University Nanosatellite Program

Mr. Maurice Martin, AFRL, martinr@plk.af.mil, (505) 853-4118, Dr. Howard Schlossberg, AFOSR,
Mr. Joe Mitola, DARPA, Dr. Dave Weidow, GSFC, Mr. Andrew Peffer, AFRL, Dr. Richard Blomquist, CMU,
Dr. Mark Campbell, UW, Dr. Christopher Hall, VT, Elaine Hansen, UCol, Dr. Stephen Horan, NMSU, Prof Chris Kitts,
Santa Clara Univ, Dr. Frank Redd, USU, Dr. Helen Reed, ASU, Dr. Harlan Spence, BU, Prof Bob Twiggs, Stanford

Abstract

DoD, NASA, and industry are jointly sponsoring the development and launch of 10 university nanosatellites (~10kg) to demonstrate miniature bus technologies, formation flying, and distributed satellite capabilities. The satellites are planned to launch late 2001. This paper provides detailed information on the technologies and science objectives of each of the 10 satellites.

Program Overview

The Air Force Office of Scientific Research (AFOSR) and the Defense Advanced Research Projects Agency (DARPA) are jointly funding 10 universities with grants of $50k/year over two years to design and assemble 10 nanosatellites (~10kg). The universities will conduct creative low-cost space experiments to explore the military usefulness of nanosatellites in such areas as formation flying, enhanced communications, miniaturized sensors, attitude control, and maneuvering.

The Air Force Research Laboratory (AFRL) is developing a deployment structure, securing a launch, and providing such advanced microsatellite hardware as high efficiency solar cells and micropropulsion units. NASA Goddard has also teamed with the universities to provide approximately $1.2M funding to demonstrate such formation flying technologies as advanced crosslink communication and navigation hardware and flight control algorithms. Numerous industry partners are also supporting the universities with hardware and design and testing services.

The universities will deliver the satellites to AFRL in April 2001 for integration onto the deployment platform. The integrated payload will then be delivered to the launch vehicle integrator in June 2001 for launch on or after November 2001. Further information on the program and presentations from the kick-off meeting can be seen at the website, http://www.nanosat.usu.edu/.

The universities selected for the program are: Arizona State University, University of Colorado at Boulder, and New Mexico State University (Three Corner Sat); Stanford University and Santa Clara University (EMERALD); Utah State University, Virginia Polytechnic Institute and State University, University of Washington (ION-F); Boston University (Constellation Pathfinder); and Carnegie Mellon University (Solar Blade Nanosat). Descriptions of their satellite programs follow.

Three Corner Sat Constellation (3⮝Sat)

Arizona State University: Brian Underhill, Assi Friedman, Helen Reed
University of Colorado Boulder: Elaine Hansen, Dan Rodier, Anthony Colaprete
New Mexico State University: Stephen Horan

Overview

This project is a joint effort among Arizona State University (ASU), University of Colorado at Boulder (CU), and New Mexico State University (NMSU). Aptly named Three Corner Sat (3⮝Sat), our proposed constellation of three identical nanosatellites will demonstrate stereo imaging, formation flying/cellular-phone communications, and innovative command and data handling. In addition, each University in our 3⮝Sat constellation has the opportunity to fly an individual unique payload should it desire. Because of our team's heritage in space flight (CU's DATA-CHASER payload via August '97 Space Shuttle), conventional satellite design (CU's Citizen Explorer via Delta, December '99), and nanosatellite design (ASU's 4.5kg ASUSat1 via OSP Minotaur, September '99), our constellation will be ready for launch in late 2001.

1. Mission Goals

Stereo Imaging. The primary science objective of the 3⮝Sat constellation is to stereo image small (< 100 meter), highly dynamic (< 1 minute) scenes including deep convective towers, atmospheric waves, and sand/dust storms. These stereo images will enable the computation of range to within 100 meters giving accurate data regarding the shape, thickness and height of the observed phenomena.

Stereo imaging from space has several advantages over conventional imaging, the most obvious being the ability to derive range data. This range data can be substantially more accurate than range data acquired by other more usual means and also can cover a much greater area. Stereo imaging involves correspondence matching between an image pair and calculation of the resulting disparity. From the disparity, triangulation can be used to determine range data, and three-dimensional images and depth maps can be created. Accurate depth maps with range resolutions of about 100 meters enable the study of relatively small-scale, short-lived atmospheric events such as cumulus-cloud towers.

Zones of deep convection, in areas such as the Midwest, frequently create large cumulus towers that extend from the middle troposphere into the lower stratosphere. These zones of convection are frequently impassable to air traffic due to the highly unstable air. Radar, while able to warn aircraft of large convection cells, is unable to give accurate data as to their extent in altitude. Thus, air traffic is frequently diverted hundreds of miles regardless of the altitude extent of the convection cells. With better estimates of cloud heights, some air traffic may be able to traverse these convective boundaries by flying over areas of shallow convection.

Cloud heights are critical to our understanding of the Earth’s climate and our ability to better model it. Because of their dynamic nature, both spatially and temporally, incorporating clouds and their effects into Global Circulation Models has been difficult. One key piece of data that is missing is the height and thickness of clouds at a global level. Using stereo imaging, we will measure the heights of clouds with a precision of less than 100 meters and make a statistical study of their type, height, and thickness.

In the last decade, studies have indicated that just as important as clouds, other aerosols, including mineral aerosols such as dust or sand, play an important role in Earth’s climate system. Recent experiments have been undertaken or planned to understand the composition, structure, and distribution of mineral aerosols on both a local and global scale. Stereo imaging allows the statistical study of aerosol cloud structures, such as sand storms, and can provide information on the relationship between uplift efficiencies, boundary-layer thickness, and particle sizes with local environments.

As the time between typical satellite images can be long, highly dynamic objects such as clouds and dust storms are currently stereo imaged in a way that makes the range data inaccurate. Stereo images from the GOES8 and GOES9 weather satellites have proven the effectiveness of using two satellites to view the same scene, however, these satellites can only view together for a few hours a day, and, since they have relatively low image resolution, the range data is poor. For highly dynamic objects, several satellites with relatively good resolution need to image the same location at the same time. By using a formation of satellites, stereo images of small, highly dynamic objects can be made, and from these stereo images, accurate range data may be calculated.

Formation Flying / Communications. To accomplish the science objectives, a “virtual formation” is proposed and will be demonstrated as part of our program. The virtual formation is a cooperative effort between satellites operating as a network where targeting and data acquisition are accomplished and results transmitted to the ground segment and to the other satellites via communications links without the need for strict physical proximity of the satellites. In this mode, the communications links carry the command and control data necessary to accomplish the mission regardless of the physical location of the satellites. For the mission to be accomplished, the locations of the satellites will need to be “in range” and mutually known in order for each to support its portion of the mission, but physical proximity is not a requirement for the formation network.

For stereo imaging, a nominal spacing of tens of kilometers between the satellites is required. With a controlled deployment to achieve this initial spacing, the satellites will remain within range for the suggested four-month lifetime of the mission. Therefore propulsive capability is not needed.

The design of the mission utilizes a commercial communications network in Low Earth Orbit (LEO) which supplies the communications links as shown in Figure 1. This will allow each satellite to be contacted via the LEO network regardless of the position of the satellite relative to the ground station – with predictable visibility outages. Because each satellite in the network will be visible to the LEO communications constellation, there will be the ability for satellites to perform their mission coordination without the need for visibility from the ground station or with each other. The LEO communications network knits together the virtual formation.

LEO satellites utilizing cellular telephone constellations is a new concept but one in which there is considerable interest in the government and private-sector space communities. This natural extension to the use of ground-based systems will be explored not only to demonstrate the utility of this mode of communications but also to act as an experiment to characterize the constellation itself and the limits on the operations. A technology goal of 3∧Sat is to perform the first steps in this characterization.

Command and Data Handling (C&DH) System. The C&DH for the 3∧Sat constellation is designed as a distributed and simple system. As part of this distributed arrangement, each satellite uses a Satellite Processor Board that serves as its local controller, data interface, on-board memory, and processor. The three-satellite constellation can be controlled and managed by a processor on any of the three satellites via the communication links. The Satellite Processor can be responsible for supervising the operation of the three spacecraft and managing their resources. This supervision can be automatically accomplished within the constellation by the selected satellite processor which can initialize and distribute commands and which can monitor and react to science and engineering data from the three spacecraft.

University Specific Experiment – ASU Micropropulsion System. Micropropulsion systems can offer a wide variety of mission options, all relevant to formation flying: attitude control, orbital drag make-up, altitude raising, plane changes, and de-orbit. For its University-specific experiment, ASU is collaborating with AFRL and industry to design and fly a micropropulsion system. The objective of ASU’s research is to take a systems point of view and develop a safe and simple micropropulsion system for nanosatellites. In particular, the ASU satellite will demonstrate orbit raising and de-orbiting once the 3^Sat virtual-formation/stereo-imaging mission is completed.

2. Mission Implementation

Mission Design. The 3^Sat constellation will consist of three satellites flying in a linear follow-formation with relatively constant separation from each other. The separation distance selected is based on altitude and camera field of view (FOV), with final determination based on the chosen launch vehicle. The mounting configuration within the launch vehicle will depend upon the launch vehicle and other satellites selected. The satellite will use gravity-gradient (GG) forces for stabilization with +/- 5 degrees pointing accuracy.

Spacecraft. All satellites will be identical, except for a standard payload envelope where each university will have the option to fly its own unique experiment after the primary science objective has been met. The spacecraft structure will be low-cost and reliable. The exterior envelope of the structure is a six-sided disk structure consisting of tubular supports and machined end caps to hold the bulk of the loading (Figure 2). The design will feature a number of modular, removable trays, allowing for on-the-spot modifications without extra machining or irreversible processes. The design incorporates a common electrical bus that is easily accessible and durable. The material selection and component placement will eliminate the need for any extra shielding from EMI or radiation in space. The solar array panels will be mounted on thin aluminum sheets that mount to the exterior of the frame. All components will mount to aluminum honeycomb plates, which fasten to the main frame via slide-in interface brackets, and/or standard socket head cap screws. The batteries will be stored in the middle of the structure to avoid an unbalanced inertial configuration. These cells will be housed in an eccofoam/aluminum structure attached in a manner to stiffen the component panels from harsh vibration environments.

Project Schedule

Milestone	Date
Project Start	January 1999
System Requirements Review	May 1999
Technical Interchange Meetings	(every 2 months)
Preliminary Design Review	August 1999
Critical Design Review	March 2000
Build	March-August 2000
Integration and Test	Fall 2000
Environmental Test	November 2000
Qualification Readiness Review	December 2000
Flight Readiness Review	February 2001
Launch-Vehicle Integration	April 2001
Launch	late 2001

3. Sponsors

AFOSR/DARPA, NASA Space Grant Program, Lockheed Martin Tactical Defense Systems, Honeywell, Lockheed Martin Astronautics, Motorola, KinetX, AFRL, Cogitec, Space Quest, Microchip, Ball Aerospace, Spectro Lab, and JPL.

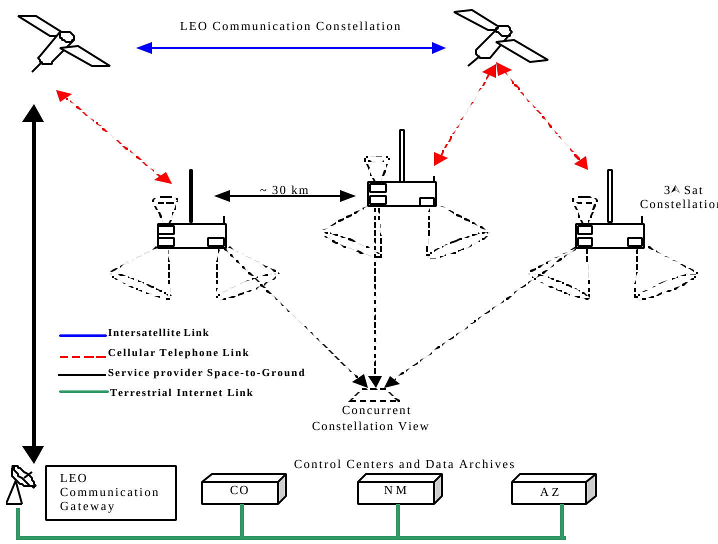


Figure 1. 3^Sat Constellation Overview

Primary exterior components shown:
1. Phone antenna
2. Star mapper (15^{O} FOV)
3. Parallel gravity gradient booms with tip masses
4. Integrated battery pack/release mechanism
5. GPS patch antenna
6. GaAs body mounted solar array (18% efficient)
7. Hard mounting points / lateral movement restraint
8. Four CMOS cameras (FOV 15^{O} single/54^{O} composite)

Primary interior components not shown:
1. Boom deployment mechanism
2. C&DH electronics
3. Power control board
4. Cell phone
5. GPS receiver
6. Paraffin actuated pin-pullers
7. Structural supports, tubes and panels
8. Camera boards with micro controllers

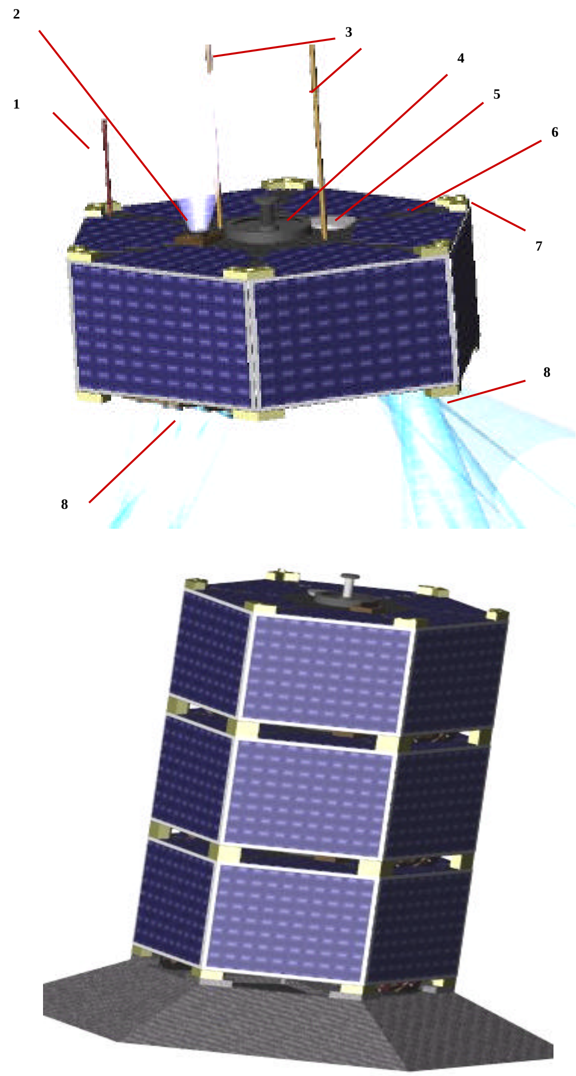


Figure 2. 3^Sat w/Launch Configuration

EMERALD: A Low-Cost Spacecraft Mission for Validating Formation Flying Technologies

Bob Twiggs - Stanford Space Systems Development Laboratory
Chris Kitts - Santa Clara Remote Extreme Environment Mechanisms Laboratory
Jon How - Stanford Aerospace Robotics Laboratory
Student Managers: Bryan Palmintier and Freddy Pranajaya

Spacecraft formation flying is an evolving technology with vast scientific, military, and commercial potentials that range from enhanced mission performance to radical reductions in operations cost. As part of the TechSat 21 University Nanosatellite Program, Stanford University and Santa Clara University are jointly developing EMERALD, a low cost, two-satellite mission for validating formation flying technologies. Stanford's SSDL (Space Systems Development Lab) and Santa Clara University's SCREEM (Santa Clara Remote Extreme Environment Mechanisms Laboratory) will work as a unified team to develop, construct, test and eventually operate the EMERALD spacecraft. The formation flying experiments will be coordinated through Stanford's ARL (Aerospace Robotics Lab)

The EMERALD Mission is divided into three distinct stages that progress from a simple single satellite to two free flying satellites in a coarse formation. Using a building block experimental strategy, the research payloads first will be characterized in isolation. Then, they will be coordinated and combined to permit simple demonstrations of fundamental formation flying control functions such as relative position determination and position control.

- At release, the two spacecraft will be stacked together and will travel as a single object. This will allow initial checkout, calibration, and some limited experimentation.
- During the second stage of operation, the satellites will separate and a simple tether or flexible boom will uncoil, linking the two vehicles. This tethered stage will allow full formation flying experimentation including on-orbit relative position determination and simple closed loop relative position control using the drag panels and microthrusters.
- During the final stage of operation, the tether will be cut in order to permit true two-body formation flying for a limited period of time. The tether will have a simple sub-satellite at its midpoint. Upon ground command, the two halves of the sub-satellite will separate. Each satellite will retain half of the tether and half of the sub-satellite, providing very rough gravity gradient stabilization.

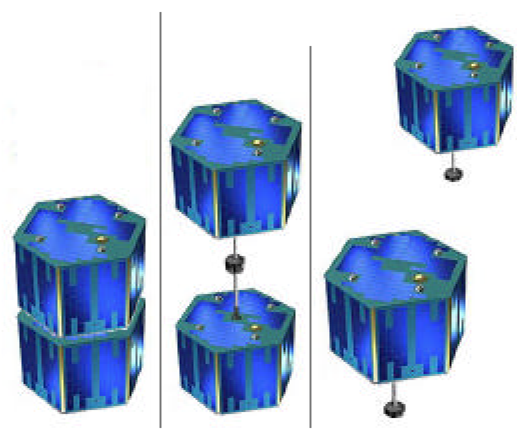


Figure 3. EMERALD Mission Sequence (Joined, Tethered, Formation Flying)

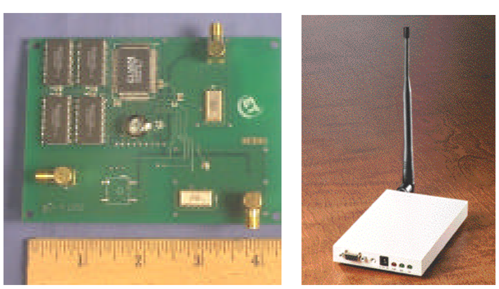
The two EMERALD spacecraft will demonstrate several critical technologies for future formation flying missions:

- **GPS-based positioning** For onboard orbit determination and relative navigation, a Stanford-modified Mitel 12-channel GPS receiver will be flown on each spacecraft. This receiver can compute relative position to approximately 2-5 meter level accuracy in real-time using differential GPS techniques. They will be modified-for-space versions of the receivers currently in use by ARL's other formation flying experiments.

- **Inter-satellite communication** EMERALD plans to develop a simple inter-satellite communication link from the commercially available19.2 kbs wireless radio modems currently used by ARL for ground based formation flying systems. This will provide the real-time communication link necessary for differential GPS measurements.

- **Advanced colloid microthrusters** To enable small scale position control, these thrusters can supply vectored thrust on the order of 0.11 milli-Newtons, and have a specific impulse of approximately 1000 seconds. These components are currently in development by Stanford's Plasma Dynamics Laboratory (PDL).

- **Simple, passive position control devices**
  - A simple tether or flexible boom will maintain the satellites within a given distance, on the order of tens of meters. This tether may be cut later in the mission in order to demonstrate advanced formation flying capabilities.
  - Deployable panels on both spacecraft will allow simple, low performance drag control. During the tethered mission phase, these panels can be used to maintain tether tension as well as to attempt closer positioning.



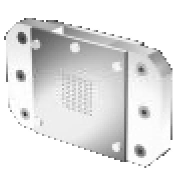


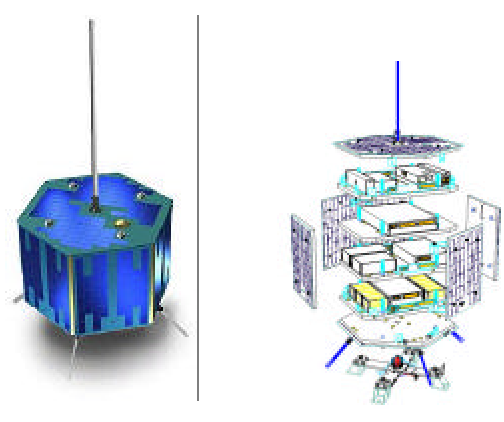
Figure 4. Mitel-1GPS Receiver (Top left), ARL Radio Modem, Colloid Microthruster

In addition to these mission critical payloads, EMERALD will support a couple of auxiliary payloads:

- **VLF receivers** will record radio waves emitted by high altitude atmospheric phenomena associated with lightning. The experiment will help understand some of the fundamental happenings in the Earth Ionosphere. The distributed sensing enabled by formation flying capabilities, will enhance the scientific data and help ***validate*** the benefits of satellite formation flying. The receivers will be based on an existing design developed at STAR Lab (Stanford Space Telecommunications and Radioscience Laboratory) The mission name, EMERALD (Electromagnetic Radiation And Lightning Detection), refers to this experiment.

- **MERIT**, the MicroElectronics Radiation In-flight Testbed, will characterize the performance of advanced microprocessors, MEMS technologies, and other electronic components in the space environment. This payload is being developed as part of a separate SSDL research program in conjunction with Boeing, the Naval Research Laboratory (NRL), The Aerospace Corporation, Honeywell, UTMC, and the Laurence Berkeley Labs.

These experiments will be built into a 12-inch tall, 18-inch diameter hexagonal bus adapted from heritage designs at SSDL. The structure employs a modular, stackable tray structure made of aluminum honeycomb. Inside, command and data handling is provided by a Motorola 68332-based processor built into a student developed radiation tolerant architecture. Ground communication will be handled by a 9.6 kbs packet communications system. The heritage power system consists of body mounted Silicon cell solar panels and a single Ni-Cad battery. This system will provide 7 Watts of average power to components via a 5V regulated bus. Passive thermal control will be achieved through the use of insulation and thermal coatings.



(a) Assembled View *(b) Exploded View.*

Figure 5: Heritage Bus Configuration

One of the most important upgrades to the heritage architecture is the shift to a serial command and data bus. As shown below, EMERALD will use I^2C to connect all of the subsystems and experiments. This modular design simplifies integration and allows stand-alone testing of components. It also allows the project to maintain a schedule driven design: If a payload fails to show enough progress at a quarterly design review, it can be removed from the mission, with minimal effect on the rest of the satellite. For future projects, this modular bus structure will allow subsystems and experiments to be selectively swapped-out, upgraded, and interchanged, similar to reconfiguring a PC.

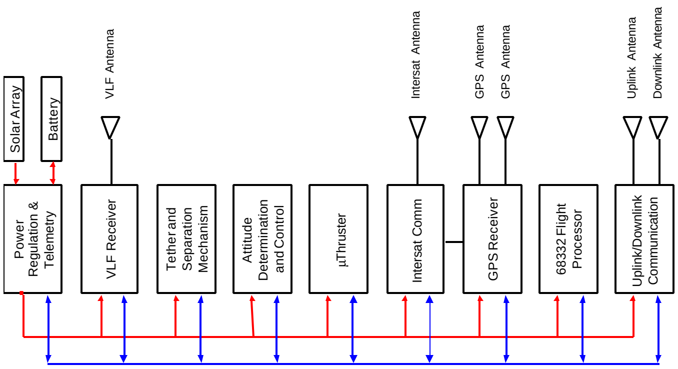


Figure 6: EMERALD System Block Diagram

Ionospheric Observation Nanosatellite Formation (ION-F)

Utah State University: Dr. Frank Redd (PI), Dr. Charles Swenson, Dr. Rees Fullmer

University of Washington: Dr. Mark Campbell (PI), Dr. Adam Bracken

Virginia Polytechnic Institute & State University:

Dr. Chris Hall (PI), Dr. Nathaniel Davis, Dr. Jaime DeLaRee, Dr. Wayne Scales, Dr. Warren Stutzman

Program Overview

Utah State University, University of Washington, and Virginia Polytechnic Institute are designing and developing a system of three 10-kg spacecraft to investigate satellite coordination and management technologies and distributed ionospheric measurements. The three will coordinate on satellite design, formation flying and management mission development, and science instruments and mission. Advanced hardware for distributed space system to be demonstrated includes m-pulsed plasma thrusters, gimbaling magnetic attitude control, and an advanced tether system. In addition, an Internet based operations center will be designed to enable each university to control its satellite from its own remote location. ION-F will focus on mission objectives that would benefit TechSat 21 and future Air Force and NASA missions. Coordination between the different university teams will be by conferencing, Internet, and telephone. In addition, industrial (SDL, Primex, Honeywell) support has been identified, including funding for students, hardware, and satellite design support.

Objectives and Research Issues

The program objectives (PO's) for the ION-F follow:

PO1. Basic research mission of investigating global ionospheric effects which affect the performance of space based radars, and other distributed satellite measurements.

PO2. Formation flying and local communication in a constellation, including upgrade from a 3 nanosatellite constellation to 4 nanosatellites.

PO3. Baseline new technologies including micro-thrusters, magnetic gimbaled attitude control, advanced tether system, and an Internet based operations center.

PO4. Bring a unique, hand-on space experience to graduate students, undergraduate and graduate space design students, and undergraduate engineering students in independent research projects.

Formation Flying

Because formation flying is a primary mission objective for ION-F, and because at least one satellite will have propulsion capability, the UW-VT-USU team is very interested in working with the NASA Goddard formation flying program. Communications cross-links are the top priority, and the relative navigation chip and software are important as well. Because of the tight constraints and high capability of the ION-F nanosatellites (including propulsion), there is little power or mass budget for additional instruments in the preliminary designs. The UW-VT-USU team intends to fly their control and formation algorithms but are investigating additional collaboration with NASA Goddard and their partners.

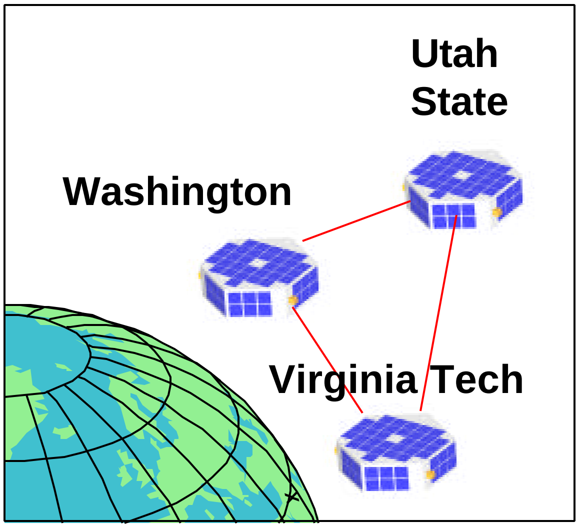


Figure 7: Ionospheric Observation Nanosatellites

It is expected that each of the three satellites will have cross-communication links and relative navigation capabilities. In addition, UW will have propulsion capability and USU will attempt to use differential drag. VT is undecided at this time, but is examining AFRL micro-propulsion concepts. With this in mind, the following activities were outlined as part of the formation flying mission of ION-F:

- After deployment of the three linked satellites, a checkout will occur of the subsystems, including GPS calibration, attitude determination, and possibly communications.
- After initial checkout and relative calibration, the satellites will separate. The satellites will deploy into a close leader-follower formation, and individual performance characterization and disturbance quantification will be performed.
- Using UW/Primex Micro-Pulsed Plasma Thrusters (μPPT's) and differential drag capability of USU, two-satellite formationkeeping will be accomplished relative to the VT satellite.
- More complex two-satellite formations will be examined such as side-by-side (same altitude but different inclination) and same ground track (NASA Goddard's "ideal" formation). The operations will include maneuvering into a new formation, and subsequent formationkeeping.
- Complex three-satellite formations will be attempted. Two examples include 1) maneuvering three satellites in a leader-follower formation to three satellites with the same ground track and 2) a rotating formation about an equidistant point.
- Formationkeeping using both position and attitude.
- Additional NASA Goddard collaboration and control algorithms can be accommodated.

Distributed Ionospheric Data

The objective is the understanding of ionospheric density structures that can impose large amplitude and phase fluctuations on radio waves passing through the ionosphere. The constellation provides a unique opportunity to answer questions about ionospheric disturbances that can not be addressed any other way. A single satellite can only provided very limited information on the dimensions and evolutionary time scales of the ionospheric disturbances it flies through because a full orbit (90 minutes) must occur between the next observation. In general the situation is even worse than this because only truly zero inclination equatorial satellites have a good possibility of measuring the same region twice due to the co-rotation of the ionosphere with the Earth. This science investigation contributes to the TechSat 21 basic research mission of investigating global ionospheric effects which affect the performance of space based radars. It also addresses broader Air Force interests in ionospheric effects on navigation and communication links.

We propose using the nanosat constellation to make the first global multi-satellite electron density measurements in the ionosphere. We also propose to make the first global multi-baseline RF-scintillation measurements of the ionosphere. The scintillation of GPS signals using receivers on each spacecraft will provide information about the scale sizes of disturbances between the nanosatellite constellation and the GPS transmitter.

The Earth's ionosphere frequently shows density disturbances and fluctuations over a very large range of scale sizes (from hundreds of kilometers to centimeters) at all latitudes, longitudes and nearly all altitudes. Ionospheric plasma density irregularities are associated with two-dimensional turbulent processes driven by both low latitude tidal neutral winds and high latitude current systems. We propose to determine the global distribution of plasma structure in both the quite and disturbed ionosphere. The proposed measurements would provide essential information for the understanding of ionospheric effects on communications, navigation, and GPS systems and for the development and validation of realistic predictive global ionospheric models. These observations are related to the priority measurements set up the by the National Space Weather Program.

One of two possible instruments will be deployed on each of the satellites in the constellation, either a plasma frequency probe from which an absolute electron density can be determined or an electron saturation current probe which can measure relative electron density variations. The electron saturation current probe is based on the DC response of a plasma to an applied potential on a probe. These types of probes were pioneered in the early 1920s by I. Langmuir and consequently are also known as Langmuir probes. The plasma frequency probe technique is based on the AC response of the probe. Early work in this technique can be traced back to diagnostics on V2 rockets shortly after World War II. These types of probes have been called impedance probes, RF-probes, and capacitance probes. The instrument to be selected will be based on the resources available on the nanosat but in general these instruments will be small, low-power, and have low impact on their host satellites.

The scintillation measurements will be extracted from the GPS receivers that are part of the orbit determination system on the nanosats. The 1575 MHz signal from the GPS satellites originate at 20,000 km over the Earth and must travel through the ionosphere, line of site, to the location of the nanosats at 360 km altitude. The signal will encounter regions of disturbed ionospheric plasma which will slightly increase or decrease the signal strength at the receivers. The size of these disturbed regions can be estimated by comparing signals measured over closely related propagation paths, such as between two nanosats.

Satellite Design

The basic satellite design is configured for released from a Shuttle Hitch-hiker canister and will also accommodate AFRL's proposed deployment from the shuttle SHELS. The structure is hexagonal with an approximate 18 in. width and a 5 in. height. This configuration can be modified as needed to meet the specific launch environment conditions. The structure will consist of two aluminum hexagonal plates and six end covers. One of these plates will serve as the mounting base plate for the spacecraft. The power subsystem will be a typical solar cell/battery design using high grade commercial industry NiCd battery technology. The entire spacecraft will be covered with solar cells, with the exception of the areas designated for the sensors. The power regulation electronics will leverage high quality commercial NiCd batteries which have been developed commercially for portable laptop computers.

Advanced Hardware

In addition to the science mission and formation flying experiments, at least one new technology will also be baselined on each of the satellites in ION-F. Four possible technologies, and their researchers, are described subsequently. The process will include keeping the collaborators up to date with the nanosatellite design. During the critical design phase of the program, a decision will be made as to the maturity of each technology for the nanosatellites, and whether it can be flown. Because of complexity and reliability issues, these technologies must have a high probably of success. Currently, the new technology options include: microthrusters, magnetic control, tethered deployment, satellite cross-links, and Internet operations.

Two versions of microthrusters are currently in development. Primex Aerospace Company is working with the University of Washington to scale down the power requirements of their Pulsed Plasma Thrusters. The UW nanosatellite will fly a propulsion system, and will be either the m-PPT's, or a cold gas system. Primex, Honeywell and AFRL are working separately on MEMS based thrusters such as micro-hydrazine. These will be flown on either the USU or VT nanosatellite if the maturity of the technology will allow it. The small modular nozzles would allow many options as to microthruster size. Although development time will most likely require more than two years, the potential for nanosatellites is very high.

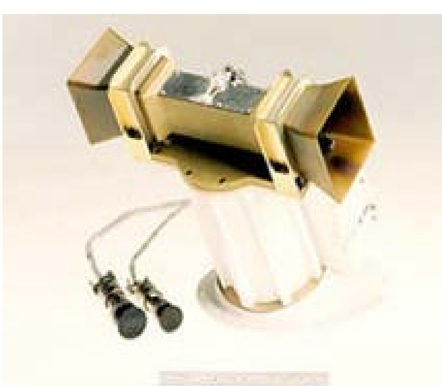


Figure 8: Full-sized Pulsed Plasma Thrusters from Primex Aerospace Company

Magnetic Control: One objective is to develop 3-axis attitude control given the very limited power and weight availability on a nanosatellite. We will meet this challenge with an all magnetic torquer system where permanent magnets on stepper motors are used instead of traditional torquer coils. The attitude determination will be achieved by a combination of Earth horizon and sun sensors, giving three-axis control to approximately two to three degrees.

Tethered system: Adding a low-mass tether for gravity gradient stability will provide simple attitude control for the VT satellite. Nominally the tether will be a simple non-conducting ribbon. The spacecraft will also include a small digital camera for imaging the tether during deployment and during the eclipse exit period of the orbit. This will provide useful data on the flexible dynamics of tether systems.

Satellite Cross-links: Collaborating with NASA Goddard and building on the past experiences of USU and the SDL, the ION-F team will demonstrate satellite cross-links, exchanging relative GPS information and possibly attitude information.

Ground Operations via Internet: The USU ground station will be used for ION-F, and another ground station, most likely at VT, will be developed. In order to successfully coordinate the three satellites, an Internet based ground station will be developed. This will allow coordination of experiments by the different universities as well as individual satellite control and data dissemination. VT is also investigating use of the GlobalStar LEO constellation for satellite telemetry, tracking and commanding of the satellite using commercial communications technology.

CONSTELLATION PATHFINDER: A UNIVERSITY NANOSATELLITE

BOSTON UNIVERSITY AND DRAPER LAB
DR. HARLAN SPENCE

MISSION OBJECTIVE

The Constellation Pathfinder program demonstrates the feasibility of fabricating and launching one to three, <1 kg satellites that are capable of collecting and returning quality scientific and engineering data for one to four or more months. The particular satellite we propose to use is based on one developed over the past two years through a NASA-supported study called the Magnetospheric Mapping Mission (MMM) at Boston University. That study objective has been to assess the feasibility of placing hundreds of satellites equipped with magnetometers, into orbits extending into the tail of the magnetosphere, thereby obtaining a much more detailed three-dimensional picture of dynamic phenomena in geospace than has been possible previously. The Constellation Pathfinder proposal will take the first pathfinding step toward such an ultimate implementation. We propose a simplification of our current conceptual design in that the launch mechanism is provided by the Shuttle Hitchhiker, the magnetometer will be measuring larger (and therefore easier to measure) fields in the Earth's ionosphere, the lower altitude reduces RF communication requirements as does relaxation of the required data transmission rate, and the natural radiation environment will be much lower. **The hardware demonstration of building and flying such a satellite, or small suite of satellites, will provide a proof of principle that will be helpful in many scientific and strategic applications where a fleet of coordinated small satellites is required. Demonstration of satellite-to-satellite communication may also be possible.**

SATELLITE AND PAYLOAD DESIGN

The nanosatellite configuration and functional block diagrams are shown schematically below. The outer cylindrical surface consists of power-providing GaAs solar cells. The RF antenna is along the axis of the cylinder. Satellite spin will maintain the orientation of both the antenna and the solar cells within 10 or 20 degrees of the ecliptic plane assuming that we can select the shuttle orientation at the time of release to be in this range. The satellite electronics including batteries will be concentrated in the center. The magnetometer location is chosen to minimize contamination by spacecraft magnetic fields and will be located within the cylindrical volume. The sun sensor looks radially outward and will be used to determine the phase of rotation. Additionally in conjunction with the magnetometer it will determine the direction of the spin axis.

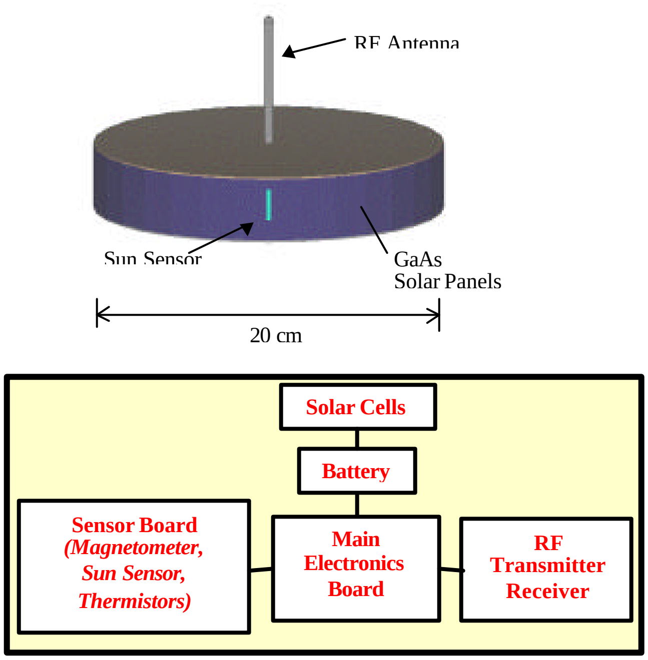


Figure 9: Pathfinder Satellite and Functional Layout

As compared to typical satellite designs this mission is particularly stringent in terms of requiring low mass and low power. In view of the large numbers of satellites eventually involved, the design must address manufacturability – simplicity of fabrication, assembly and calibration. On the other hand, the large number of satellites also reduces the reliability requirements. Failure of a few satellites simply reduces the number of data points but it does not lead to mission failure.

SOLAR BLADE HELIOGYRO NANOSATELLITE

Dr. Richard Blomquist and Dr. William Whittaker
Carnegie Mellon University

Solar sail concepts have existed for decades, but their implementation has been elusive, and none have flown. The primary difficulty has been the need for great surface area relative to mass. Traditional spacecraft designs with hundreds of kilograms of mass led to kilometers of blade dimensions, which were impossible to rationalize, build, and fly. Nanosat technology drastically reduces mass and makes heliogyro design eminently practical and flyable.

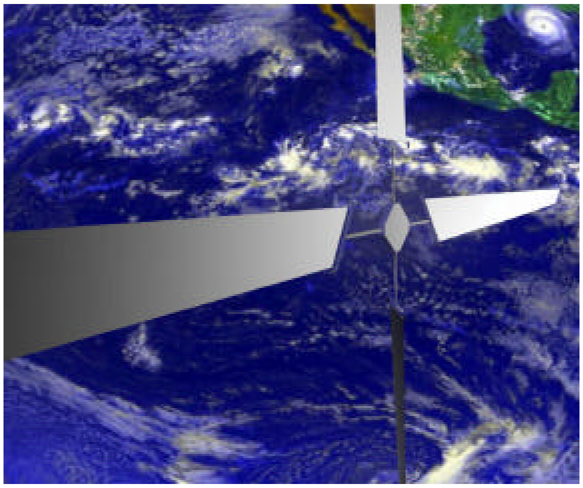


Figure 10. Solar Blade Heliogyro Nanosatellite

Carnegie Mellon proposes to develop and fly the first solar sail, a spacecraft which utilizes solar radiation pressure as its only means of propulsion and attitude control. The solar pressure will enable changes to altitude, attitude precession, spin rate and orbital position.

The Solar Blade Heliogyro Nanosatellite has the appearance of a Dutch windmill and employs control akin to a helicopter. Four solar reflecting blades mount radially from a central spacecraft bus and actuate along their radial axis. The satellite uses collective and cyclic pitch of these solar blades relative to the sun's rays to control its attitude and thrust. The spacecraft weighs less than 5 kilograms, and, when stowed, is a package approximately the size of a fire extinguisher.

The satellite will demonstrate attitude precession, spin rate management, and orbital adjustments, after which it will spiral out past the orbit of the moon. For the Solar Blade Nanosat, plane change maneuvers will be most efficient when the sun is furthest out of the orbit plane. This increases the magnitude of the orbit-normal component of force that can be used for the plane change maneuver. Plane change maneuvers can also be conducted if the sun lies in the orbit plane by orienting the solar blades at an angle relative to the orbit plane, optimally 45°. Unlike eccentricity changes, which can be implemented throughout the orbit using a single solar blade orientation, plane change maneuvers must change polarity on opposite ends of the axis of plane rotation. This is not possible unless the sun is in the plane of the orbit (the solar blades cannot produce a positive orbit normal force if the sun is above the orbit plane). Therefore, in most situations, plane change maneuvers will be conducted over an orbital arc on one side of the orbit near the axis of desired orbit rotation. In addition to attitude and orbital maneuvering, the ultra-light spacecraft will communicate with the Earth, uplinking commands and relaying orbital and attitude information to ground stations.

The Solar Blade Nanosatellite consists of a core containing the computer, communications system, and attitude determination hardware. Four bending struts emanate from the core and solar cells cover the top surface. The blades attach to the struts through individual actuators.

Each blade of the Solar Blade is a 20 meter long by 1 meter wide aluminized Kapton sheet 8 microns thick. Edge reinforcing Kevlar and battens of 80 micron-thick Kapton provide added stiffness and resistance to tears. Small brushless motors rotate the blades.

Solar cells embedded on the flanges of the C-beam frame provide up to 28 Watts of power. The spacecraft computer, communication system, and station-keeping sensors at the center of the square connect to the frame through thin lenticular beams. Wiring between the solar cells and the other subsystems consists of thin-film flexible printed circuits.

Deployment Structure Design

Andrew Peffer and Jeff Ganley, AFRL/VSD

The AFRL Space Vehicles Directorate will design, fabricate, and test a deployment structure to eject from the launch vehicle and deploy the 10 university nanosatellites. Two preliminary designs have been formulated to accommodate launch from an expendable launch vehicle as a secondary payload or from the Shuttle Hitchhiker Experiment Launch System (SHELS). The SHELS is a side bay ejection system under development that accommodates significantly greater weight and volume (180kg and 54" x 42.5" x 24") than the typical hitchhiker canisters.

The primary objective for the deployment structure is to 1) provide an interface to the shuttle SHELS system and 2) eject the nanosatellites following separation from the

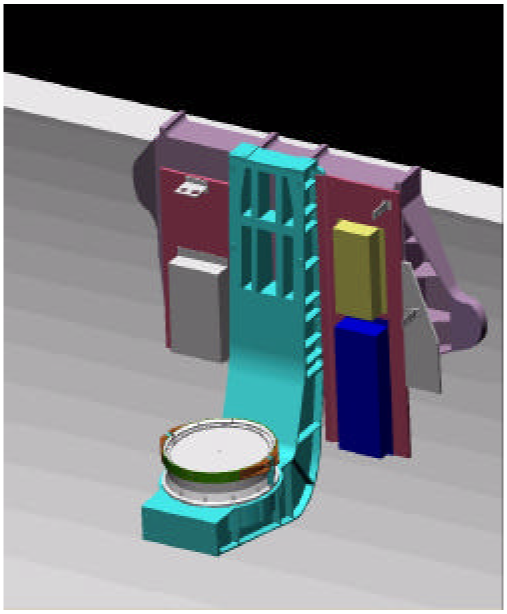


Figure 11. Shuttle Hitchhiker Experiment Launch System (SHELS)

shuttle. It will not provide orientation, communication, or spin up capability, and the nanosat separations are executed via timer using battery power.

This project poses a unique problem with regard to the design of a deployment structure. Since each of the universities has unique configurations within volume and weight constraints, this increases design complexity for load transfer to the supporting structure and for arrangement within the launch vehicle. Preliminary design concepts for launching on 2 SHELS or on the Pegasus or OSP Minotaur follow.

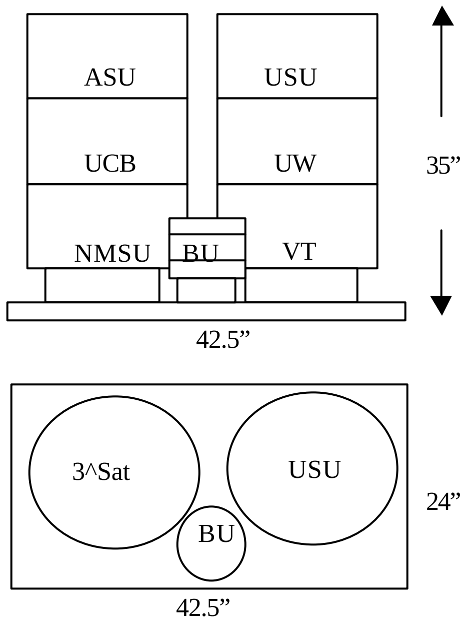


Figure 12. SHELS Payload A Configuration

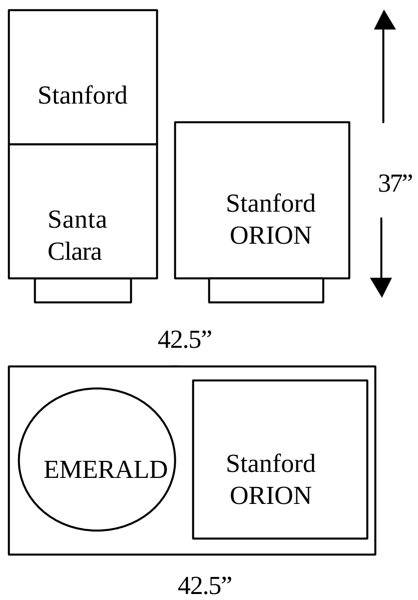


Figure 12. SHELS Payload B Configuration (Includes Stanford ORION Satellite funded by NASA Goddard)

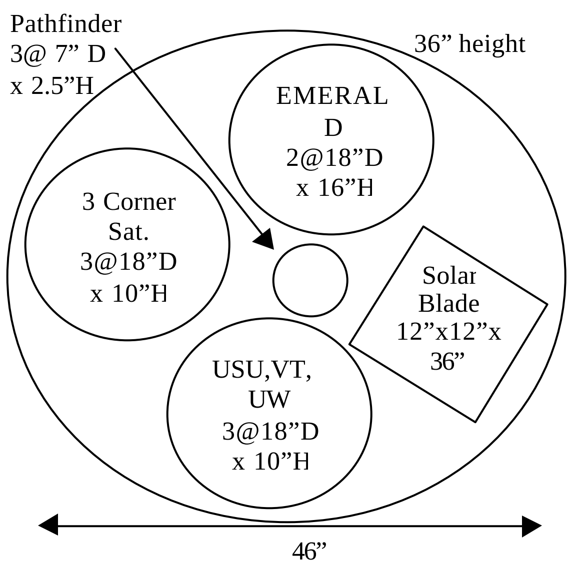


Figure 13. Pegasus/OSP Minotaur Launch Vehicle Configuration

Conclusion

The 10 university nanosatellites provide a broad range of technology demonstrations in the areas of miniature spacecraft subsystem components and formation flying.

There are also numerous science measurements and experiments in such areas as GPS scintillation, solar wind, magnetic fields, and upper atmosphere ion density.

This program has the potential to provide significant payoff for very modest funding by DoD and NASA given the broad university resources being applied and support by industry partners. If these flight demonstrations are successful, it is very likely government sponsorship can be secured for follow-on launches of nanosatellites built by universities and other agencies.