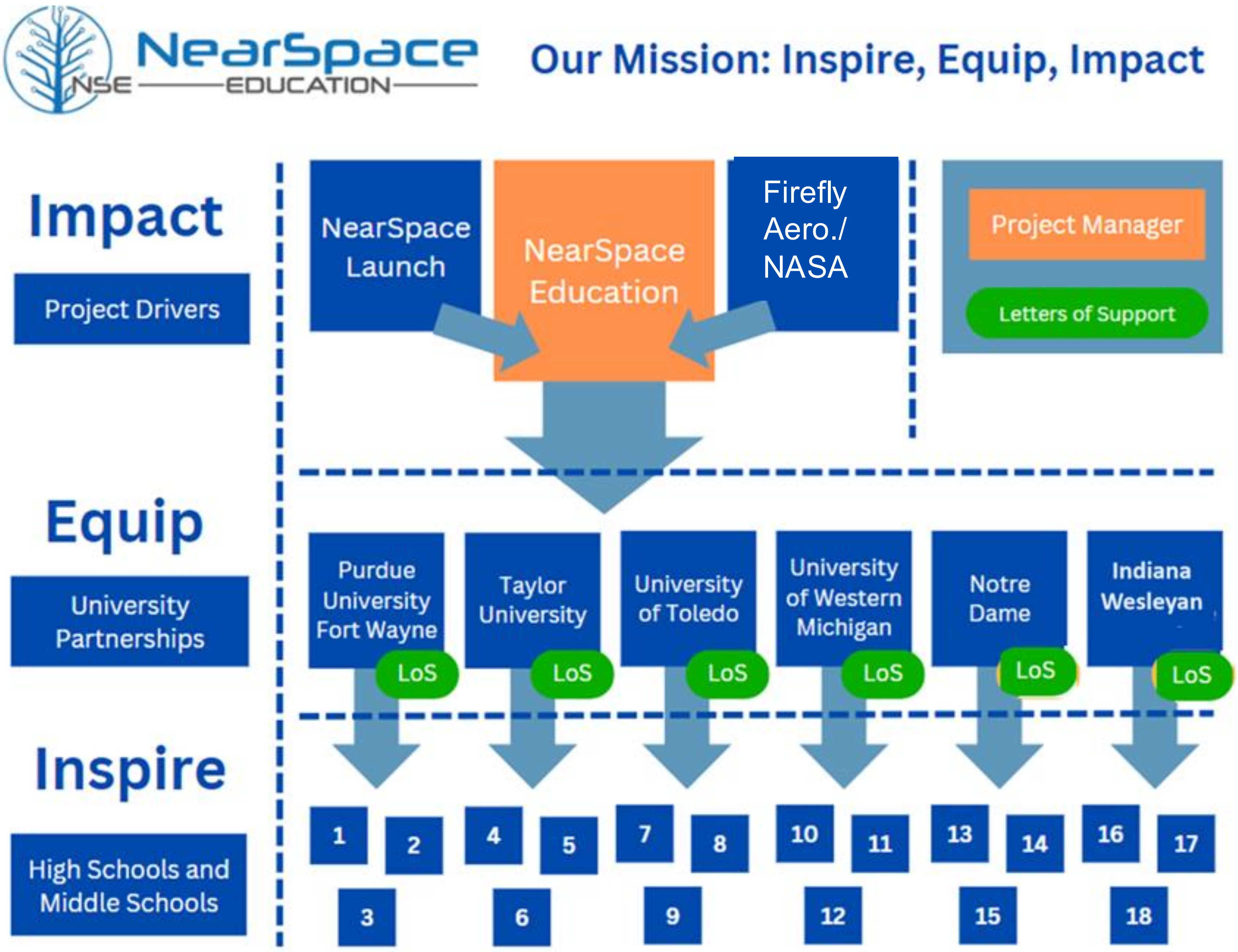
Manufacturing of 6 SmallSat Spacecraft

with

University Partners

Phase I
Dream Big





Phase I - Dream Big

Outreach and Balloon Program

Outreach Plan

- Groups
  - St. Adalbert Elementary School
  - Robinson Community Center
  - Success Academy
- Level of Involvement
  - Presentations
  - HAB experiment
- Current Status
  - Working with Success Academy on dates for HAB launch
  - Presentation at Success Academy, one planned for St. Adalbert, one getting set up at Robinson Community Center

Team Project Overview

Gantt Chart


Project:
Project Start Date: Sep-25-24
TASKS START END
October
November
PDR
ADCS: 25-Sep 15-Dec
Research b-dot 25-Sep 20-Oct
Research determining nadir vector from horizon sensor 25-Sep 20-Oct
Research how to test horizon sensors 15-Oct 23-Oct
Build equations of motion so that we can simulate control (in constant b-field) 17-Oct 25-Oct
Combine equations of motion with PySol to simulate control with realistic varying b-field 25-Oct 5-Nov
Research finding position from magnetometer and horizon data - talk to Jim 20-Oct 30-Oct
Figure out how to simulate horizon sensor 30-Oct 5-Nov
Image processing software to get horizon - look at IRIS v1 sun tracking code 25-Oct 5-Nov
Write search algorithm to find horizon if we currently don't see it 1-Nov 20-Nov
Control algorithm to point "nadir" (just 70 deg down from horizon) - probably just a PD or PID to start 5-Nov 20-Nov
Simulate detumble and nadir point 15-Nov 1-Dec
Build orbit determination software for use with magnetorquers and horizon sensors only 1-Dec 15-Dec
Electronics: 25-Sep 15-Dec
Research hysteresis and what a demagnetizing process would look like
Research I2C or SPI enables space sensors (sun tracker/IR camera, magnetometer, GPS, Gyro). Can you find magnetometer that can be calibrated and that is small and can be put directly on a board? Keep in mind maximum b-field it may experience. 2-Oct 7-Oct
Identify suitable mag drivers (H-Bridge, etc), current sensors, and feedback components for low power space rated application to be parts of mag circuit design 2-Oct 7-Oct
Research gyros that can survive launch and can help give us rates 2-Oct 7-Oct
Research MCU's (rad-hard or close enough?) 2-Oct 7-Oct
Determine how much memory we need and if need extra external 2-Oct 7-Oct
Preliminary magnetorquer design. What ferromagnetic material for core? How many winds? What gauge wire? How much current? Not my area but I would say start with the current limits we are given and build out from there to get max torque keeping in mind size constraints. Dual windings for redundancy? 2-Oct 15-Oct
Work from ICD to allocate power, starting with microcontroller and sensors, and then the rest to magnetorquers 7-Oct 15-Oct
After selection of parts, create full schematic 16-Oct 26-Oct
Order sensors and breadboard system to understand if it is functional 23-Oct 5-Nov
After full schematic is created, make a full board layout 30-Oct 12-Nov
Write software to interface with the UART comms link and follow packet structure. 30-Oct 11-19
Order first prototype and test functionality. design, fabricate PCB with MCU <-> our sensors. NSL UART interfaces 13-Nov 9-Dec
GOAT/Structures: 25-Sep 15-Dec
Research, design, and test 1D testbed with encoders for tracking position 25-Sep 20-Oct
Get helmholtz cage working and consistent (produces a very known b-field). You should be able to model what b-field should be and then measure with magnetometer. Maybe add feedback loop so that current adjusts until it is producing the desired magnetic field? 25-Sep 25-Oct

Objectives of Team Mission

Executive Summary

- Develop Innovative Technology:
  - Design and implement a modular Magnetorquer-Only ADCS system, providing a low-power, scalable solution for CubeSat autonomous pointing and stabilization.
- Educate Students:
  - Offer hands-on experience in space systems development, enhancing interdisciplinary problem-solving and real-world application of engineering skills.
- Contribute to the Advancement of Space Tech:
  - Advance CubeSat technology by developing a cost-effective, reliable ADCS system using magnetorquers only control with reduced sensor data requirements.
- Benefit the IrishSat Organization:
  - Strengthen IrishSat's technical capabilities and reputation through successful execution of a challenging space mission.
- Bring Recognition to the University of Notre Dame:
  - Showcase Notre Dame's student leadership and excellence in space innovation and research through the University's first successful in-orbit mission.
- Impact the Youth Community through Outreach:
  - Inspire and engage younger generations through outreach activities, promoting STEM education and interest in aerospace.

Objectives of Team Mission

Data, Learning Goals, Scientific Conclusions

Data –

- effective torque, pointing accuracy, Current through magnetometers, correlated magnetometer reading, gyro reading over time (are we slowing down our rotation)

Learning Goals –

- Main goal to learn how to make a low power ADCS solution
- Discern the best material and magnetorquer design for optimal torque
- Learn the most efficient, autonomous software design for the system

Scientific Conclusions –

- Optimized magnetorquer design with new materials
- Low-power, low-cost magnetorquer-only solution with reduced sensor suite

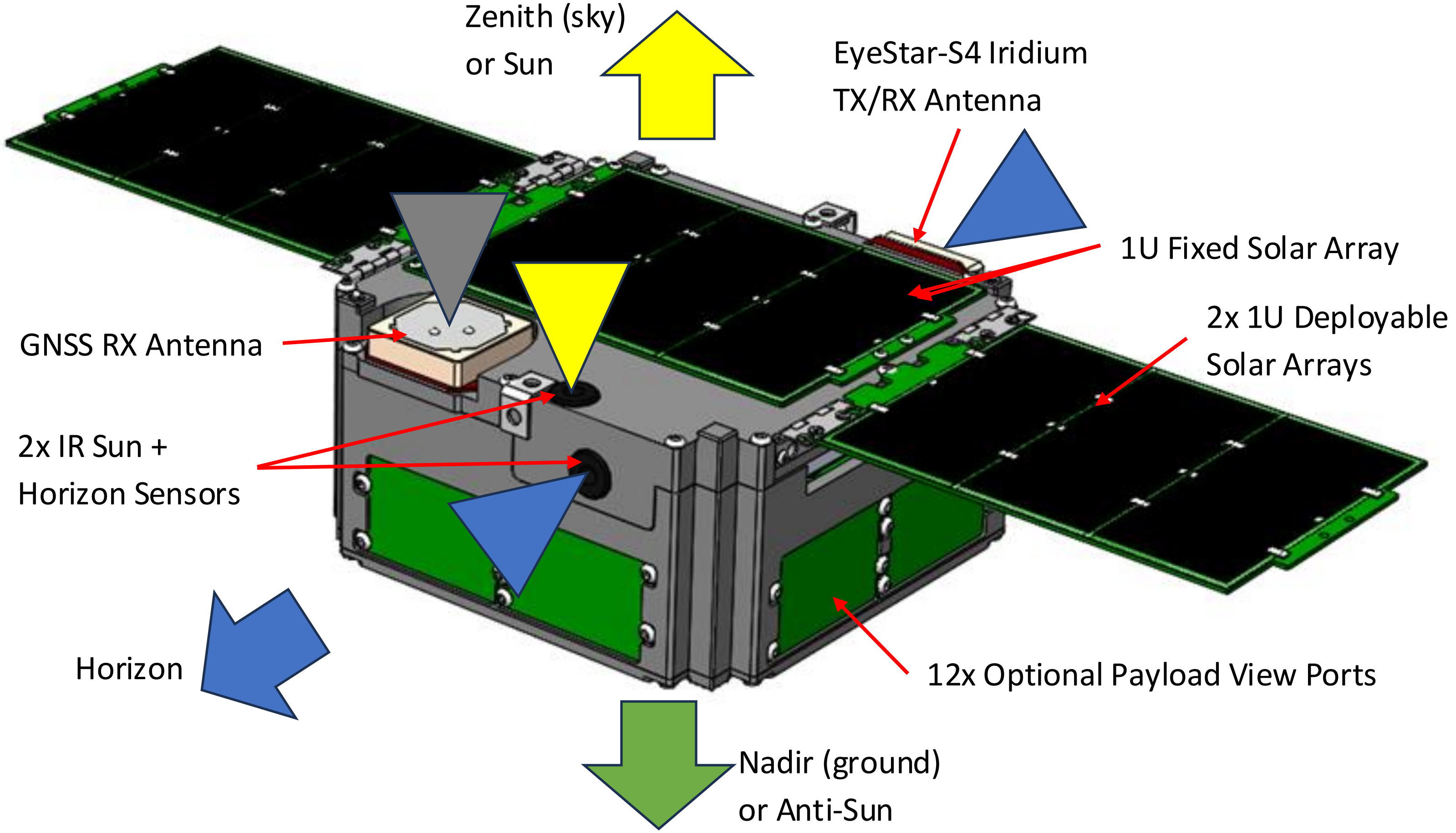
Defining Objectives

- Provide detumble, sun pointing, and nadir pointing for an 0.5U Cubesat.
- Requirements:
  - Sun sensor to see where we're pointing
  - IMU for acceleration, magnetic field measurements
  - Actuation system (magnetorquers!)

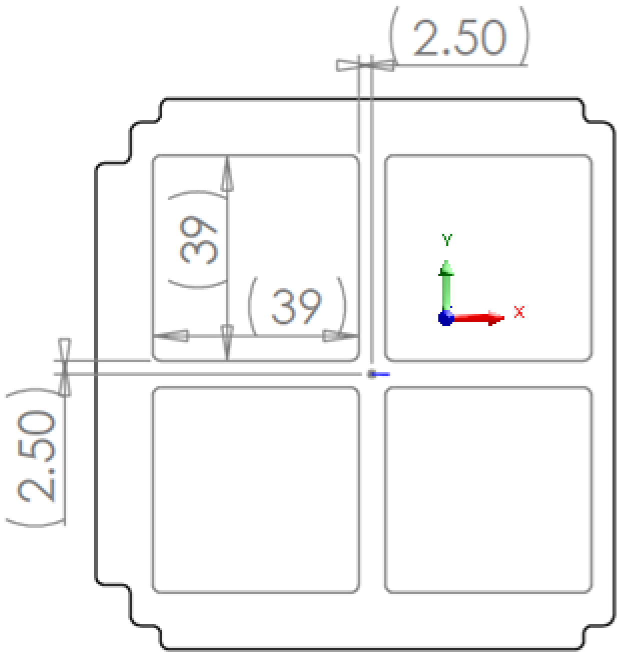
Precision for measurements	Base Tier	Middle Tier	Stretch Tier
Dipole moments of mu-metal rod	5 Am^2	10 Am^2	20 Am^2
Dipole moments of air core rod (Cm)	0.1 Am^2	0.2 Am^2	0.3 Am^2
Pointing accuracy (degs)	+/- 15 degrees	+/- 10 degrees	+/- 5 degrees
Measurements of Success			
Sun point time (min)	45 mins	30 mins	15 mins
Detumble time (min)	1 hr 15 mins	45 mins	30 mins

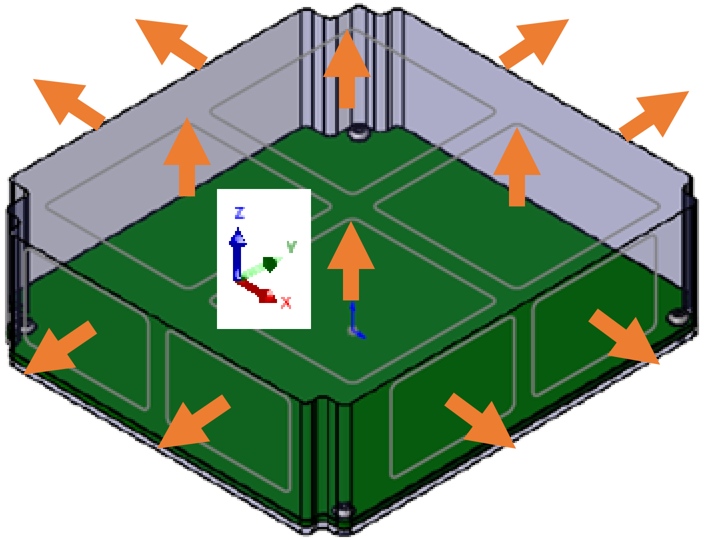
Payload specifications

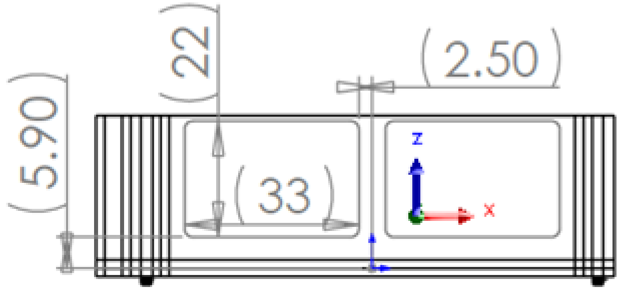
ThinSat 0.5U Design

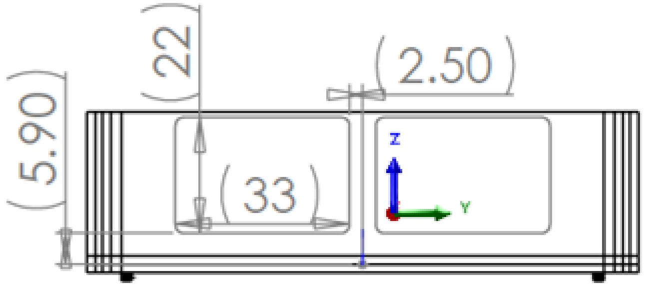


Available Payload Viewports



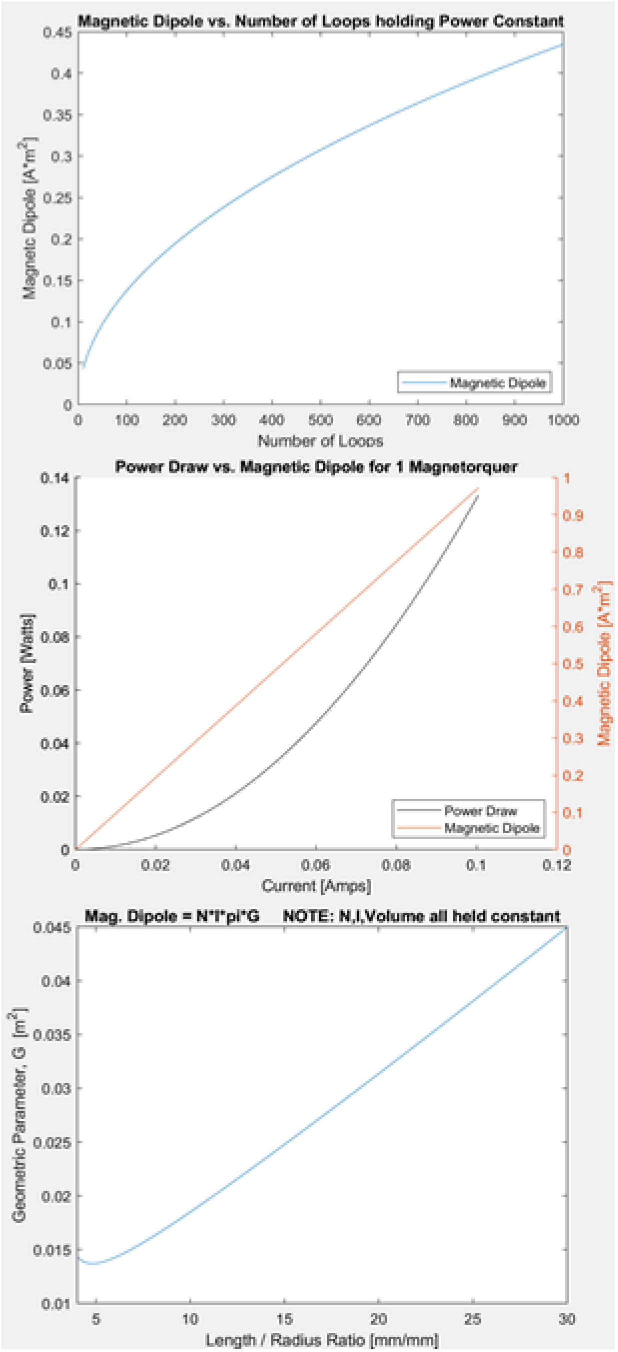






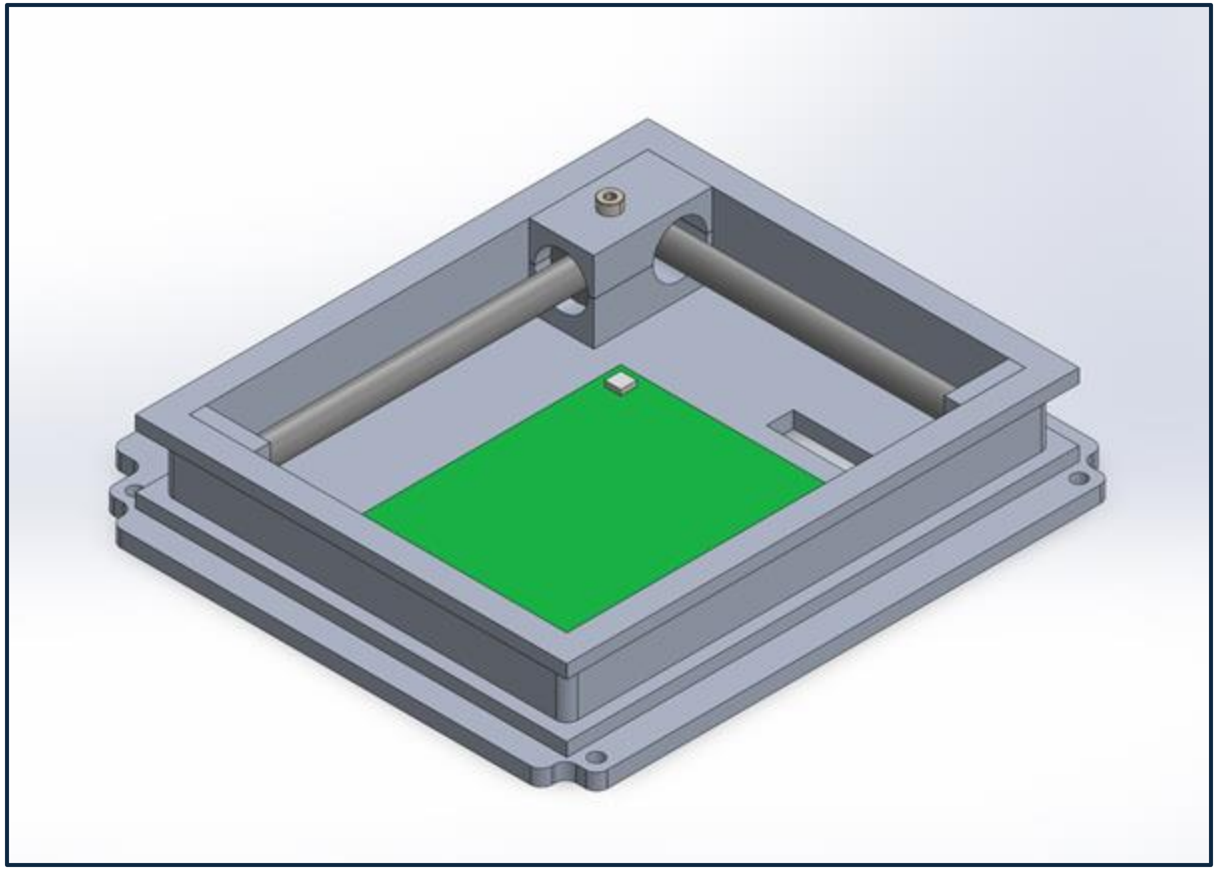
Magnetorquer Design Considerations

- Optimizing Magnetic Dipole from key parameters:
  - Rod radius, length, number of wire turns
  - Power Draw
    - Current draw and resistance of coils
- Findings from Qualitative analysis:
  - Maximize length/radius ratio for power draw efficiency
  - Maximize number of wire turns for maximum magnetic dipole

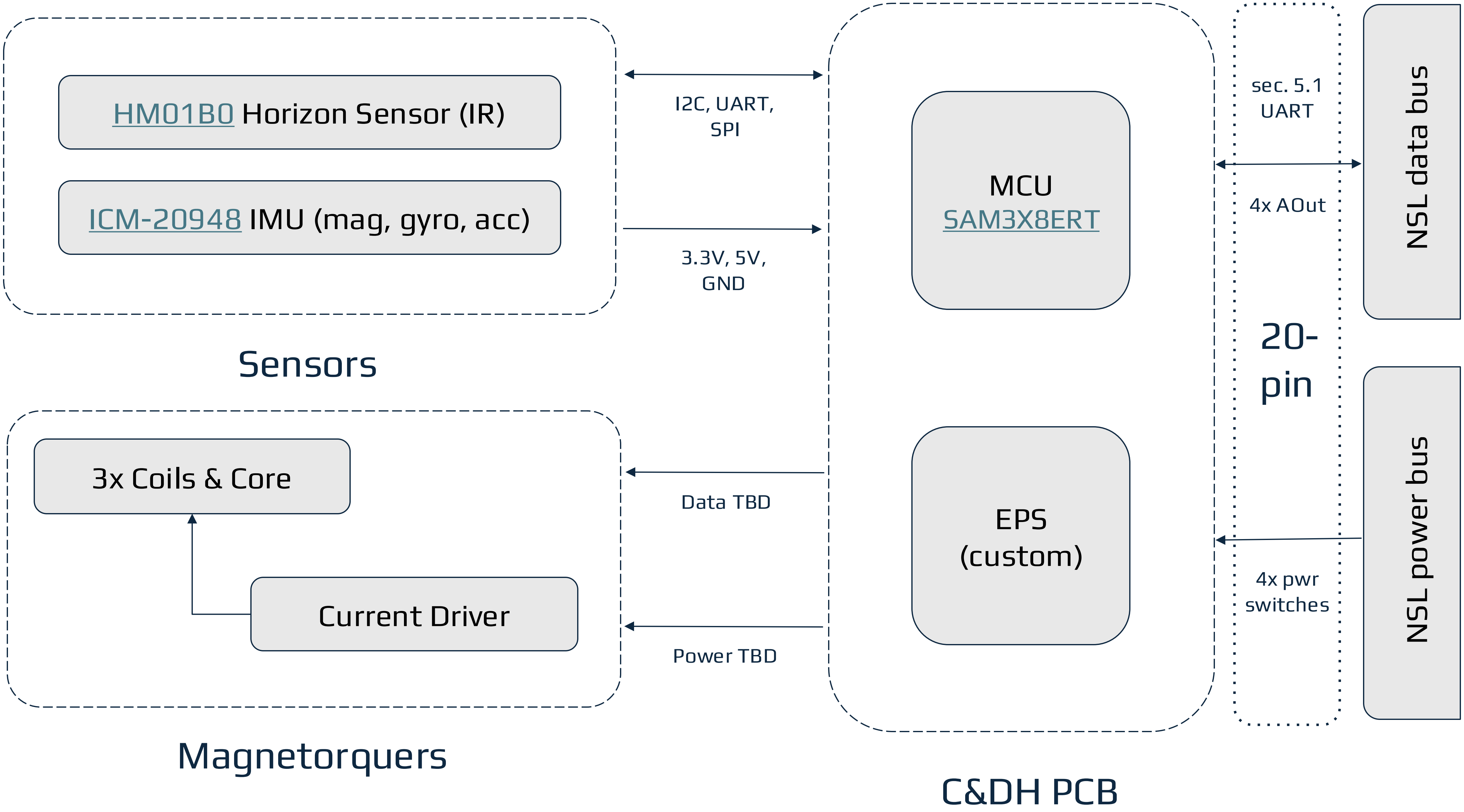


Rough Payload CAD

- Mass: 185g
- Camera pointing out any face
- Volume [mm]: 98x104.5x20



Note: Wire wraps not shown for core clarity.



HM01B0 Horizon Sensor (IR)
ICM-20948 IMU (mag, gyro, acc)
Sensors
I2C, UART, SPI
3.3V, 5V, GND
3x Coils & Core
Current Driver
Magnetorquers
Data TBD
Power TBD
MCU
SAM3X8ERT
EPS (custom)
C&DH PCB
sec. 5.1 UART
4x AOut
20-pin
4x pwr switches
NSL data bus
NSL power bus

Firmware Operation

- Types of data
  - Operational Data
    - Current through magnetometers, correlated magnetometer reading, gyro reading over time (are we slowing down our rotation)
  - Final State Data
    - Sun and Horizon sensor readings (are we pointing where we wanted to)
- Amount of Data
  - 10, 200-byte packets a day
- Data integrity
  - Iridium error checking, 38400 baud rate for UART, no complex data error correction needed
  - Implement simple checksum or parity bit
- Bus request used
  - Send Payload Data to Ground, Set ADCS Mode, Check Last Serial Packet Status, Check Buffer for Uplink Data, Request GPS Cartesian Packet, Request UTC Time
- Checkin
  - Every minute to make sure no payload power cycle

Power

Stay within the bus power restrictions

- 3.3V and 5V rail max 1 A, 6-9V rail max 2 A

Can we rework "Proposed Payload Power Draw"?

- Right now, 0.5 W draw for Nadir, 3 W draw for Sun Pointing
  - During testing on orbit, our payload will be somewhere in between
  - What power draw is reasonable during our specific payload ops?

Our power nominal requirements

- Sensors + MCU → IMU - 2.5 mW, IR Cam - 4 mW, MCU - 132.56 mW
- Magnetorquer will take the rest of the available power

Idle means only power draw from sensors and MCU

Avg. power difficult to characterize (dynamic operation), but will use as much power as available to maximize torque capabilities.

- Can characterize through future testing

Test planning

Pre-environmental testing:

1. Test all operational modes of the satellite
    a. Sun-pointing control, Earth-pointing control, Detumble control, Induce Tumble, System off
2. Interface with **emulator** and test data interface with bus in all modes

TVAC testing:

1. Use **on-campus TVAC system**, run our payload through TVAC cycling meeting ICD testing requirements
    a. 60 degrees celsius , 1E-4 Torr, 6 hours
2. Run TVAC thermal cycling test
    a. -30 degrees to 60 degrees celsius, 1 hour dwell at each extreme, 4 cycles

Vibration testing:

1. Use NASA GEVS Qual levels (14.1 GRMS) on EM units and Acceptance levels (10.0 GRMS) on FM units
    a. Utilize **Near Space Launch vibration table or GOAT Lab vibration table** for testing

Radiation testing (if possible):

1. [Plan TBD, need to find facility with these capabilities, MIL-STD-461 RE102]

Post-environmental testing:

1. After all other testing, make sure the system still functions. Repeat pre-environmental testing.

BOM

Horizon Sensor (Low Power Image Sensor):

- HM01B0 Datasheet
- 324x324 pixel res
- <5mm^2, I2C
- <4mW

IMU (magnetometer, gyro, accelerometer):

- ICM-20948 Datasheet
- Hermetically sealed MEMS, 3-axis gyro, 3-axis accelerometer, magnetometer, temp sensor
- 3mm x 3mm x 1mm, I2C
- <2.5mW

MCU (Microchip):

- SAM3X8ERT Datasheet
- Rad-tolerant, Cortex M3 RISC, watchdog, 3-20MHz
- 22 x 22mm, 2x TWI (I2C compatible)
- 130mA * 1.8V = 0.234W absolute max

We are concerned about not finding specifically space rated sensors and cameras. Do you have any suggestions on how to pick specific sensors? Do the ones below look good?

Other parts:

- EPS (H bridge IC, power FETs, etc.)
- 20-pin Connector (TBD)
- PCB & associated RLC components (filtering caps, I2C pull-up resistors)
- Mu-metal
- Copper wire (gauge TBD)
- mounting materials (Aluminum, screws, standoffs, adhesive)
- Thermal (insulation, rad protection)

Risk analysis and mitigation

Risk	Potential Effect	Mitigation Measure
MEMS Sensor Helium Effect	Sensor performance drift or failure due to helium permeation	Use helium-resistant packaging options or select alternative sensors less susceptible to helium exposure. Test and monitor sensor performance during environmental testing.
3 Sensors with No Redundancy	Each sensor could be a single point of failure	Implement watchdog timers for resetting faulty sensors, using software-based fault detection and safe mode reinitialization for recovery from sensor failures.
Structural Integrity	Physical damage to board, connections, or magnetorquers during launch or operation	Conduct extensive FEA, vibration, thermal, and shock testing to aerospace standards. Use robust design and secure mounting techniques to avoid physical breakage.
Circuitry Incorrectness	Non-functional or suboptimal performance limiting mission success	Validate circuits through SPICE modeling, breadboarding, logic analyzers, and in-depth testing with test pads before final assembly to ensure performance.
Overconsuming Power	Exceeding power budget leading to mission failure	Perform detailed power budgeting, implement low-power modes, power cycling, and optimize component usage to stay within mission power constraints.
Cosmic Radiation	Hardware damage or bit flips in data	Use radiation-tolerant or rad-hardened components, apply error-correction coding (ECC), and implement redundant systems such as Triple Modular Redundancy (TMR) for reliability.
Thermal Management Failure	Overheating or undercooling of critical components	Incorporate thermal modeling and design thermal dissipation systems (heatsinks, radiators). Use temperature monitoring to enable active thermal management.
Sensor Data Inaccuracy	Inaccurate sensor readings affecting ADCS performance	Apply sensor calibration before flight, and implement filtering algorithms (e.g., Kalman filters) to validate sensor data in real-time.
Software Bugs	Unexpected software behavior leading to mission degradation	Thorough testing of software in simulation and HIL environments
Communication Failure	Loss of data link between payload and bus	Implement redundant communication channels and periodic communication checks. Include software-based reconnection protocols for link recovery.

Deliverables For CDR Dec 24'

- R2B
- Payload schematic
- Draft on functional testing payload
- Packet Definitions 90%
- Bus Configuration

Questions and Comments