# THE ARTEMIS PROJECT: PICOSATELLITE-BASED MISSIONS TO STUDY VLF PHENOMENON

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**Abstract**: During the 1998-99 academic year, six Santa Clara University undergraduate students conducted an experimental investigation of developing science missions with very small, very inexpensive spacecraft. Known as the Artemis project, this effort resulted in the development of three sub-kilogram "picosatellite" vehicles which are manifested for launch from Vandenberg Air Force Base in September 1999. Two of these satellites will collaboratively gather data on lightning as part of a broad study of space telecommunications. The three Artemis picosatellites were developed in 10 months at a total program cost of $8,000. This paper motivates the applicability of picosatellite missions, describes the Artemis project goals, and provides a technical description of the satellites.

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## 1. INTRODUCTION

The Santa Clara Remote Extreme Environment Mechanisms (SCREEM) Laboratory, founded in 1998, conducts world-class education and research in the development of advanced mission systems capable of operating in remote and extreme environments. SCREEM conducts a variety of yearly projects involving the complete development of robotic vehicles such as spacecraft, underwater and terrestrial rovers. Students then operate these systems during applied missions or expeditions in order to perform scientific studies, to validate advanced technology, and/or to provide educational services. These project-based activities are tailored for small teams of senior-level undergraduates, are student managed and engineered, require the integration of knowledge across a variety of disciplines, and involve development activities across all lifecycle phases.

### *The ParaSat Spacecraft Program*

SCREEM's spacecraft program has the goal of producing student managed and engineered spacecraft that contribute to each participant's education while providing a platform capable of supporting inexpensive, albeit risky, space experiments [1]. Named the ParaSat space flight program, this initiative relies heavily on the use of corporate donations, reengineered commercial, off-the-shelf (COTS) equipment, HAM radio communications, battery power, and simple operational strategies. Configurations are modular with general volume and mass limitations of one cubic foot and 15 kilograms. The development time for these systems is less than one year, and the orbital lifetime is on the order of days or weeks. Cash equipment budgets are targeted at $5,000, limited functionality for several subsystems is permitted, and permanent attachment to spacecraft and/or rocket stages is considered acceptable.

The first ParaSat spacecraft, named Barnacle, is currently being prepared for launch on board an experimental sounding rocket [2]. A second version of this same design is being considered for an orbital launch in late 1999. See Figure 1. The Barnacle

Microsatellite a) sounding rocket configuration (left) and b) orbital configuration (right). Barnacle's missions include characterizing experimental sensors and validating the space operation of a new low cost spacecraft computer. Barnacle was developed in less than one year, involved six undergraduate engineering students, and required a budget of less than $7,500.

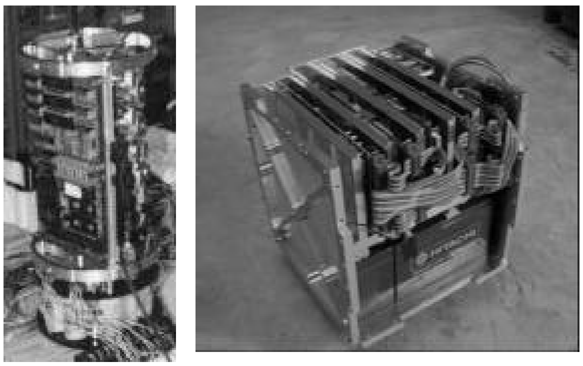

Figure 1. The Barnacle Microsatellite a) sounding rocket configuration (left) and b) orbital configuration (right).

## 2. THE PICOSATELLITE CONCEPT

Picosatellites are at the forefront of the new trend of micro/nano-technology. These sub-kilogram spacecraft are generally on the order of a few cubic inches, carry very mission-specific functionality onboard, and satisfy their mission in relatively short operational lifetimes.

Existing micro/nano-technology strives to incorporate complex functionality into low power, low mass, and physically small packages. Typical missions can be, and have been, successfully completed on smaller platforms. However, the question of how small a useful spacecraft can be still remains. Picosatellites are an extreme and futuristic vision of such a trend in technology.

Maximal efficiency is essential in the design of the picosatellites due to volume constraints. Only the most fundamental subsystems can be considered a part of the design process. Unnecessarily complex subsystems could result in inflated budgets and prolonged project lifetimes. Developments on a pico-class spacecraft need to place an emphasis on minimum missions and the simplest way of meeting a set of specifications. On the scale of a student-managed team, this is especially crucial to the success of the project. Picosatellites encompass all of the advantages of a smaller, faster, and cheaper satellite.

*Distributed Sensing*

A traditional satellite is limited to collecting a single data point at an instant in time. This satellite is able to collect different data points as it orbits the earth. However, some events occur so rapidly that the orbital velocity of the satellite and its sampling rate is not adequate to portray a very accurate picture of the entire field. Recently, more importance has been placed on constellations of satellites. Complex missions are performed utilizing a network of distributed simple satellites; however, building multiple satellites is expensive. With the smaller, cheaper, faster approach of picosatellite design, multiple spacecraft can readily be constructed for the same mission. After multiple picosatellites are scattered in the region of interest, simultaneous data can be obtained to gain a better perspective of the field at one instance in time. These picosatellites time-stamp their data and transmit it back to the mothership as a collective set, enabling us to be able to examine a particular occurrence with more detail and precision.

Free-flying magnetometers is an experiment [3], proposed by the Jet Propulsion Laboratory (JPL), that uses this distributive sensing technique to measure the earth's magnetic field with simultaneous data sets. This concept has been undergoing constant development at JPL.

A picosatellite constellation for magnetospheric characterization is also being explored by Boston University. It's Constellation Pathfinder mission, slated for a space shuttle launch in 2001 as part of the University Nanosatellite Program, will be a test of this application [4].

Dr. Rick Fleeter, president of the Aero/Astro Corp., has suggested using pico-class spacecraft with the distributive sensing technique for purposes of local inspection [5]. These picosatellites would carry cameras as their payload and inspect areas on the exterior of space stations for signs of deterioration or damage. This would also reduce the overall cost of maintaining a space station.

Some of the challenges faced in designing small satellites are size, mass, and power constraints.

The purpose of the Artemis project is to explore these challenges and address the feasibility of such a spacecraft. With only a year to build several picosatellites and no previous aerospace knowledge, the students have confronted these challenges and solutions are being researched and investigated.

## 3. ARTEMIS PROJECT

### *Project Goals*

Given the aerospace industry's existing interest in picosatellite-based missions, the Artemis team adopted the following goals.

The first was to explore the limits of smaller, faster, cheaper in spacecraft design by developing several picosatellite vehicles in under a year for less than $10,000. In accordance with the trend toward smaller designs for satellite development, the team members were interested in examining the level of sophistication that can be incorporated into the functionality of a sub-kilogram spacecraft. To set a precedent of a faster developmental timeline, the Artemis team established a one-year limit on their project duration. To exemplify how inexpensive such a project can be carried out, approximately $8,000 was spent to complete the three Artemis picosatellites.

The second was to validate the picosatellite architecture by using the vehicles to perform a compelling scientific mission. Science on picosatellites has been a highly debated issue in the aerospace industry. The Artemis team challenges any existing skepticism by launching functional picosatellites into orbit with specific scientific objectives.

Beyond theses primary goals, the Artemis team members also had specific personal goals they hoped to address through this project. Advancing the charter of the SCREEM Laboratory and promoting future opportunities for Santa Clara students were among their top priorities. They hoped to encourage future students to work in interdisciplinary groups and to pursue challenging projects in various remote extreme environments. Artemis chose to pursue the picosatellite project because of the technical challenges that it offered.

### *Artemis Picosatellite Test Mission*

The first picosatellite completed by the Artemis team was 4”x3”x1”. It contains a simplified version of all the fundamental subsystems crucial to a satellite. Its mission is to broadcast the Artemis website in Morse code upon launch. Its lifetime is limited by the capacity of the batteries onboard, which is approximately 12 hours. See Figure 2. Morse Code Mission Picosatellite.

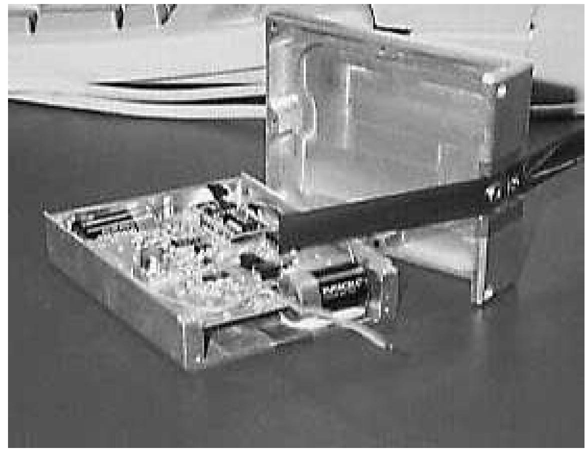

Figure 2. Morse Code Mission Picosatellite

### *Artemis Picosatellite Scientific Mission*

For the final mission, two picosatellites will collect data on lightning phenomena simultaneously. Artemis is working with Stanford’s STARLab (Space Telecommunications And Radioscience Laboratory), an electrical engineering laboratory with world class expertise in this scientific field [6]. The lightning science was chosen as the objective for the mission due to established relations with researchers at the STARLab and the ability to collect data through receivers built by undergraduate students.

The Artemis data will be compared with lightning data collected on the ground by the U.S. National Lightning Detection Network (NLDN). The NLDN track lightning strike locations and discharge parameters concentrated in the Midwestern and the Southern United States. By comparing the NLDN data collected at the same time as the Artemis data, the number of horizontal vs. vertical strikes can be determined. Horizontal lightning is lightning that strikes from cloud to cloud. Vertical lightning is lightning that strikes from ground to cloud or vice versa. The Artemis picosatellites will be able to record both horizontal and vertical lightning, whereas on the ground only horizontal lightning can be recorded. By simply subtracting the NLDN data from the Artemis picosatellite data, the number of horizontal lightning counts can be determined. The picosatellites will acquire this data through a VLF (Very Low Frequency) receiver and transmit the resulting information down to the ground. Accomplishing this feat would make Artemis the first satellite design team to perform world-class science utilizing orbiting picosatellites. The dual-picosatellite capability will allow the collection of simultaneous and distributed measurements of lightning-induced radiation in order to study the structure and variation of the Earth's ionosphere.

*OPAL*

The Artemis picosatellites had secured a launch opportunity onboard SSDL's (Space Systems Development Laboratory) OPAL (Orbiting Picosatellite Automatic Launcher) microsatellite from Stanford University. OPAL's primary mission is to conduct an end-to-end demonstration of mothership and daughtership technologies. In order to fulfill this mission requirement, OPAL [7] must store several picosatellites onboard and deploy them once in orbit. See Figure 3. Opal ejecting a picosatellite. Upon deployment, the picosatellites will collect the necessary data, establish a ground-link to transmit that data, and complete OPAL's primary mission.

OPAL has three independent teams providing the picosatellites. The Artemis team from Santa Clara University will be conducting a science experiment using multiple picosatellites to research the effects of lightning on the outer ionosphere. In addition, a team from DARPA, Aerospace Corp., and UCLA will test MEMS technology and an intersatellite communication network. A team of amateur radio enthusiasts will build a FM voice repeater.

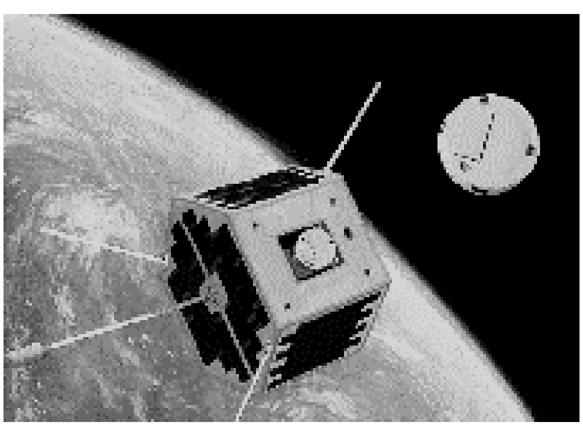

Figure 3. Opal ejecting a picosatellite.

OPAL has obtained a flight opportunity as a secondary payload onboard JAWSAT's (Joint Airforce Weber State SATellite) multi-payload adapter. JAWSAT is slated for launch on the OSP (Orbital Suborbital Platform) Space Launch Vehicle in September 1999 from Vandenberg, California.

## 4. PICOSATELLITE TECHNICAL DESIGN

The picosatellites are divided into five subsystems - payloads, mechanical structure, power, communications, and CPU.

*Payloads*

The primary payload onboard the 8"x3"x1" picosatellites will be a VLF receiver. See Figure 4. VLF Receiver Board. The Artemis team is collaborating with Stanford University's STARLab to pursue the exploration of the lightning experiment. The STARLab's main interest is to take measurements using radio signals traveling between the ground and planetary spacecraft. Lightning discharges and the effects on the earth's near space environment can be recorded with the VLF receiver. The VLF receive frequency range is 0.1 to 12kHz, with 5kHz being the typical frequency of a lightning strike.

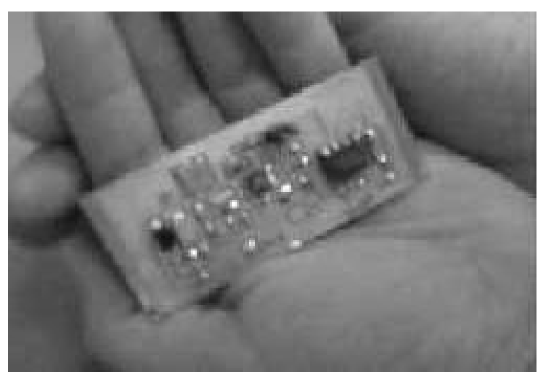

Figure 4. VLF Receiver board

The VLF receiver design used on the two picosatellites has the same approximate passband peak of 2kHz. Each picosatellite is set to a different sensitivity threshold. One picosatellite will count events that are over 10mV. The other will count events that are over 100mV. Both VLF receivers on the satellites will simultaneously be enabled and count the number of VLF events that each satellite receives over the set thresholds. The VLF receivers were designed specifically for Artemis Picosatellites. The circuit has an incredibly small footprint of 3"x1" and all surface mount components. The VLF antenna is a one-meter whip antenna. Along with the VLF data, both satellites will transmit attitude data taken from the four on-board infrared sensors. The infrared sensor data will be used to determine the approximate orientation of each satellite when the VLF experiment is run. Magnets will be on-board both 8"x3"x1" picosatellites in order to achieve the best alignment with the ionosphere.

*Mechanical Structure*

As with most spacecraft design, a set of structural constraints pertaining to weight and size were given to interface with the launcher tubes onboard OPAL. These constraints included a size limitation of 8"x3"x1", a weight limitation of 1 kg, a center of gravity no more than 3/4" from the geometric center, 45° chamfers on the four longer sides, and a 0.1 radius on the shorter-front corners. The structural design includes two circuit board slots on all four inner walls. The location of the boards is strategically placed in order to allot the proper space for batteries and other electrical components. The design requirements also included a one-meter whip antenna (for the VLF receiver) and a half-wave dipole antenna (for the communications subsystem). Both antennas are contained, while in the launcher, to the dimensions specified and are released upon launch. See Figure 5. Structure with antennas deployed.

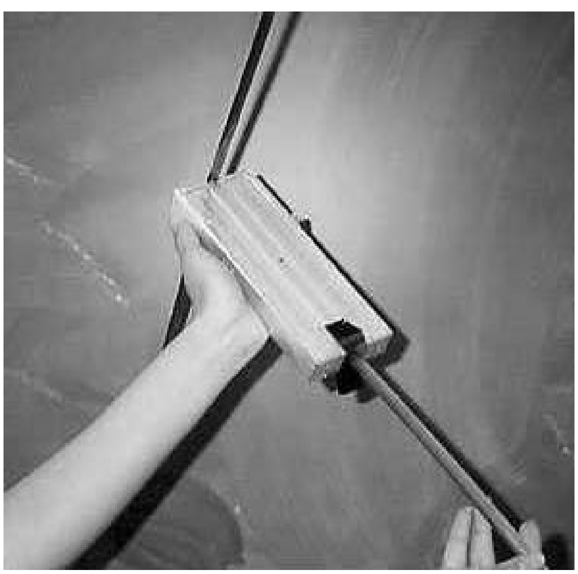

Figure 5. Structure with antennas deployed.

Due to the length of the VLF antenna, a 1"x1" compartment inside the structure is allocated to maintain it while the communications antenna has a groove machined on the top and bottom surfaces of the craft. The four sensors on the 8"x1" and 3"x1" sides merely protrude from the structure as does the micro-switch. For the picosatellites, optimizing the structural design relied heavily on optimization of space.

*Power*

Two AA alkaline batteries, rated at 1.5V and 800mAh, wired in series, were designed to power the picosatellites. The alkaline batteries were chosen because they have flown in space and have been proven to perform well. The battery capacity will allow for completion of the VLF experiment within hours of ejection from OPAL. The microprocessor monitors battery voltage levels and determines if the picosatellite can continue operating. A National Semiconductor LM2621 Step-Up DC-DC Converter is used for regulation.

*Communications*

The communications subsystems consisted of a modem, transmitter, power amplifier, antenna switch and receiver circuitry.

The Texas Instruments TCM3105 FSK Modem IC provided an interface between the transmitter circuit and the CPU. The modem chip was selected due to the constraints of time, ease of implementation and simple testing capabilities. The modem modulated the digital data of 0s and 1s from the microprocessor to an analog signal that is transmitted. The frequency of the analog signal shifts depending on whether the data is a 0 or a 1. Both the modem and the transmitter transmit at 1200 baud.

The transmitter circuit was designed by a group of local communications mentors and built around the Motorola MC13176 UHF FM/AM transmitter chip. The FM transmitter operates on amateur radio frequencies in the 70-cm band. Since the MC13176 was a surface-mount chip and funds were limited, initially the transmitter boards were milled on FR-4 copper clad material. Later on, the entire communication system would be mounted to high frequency FR-4 copper clad material. Since knowledge of layout design was very basic, several revisions of the transmitter test boards were milled in a lab at Santa Clara University.

The transmitter circuit alone did not provide enough output power to ensure a successful communications link with a standard OSCAR (Orbiting Satellite Carrying Amateur Radio) class ground station. The RF2114, a medium power RF amplifier made by RF Micro Devices, was used to increase the power output of the transmitter circuit. The circuit was configured to produce 200mW at the output of the amplifier and was the biggest draw of current at 250mA. Problems with power being reflected into the chip caused several delays in finishing the project. A faulty attenuator and large amounts of reflected power damaged several amplifier chips.

Since the reflected power damaged the power amplifier chips, a concern arose about the reflected amplifier power damaging the receiver chip. As a result of this concern, the RF2436, a single-pole, double-throw transmit/receive antenna switch made by RF Micro Devices, was interfaced between the power amplifier, receiver, and the antenna. The quarter-inch wide, half-wave dipole antenna, designed to utilize untreated Stanley Tools tape measure material, deploys once the picosatellite has been ejected from the mothership. The downlink of the transmitter has the capability to transmit directly to an OSCAR class receiving station on the ground

The RF Monolithics RX1000 receiver utilized the same frequency band and antenna as the transmitter. The receiver is a single-chip, which converts a RF signal down to digital data. The microprocessor will periodically turn on the receiver and listen for an OOK (On-Off Keying) modulated command from the ground station. When the picosatellite is within visible range of the ground station, an uplink command will be sent to enable the VLF receiver to begin collecting data.

*CPU*

The microprocessor onboard the picosatellites will be the BASIC Stamp II. These processors are made by Parallax, Inc. and run PBASIC (Parallax BASIC) programs. The microprocessor contains 2048 bytes of EEPROM (Electrically Erasable Programmable Read Only Memory), 16 word registers of RAM, 16 I/O pins, two RS-232 I/O pins, and runs at 200 MHz. The BASIC Stamp II was chosen for its simplicity and low power design. It requires about 7mA of current at 5V during operation and only 5uA in sleep modes.

Two external dual-channel analog-to-digital converters were added in addition to the BASIC Stamp II module purchased from Parallax. The A/D converters were needed in order to collect data from the infrared attitude sensors located on four of the six faces of the structure. Each of the four sensors feed into an I/O line on the BASIC Stamp II through a channel on one of the A/D converters. A "snapshot" of the values from the four infrared sensors is taken before and after each iteration of the VLF experiment to provide a rough estimate of the spacecraft's attitude.

## 5. Analysis and Testing

With a ten-month design schedule from conceptualization to flight-ready satellites, the Artemis team was limited to testing only the most critical systems of the satellite. The students relied on COTS hardware that was already proven to be reliable in space. With quick prototyping, trade off sheets, and advice from industry mentors, the Artemis team was able to meet their design and cost goals by making educated engineering decisions.

Some critical tests preformed included participating in OPAL's shake test at NASA Ames Research Center last November. Mass models of the Artemis picosatellites were contained in the launching tubes during the OPAL shake test. See Figure 6. Picosatellites in OPAL during shake test. The Picosatellites and OPAL successfully completed the test.

Figure 6. Picosatellites in OPAL during shake test.

The VLF receiver payload was tested in an electromagnetically isolated laboratory for circuit sensitivity and response. Intense frequency response measurements were collected on the VLF receivers and compared with theoretical modeling of the circuitry. See Figure 7. VLF Receiver Frequency Analysis. The stability of the circuit was examined with Spice models and the circuit was verified not to ring or oscillate. To prevent interference from spurious RF noise from the communications subsystem, an aluminum bridge was placed into the structural design to isolate the two subsystems.

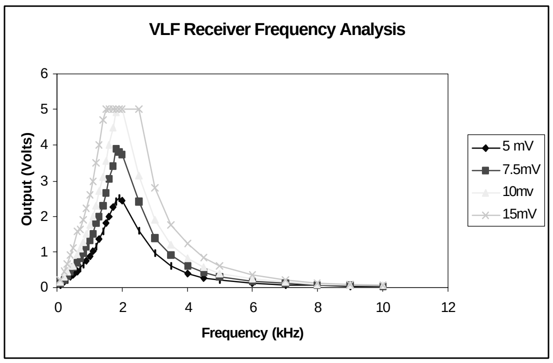


Figure 7. VLF Receiver Frequency Analysis

Standard calculations and analyses completed for the different engineering subsystems included thermal analysis, attitude calculations, battery/lifetime calculations, link budgets, and antenna matching. Without previous formal aerospace education or experience, these calculations were at the core of subsystem designs for the Artemis picosatellites.

## 6. MISSION OPERATIONS

OPAL will be launching on JAWSAT in September 1999 from the Vandenberg Air Force Base. The Artemis Ground Operation's team will be monitoring the National Weather Service for major lightning storms in the Midwest. At any point in time there can be up to 2000 thunderstorms active with an average of 100 lightning strikes per second [8]. When there is a great amount of lightning activity, an uplink will be sent from SSDL to release the scientific picosatellites from their launching tubes.

Upon ejection from the mothership, the picosatellites deploy their communications and VLF antennae. A brief sleeping period occurs to protect the mothership, OPAL, from communications interference. The picosatellites will begin to periodically broadcast their callsigns for tracking purposes every minute. In between the intermittent broadcasts, the CPU will be in a wait mode. During this wait state, the transmitter is turned off and the receiver is turned on periodically to listen for uplink commands from the ground station. To optimize battery lifetime, the picosatellites duty cycle between sleep mode and turning the receiver on. Once an uplink command is received, the CPU will initiate the VLF experiment by enabling the VLF receiver. The VLF experiment is carried out in one minute during which the CPU simply counts the number of pulses the VLF receiver detects above a set voltage threshold. Upon completion of the one minute VLF experiment, the picosatellites will add to their periodic transmission the number of VLF pulses counted during the experiment, how old the data is, and the corresponding attitude data. The picosatellites broadcast the data every minute until it is prompted by the next uplink command to repeat the experiment and record a new data set.

The raw VLF data taken by the picosatellites will be posted on the Artemis Project web site and made freely available to the public.

*Mission Success Criteria*

There are three different levels of success to the Artemis mission. The Artemis picosatellites will be among the world's first orbital picosatellites. By successfully surviving launch, deploying from OPAL, and transmitting a beacon signal to the ground, picosatellites will become proven technology.

The second level of success will be technology prototyping of the VLF receiver. The designs of the VLF receivers were specific to the parameters of the picosatellites. The Artemis Team is establishing a baseline of the VLF mission. The picosatellite VLF receivers have not been in space before. They are the first satellites out of a new program from the SCREEM Lab to incorporate a VLF payload. The limitations of scope and performance were explored on the Artemis picosatellites. An improved version of the same VLF receiver will fly on EMERALD (Electromagnetic Radiation and Lightning Detection), a joint collaboration between the SCREEM Lab and SSDL. See Figure 8. The EMERALD Microsatellites.

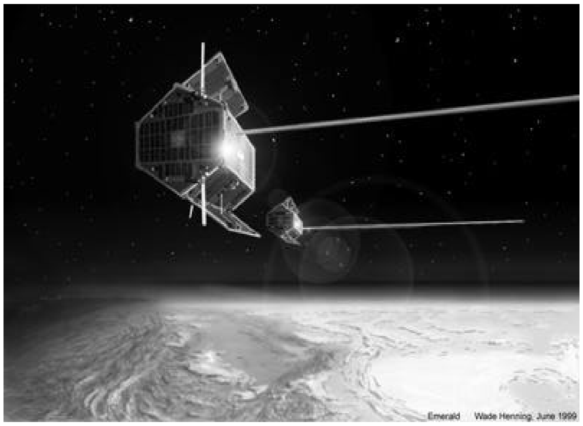

Figure 8. The EMERALD Microsatellites.

EMERALD is two 10kg microsatellites with a three month mission life that are being developed in preparation for the DARPA/AFOSR University Satellite Research Initiative [6]. Extensive testing and analysis was preformed on the VLF receivers during their development to ensure they would operate according to their specifications in space. The final criterion for a successful technology prototyping of the VLF receiver is successful functioning of both the 10mV and 100mV receivers in space.

The Artemis picosatellites will be the first scientific mission on a sub-kilogram satellite. Along with extensive research on the necessary requirements to do science on a picosatellite, the Artemis picosatellites will offer extremely useful data to the scientific community. Enhancing scientific knowledge is the third level of success on the picosatellite project. Through analysis of the data, the occurrence of horizontal vs. vertical lightning can be explored. The intensity level of lightning observed in a storm will be another area in which the Artemis data is useful. Practical applications of the analysis can be applied to weather prediction, robust communications, electronic protection, and golfer safety [6].

## 7. CONCLUSIONS

The picosatellite architecture has been debated for several years as a potential way of conducting new styles of compelling and low cost missions. Exploring the feasibility of such a controversial approach within an educational setting ensures a low cost, albeit high risk project. The Artemis team at Santa Clara University investigated the plausibility of performing meaningful science onboard picosatellites. Through involving their picosatellites in the experiment to monitor lightning-induced atmospheric fluctuations, the Artemis team has a chance to prove that such technology is indeed worth a significant amount of attention from the aerospace industry.

Using university-based projects to explore novel space concepts is beneficial for several reasons. Such programs support educational institutions and provide students with the opportunity to design, manage, and engineer a spacecraft through its complete design cycle. These programs also allow for innovative ideas to be offered by students. Students can often provide different viewpoints and insights from those that surface in the industry. A third benefit is the low-cost approach students adopt to examine a new concept. Since student teams can afford to take on higher risks, they can work with a significantly smaller budget. COTS parts are readily used in student-built spacecraft while space-rated parts would be required in their place in industry. Many companies also provide sample parts and donations to students; this is something an industry team cannot rely on.

## 8. ACKNOWLEDGMENTS

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Amy Slaughterbeck is an undergraduate electrical engineering student working in the SCREEM Laboratory where she manages the power subsystem.

Adelia Valdez is an undergraduate electrical engineering student working in the SCREEM Laboratory where she is developing the receiver for the communications subsystem onboard the picosatellites. She leads the communications subsystem.

## REFERENCES

[1] C. Kitts and J. Ota, "The ParaSat Space Flight Program", Invited for publication at the *International Astronautical Federation Specialist Symposium: Novel Concepts for Smaller, Faster & Better Space Missions*, Los Angeles, April 19-21, 1999

[2] J. O'Boyle, P. Stang, N. Woods, "The Barnacle Microsatellite", In *Proceedings of the 12th Annual AIAA/USU Conference on Small Satellites*, Logan, Utah, August 31 – September 3, 1998.

[3] D. Clarke, M. Hicks, A. Fitzgerald, J. Suchman, R. Twiggs, J. Randolf, T. Kenny, "Picosat Free Flying Magnetometer Experiment", In *Proceedings of the 10th Annual AIAA/USU Conference on Small Satellites*, Logan, Utah, September 16-19, 1996.

[4] R. Blomquist, et. al., "University Nanosatellite Program", Accepted for publication at the 2nd International Conference on Integrated Micro-Nanotechnology for Space Applications: Enabling Technologies for New Space Systems, Pasadena, CA, April 11-15, 1999. Also accepted for publication at the International Astronautical Federation Specialist Symposium: Novel Concepts for Smaller, Faster, & Better Missions, Los Angeles, April 19-21, 1999.

[5] Dr. Rick Fleeter, "Management of Small Satellite Programs - Lessons Learned", *Proceedings of the IAF/COSPAR World Space Congress*, September 2, 1992.

[6] Christopher Kitts, "A Small/Mico-/Pico- Satellite Program for Investigating Thunderstorm-Related Atmospheric Phenomena", In *Proceedings of the 12th Annual AIAA/USU Conference on Small Satellites*, Logan, Utah, August 31 – September 3, 1998.

[7] Brian Engberg, et.al., "The OPAL Satellite Project: Continuing the Next Generation Small Satellite Development", In *Proceedings of the 9th Annual AIAA/USU Conference on Small Satellites*, Logan, Utah, September 19-22, 1995.

[8] Volland, H., Atmospheric Electrodynamics, Springer-Verlag, New York, 1984.