Intel Array for Non-Static Application: A Mobile Approach to Ground Stations

Nick Parrott*, Ray Gregorich†, Mariam Soliman‡, Will Busse§, Ayan Brayzen Gogri¶
North Carolina State University, Raleigh, NC, 27607, United States of America

The Ground Station Team for Aerospace Senior Design, is tasked with creating a communications hub for all current and future Low Earth Orbit launches for North Carolina State University. The ground station team, *Redline Command*, will receive and transmit data with any balloon or CubeSat launches that the university undergoes, with one balloon launch planned for Spring 2026 and a CubeSat launch planned in 2027. The Ground Station Team is targeting to communicate with the CLEOSATRA CubeSat in Low Earth Orbit, withstanding all weather conditions and maximizing accessibility in space-based processing. This senior design initiative addresses the need for a ground-based communication system that will interface with CLEOSATRA as well as any future projects at NC State.

Nomenclature

P	=	Power (W)
Ph	=	Maximum energy usage (Wh)
I	=	Current (A)
V	=	Voltage (V)
Q	=	Required Airflow (CFM)
C_p	=	Specific Heat of Air
ρ	=	Density of Air
ΔT	=	Temperature difference between component and ambient air

I. Introduction

The explosion of the industries of communication constellations, observation, and scientific study in Low Earth Orbit (LEO) has created a large demand in the launch and operation of CubeSats. The surge in the satellite population in LEO is outpacing the traditional approach to ground station infrastructure, where a large fixed installation is used to monitor several satellites at once. Not only are these large permanent installations expensive to put up and maintain, but for the purposes of communicating with satellites in LEO, the fixed stations' lack of geographic mobility leads to large gaps in satellite visibility, decreased data transmission rates during low-elevation flyovers, and weakened or interrupted communications during extreme weather conditions. As LEO satellites complete orbits in approximately 90 minutes, with communication windows lasting only a few minutes per pass, the need for dynamic and rapidly deployable ground station infrastructure is growing critical, particularly for time-sensitive research applications.

In the context of fledgling university satellite programs, CubeSat launches are often a more cost-effective method of performing experiments in space as a way of providing proof of concept for more elaborate and expensive projects. North Carolina State University is one such program attempting to utilize these small-scale platforms. Alongside this new objective and associated clubs being created to support this end, Redline Command has been tasked with the creation of a portable ground station intended to be transportable alongside university-sponsored CubeSat launches. The Intel Array for Non-static Application (IANA) is Redline Command's solution to this problem by performing as a

*Undergraduate Student, Mechanical and Aerospace Engineering, AIAA University Student Member 1930930
†Undergraduate Student, Mechanical and Aerospace Engineering, AIAA University Student Member 1930920
‡Undergraduate Student, Mechanical and Aerospace Engineering, AIAA University Student Member 1739031
§Undergraduate Student, Mechanical and Aerospace Engineering, AIAA University Student Member 1923950
¶Undergraduate Student, Mechanical and Aerospace Engineering, AIAA University Student Member 1930921

ground station designed for vehicle transportation that is capable of tracking a CubeSat for an extended period of time in any location in the continental United States. IANA is designed for long-term functionality away from any permanent power source that is capable of recharging its power system on-site while maintaining high tracking functionality, along with on-board data storage and processing capabilities.

II. Background

A. Ground Stations

Ground stations serve as the terrestrial interface between spacecraft and mission operators, enabling telemetry reception, command uplink, and payload data downlink through the transmission and reception of radio frequency (RF) signals. At a minimum, a ground station requires an antenna and transmitter; however, most operational systems include additional components such as RF front-end hardware, including low-noise amplifiers, filters, and power amplifiers, to improve signal quality and ensure sufficient transmission strength over long distances. A transceiver or software-defined radio (SDR) is typically used to perform signal modulation, demodulation, and processing, while custom user-made software enables flexible control of communication protocols, data handling, and system operation.

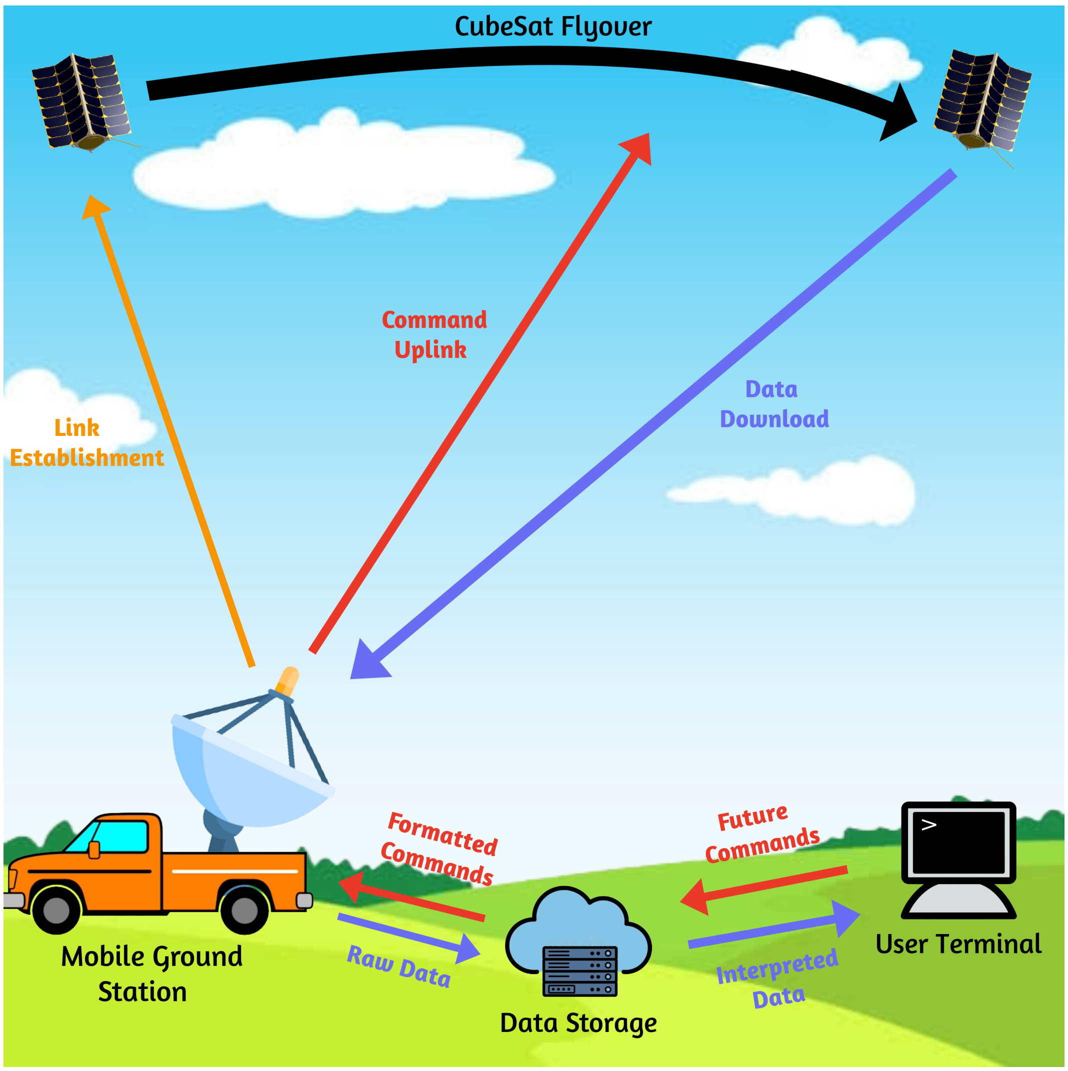


Fig. 1 IANA Concept of Operations

A complementary thread in recent AIAA literature discusses the option of student-built VHF/UHF stations that pair crossed-Yagis on az-el rotators with low-noise/power amplification, two-line-element-driven tracking, and software-defined radio (SDR) backends. These designs are inexpensive and reproducible and close low-rate TT&C links reliably; yet they confront persistent data-rate ceilings, require on-site staffing for critical passes, and remain sensitive to local RFI and weather limitations that directly motivate the project's shift toward higher-throughput bands and increased automation. In parallel, AIAA reports on portable S-band survey stations show that truck-deployable nodes can characterize interference, terrain masking, and siting constraints prior to permanent build-out, improving coverage planning while introducing backhaul dependencies and added environmental-hardening needs [1].

B. Ground Stations at NC State

Currently at North Carolina State University, the Student Amateur Radio Society has developed an Earth-Moon-Earth (EME) communication system, which enables radio communication over extremely long distances by using the Moon as a passive reflector. This technique allows signals transmitted from Earth to reflect off the lunar surface and return to another location on Earth, enabling global communication when both stations have a line-of-sight to the Moon. The system operates primarily in the VHF and higher frequency bands and utilizes directional antennas for lower frequency operation and parabolic dish antennas for higher frequency communication to achieve the required antenna gain. These antennas are mounted on azimuth-elevation (az-el) rotators, which allow precise tracking of the Moon's position. The RF signal chain includes a low-noise preamplifier to improve received signal sensitivity, a sequencer to coordinate transmit and receive switching, and a transceiver for signal generation and reception, all integrated with specialized computer software for control and signal processing. Successful operation of this system requires consideration of effects such as Doppler shift, where the relative motion between the Earth and Moon causes a measurable change in the transmitted and received frequencies, requiring compensation to maintain reliable communication.

Fig. 2 NCSU Student Amateur Radio Society Dish Antenna Setup

The current efforts of the Student Amateur Radio Society provide a strong technical foundation for future RF communication projects, including communication with CubeSats in low Earth orbit (LEO), high-altitude balloon platforms, and other aerospace systems. However, a key limitation of the existing ground station infrastructure is its fixed location, which restricts communication opportunities to periods when a satellite's ground track passes within range of the stationary antennas. This constraint can significantly limit communication windows, particularly for low Earth orbit CubeSats with short pass durations. To address this limitation, the development of a portable ground station is desirable. A portable system would enable deployment in geographically optimal locations, including remote or off-grid environments, thus increasing communication opportunities and improving the ability to establish and maintain reliable contact with satellites during brief visibility windows.

III. Intel Array for Non-static Applications (IANA)

A. Design Solution

The primary IANA structure is a light T-slot 1080 aluminum frame from *Vention* that are paired with 6061-T6 aluminum panels that is a 1'x 1'x 3' enclosure with a 20A DC-DC charger, a 100 Ah battery, a Raspberry Pi 5 running SDR++ as the software defined radio (SDR), a UHF transceiver with a digirig feeding to the Pi acting as a manual/offline mode for communication if the SDR software is not running properly, a Yagi-Uda antenna controlled by two *Vention* motors and two TB6600 stepper motor controls for point tracking. A series of fans and smoke detectors acts as primary thermal regulation and safety protection. The design will be tested with a series of established amateur radio satellites to perform validation testing for range and accuracy, while maintaining secure and rapid downlink and uplink speeds. Below is the overall and exploded view model of the current IANA design:

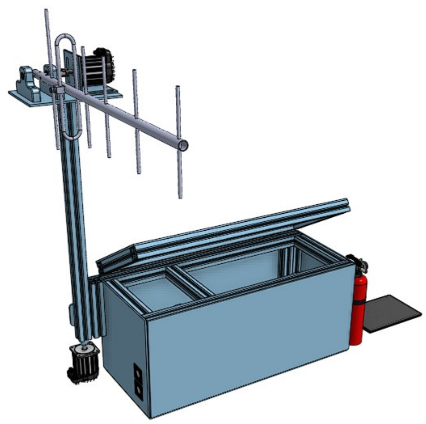


Fig. 3 CAD Render of Current IANA Design

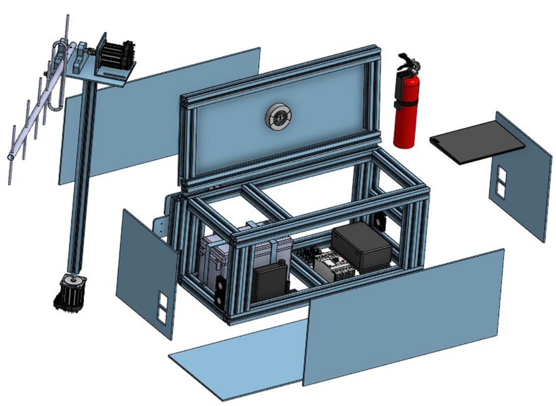


Fig. 4 Exploded View of Current IANA Design

B. Subsystem Breakdown

IANA is composed of 7 main subsystems: antenna system, transceiver system, data processing system, terminal station system, power system, thermal and safety systems, and structures system. The antenna subsystem uses a Yagi-Uda antenna centered on 435 MHz (± 10 MHz) with a mass of 6 lbs, a power draw of 100 W and a gain of +10 dBi. The antenna sits on a mounting bracket that spins on a shaft that runs through a vertical piece of t-slot aluminum. There are 2 motors, one to control the azimuth and one for elevation, that control the orientation of the antenna.

The transceiver system is encapsulated via the Anytone AT-778UV VHF/UHF transceiver. The transceiver will handle outputting and receiving any RF waves received by the antenna. The processing and storage of that data is then handled by the data processing subsystem, which involves a Raspberry Pi 5, a DigiRig to convert the audio radio signals into usable computer data, and an onboard SSD for storage. This subsystem will take all the data from the transceiver and convert it into a usable form of data that can then be decoded via terminal station software.

The terminal station subsystem handles the software that will turn received computer data into readable values that can be interpreted for research. Our system will use a combination of SDR++ (Software Defined Radio plugin) and DireWolf (Virtual TNC) to adjust the frequency and transmission of the transceiver and decrypt packet information in real time. This software will be installed on the Raspberry Pi and on personal computers. Powering the entire system is the power subsystem. This system is composed of a GRNOE 100Ah 12V Battery recharged using a Renogy DC-DC charger paired with circuit breakers and fuse boxes for electrical safety. This system will keep all other subsystems online and powered for several CubeSat passes of transmission and reception.

To keep the system cool and protected from fire, we implemented a thermal safety system involving active coolers on essential components and system-wide fans for cooling, along with a smoke detector and electrical rated dry powder fire extinguisher to prevent the system from causing cascading damage to whatever transport platform it is using.

Lastly, the structures subsystem is in place to make sure the system stays intact and protected during both transport and operation in inclement weather. This system is comprised of 3-foot and 1-foot 1.5"x1.5" T-slot aluminum rails and sealed using silicon sealant around 6061 T6 aluminum sheet metal.

Each subsystem works together to keep IANA operational in remote environments to ensure that every CubeSat flyover can be utilized to gather and download data efficiently for continued research in space.

IV. Methodology

A. Evidence of Feasibility

1. Power System Testing

The feasibility of the power system lies in the simple math that underlays all power systems, the power formula.

$$P = I * V$$

Given that every battery has a current capacity and voltage rating, we are able to easily design our circuit so as to provide adequate voltage and current to the system by wiring batteries in series or in parallel.

For the purpose of simulating the viability of the power system design, first, the scale of time that IANA operates under must be defined. The average period of a satellite orbiting in LEO is 90 minutes, with the average window of communications being 10 minutes [6]. Based on this time frame, simulations were run based on four operational modes:

- 1 - Communications: Communications persist over the 10-minute communications window of a satellite orbiting in LEO. During this time, all systems aboard IANA will be operating at full capacity.
- 2 - Realignment: Realignment persists over the subsequent 10-minute window after communications and focuses on supplying power to the motors to realign the antenna, preparing it for the next window of communication.

- 3 - Data Processing/Debugging: Data Processing/Debugging occurs in the 20 minutes after Realignment, in which data provided from the satellite during the communications window is processed and stored, and any maintenance to the communication components can occur.
- 4 - Standby: When the system is not accomplishing any of the above-listed tasks, it goes into standby mode, in which most components are not drawing power and only the essential components are receiving a trickle of power so as to negate any reboot that would be necessary should they lose power completely. Realistically, IANA can be put into standby mode at any time, but for the purpose of modeling the projected 5-window model, standby mode serves as the bridge between the data handling of one cycle and the communications of the next window.

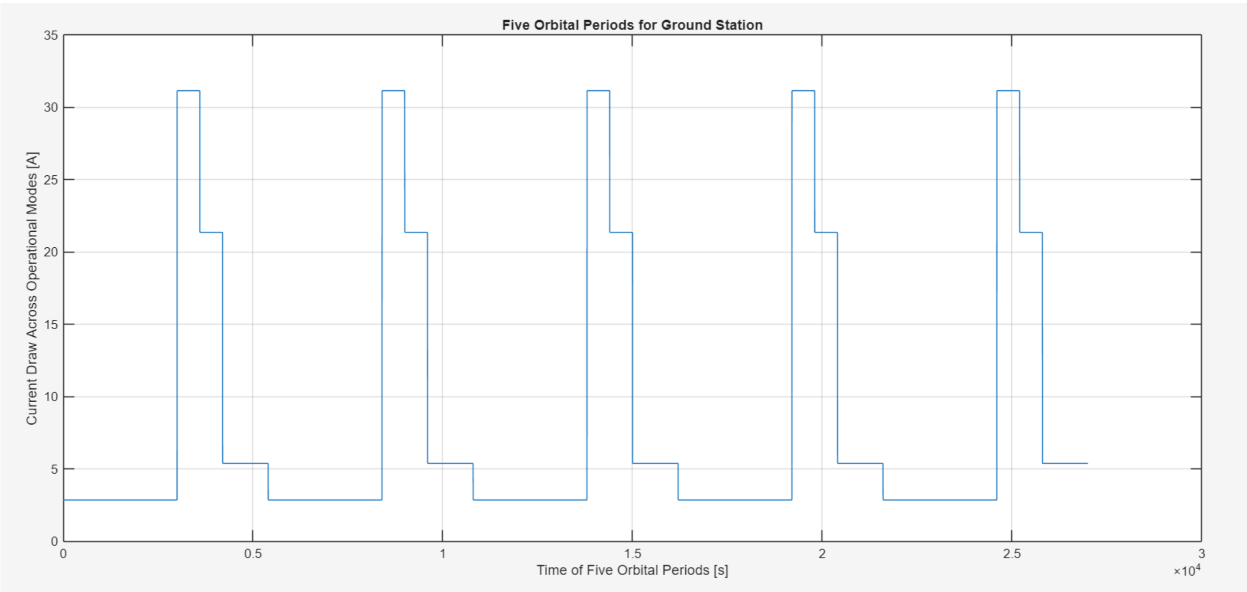


Fig. 5 IANA System Current Draw for Five Consecutive Passes of a satellite in LEO

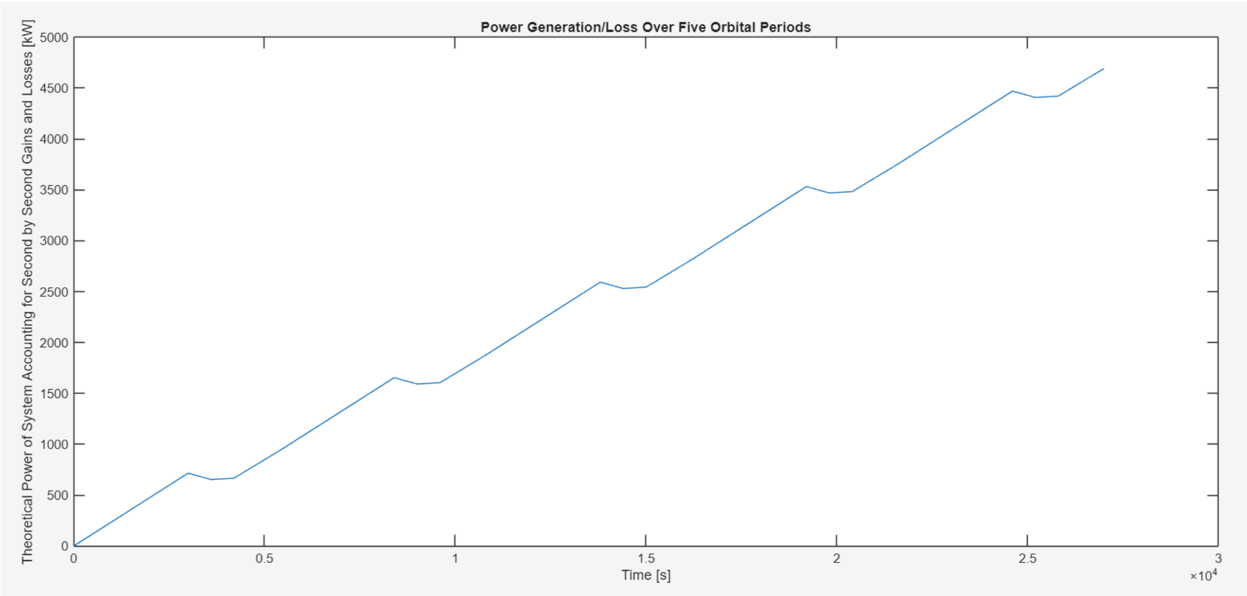


Fig. 6 IANA Net Power Change Over Five Passes

As visualized in the first figure above, the current draw at its maximum level is **31.15A** during the communication phase, second highest during the rotation phase at **21.36A**, third highest during data processing/debugging at **5.39A** and at its lowest during standby at a mere **2.86A**. The battery is capable of a maximum current of **100A**, meaning that all operational modes will sit comfortably within safe operating range of the battery. The current supported by the recharge method is **20A**, which sits slightly below the two highest operational modes and well above the two lowest operational modes. The second figure in the subsection above demonstrates the general power trend of IANA's system across five orbital periods of the tracked satellite. The upward trend demonstrates that during most if its usage, IANA will be operating at a power surplus, as the vehicle that it will be attached to will provide more power than what it is using. The dips represent periods of operation in which the current that IANA will draw will exceed the current provided by the power source. Because the amount of time that IANA spends in a net power deficit is lower than the amount of time that IANA spends in a net power increase, this demonstrates the capacity of the power system to support the rest of the subsystems within the project.

2. Thermal and Safety Testing

Minimum Airflow Requirement

$$Q = \frac{C_p \rho P}{\Delta T}$$

From the above equation, we can find the airflow necessary to manage our system based on external temperatures. The operating temperature range of our components sit around -20 to 85°C [2]. External operation temperatures for the local Raleigh-Durham area is extremely unlikely to drop below -10°C per historic temperature data [5] thus we can ignore the bottom half of that operating range. A typical day in Raleigh sits at 15°C ranging yearly from 4-26°C [3]. From these numbers, we can see that an ideal operating temperature for the internal components should be kept at or under 55°C and thus the minimum airflow to maintain that 55°C would induce a temperature difference of 50-20°C in typical operation.

The main heat-generating internal components of IANA include the Raspberry Pi 5, the Transciever, and the attached NVME SSD as each of these are power-hungry electrical components that use lots of power but do not output much, thus by the Joule law of heating they must emit the most amount of power as heat. From consumer reports, the Raspberry Pi and NVME SSD emit around 10W of heat each under a heavy load. The Transciever in UHF mode draws 13.6V at a current draw of up to 11A (150W) but only uses 45W to transfer power [4], therefore power released in the form of heat is around 105 W. The highest power-drawing components produce nearly 105W of heat and with standard sea level conditions for density and specific heat, the minimum required airflow for the coldest temperatures is $Q = \frac{3.16*105}{50}$ which equals **6.636 CFM** and for the hottest temperatures $Q = \frac{3.16*105}{20}$ which equals **16.59 CFM**. If components are intended to be kept around 35°C, then low temperatures result in a CFM requirement of **11.06** and high temperatures result in a CFM requirement of **33.18**.

To ensure that all excess heat generated is effectively removed from the system and internal components are kept at a low operating temperature, the combined CFM of the fan management system shall be able to deliver more than 33.18 CFM of airflow. The selected setup of using 4 fans (2 inflow, 2 outflow) with 17.6 CFM per unit provides a total airflow of **35.2 CFM**, of total airflow which is more than enough for the worst-case scenario temperature-wise to maintain a low internal temperature.

B. VV&T Testing

To confirm that our individual systems are functional, we have several tests that we have performed or plan to perform on the subsystem level. Three of these tests include a transmission and reception test for the antenna subsystem, a system power draw test for the power subsystem, and a shock test for the structures subsystem. The antenna transmission and reception tests involve linking the antenna to the transceiver and power system and then attempting to have 2-way radio communication using the antenna. The purpose of this test is to verify the correct operation of the transmission capabilities of IANA, ensuring that the system is capable of reaching space under a realistic operating environment and transmitting quality data. The experiment setup requires using the antenna, transceiver, any power source (but preferably the one built into the system), the connecting cables to ensure proper data communication, and any required software and amplifiers to permit communication. Completion of this test will ensure that our setup is conducive to long-range communication.

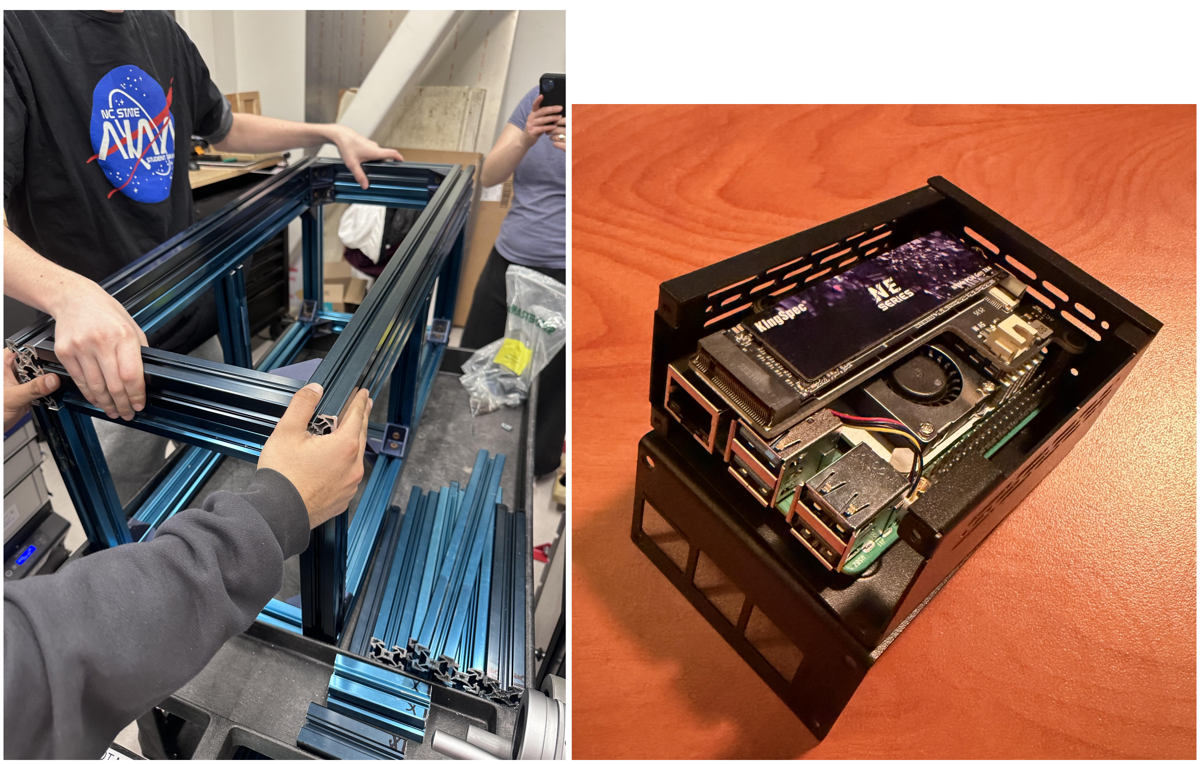
The system power draw test involves either turning the entire completed system on or simulating that power draw to analyze how long the battery can provide charge for system operations. The purpose of this test is to verify the manufacturer's specifications of the battery and to confirm that our previous assumptions when designing the power system are still upheld. The setup of the experiment involves placing the battery with a power sink in line with a multimeter. The battery is then given time to lose charge, and the results are measured and then compared to manufacturer's specifications. The power draw rate also allows us to verify our initial assumptions used in our evidence of feasibility. Completion of this test will ensure our system can remain operational for several satellite flyovers.

Lastly, the shock test involves subjecting a connection in the overall structure to a series of shocks to ensure that joints will not slip, resulting in structural breakdown. This is important as with t-slot aluminum, pieces are held together using angled pieces with tensioned bolts. The setup of the experiment involves assembling 2 pieces of t-slot aluminum, subjecting the joint to repeated strikes from a rubber mallet, and then measuring any displacement of the joint. If the joint can withstand 20 large strikes, we can be certain that vibrational and shocks from transport and operation will not be sufficient to damage or dismantle the structure.

V. Current Results

A. Assembly Progress

The current assembly of IANA sits at 55%. The main structures have been measured, cut, and assembled, and the internal components are being bolted in place for internal wiring and power testing. Missing and delayed component orders are hindering the progress of the full structural assembly. In terms of components, the Raspberry Pi has been fully assembled and tested with software and storage partitions. The next step is incorporating the antenna assembly and checking transmission capabilities. Some images of our current assembly progress can be seen below in Figures 7a and 7b.



(a) Structural Assembly Photos **(b) Finished Pi Assembly**

Fig. 7 Assembly Progress Pictures

B. Future Schedule and Necessary Work

The expected work we need to accomplish to complete IANA on schedule follows the work breakdown seen in Figure 8. The main work that needs to be done is the integration of separate systems into one cohesive product, and ensuring that subsystems that require a fully integrated system are tested to ensure they continue to fulfill our project's desired goals and objectives. For the transceiving team, antenna integration is most important as confirming transmission and reception capabilities is the hinge point of our project. The terminal and data processing teams must integrate their developed software with the transceiving team to ensure that data is in the right format and readable. And lastly, thermal, power, and structural must all integrate to ensure everything is within and protected by the outer structure.

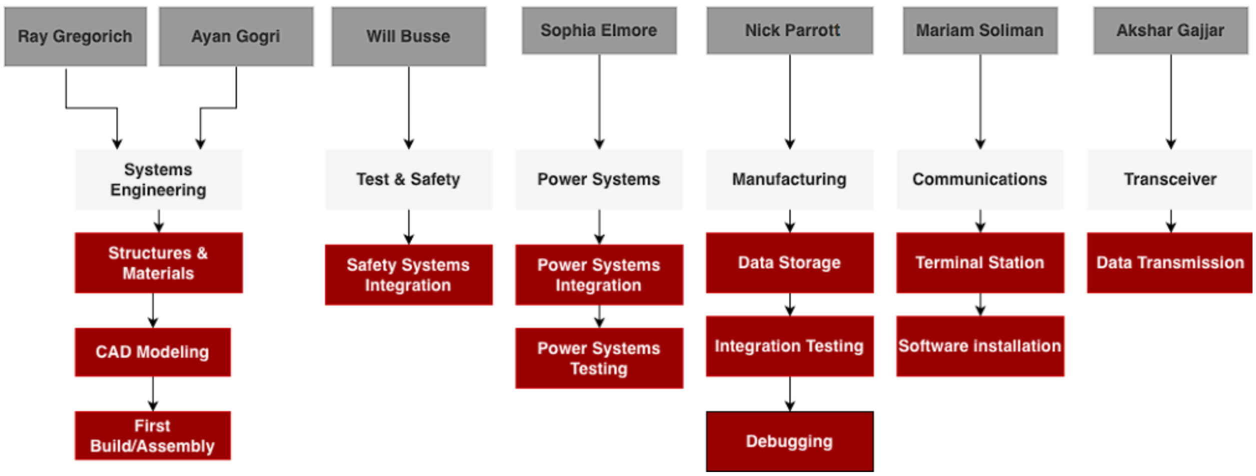


Fig. 8 IANA Work Breakdown

VI. Conclusion

The Intel Array for Non-static Application (IANA) provides North Carolina State University with a portable, self-sustaining ground station designed to maximize CubeSat communication opportunities. Feasibility analyses confirm that the power subsystem maintains a net positive energy balance across multiple orbital passes while operating within safe current limits. Thermal modeling verifies that the selected fan configuration exceeds worst-case airflow requirements, ensuring reliable performance in varied environmental conditions. With structural assembly over halfway complete and subsystem testing underway, remaining efforts focus on full integration and transmission validation. Upon completion, IANA will expand mission flexibility, data return, and long-term ground infrastructure capability.

VII. Acknowledgments

Team Redline Command thanks Dr. Felix Ewere for his ongoing support and assistance with the project itself and the writing of this report.

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