Pleiades CubeSat Cluster

General Concept Proposal

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Developed by Blue Dot Consortium Members:

Cal Poly Pomona Bronco Space, Portland State Aerospace Society,
Stanford Student Space Initiative, and the Hawaii Space Flight Lab

Mission Statement:

The Pleiades CubeSat Cluster is a proposed flight of eight Cube Satellites to provide essential flight heritage for open CubeSat architectures, investigate methods to establish relative navigation & in space situational awareness for collaboration in Small Satellite Swarms, and create educational pathways for students towards the future of the New Space Industry. The Pleiades Cluster is developed by members of the Blue Dot Consortium, an international inter-university network of over 30 student-led or student focused CubeSat development groups.

CubeSat Mission Parameters					
Satellite Integrator	Estimated Mass	CubeSat Size	Desired Orbit	Acceptable Orbit	Expected Mission Life
PSAS	5.5kg	3U	Attitude: 450km Inclination: 98°	Attitude: 300km - 550km Inclination: 45° - 100°	1 Year
PSAS / CPP	5.5kg	3U			
SSI	1.5kg	1U			
SSI	1.5kg	1U			
SSI / CPP	1.5kg	1U			
HSFL	1.5kg	1U			
HSFL	1.5kg	1U			
HSFL / CPP	1.5kg	1U			
Total	20.0kg	12U			

**Note in order of appearance: PSAS = Portland State Aerospace Society, CPP = Cal Poly Pomona Bronco Space, SSI = Stanford Student Space Initiative, HSLF = Hawaii Space Flight Lab*

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Proposal Abstract

The Pleiades CubeSat Cluster is a large-scale inter-university collaboration to test open architectures for small satellites, develop methods for safer and more capable formation flight of spacecraft, while also creating robust pathways for the future of the New Space Industry. This is all set to be accomplished through the design, integration, test, and on-orbit demonstration of a fleet of multiple CubeSats, simultaneously deployed by a single launch. The Pleiades Program seeks to combine the unique satellite architectures, expertises, and resources of a diverse consortium of US universities into this satellite fleet to encourage and create the collaborative communities that are a hallmark of space exploration.

The Pleiades CubeSats: A Diverse Fleet of Open Architectures

The primary objective for the Pleiades Program shall be to flight test select, prevailing, open architectures for CubeSat development. As a consortium of university CubeSat developers, one of the universal frustrations is the highly proprietary and closed nature of the traditional space industry. This often results in high costs, long lead times, and confusing interfacing between components from different manufacturers - all factors that are incompatible with the academic space and are believed to hamper the growth of the CubeSat market.

Three different architectures shall be included within the scope of Pleiades: OreSat, PyCubed based, and the Artemis Kit. Each architecture represents a different design philosophy and the three together reflect the three major schools of thought for CubeSat hardware design (backplane / card cage, single board, and PCI/104 stackup respectively). The cluster currently intends to incorporate 2x OreSat Type 3U CubeSats, 3x PyCubed Type 1U CubeSats, and 3x Artemis Kit Type 1U CubeSats for a total of 12U's of payload. The Pleiades Cluster therefore intends to not just provide an opportunity for valuable flight heritage of these architectures, but also a test batch manufacturing methods for each architecture that may greatly reduce cost.

Enabling Tech Tests: Situational Awareness and Formation Flight

The secondary objective for Pleiades shall be the development and demonstration of new methods for satellites to establish in-space situational awareness and collaboration when in a formation flight. This is intended to be accomplished through the use of inexpensive cameras, optical footprint enhancers, and radio techniques using a wireless mesh network. Success in establishing in-space situational awareness may have significant broader impacts on collision avoidance for spacecraft fleets. The ability to characterize the size and shape of a swarm, while also facilitating inter-craft communication and coordination, will enable greatly enhanced exploration of the solar system with multipoint science investigations.

Pathways of the Future: Enabling and Enhancing Education

The final objective of the Pleiades shall be to inspire, enable, and enhance educational outcomes for students entering the Space Industry. As a student initiated, and university focused project, the Pleiades team believes that access to comprehensive hands-on learning experiences are indispensable in preparing for the future. This is accomplished by providing opportunities for students to participate in the cutting edge of satellite development. Additionally, the culture of collaboration inspired by this inter-university team will be essential for building a more united and cooperative future.

1 Why is the Pleiades Cluster Needed?

With the exponential trajectory of the Small Satellite Industry, it is more important than ever to take the appropriate steps to prepare for a safe and secure future. New launch providers continue to enter the market and enable a supply of available rides to orbit like never before. Thus it becomes increasingly important to ensure development and support of open, efficient, and trusted architectures for the creation of robust small spacecraft that can meet the rising supply of launches with appropriate demand.

Although the SmallSat industry has seen major strides in recent years, with the launch of SmallSat constellations creating an over 2-fold increase in operational satellites since 2015 [1], the entry of new developers into the industry still faces many roadblocks. Roadblocks that are especially apparent to university class developers, who almost universally struggle with prohibitively high costs, exceedingly long lead times, and the highly proprietary & closed source nature of the traditional Space Industry. Compounding these challenges, unlike most other industries, there exists virtually no hobbyist or amateur community that can act as an on-ramp for new entrants. Considerations of how to design for or operate in a space environment are also usually devoid from formal education programs until the graduate level. This leaves an immense burden on university class developers to either: find huge amounts of funding to sub-contract satellite fabrication to a commercial company or commit huge amounts of time and talent (often unpaid and inconsistent student talent) to create the institutional knowledge and infrastructure for a space mission from scratch.

A 2019 study by a multi-university team, led by Lucinda Berthoud and featuring the prolific Dr. Michael Swartwout (who keeps one of the most detailed CubeSat databases in existence), found that 55% percent of universities have only ever flown a single mission and only 17 independent institutions in the world can be considered “prolific,” with four or more missions (N=192). This study also found that among the non prolific independent universities (universities programs that are not proxies for a national government’s laboratory) there was an abysmally low 9.8% rate of full mission success from 2014 - 2018 [2]. When combined with the historically extremely high costs and immense technical challenge of executing a space mission, such a high failure rate has no doubt resulted in the death of many promising CubeSat programs.

Most of the universities that have achieved prolific status were only able to do so given the opportunity to repeatedly fly their architectures and improve through a cycle of failure, lessons learned, and iteration. This is extremely resource intensive and is often only possible with unwavering funding, unusually zealous program leaders, exceptional talent, or all of the above. It can be seen from the study’s data that once a program is able to graduate from growing pains to prolific status, a steady stream of delivered missions is almost assured. Out of the 428 university class missions flown up to 2018, 197 (46%) came from prolific universities [2].

So it appears that once a program is able to design, test, and iterate their spacecraft heritage over just a handful of flights, continued participation in the Space Industry is almost assured. The unfortunate reality for many who start on this path though, is that after meeting, almost inevitable, failure with their first attempt their programs will also almost certainly fail to continue. Perhaps if there were platforms for new developers to adopt that ensure at least some core level of success, no matter their institutional heritage, it would be possible for many more groups to succeed. This could create a fast track, through the exceedingly difficult process of bootstrapping a new flight architecture from scratch, and allow these groups to graduate into becoming prolific programs. Hence a need is established, for proven architectures that are not only readily available but also open to being accessed by all, no matter their institutional heritage or present resources. These architectures would also directly serve the industry by lowering failure rates and widening the potential demand for space exploration and exploitation.

One of the related effects of an exponential increase in launch availability, combined with more widespread mass production of satellites, will be the allure of conducting swarm or formation flight missions. This new class of mission involves multiple satellites launched simultaneously and collaborating in some way to complete the mission as a unified entity. Proposed concepts for these satellite fleets range from data relay networks that enable large savings in size, weight, and power (SWaP) to gravitational interferometry or advanced parallax observations. Unfortunately, these types of missions remain on the fringes of the state of the art until certain enabling technologies gain the flight heritage needed to be trusted on operational missions. Therefore, a need is established for the development and test of technologies that enable collaborative operations between groups of satellites.

Additionally, as the Space above us continues to fill with spacecraft, both the risk of in-space catastrophe and the promise of unlocking vast untapped capabilities blossom, with the growing market for formation flights of tens, if not hundreds or thousands, of spacecraft. To protect the common heritage of humanity, and enable its exploration on an unprecedented scale, enabling systems for in-space situational awareness and cooperative formation flight must be developed and demonstrated.

In-space situational awareness, in this context, is the ability of a spacecraft to become aware of its surroundings without being explicitly fed information from mission control. An example would be a satellite having the capability to autonomously sense the relative location and motion of a cooperative satellite within its proximity or perhaps an uncooperative piece of space debris that may threaten a collision. From these reference missions, a need is determined to develop and test a technological basis for establishing in-space situational awareness.

Finally, as the horizons of the Space Industry broaden, what was once a very niche and exclusive field shall also need to inspire, educate, and enable a workforce for the future that is larger than ever before. With the industry conservatively expected to grow three fold, to become the next trillion dollar industry, in the coming decades [3] it is only reasonable to expect that the workforce must multiply to match. As a result, robust academic access to designing, building, and flying small spacecraft (in particular CubeSats) is essential to establish a strong foundation for hands-on experiences that shall prepare students for the great challenges of the Space Industry. The need for robust academic outcomes that can inspire, educate, and prepare our future workforce should not be understated.

Table 1: Overall Need Statements

#	Need Statement
N.1.0	A need for proven, readily available, and open space mission architectures that will accelerate the pace of small satellite production and increase access to space ready platforms.
N.2.0	A need to greatly reduce the failure rate of space missions from first time developers and lower the barriers to entry.
N.3.0	A need for groups of satellites to have the ability to collaborate with one another to complete complex missions.
N.4.0	A need for technology that will enable spacecraft to establish in space situational awareness relative to one another.
N.5.0	A need to inspire, educate, and prepare students to become the future generation of the Space Industry.

2 Primary Mission: Proving and Improving Open Architectures

As previously described, the availability of launch opportunities continues to grow rapidly with the entry of new launch providers into the commercial space. While getting to space has never been easier putting something in space, that works as intended, remains an extremely difficult task. Pleiades seeks to address part of this issue by creating a runway for low cost and open CubeSat architectures to become flight proven. Through flight heritage these architectures can gain more stability as robust choices for new developers in the New Space Industry.

The Pleiades Program intends to specifically emphasize on elevating open architectures in order to ensure widespread access with strong community support, trust via transparency, as well as vastly improved availability & lower costs through higher volume.

2.1 The OreSat Bus as a High Performance Open Architecture

The OreSat bus has been a longstanding and extremely well mainted open-sourced platform, developed primarily by the Portland State Aerospace Society (PSAS) at Portland State University, for 1U-3U CubeSats. Originally developed for PSAS's 2U OreSat-1, a STEM education and climate science mission, the OreSat platform has also manifested as the 1U OreSat-0 demonstrator, which was delivered to a launch integrator in April 2021. The core value proposition of the OreSat bus is an abandonment of the PCI/104 hardware stack, which has become a de facto standard for commercial CubeSat flight hardware, for a modular card cage / backplane system.

It should be noted then that the OreSat bus is not just a mechanical integration methodology (i.e. just the mechanical and electrical connections for the individual cards to the backplane and structure), but it is also a holistic design philosophy for spaceflight hardware. With most de facto or official standards in the CubeSat industry (such as the PCI/104 stack up or UNISEC Europe's backplane standard) there are only guidelines on the integration of unique components and not a true standard of practice on their implementation. This can cause extensive issues with integration of custom components, or even just components from different manufacturers, because the individual design methodologies of each component do not always fit together despite a shared integration architecture.

There exist two essential design elements of the OreSat bus that define its unique philosophy:

1. **The OreSat Card Architecture**
    - Each element that goes into an OreSat bus, such as the Electrical Power System (EPS), Command and Data Handling (CD&H), or even highly customized payload systems, most conform to the OreSat Card design philosophy.
    - Each individual card is designed to be isolatable from the rest of the system to allow for debugging without incurring overall system downtime. This allows a developer to divide up all the systems that make up a CubeSat into self-contained projects for a single responsible engineer (or a single student for an educational mission!). This functionality avoids the common issue of one or two difficult components on the critical path, stalling development for the system at large, as the system can only function as an entire assembly rather than stand alone elements.
    - Predefined card layouts for key components that form the core of most satellites, such as dedicated EPS or ADCS boards, greatly ease the process of system integration by ensuring that common components do not need to be extensively tailored or entirely redesigned for novel missions.
    - Operation of the OreSat bus is centralized around the C3 core flight computer card, which contains radiation hardened watchdog protections, and has the ability to access and reprogram any other card on the bus that conforms to the OreSat card methodology.

2. **The OreSat Power Domain**
    - Power distribution throughout the OreSat bus is unregulated until it reaches the individual OreSat cards.
    - On each OreSat card there is special control circuitry that regulates the power, as needed, for that card's specific needs. This circuitry also allows for full isolation, or a hard power cycle of any OreSat card at any time. The ability to isolate and power cycle is an additional layer of redundancy that can be an enabling factor in clearing single event upsets or other stalls due to the space environment.
    - The OreSat Power Domain also implements Maximum Power Point Tracking to ensure the ability to adapt to unique power generation sources with maximized efficiency.

There are many other robust features designed into the OreSat bus that can provide performance benefits unprecedented in the CubeSat space. For example, each OreSat card is intended to also provide a strong thermal connection to the frame via OreSat's card cage system. Another feature is the Engineering Data Link, which can theoretically allow for an almost complete reprogramming of the entire satellite over the air. This can enable the OreSat bus to be significantly more dynamic and adaptable once on orbit compared to other architectures.

Although the OreSat bus is already booked for two flights, Pleiades intends to push the capabilities and claimed ease of customizability of the OreSat bus to its limit. If the OreSat concept proves successful, its modular paradigm and deeply fail-safe design could become a new standard for highly performing missions in the CubeSat space.

2.2 PyCubed Based Satellites for Open Sourced Simplicity

Originally designed by Max Holliday at Stanford University's REx Lab for the KickSat mission, the PyCubed single board solution to CubeSat flight hardware was received with excitement at the 33rd Annual Small Satellite Conference in 2019. Open source, just like the OreSat architecture, and with the promise of ease of use via its Circuit Python based programming language / operating system, the PyCubed promised the ability for more people to access proven spaceflight hardware than ever before. Not only could the novel single board solution vastly simplify the complex stacks seen in traditional CubeSats, but it also promised substantial cost savings by consolidating components.

Since its initial public release the PyCubed has seen widespread interest, and is currently adopted as the platform of choice by many university groups such as Stanford's Student Space Initiative (SSI), Cal Poly Pomona's Bronco Space (CPP), and UC Berkeley's Space Technologies at Cal (STAC) with many others looking on with interest. Recently, NASA Ames also sponsored the flight of 3 PyCubed based 1U CubeSats for the V-R3x technology demonstration swarm, making PyCubed the first open source architecture to successfully demonstrate a satellite network in space. Cal Poly Pomona also made major modifications to the original PyCubed design to create the PolyCubed architecture, which concentrates even more functionality into the PyCubed's single board design space.

One of the greatest strengths of the PyCubed system is its simplicity. The single board design can easily be hand soldered, and the software suite simple for amateurs to code in. This means that technical overhead is relatively low for new developers or educational users looking to become quickly acquainted with the CubeSat design space. A novel "payload slot" concept also allows makers to attach small add-on boards to enhance the feature set. Having been designed with a Maker mentality, by a single person to be understandable and usable by individuals around the world, has made the PyCubed a fantastic platform for simple single purpose missions.

It should be noted though that the original PyCubed design does not easily adapt to more complex missions, or the highly custom missions that are often flown in the university research space. Additionally, the PyCubed still needs more supporting infrastructure to create a platform that lends to a team based satellite development ecosystem that is more common in the Space Industry. Pleiades plans to take steps to expand the educational infrastructure around the PyCubed platform and develop a strong body of knowledge to support future developers.

2.3 The Artemis CubeSat Kit

Designed by the Hawaii Space Flight Lab (HSFL) at the University of Hawaii at Manoa, the Artemis CubeSat Kit was chartered by NASA with the goal of creating a comprehensive CubeSat to be used as an educational tool for $5,000 per unit. The Artemis Kit uses a PCI/104 stackup, the de facto standard as mentioned previously, to integrate prosumer grade electronics hardware into a functioning satellite. The hardware stack for the Artemis Kit is open source and it is designed to run HSFL's open source Comprehensive Open-architecture Solution of Mission Operations Systems (COSMOS), which is a Linux based full software stack that incorporates mission ops, control, and flight software into a single ecosystem.

An industrial BeagleBone Black sits at the center of the Artemis CubeSat stack and is connected via a PCI/104 header to a power distribution board which in turn is wired to a PyCubed battery board. A PyCubed was also originally a part of this design, but the sensors and other PyCubed unique hardware were recently consolidated to the BeagleBone's daughter board to save space in the bus. This then allows the 1U sized kit to facilitate a unique custom payload to complement its Raspberry Pi Zero + Camera Module combination.

As an inherently educational product, the Artemis CubeSat kit has also been developed with strong provisions for the students who will use it. In parallel with its development a comprehensive spacecraft design curriculum and laboratory course has been written. With an intention to deploy these CubeSat kits in as many classrooms as will accept them, it may usher in an entirely new way of engaging the future of the Space Industry via hands-on learning. Participation in the Pleiades Cluster will provide much needed flight heritage for the Artemis platform, and an avenue to hopefully expand student participation in real space missions from intensive extra-curricular projects, to a well tuned standard of the classroom.

2.4 Enabling CubeSat Production at Scale for Universities

One of the most prevalent issues with opening the traditional aerospace industry to new developers is the extremely high costs associated with the extremely low volumes satellite components are usually produced at. To address this Pleiades intends to go beyond the essential demonstration of flight heritage for each of these CubeSat architectures, and attempt to prove that these open architectures can be produced at greater scales to greatly reduce costs and barriers to entry. While every mission will of course be customized or bespoke in some way for its unique mission requirements, oftentimes core systems such as computers, radios, or power systems do not need to be redesigned for each flight. Economies of scale may then play a key role in reducing costs for novel space missions.

3 Extended Mission: Demonstrating In-Space Situational Awareness and Satellite Cooperation with Mesh Networking

When given the opportunity to launch 12U's worth of satellites on a single rocket, it becomes an indispensable chance to also advance the field of Small Satellite swarms and formation flight. The Pleiades Cluster intends to develop and demonstrate methods for a satellite swarm to establish relative in-space situational awareness without external inputs (such as ground based radar ranging or relying on GPS locks). This has the potential to enable swarm operations beyond Low Earth Orbit (where GPS is no longer available) and into cislunar or even interplanetary space (where ground based methods of accurate position determination become impossible). It is also possible that the methods developed under Pleiades can assist in establishing situational awareness for non-cooperative targets (such as malfunctioning spacecraft or space debris) to create a safer and more secure environment in Earth Orbit.

3.1 Swarms, and Why They Need Situational Awareness

Satellite swarms are groups of satellites that work together in formation to collaboratively investigate a natural phenomena or provide a service. Examples of missions that swarms might enable include virtualized space telescopes, in-space interferometry to measure gravitational waves, and multipoint observations of the heliosphere. The need for swarms to revolutionize our capabilities for scientific understanding is often analogized with weather forecasting. Currently with only the capability for single or dual satellites to operate in a mission space, it is like trying to understand the weather of the entire United States with only a single weather station. With a swarm of satellites, it becomes possible to capture a much wider and three dimensional understanding of the universe.

A key distinction between a satellite swarm and a constellation is the requirement for accurate (and often tight) formation flight & proximity operations. This leads to many technical challenges that have prohibited swarm operations in the past, such as accurate models for understanding how satellites move relative to each other and how a swarm should be coordinated to maintain its shape over the course of a mission. While the relative motion of two satellites can be well understood, the problem takes on exponential difficulty as the number of satellites increases. To date, the most complex formation maintained on orbit has been a diamond formation flown by NASA’s four satellite Magnetospheric Multiscale Mission.

Pleiades seeks to provide an enhancing technology to the swarm design space by creating methods for satellites to become aware of each other’s relative location without the need for external inputs. Possessing this relative positional information is a key aspect in the feedback loop for proximity operations, as it would be quite impossible for a formation to maintain itself without knowledge of its own state. Additionally, deep space operations introduce the need for relative awareness as a hard requirement for responsive performance when round trip communications with Earth can take minutes if not hours.

3.3 Optical Acquisition for In-Space Situational Awareness

One of the most logical choices, and a common one for terrestrial networks of robots, is to use machine vision to become aware of a satellite’s surroundings. This does come with a unique set of challenges in the space environment. These challenges include the extreme ranges and relative speeds that can exist between two satellites, the difficulty of operating an optical system that is not field serviceable, and meeting the pointing stability requirements of an optical system.

As denoted in the following figure, Pleiades proposes to tackle some of these issues with a novel approach utilizing a semi-cooperative architecture for optical acquisition. Within this architecture cameras on the 3U “Seeker” CubeSats will attempt to use common machine vision algorithms to spot and characterize the 1U “Snitches.” The 1U’s will also possess LEDs or other optical footprint enhancers to assist the 3U’s in their spotting at long ranges.

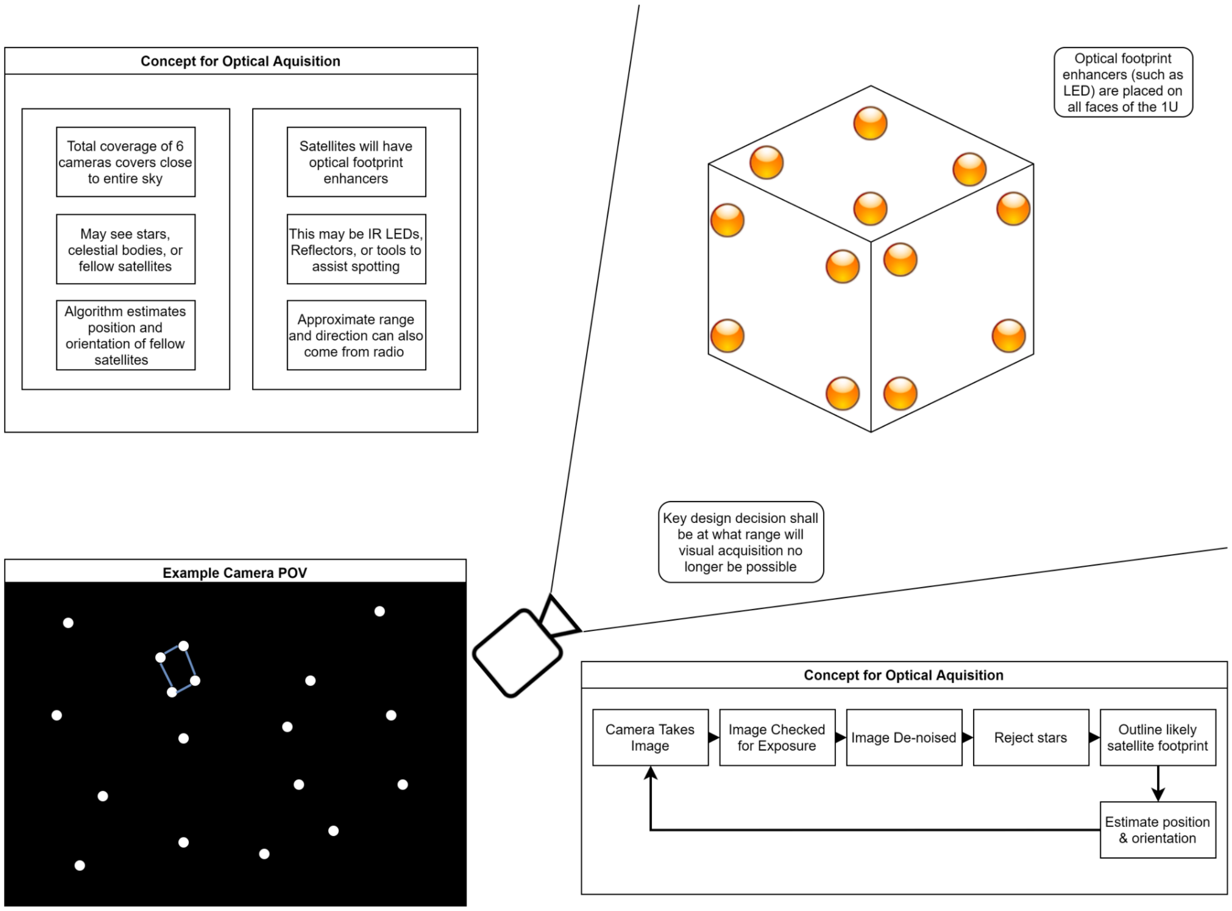


Figure 1: Optical System Concept

3.4 Ad-Hoc Mesh Networking for Awareness & Collaboration

Another option for satellites to coordinate with each other is for them to simply be able to tell each other what their current states are. Pleiades proposes to allow this by constructing an ad-hoc mesh network between the satellites once they are on orbit. The satellite to satellite connections then allow direct collaboration between the satellites, rather than requiring routing through Earth stations. Creating this mesh network also has the benefit of allowing for a different communications topology where data can be shared or fed to a single “gateway” for communication with Earth. Equipping a single satellite with high bandwidth communications, rather than every satellite in the swarn, allows for significant size, weight, and power (SWaP) savings.

Additionally, establishing this collaborative network in space can present an opportunity for a unique synergy with high performance computing hardware that shall be required to facilitate the machine vision elements of the proposed technology demonstration. Once the CubeSat Cluster is no longer in a swarm configuration, and instead dispersed into a constellation, the computational resources previously allocated to machine vision can be retasked as Edge Computing resources. It would then be possible to attempt use of these Edge Computing resources as vehicles for completely autonomous data processing and decision making for the Constellation.

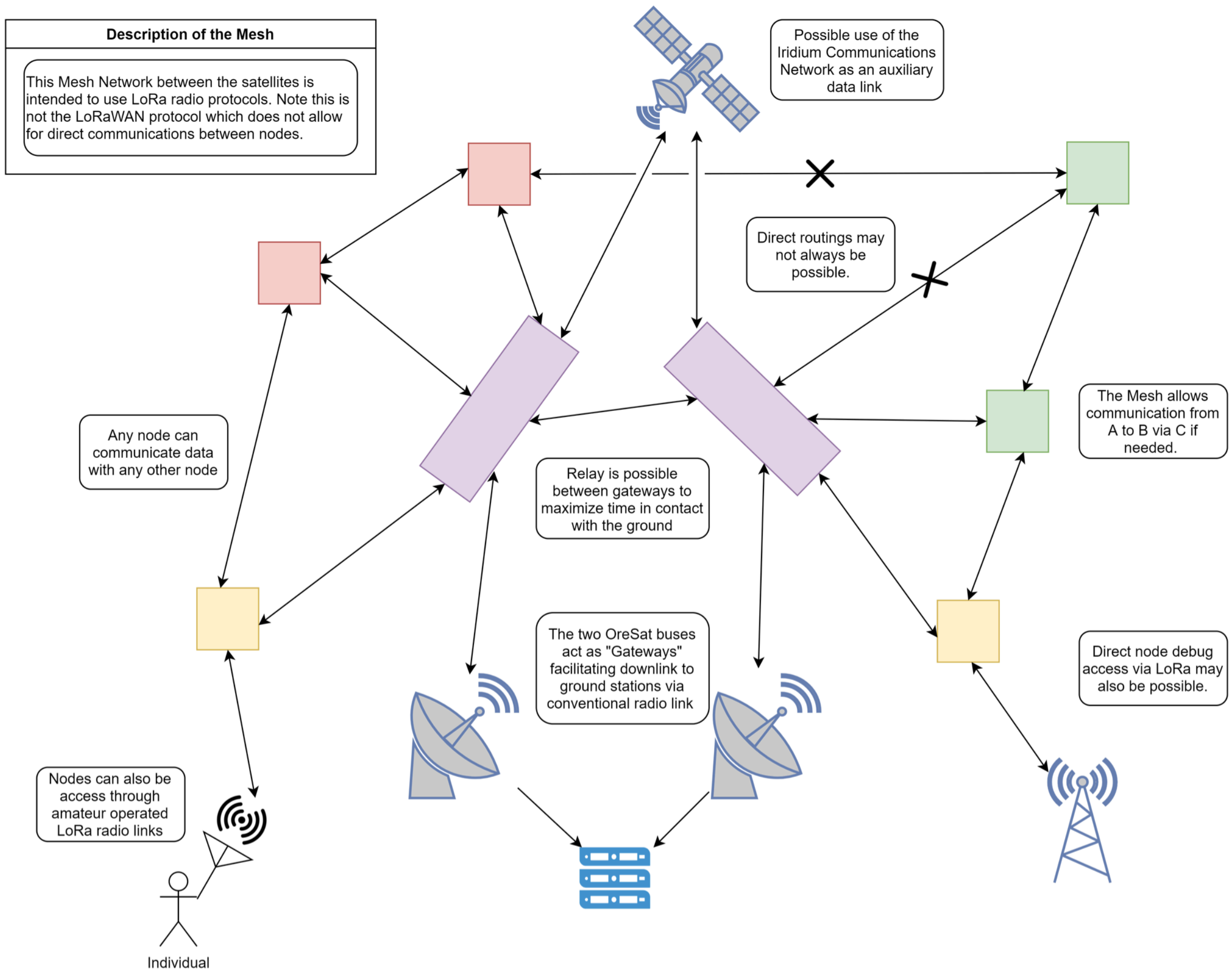


Figure 2: Mesh Network Concept

4 Creating Pathways for the Future Space Industry

As a proposed effort from a consortium of academic institutions, there is naturally a deep desire to ensure extensive educational outcomes. The New Space Industry is projected by Morgan Stanely to grow to become the new Trillion Dollar Industry by 2040, representing an almost 3 fold increase from present day [3]. The Bank of America expects this threshold to be surpassed even sooner in 2030 based on an average year over year growth of 10.6% in the last two years alone. This means that a once niche and slow moving industry must take strong steps towards preparing the youth of today to become the innovators, explorers, and star sailers of tomorrow.

4.1 Directly Enabling More Student Participation in CubeSats

The Pleiades mission naturally supports more undergraduate participation in CubeSats, as a student initiated and primarily student implemented space mission. Across all four participating organizations undergraduates have been able to gain valuable hands-on experiences in existing and previous satellite programs that cannot easily be replicated in a traditional classroom environment. The advancement of Pleiades shall continue this legacy, and build through an inter-university collaboration that reflects the diverse collaborative networks that make up virtually all missions in the greater space industry.

Based on the teams involved with recent student-led CubeSat deliveries (BroncoSat-1 and OreSat-0), it is anticipated that an overall team of at least 100 undergraduates may be engaged across the four institutions involved in this mission. University based multi-cubesat missions, such as UCLA ELFIN* and its duo 3U's, have easily engaged over 200 students over its 5 year mission lifetime from design through delivery and operation. These students shall be given the opportunity to directly interface and gain experience with all aspects of the space mission process, from design to integration, test, and mission operations. Students able to gain this level of real world experience are regularly top choices for recruitment into the growing Space Industry workforce thanks to their enhanced readiness.

Placing students in roles that allow them to directly interface with members of the Space Industry also helps to strengthen the education to workforce pipeline. This manifests as the introduction of students to industry led technical review boards, encouraging research participation at technical conferences and seminars, and developing mentor relationships with prominent members of industry. Co-op or joint research programs where students are able to directly co-develop technology alongside members of industry can also be extremely beneficial.

One of the most common criticisms of the Aerospace Industry is its institutional exclusivity compared to other STEM disciplines. To address this, the Pleiades program intends to also build on existing outreach programs to greatly expand understanding and participation with the Space Industry. Common techniques for these outreach activities include creating sentimental connections via "send your name to space" programs, or the creation of data time capsules that can be attached to the satellites. As a program directly supporting improved educational platforms for bringing CubeSats into the classroom, Pleiades also plans to host special workshops and activities to introduce traditionally underrepresented groups to the challenges of spaceflight as well. It is expected that outreach efforts shall reach a wide audience both among the respective university communities and K-12 classrooms via existing outreach channels.

4.2 Indirectly Enabling Enhanced Pathways to the Space Industry

As mentioned previously, out of over a hundred universities worldwide that have flown space missions, only a small handful have reached the "prolific" status. This is often attributed to the immense difficulty of creating a space ready satellite, and the inherent loss of institutional knowledge when students graduate from their programs. Due to the historically closed nature of the Space Industry, new programs often struggle to get off the ground unless they are in proximity to existing Space Industry members who are willing and able to mentor them. The Blue Dot Consortium (BDC) was founded, in the Summer of 2020 by engineers from CPP Bronco Space and Stanford SSI, to directly attack this problem by building collaborative channels that enable the exchange of knowledge and experience between student-led university CubeSat programs.

The BDC connected most of the Californian university groups, where the concept of a joint “CalSat” mission was first introduced. Throughout the remainder of 2020 BDC continued to welcome new university groups from across the United States and Canada, with various informal working groups forming to develop a body of knowledge for the most difficult aspects of designing a space mission. January 2021 saw the first annual “Blue Dawn Hackathon” where representatives from Blue Dot universities held a week of workshops at an introductory level to all the major aspects of CubeSat design [4]. This event saw an attendance of over 50 students from eight universities and culminated in a weekend long CubeSat concept design competition that was judged by a panel of industry professionals.

The BDC continues to collect an open body of knowledge so new or existing developers in the CubeSat space can come to a collaborative community that is willing and able to assist in bootstrapping any situation. While the BDC does not yet have formal programs to provide launch opportunities, internships, or technology transfer, the community based exchanges can be an enabling factor in allowing developers to beat the challenge of institutional knowledge and stay on a path towards success in the New Space Industry.

5 Implementation Plan

A set of broad program goals have been set for the Pleiades Program to meet the three mission areas of open architecture improvement, technology demonstration, and educational impacts.

Table 2: Mission Goal Statements

#	Goal Statement	Need #
G.1.0	Reduce the cost and complexity of developing space missions in the CubeSat form factor.	N.1.0
G.2.0	Improve educational access to open CubeSat platforms to better prepare the future space industry workforce.	N.5.0
G.3.0	Provide flight heritage to raise the technology readiness of open CubeSat architectures.	N.1.0 N.2.0
G.4.0	Raise the technology readiness of technologies for inter-satellite collaboration.	N.3.0
G.5.0	Raise the technology readiness level for technologies related to establishing in-space situational awareness for satellites.	N.4.0

The Pleiades Program has also defined a set of initial technology objectives that relate to the mission goals seen in **Table 2.** Note that the goal these objectives appear in does not necessarily reflect their priority. As discussed later, in section 5.6, descope of mission objectives is anticipated to match the final launch opportunity and anticipated available funding. A separate “Technology Taxonomy” document is currently being drafted to better define the specific technology areas, their respective Technology Readiness Levels (TRL’s), Key Performance Parameters (KPP’s), and their priority with respect to systematic descoping.

Table 3: Primary Mission Terrestrial Objective Statements

#	Objective Statement	Goal #
OT.1.0	Create and test a method for determining range between two small satellites that have no prior knowledge nor any input from a terrestrial source	G.5.0
OT.2.0	Create and test a method for determining direction from one small satellite to another, with no prior knowledge nor terrestrial input, relative to a single static reference frame	G.5.0
OT.3.0	Create and test a method to fuse multiple range and direction measurements between multiple targets relative to a single static reference frame into a near real time three dimensional understanding of the relative locations of the targets	G.5.0
OT.4.0	Improve the robustness and interfacability of the selected open-source satellite architectures	G.1.0 G.2.0
OT.5.0	Establish best practices, a trusted supply chain, and institutional knowledge surrounding the fabrication and application of the selected open-source satellite architectures	G.2.0
OT.6.0	Implement batch manufacturing practices to reduce net unit cost of the selected satellite architectures for this and future missions	G.1.0

Table 4: Primary Mission On-Orbit Objective Statements

#	Objective Statement	Goal #
OB.1.0	Demonstrate the operation of multiple satellites using batch manufactured open source architectures.	G.3.0
OB.2.0	Observe the range between two small satellites without prior knowledge or terrestrial data input.	G.5.0
OB.3.0	Observe the direction from one satellite to another with no prior knowledge or terrestrial data input relative to a single static reference frame	G.5.0

OB.4.0	Observe the range and direction from a single satellite to multiple satellites	G.5.0
OB.5.0	Fuse and downlink a three dimensional understanding of the locations of multiple satellite relative to a single static reference frame	G.5.0
OB.6.0	Demonstrate the relay of data from one satellite to another satellite through one or more "nodes"	G.4.0
OB.7.0	Demonstrate ad hoc connectivity between two or more satellites	G.4.0

5.1 Cluster Architecture

The original premise for the Pleiades CubeSat cluster was to design a mission that would fill an entire 12U CubeSat "Quadpack." As such, once the mission concept was selected, the overall hardware architecture for the cluster was designed to fit this premise. In total, eight satellites shall make up the Cluster for flight. Two 3U's (called "Seekers") shall fly based on the OreSat Architecture. Three 1U's shall fly based on Stanford's PyCubed Architecture, and three 1U's shall fly based on the Artemis Architecture - for a total of six 1U ("Snitches) CubeSats.

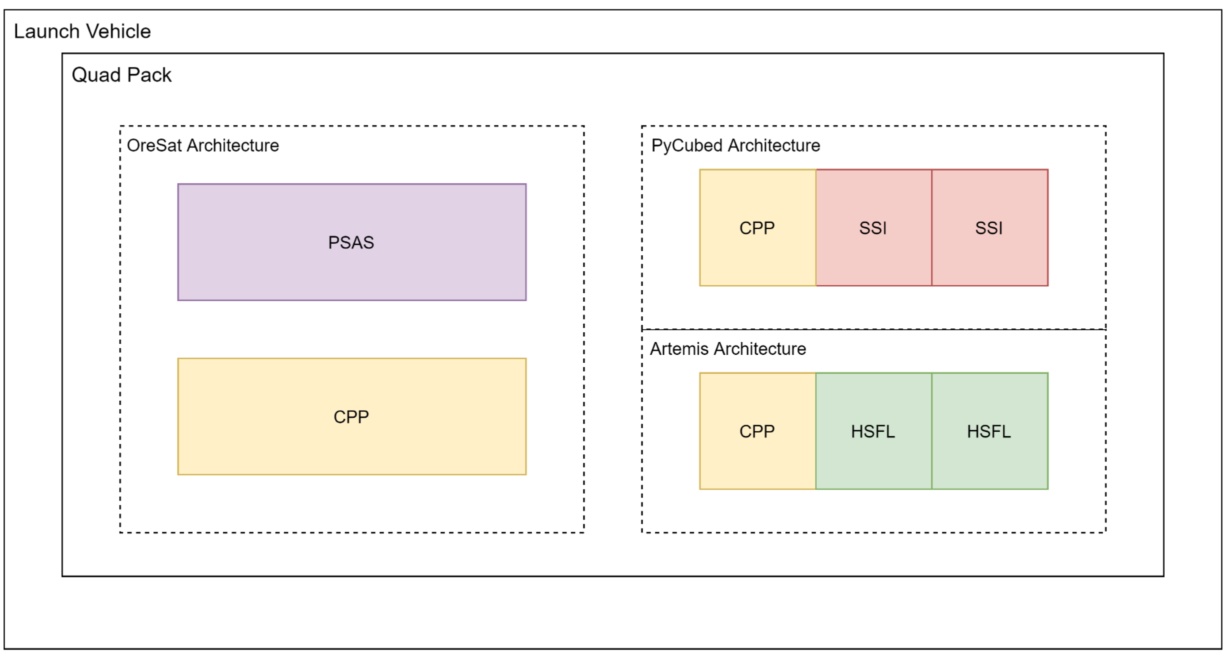


Figure 3: Architecture Allocations

5.2 Technology Development

Three technology areas underline the planned efforts of the Pleiades Program: In-Space Situational Awareness, Collaborative CubeSat Networks, and the underlying CubeSat Bus Architectures.

The three selected open CubeSat Architectures (OreSat, PyCubed, and Artemis) are currently considered flight ready in some capacity with TRL's ranging from 6 to 8. The primary focus of Pleiades development within these architectures shall be customization for the Pleiades Mission and systemic improvements to make the architectures more accessible. Anticipated ending TRL's for the respective architectures are in the TRL 8 or 9 range. At this level of TRL it is expected that a new developer can select one of the open architectures and access enough documentation and institutional knowledge to construct a custom mission without the need for direct assistance from the original design engineers. Proof of this capability shall also prove the viability of open architectures as robust and long term options for greatly increasing the number of "prolific" developers in the CubeSat space.

To further develop the In-Space Situational Awareness topic area, an instrument tentatively known as the "Octopus Camera" shall be created which will use multi-camera machine vision techniques to facilitate spotting the optical footprints of satellites within the vicinity of the Seeker. This instrument is based on imaging systems already designed for the OreSat architecture and integrates as many existing COTS components as possible to minimize design overhead. The Stanford SSI team also intends to contribute heavily to the machine vision algorithms and underlying software to facilitate the operation of the Octopus Camera.

The Collaborative CubeSat Networks shall be built on existing methodologies for deploying LoRa (Low power long Range) radio mesh networks intended for terrestrial Internet of Things (IoT) applications. A demonstration system is under development by the Bronco Space SPEED team to create a terrestrial testbed for a data relay network that approximates CubeSat flight hardware. Deployments of this demonstration system at long ranges and on high altitude balloon flights are intended to provide the primary method of validation before implementation into the CubeSat systems. A common interface shall be created to facilitate the additional radio and processing requirements of the mesh network on the three unique architectures.

5.3 Integration & Test

Integration and testing of the satellite flight units will dominate most of the timeline for the Pleiades Program. Parallelization of this aspect of the program will be essential to maintain efficiency and presumed cost savings from collaborative problem solving.

While the home organization of each CubeSat architecture shall be expected to lead design and integration of their respective satellites, Cal Poly Pomona's Bronco Space shall oversee final integration with the launch provider as well as integration and test of at least one flight unit of each architecture. As a key objective of the Pleiades Program is to prove that these open architectures can be easily replicated by third parties, extensive documentation and procedures shall be developed, to facilitate integration and test of the satellites without direct guidance from the design engineers. The Bronco Space team shall then engage students who do not have previous experience on a university class space mission to be the integration and test team. The resulting speed and efficacy at which the CubeSat architectures can be assembled will be used as a benchmark for their overall viability as a general use platform.

Pleiades intends to take a two generation protoflight fleet approach to the satellite integration & test process. This approach calls for multiples of each satellite architecture to be created with a "point design" mentality (in which each unit meets bare minimum requirements for function, but is not yet optimized for mission objectives). Each protoflight unit will then progressively be up-revved to improve performance until optimal mission targets are reached or until schedule runs out, whichever comes first. Schedule crunch is often the biggest risk factor for small satellites, and taking a protoflight approach ensures that integration of a system that meets the bare minimum requirements for flight can be achieved very quickly. Additionally, the fleet integration approach seeks to tap into economies of scale for reducing cost, and guarantees spares will be readily available in the case of hardware failure during testing.

There is also intended to be at least two distinct "Alpha" and "Beta" generations of the protoflight hardware. The first generation shall be seen as a production pathfinding generation, where the expectation is that a significant number of issues shall be encountered during integration or discovered during testing. Hotfixes can be applied to the Alpha generation to address these issues, which will then be fundamentally fixed on the Beta generation. This minimum two generation approach shall also allow for disbursement of the financial burden of the Satellite Cluster while maintaining schedule, as funding may be subjected to various administrative delays incompatible with a rapid development schedule.

Final checkouts of flight systems and verification of launch requirements shall be conducted by the Bronco Space team to the specifications of their home organizations, before delivery to the launch service provider. It is anticipated that random vibration tests shall be the only major environmental test that the satellites must conform to.

5.4 Outreach Activities

In addition to the direct involvement of undergraduate students in the Pleiades Program, outreach activities to expand STEM engagement and awareness of the New Space Industry shall also be executed. These outreach activities will emphasize on the engagement of groups that are traditionally underrepresented within the Space Industry, as well as providing introductory experiences to current STEM students who have not yet engaged in Space Industry activities.

Examples of possible outreach activities include the deployment of CubeSat hardware kits to classrooms to introduce students to the mechanics of satellite hardware. The Blue Dot Consortium also plans to host a variety of special workshops, and the second annual installment of its CubeSat themed hackathon to challenge space interested students with rapidly designing a minimum viable CubeSat.

5.5 Schedule

The optimal timeline for achieving flight readiness with the Pleiades CubeSat Swarm shall be no longer than 1 academic year. This is both defined by the proposed launch opportunity, and as a practical constraint given the student focused premise of the mission. Operations and analytics of the results from the Pleiades Program shall likely continue for an additional one to two years following launch, but completion and delivery of the flight units within a single year ensures minimal schedule impact from inevitable student turnover within the program.

Depending on the projected launch date, the Pleiades schedule shall remain fluid. A fair projection for flight readiness of the Alpha generation of Pleiades CubeSats estimates a

December 2021 readiness date with completion of any required environmental testing. See Appendix B for a bulleted denotation of the various critical path elements on the road to readiness. Schedule definition for subsequent generations of Pleiades CubeSats shall be defined at a later date based on the final state of the launch opportunity and available funding.

5.6 Descope Plan

The need to effectively constrain and descope, depending on available resources, time, and talent, is a core part of university class space missions which are usually tightly constrained in all three of these areas. The Pleiades Program plans to use a bottom up approach to program scope, wherein a scope hierarchy is created and the core foundational elements are completed first to guarantee a minimum viable mission before proceeding up to higher level elements. If cost or schedule run out, then items that have the most difficulty and / or the highest risk shall be left out of the scope of this mission.

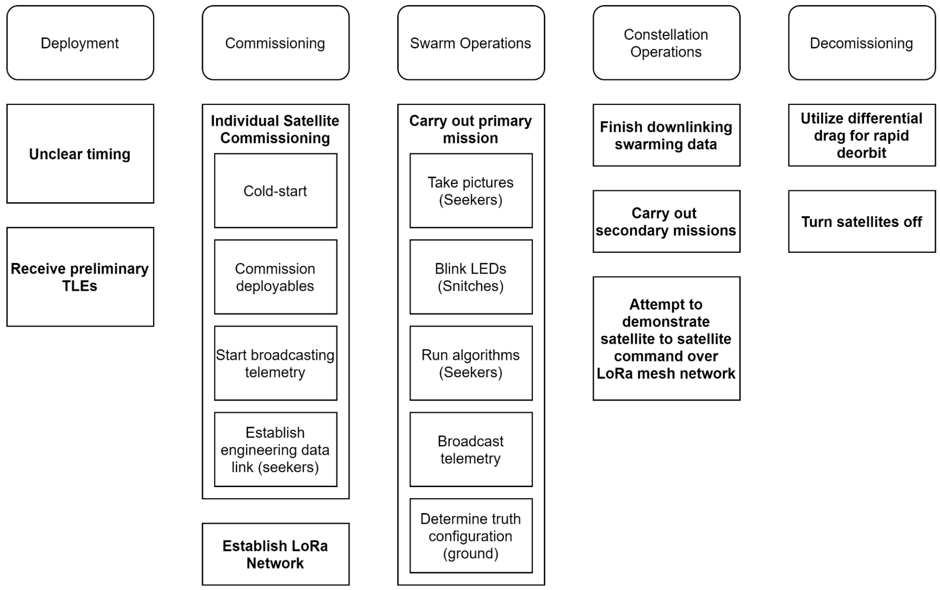
6 Proposed CONOPS

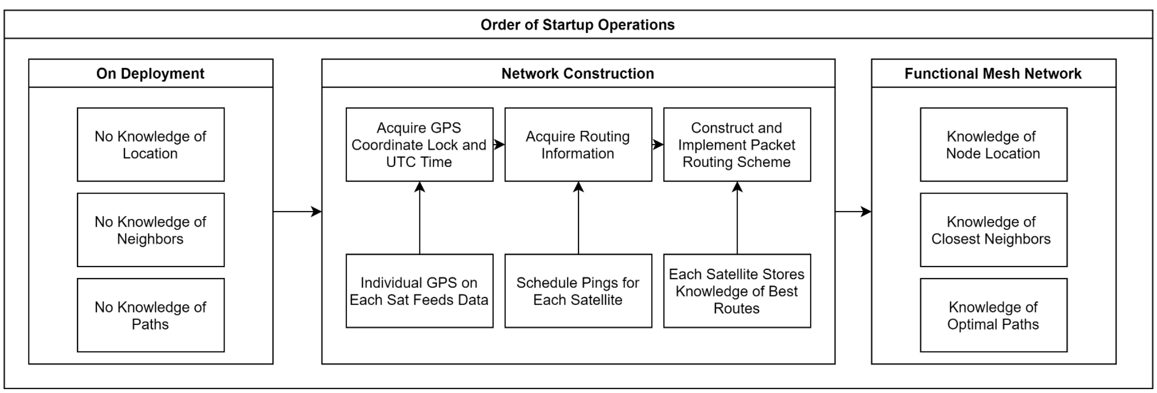
On-orbit operations underline the demonstration aspects of the Pleiades Mission. The Concept of Operations (CONOPS) assumes two phases for nominal operations, the swarm phase and constellation phase, and accounts for different mission profiles for each phase. The Pleiades Cluster mission also assumes near simultaneous deployment of all eight satellite elements from a single launch provider. Once a launch profile is defined, extensive simulation shall define the exact order of deployment.

6.2 Operations Phases

There are five operational phases for the Pleiades mission:

1. Deployment
2. Commissioning
3. Swarm Operations
4. Constellation Operations
5. Decommissioning (End of Life)





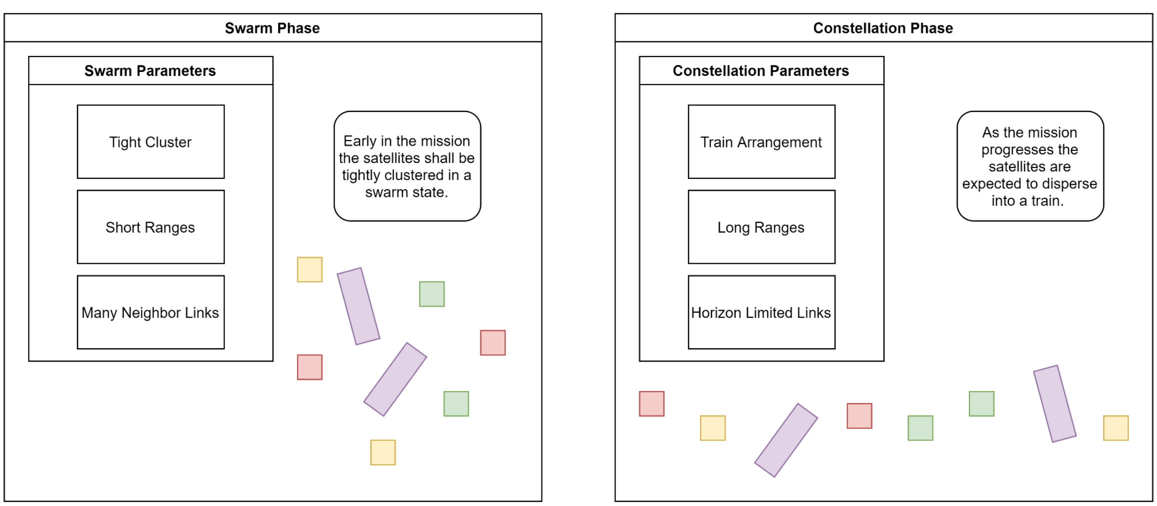


Figure 4: CONOPS Diagrams

6.3 Operations Architecture

The Pleiades Cluster intends to merge the collective operations resources of the 4 constituent universities into a single operations unit. This is intended to facilitate more efficient collaborative operations and greatly simplify licensing proceedings by permitting the cluster to be jointly licensed. During the swarm phase of the mission, command and control shall be centralized to maximize coordination efficiency. Once the satellites disperse into a constellation command and control authority may be delegated back to the respective constituent universities, but a structure for single source override of operations shall be retained.

Most of the mission operations will be automated due to the inherent nature of CubeSat missions only allowing occasional acquisition of signal (AoS) by ground stations. The mission shall also attempt to leverage community based ground station networks such as SATNOGS or TinyGS to increase downlink opportunities. Data gathered from the Cluster shall be aggregated to a single cloud based database.

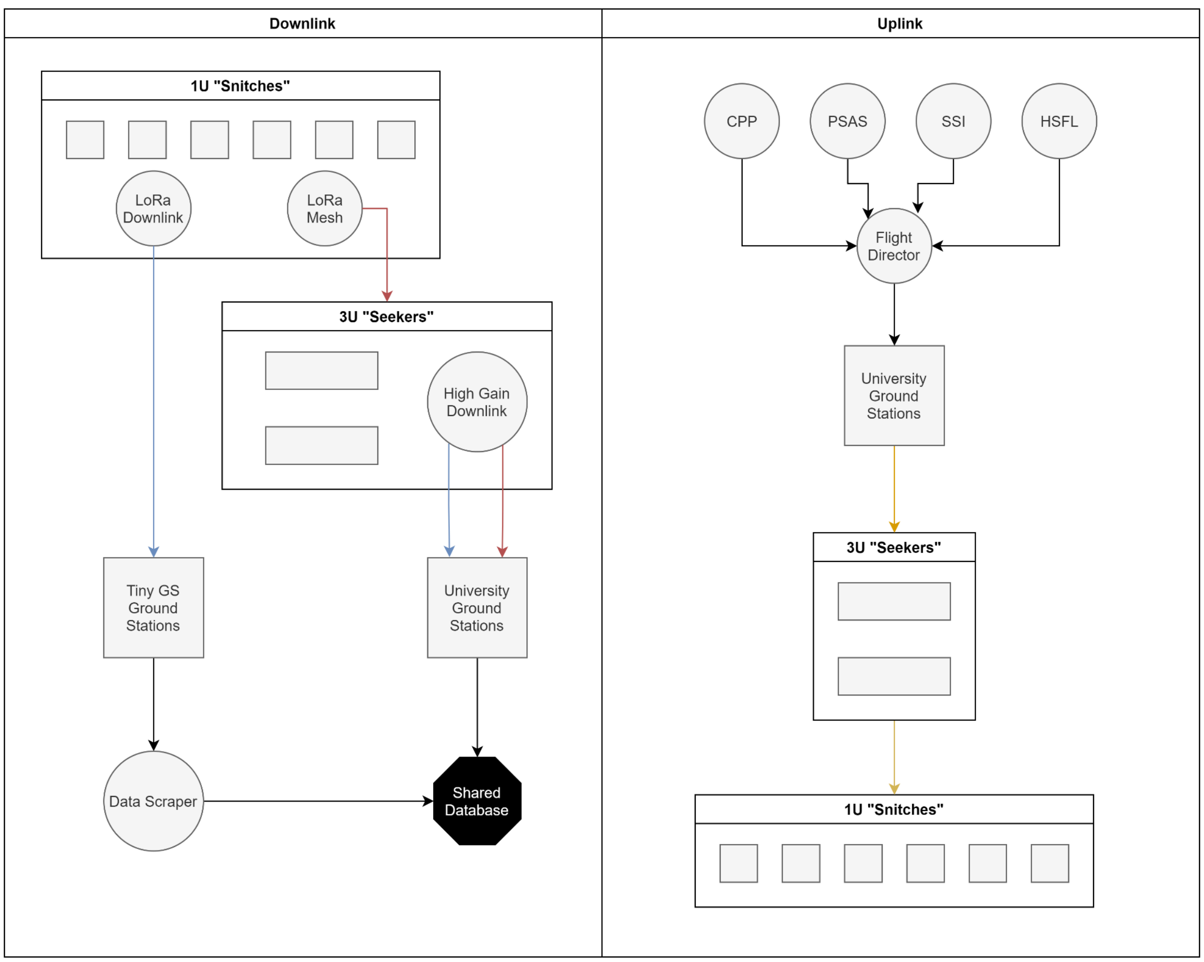


Figure 5: Datalink Architecture

Licensing constraints limit command authority of the satellite cluster to only pre-designated ground stations. Therefore, command of the Cluster shall only be possible when one of the university based ground stations makes successful acquisition of signal. Within the OreSat architecture, the Engineering Data Link (EDL) allows for reprogramming of the Seekers on orbit, if needed. A single flight director shall be nominated to manage and approve all command and control operations. This individual shall also act as “Stop Buzzer” and be the responsible individual for handling interference or conjunction alerts from the respective government entities. As a result of this increased responsibility, the Flight Director must be an individual that receives funded compensation for their role. Separate mission ops teams at each university shall be designated to contribute operational requests and facilitate datalinks via their respective ground stations as needed.

7 The Pleiades Team

The Pleiades CubeSat Cluster shall be jointly developed by 4 university based institutions who all participate in the Blue Dot Consortium, a group founded in Summer 2020 to connect student focused university CubeSat programs. With four universities participating directly in the Pleiades Cluster work effort must be split between all four constituents.

7.1 Cal Poly Pomona’s Bronco Space

Cal Poly Pomona’s Bronco Space (CPP Bronco Space) is a student-led organization that was founded in Spring 2019 with the guiding vision of making CPP a space capable university by 2022. This mission statement has been met early, with the Bronco Space team delivering BroncoSat-1 to a launch service provider in April of 2021.

Dreamed, designed, and built by students, BroncoSat-1 is a 1.5U CubeSat technology demonstrator for the use of Artificial Intelligence and Machine Learning in Low Earth Orbit. On-orbit results from the BroncoSat-1 mission may have widespread applications across attitude control systems, earth sciences, and on-orbit data processing with edge computing. 35 undergraduate students were engaged through the BroncoSat-1 project across Aerospace Engineering, Mechanical Engineering, and Computer & Electrical Engineering disciplines in addition to participation from the College of Science and the College of Business at CPP as well. In addition to designing, integrating, and testing actual space flight hardware, students paved the way for continued space activities at CPP with student-designed and built lab infrastructure and procedures. The entire BroncoSat-1 project went from conception to delivering in a span of 10 months despite the COVID-19 pandemic.

In addition to the BroncoSat-1 program, Bronco Space has established and operates BLADE, an academic year long design, build, and flight program for 1U CubeSats on high altitude balloon flights. BLADE targets incoming first year and transfer students to provide a robust training platform that allows these new students to quickly become acquainted with Aerospace Industry and Systems Engineer focused design processes. An average of 25 students are engaged by the BLADE program every year, and it is anticipated that graduates of the 2020-2021 BLADE “Excalibur” class shall form the core student development team for the Pleiades Program.

Presently the CPP Bronco Space team serves as the primary mission designers, and shall transition to a role of mission management as the Pleiades program proceeds. Bronco Space also facilitates coordination of work on the cluster, and its members shall act in the role of final integrators for three of the eight satellites within the cluster (one satellite from each of the three architectures). Interface and final delivery of the Pleiades cluster flight units to the launch provider shall also be facilitated by the Bronco Space team.

7.2 Portland State Aerospace Society

The Portland State Aerospace Society (PSAS) is a well-established student focused aerospace engineering organization based at Portland State University. Formed in 1997, PSAS has a number of innovative “firsts” in amateur rocketry and has developed a collection of sophisticated avionics for amatuer rockets, many of which are now featured in the OreSat Bus. The OreSat project began in 2016, and was subsequently accepted into NASA’s 2017 CubeSat Launch Initiative with a 2U CubeSat for interactive space-based Science, Technology, Engineering, and Math (STEM) outreach in the state of Oregon.

That satellite, OreSat-1 proposed Space-Based STEM Outreach using PSAS’s novel DxWiFi project, which pioneered creating an extremely long range WiFi-based (802.11b) amatuer radio link in the 2.4GHz band. OreSat-1 plans to use this experimental WiFi link to deliver live video directly from Low Earth Orbit to K-12 classrooms to teach students about wireless communication, space, and nanosatellites. In addition to the outreach mission, OreSat-1 also intends to complete science objectives with a miniaturized Shortwave IR camera platform. OreSat-1 anticipates launch in the 2022 time frame.

In the Summer of 2020, PSAS also began work on OreSat-0, a pure technology demonstration mission for the OreSat open architecture bus. This satellite, a 1U, was built, tested, and delivered in April 2021 for launch. The on-orbit results of the OreSat-0 mission shall play a key role towards the validation of the OreSat architecture as a robust option for future university class CubeSat developers.

The PSAS team participates in the cluster as the lead designers and responsible organization for the OreSat Architecture. The PSAS team will therefore be the final integrators for one OreSat bus and any engineering models under the OreSat architecture. While the design burden of the novel technology demonstrations shall be split across all members of the Pleiades cluster, the PSAS team shall have final authority over their interface with the OreSat platform and the 3U Seekers in the cluster.

7.3 Stanford Student Space Initiative

The Stanford Student Space Initiative (SSI), Stanford's largest project-based student group, has an active satellite team that is currently developing an affordable, simple, and fully open source 1U CubeSat bus. SSI has more than 300 members split between six teams: rockets, balloons, biology, Mars, policy, and satellites. SSI is a student-run, faculty-advised organization that strives to craft future leaders of the space industry through project based learning and direct mentoring from university and industry professionals.

SSI is the gathering place at Stanford for people interested in space. Since 2013, SSI has broken world records in high altitude ballooning, developed a unique space-capable DNA synthesis technique, lobbied the UN, won international rocketry awards, taught an accredited Stanford class Why Go to Space, and hosted over 150 speakers at talks and conferences. With no application process, SSI is open to all students and has over thirty onboarding workshops for new members to provide engineering confidence no matter their prior experience. SSI conducts wide educational outreach such as taking local elementary and high school students along for balloon launches, making bricks out of simulated Martian soil, and teaching weekend classes on rocket engineering.

In particular, the satellite team has helped develop two previous CubeSat projects: the Stanford Nano Picture Satellite and the Polar Orbiting Infrared Tracking Receiver. The first attempted imaging a mothership CubeSat in collaboration with the Space Systems Development Laboratory, and the second attempted laser communications in collaboration with NASA's JPL. The satellite team has spent the last year and a half developing an affordable, easy to build CubeSat bus which is adaptable for a plethora of mission goals.

The SSI team leads work on the PyCubed based 1U's and is expected to deliver two flight units to the Pleiades Cluster. The Stanford SSI team shall also contribute heavily to the software components of the Pleiades cluster, ranging from potential machine vision algorithms for Seekers to ground based simulation software for swarm dynamics.

7.4 Hawaii Space Flight Laboratory

The Hawaii Space Flight Laboratory (HSFL) was established in May 2007 within the School of Ocean and Earth Science and Technology (SOEST) and the College of Engineering (CoE) at the University of Hawaii at Manoa. HSFL stands as a multi-disciplinary research and education center that has played a key role in launching STEM careers from the Hawaiian Islands and serves as established developers of microsatellites from the 1-150kg range.

Recently, HSFL successfully delivered and launched NEUTRON-1, a 3U CubeSat flying a neutron detecting payload from Arizona State University. NEUTRON-1 helps explore the complex relationship between Earth and the Sun by mapping neutron abundances in LEO. This satellite also is a key flight test and demonstration of HSFL's Comprehensive Open-architecture Solution of Mission Operations Systems (COSMOS) software stack. HSFL shall also deliver the 6U HYTI (HYperspectral Thermal Imager), in collaboration with NASA's JPL, to demonstrate a novel Earth Science technology no earlier than Fall 2021.

In the Summer of 2020 HSFL was selected by NASA to create a low cost 1U CubeSat kit that could both serve as an educational platform and a basis for building flight ready CubeSat missions. This initiative was funded to improve awareness of NASA's Artemis program, while also educating and inspiring the future generation of Artemis scientists, engineers, and explorers.

The HSFL team, as creators of the Artemis kit, shall be the responsible organization for the Artemis 1U's with an expectation to deliver two 1U flight units to the cluster. It is possible that HSFL's COSMOS software stack may also see use as the core software basis for the Pleiades Cluster. Because the HSFL team is also heavily focused on educational outcomes, it is anticipated that their educational materials shall play a large role in Pleiades outreach and educational activities.

8 Cost Estimate

This section details the expected direct costs for fabrication of the Pleiades CubeSat Cluster satellites. Salary compensation, equipment & facilities costs, and launch costs are not included in this cost projection, and are expected to be obtained primarily as in-kind contributions or funded through targeted research grants. **Table 3** presents a simplified cost project for the Pleiades Program that is based on an idealized and lumped cost model for projecting the costs of hardware for the Pleiades Program. This model is roughly based on the anticipated reproduction costs of existing university class open source CubeSat missions.

Table 3: Simplified Cost Projection

Line Item	Projected Cost
Pleiades CubeSat Flight Units	\$60k - \$120k
Pleiades CubeSat Engineering Units	\$30k
Laboratory Prototypes	\$10k
Hardware Only Cost Range:	\$100k - \$160k
Licensing Fee Range	\$10k - \$80k
Potential Net Direct Cost Range:	\$110k - \$240k

8.1 Simplified Cost Projection Justification

Using a basic cost estimate of \$5k / 1U of CubeSat hardware, a minimum cost for the 12U's of CubeSat flight units the Pleiades Cluster is \$60k. Depending on funding availability, this number would ideally be doubled to reflect the program's desire to create two distinct generations of protoflight hardware. A key risk factor that may lead to significant cost creep, with respect to flight hardware, is the ongoing global semiconductor shortage which has seriously impacted lead times and occasionally resulted in severe price gouging in all industries that require semiconductors.

The \$5k per 1U figure is derived from the projected cost to reproduce existing open source satellites such as OreSat-0 or Brown University's EquiSat. In the case of the PyCubed architecture, an exact cost figure for previous missions like V-R3X is not available, but the cost of the core hardware stack is usually below \$1k with the main cost drivers beyond that being solar panels or the inclusion of COTS (Commercial Off The Shelf) components. \$5k for a 1U kit was also the original benchmark for the Artemis CubeSat Kit, but current estimates believe that the 1U kits can be delivered fully functioning for \$2.3k each thanks to various architecture improvements in the last year.

The creation of engineering models is estimated to be done for approximately half the cost of flight at $2.5k per unit. This totals a projection of $30k for engineering models for all of the cluster satellites. These models are expected to perform as test articles and hardware twins, in the laboratory, for the flight units. While flight models may require space rated hardware and higher cleanliness standards, the engineering models can take a more cost efficient approach. It is also expected that surplus hardware for engineering models will naturally become available. This is due to the fact that commercial hardware fabrication rarely allows orders in singles, so there is only a small marginal cost associated with creating sets of hardware vs single articles.

Laboratory prototype systems for the novel technologies planned for Pleiades (specifically the in-space situational awareness and the mesh network) are estimated to take $5k per system. With two systems, prototypes take $10k total in hardware costs. This estimate is based on the belief that, for prototype demonstration, these technologies can be tested using entirely COTS parts in the hobbyist or prosumer hardware classes. While custom systems will likely be required for flight, the use of COTS for terrestrial testing allows for greatly reduced costs.

Finally, licensing fees are expected to be the largest non-hardware direct cost that shall be incurred by the program, with a potential range from $10k to $80k. Unfortunately, there does not yet exist clear guidance on how to efficiently license a cluster of satellites. Hence there is an extremely wide range in how much licensing may potentially cost. It should be noted that this cost projection does assume sub-contracting the licensing proceedings to a 3rd party that specializes in satellite licensing. It is believed to be possible to license the cluster as a single unit rather than eight individual satellites. This would greatly simplify the process, but a worst case scenario of having to license all individually may result in a nearly 8x cost growth with respect to licensing.

8.2 Potential Funding Sources

Various potential funding sources have been identified for the Pleiades Program. **Table 5** denotes sources of funding that are both likely and timely (able to deliver without a multiple months long review process). Note that sources in **Table 5** are potential, and there are not yet guarantees of funding awards.

Table 5: Potential Funding Sources

Source	Lead Organization	Possible Contribution
California Space Grant Workforce Development Fall	CPP/SSI	$30k
California Space Grant Workforce Development Spring	CPP/SSI	$30k
Misc Corporate Sponsorships - CPP	CPP	$20k
CPP Office of Academic Innovation	CPP	$8k
Misc Corporate Sponsorships - SSI	SSI	$12k
Stanford SSI Matching Funding	SSI	$22k
In-Kind Hardware Contributions - PSAS	PSAS	$30k
In-Kind Hardware Contributions - HSFL	HSFL	$10k
Possible Net Fund Raising		$172k

As mentioned previously salaries, equipment, facilities, and launch costs are anticipated to be covered primarily through in-kind project support or funded through more formal research grants. The Pleiades Program plans to submit tailored white papers and proposals to various federal government research programs to raise additional funds for the Cluster, but, due to long lead times within those funding avenues, the arrival of funds in a timely manner cannot be relied on. It is anticipated that corporate sponsorship shall play a large role in Pleiades fund raising efforts, as corporate donations of equipment, services, or direct monetary exchange have played a key role in the success of previous missions such as OreSat-0 or BroncoSat-1.

9 Appendix A - References

[1] https://www.statista.com/statistics/897719/number-of-active-satellites-by-year/
[2] https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4362&context=smallsat
[3] https://www.morganstanley.com/ideas/investing-in-space
[4] https://hackathon.bluedotconsortium.space/

10 Appendix B - Alpha Schedule Definition

Tentative Overall Schedule

- End of August - Prototype Hardware Completed
- End of September - Protoflight Design Completed
- End of October - First Flight Hardware Integrations
- End of November - Initial Environmental & Field Tests Completed
- End of December - Generation Alpha Complete

Tentative Flight Hardware Schedule

- End of August - System Prototype & Integration Plan
- End of September - Protoflight Debug
- End of October - Protoflight Configuration Integration
- End of November - Full System in the Loop Analysis
- End of December - Generation Alpha Hardware Freeze

Tentative Flight Software Schedule

- End of August - Prototype Software in the Loop
- End of September - Implement Protoflight Software and Debug
- End of October - Laboratory Debug of Flight Software
- End of November - Field Debug of Flight Software
- End of December - Generation Alpha Flight Software Freeze

Tentative Integration Schedule

- End of August - Prototype Integration of New Designs & Draft Flight Integration Plans
- End of September - Execute Protoflight Integration and Revise Plans to Streamline
- End of October - Execute Protoflight Integrations
- End of November - Workmanship Checks on Protoflight Hardware
- End of December - Integration with Launch Provider Prep

Tentative Test Schedule

- End of July - Draft Test Objectives and Procedures
- End of August - Test Prototypes of Existing Designs & Improve Objectives
- End of September - Test Protoflight Configuration
- End of October - Validate Functionality of Flight Integrations
- End of November - Field Test of Generation Alpha Protoflight Hardware
- End of December - Integration with Launch Provider Prep