The GeneSat-1 Microsatellite Mission: A Challenge in Small Satellite Design

Dr. Christopher Kitts
Robotic Systems Laboratory, Santa Clara University, 500 El Camino Real, Santa Clara CA 95053
ckitts@scu.edu

Dr. John Hines, Mr. Elwood Agasid
NASA/Ames Research Center, Moffett Field CA 94035
John.w.hines@nasa.gov, elwood.f.agasid@nasa.gov

Dr. Antonio Ricco
National Center for Space Biological Technologies, Stanford University, Stanford CA 94305
aricco@mail.arc.nasa.gov

Mr. Bruce Yost
Defouw Engineering, NASA Research Park, Moffett Field CA 94035
byost@mail.arc.nasa.gov

Ms. Karolyn Ronzano
Lockheed-Martin Corporation, NASA Research Park, Moffett Field CA 94035
kronzano@mail.arc.nasa.gov

Dr. Jordi Puig-Suari
Dept. of Aerospace Engineering, Cal Poly State University, San Louis Obispo CA 93407
jpuigsua@calpoly.edu

ABSTRACT: The mission of the GeneSat-1 technology demonstration spacecraft is to validate the use of research-quality instrumentation for *in situ* biological research and processing. GeneSat-1 is a “triple-CubeSat” vehicle currently being developed for launch as a secondary payload on a Minotaur launch vehicle in late 2006. Spacecraft and mission development is being led by the NASA Ames Research Center Astrobionics group. However, university participation is a crucial element of the program with significant contributions being made from a number of academic groups throughout the Silicon Valley region. This paper will review progress in the development of the GeneSat-1 mission. In addition, the role of each University partner will be discussed, the educational elements of the program will be described, and a discussion of technical and organization challenges will be presented. Finally, the paper will review the relevance of GeneSat-1’s technology to advanced sensing concepts, bio-technology and pharmaceutical research, astrobiology, and human space flight research.

INTRODUCTION

Over the past two years, the GeneSat-1 program has married novel biological technology with the innovative, low-cost, and streamlined approaches of the small satellite community in order to develop a program to demonstrate the feasibility of autonomous biological studies in space. The specific objectives of the GeneSat-1 technology demonstration mission are to[1]:

1) Develop, design, assemble, and test a flight-ready autonomous technology demonstration platform, which will lead to advanced sensors that exploit cellular or microscopic organisms in a small form factor. This implies a heavy reliance on miniaturized optical systems, microelectronics, microfluidic systems, and computer-based technologies.

2) Demonstrate the capability of accommodating multiple technologies including fluorescent imaging of single proteins using green fluorescent protein (GFP) techniques. Future GeneSat missions may investigate other sensor types such as imaging and polymerase chain reaction (PCR) DNA amplification techniques.

3) Support specific investigations and assessments of technologies used in ground applications, which are directly targeted at human Exploration risks. The initial GeneSat-1 mission will focus on quantitatively

detecting levels of GFP expressed in living cultures (*E. coli*). This first step will provide the basis for further development of biologically-based sensors for human exploration, including biosentinels for use on the surface of other planets as occupational health sensors.

4) The final objective for GeneSat-1 is to exploit and investigate the advantages of small satellites to accelerate the migration of key technologies and platform(s) to broader applications such as autonomous spacecraft operations, man-tended space vehicles, and novel ground-based research applications.

The needs of the GeneSat-1 biological test payload levied a number of requirements on the space system; several of these were new challenges to those on the team with previous experience developing small spacecraft. First, the payload must be regulated to within +/- 0.5° C, a particularly demanding requirement given the space environment, the small thermal mass involved, and the small amounts of power capable of being generated. Second, the viable shelf life of the biology drove design elements relating to launch preparation and ground handling. Third, numerous challenges arose relating to the ability to properly operate a microfluidics payload in a microgravity environment. Finally, the need to miniaturize high-quality instrumentation-grade optical sensors suitable for *in situ* biology required enormous attention and packaging ingenuity.

THE GENESAT-1 SPACE SYSTEM

As shown in Figure 1, the GeneSat space system consists of the GeneSat-1 spacecraft, a communication ground station, several beacon receiving ground stations, and mission operations complex. Primary command and telemetry communications are supported through a 2.4 GHz link using a pair of COTS transceivers and relying on a high-gain antenna on the ground. An amateur band beacon downlink is used to support an associated education/outreach program; several OSCAR-class amateur radio communication stations are available for use through the team's educational partners, and significant interaction with the amateur radio / university satellite community is expected to yield additional beacon messages submitted by these external partners. Communications between the communication stations and the Mission Operations Center is conducted via a secure internet link using a data streaming architecture for realtime operations.

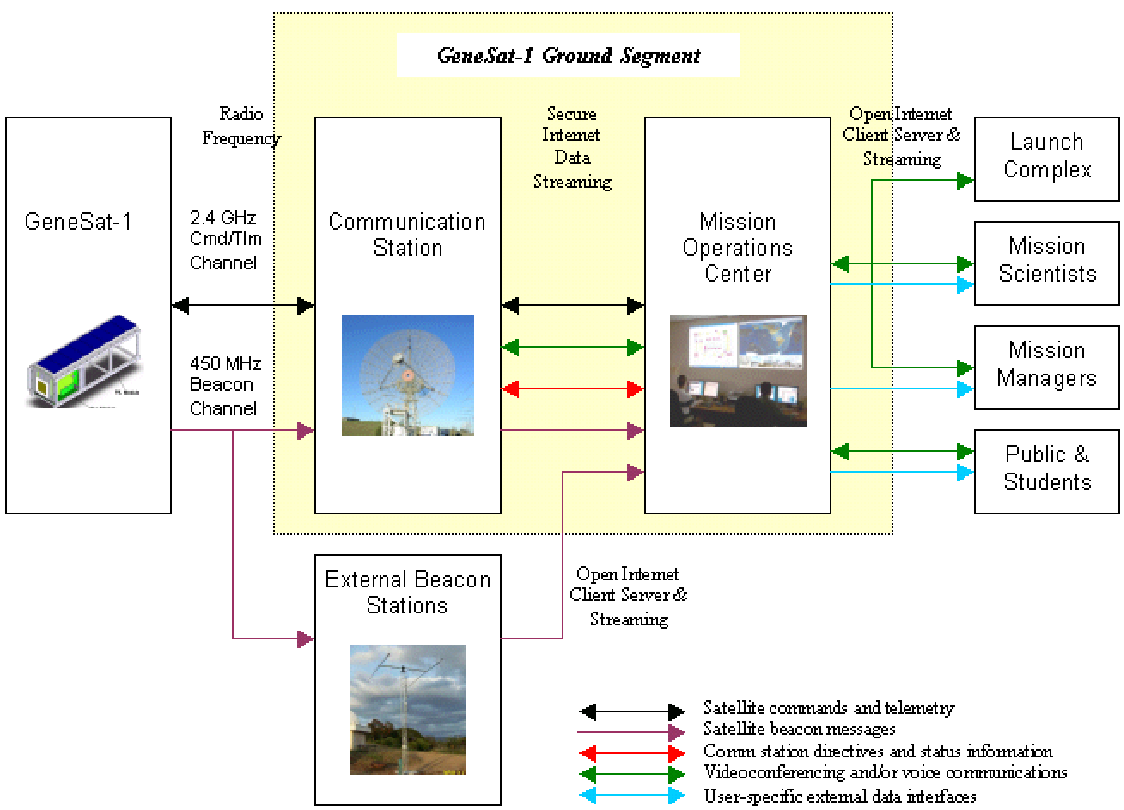


Figure 1. The GeneSat-1 Space System

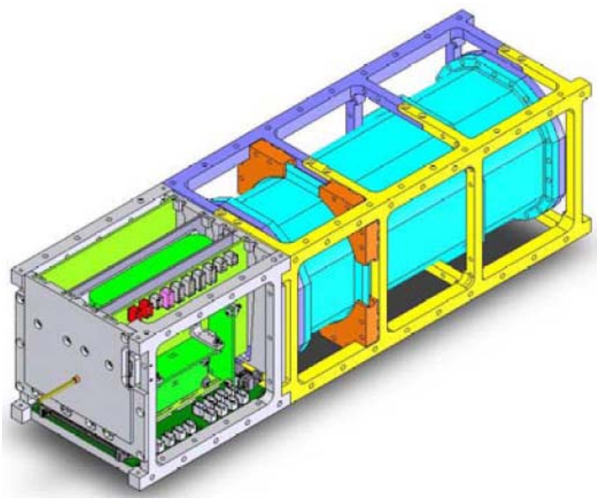


Figure 2 – The GeneSat-1 Satellite

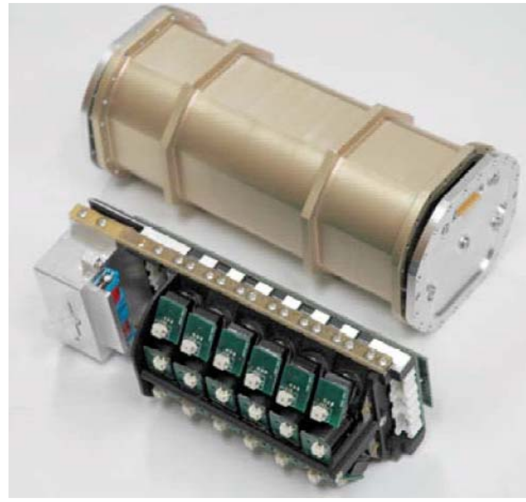


Figure 3 – The GeneSat-1 Payload Module

Genesat-1 Spacecraft

The GeneSat-1 spacecraft consists of a bus module (1 CubeSat volume) and a payload module (2 CubeSat volumes). The entire satellite, depicted in Figure 2, is approximately 100mm X 100mm X 340mmand weighs about 3 kg. The satellite bus includes body mounted solar panels, a single battery, a PIC-based command and data handling board, a passive magnet/hysteresis rod orientation control suite, a 2.4 GHz Microhard communications transceiver, and an amateur radio beacon.

The GeneSat-1 payload, pictured in Figure 3, is contained in a pressurized, sealed cylinder that houses the integrated fluidics, optical sensors, and support equipment. The internal volume also provides humidified air to exchange with the fluidic card's microwells via a gas-permeable membrane. The fluidic system includes ten 110-µL culture wells and two solid-state reference wells in microwell-plate format, as shown in Figure 4. The card is designed to ensure that all 10 wells fill evenly from the single inlet channel by restricting flow through any single well.

The fluidic card was manufactured from multiple laser-cut acrylic layers using pressure-sensitive-adhesive interlayers. The reservoir/pump unit is a 15 mL medical-grade polymer bag with a helical spring. Off-the-shelf sensors (pressure, humidity, temperature at 6 locations, radiation dose, 3-axis accelerometer) track key parameters throughout the mission.

Once in stable orbit, the system warms and maintains the *E. coli* at the growth temperature using Kapton heaters under closed-loop control. The *E. coli* is then

Figure 4 – The GeneSat Payload Microwell Plate

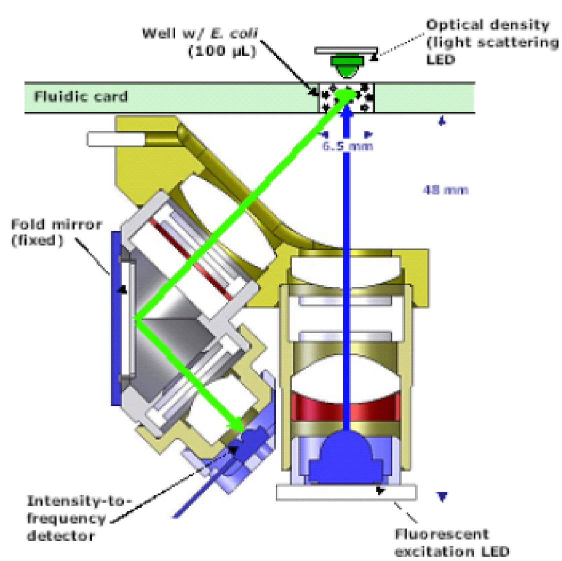


Figure 5 – The Payload Optical Detector System

"resuscitated" by pumping a sugar solution growth medium to displace the saline "stasis buffer" that is used to preserve the bacteria during loading and launch.[2] Experimental measurements are made through the use of blue-LED-excited fluorescent detection systems (one per well) that quantify levels of light emitted by green fluorescent protein which has been fused to a bacterial gene associated with metabolism. Concurrent light scattering measurements are made to normalize the readings as culture population grows. The integrated optical assembly is shown in Figure 5.

Launch Adaptor

The Cal Poly Picosatellite Orbital Developers (P-POD) is a simple device designed to release three picosatellites into space. Depicted in Figure 6, the P-POD generally mounts to the launch vehicle and carries the three picosatellites, CubeSats specifically, during launch. Deployment is initiated by the launch vehicle by means of a simple trigger signal. The body of the P-POD is an aluminum box with a spring-loaded plunger that acts like a jack-in-the-box to push the CubeSats out of the box once the door opens. The box is simple in design and built from aluminum.

The standard P-POD design is being modified for the GeneSat-1 mision. The first modifications is to the pusher plate in order to accommodate the mechanical interface with the end of the GeneSat-1 vehicle. The second modification is the installation of an NEA release mechanism for opening the door; this was motivated due to thermal loading concerns in the launch environment.

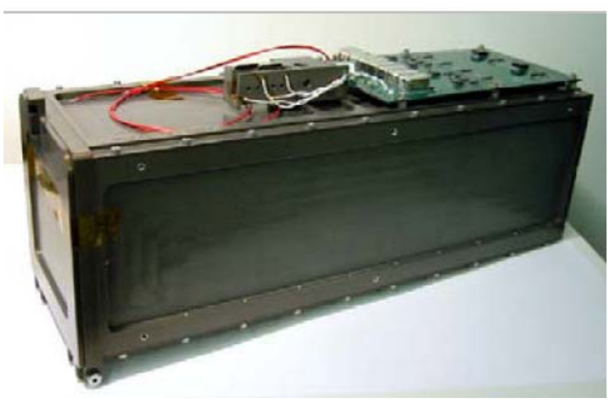


Figure 6 – The P-POD Launch Adaptor

Communications Stations

The GeneSat space system uses a dedicated station with a 60 foot parabolic antenna for its primary command and telemetry operations. In addition, several amateur radio stations are used to receive beacon messages that support the project's education/outreach mission.

Primary Station. The Communication Station is a facility owned and operated by SRI International and located on land leased from Stanford University. Refurbishments to the station are being made consistent with the needs of the GeneSat-1 mission.

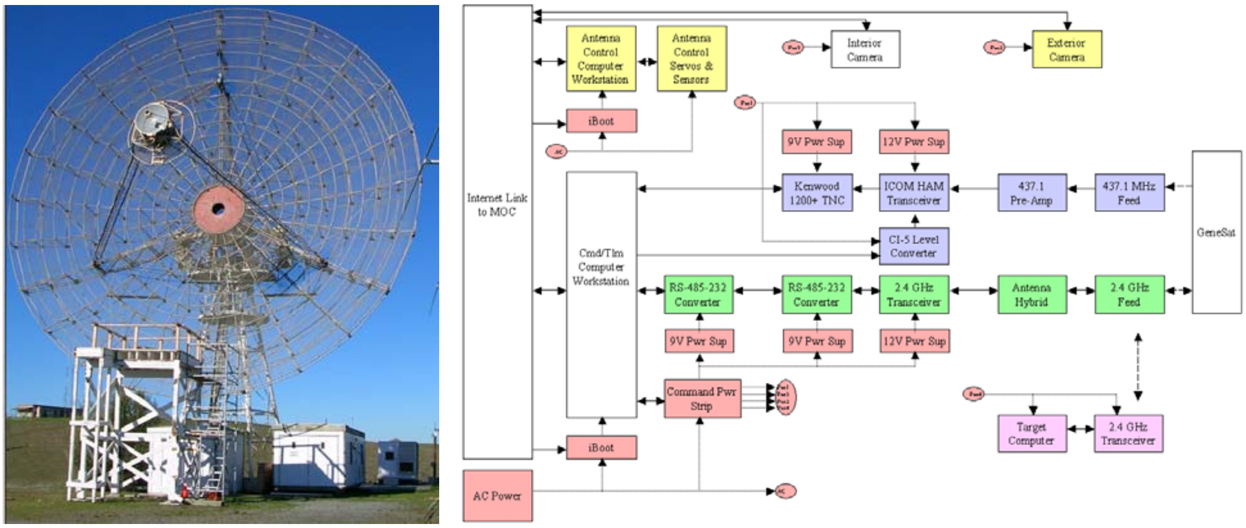
The facility's antenna is a 60-foot parabolic dish driven by a programmed track antenna pointing system. The antenna's surface mesh is being rebuilt in order to support operations at in the 2.4 GHz range. The dish, pictured in Figure 7a, is required to provide the more than 40 dBi needed to close the link with the satellite transceiver. Mounted to the antenna's tripod will be feeds for both the 2.4 GHz channel as well as the 437.1 MHz beacon receiver. A minimum elevation angle will be adopted to ensure non-interference with local receivers.

Additional equipment specific to the GeneSat-1 mission includes antenna feeds, transceivers, and data processing components/workstations for both the command/telemetry channel as well as the beacon receive channel. Also included in the system is power control equipment, a "dummy satellite" for RF-based link testing, tele-conferencing/communication equipment, and encryption equipment for the internet connection. Figure 7b provides a component overview of the station.

Beacon Receive Stations. The mission team's academic partners have numerous OSCAR-class amateur radio stations capable of receiving and decoding the periodic beacon message. In addition, external amateur and scholastic partners will be encouraged to submit beacon messages they have received. This will be done through the mission's public web site, and an automated QSL card will be returned to the submitter.

Internet Ground Communications Network

Satellite command/telemetry data and communication station configuration/status data is relayed between the communication station and the Mission Operations Center through a suite of network bus software. These software programs include drivers for the communication station components and the remote MOC operations software. The network bus uses the commercially available Creare DataTurbine Ring Buffered Network Bus server. This server is used in several amateur radio stations and realtime robotic control systems owned, developed, and operated by



(a) 60 ft Antenna (b) Component Block Diagram

Figure 7 – The GeneSat-1 Primary Communication Station

Santa Clara University, thereby allowing the development team to exploit existing designs and software.[3] Significant testing of this system has been performed to characterize communication (latency, packet loss, etc.) between remote control segment facilities; as can be seen in Figure 8, this latency is typically under 200 msec, which easily meets the near-realtime requirements of the GeneSat-1 mission.

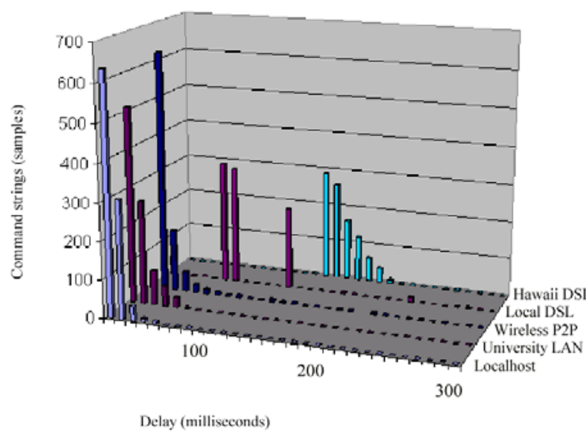


Figure 8 – Ground Network Latency

Mission Operations Complex

The MOC is a control facility operated by Santa Clara University (SCU) which is used to support tele-operation for a wide variety of robotic missions. The facility is currently housed in the Space Technology Center (Building 583c) which is located in the NASA Ames Research Park; provisions are being made to establish a new MOC in Building 240 in NASA Ames Research Center. The MOC, pictured in Figure 9, houses a number of computer workstations each with dual displays. Additional large-scale displays include a dual projector system, a plasma screen, and an LCD screen array. A multifunction printer provides networked printing in addition to copy, fax, and scanning services.

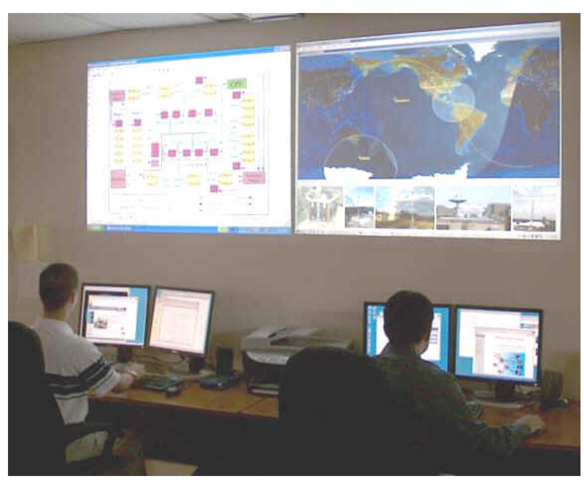


Figure 9 – Mission Operations Center

The MOC supports a wide range of functionality to include command formatting and validation, telemetry processing, data archiving, and the provision for operator graphical interfaces. The mission control software interfaces to commercial analysis packages such as Matlab for sophisticated analyses such as model-based anomaly management.[4] Orbit analysis software supports contact planning and mission visualization. Mission data is disseminated via the internet for the mission team as well as for external partners and educators.

THE MISSION TEAM

The core of the GeneSat-1 development team consists of staff scientists and engineers within the NASA Ames Research Center's Astrobionics program. However, several critical partnerships have allowed the NASA team to capitalize on local expertise in both small satellite development and space biological technologies.

- Stanford University's National Center for Space Biological Technologies (NCSBT) is contributing significant expertise regarding the development of biological instrumentation suitable for space flight.
- The California Polytechnic State University (CalPoly) at San Luis Obispo is providing its unique P-POD launch adapter component as well as its expertise in launch integration for small satellite missions.
- Santa Clara University's Robotic Systems Laboratory (SCU) is leveraging its significant expertise and infrastructure to provide the ground segment and mission operations services for the mission; SCU engineers are also providing functional test services and are contributing to the design of communications-related elements of the satellite.
- Stanford University's Space Systems Development Laboratory was involved in the early stages of the program and developed an early prototype of the bus system.
- San Jose State University was also involved in the early stages of the program as an administrative support partner.

Overall, the current Ames/NCSBT/CalPoly/SCU team has a complementary blend of expertise in order to meet the unique challenges of the GeneSat-1 mission. Furthermore, the academic partnerships provide ample opportunities for students at all levels to have meaningful educational experiences in the context of this exciting space mission. To date, more than three dozen students, ranging from undergraduates to doctoral students, have participated in some way in the development of the GeneSat-1 space system. The accommodation of such opportunities is critical to the development of the nation's future aerospace workforce.

SUMMARY AND CONCLUSIONS

The GeneSat-1 mission is being developed to demonstrate the suitability of advanced biological technologies for space flight through the use of small spacecraft. As the first such free-flying satellite genetic analysis experiment, its design is providing an array of new challenges for the approaches that have matured within the small satellite community over the past 20 years. In meeting these challenges, NASA's partnership with regional academic institutions has allowed a critical flow of expertise relating to small satellites and space biological technologies to contribute to the success of the mission.

ACKNOWLEDGEMENTS

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REFERENCES

1. Yost, B., et al., "The GeneSat-1 Test Demonstration Project: A Unique Use of Smallsats," Proc of 19th Annual AIAA/USU Conf on Small Satellites, Logan UT, 2005.

2. Ricco, A., et al., "Integrated System to Analyze the Genetic Effects of the Space Environment on Living Cells in Culture: GeneSat," 8th European Conference on Optical Chemical and Biosensors, Tubingen, Germany, April 2006.

3. D. Schuet and C. Kitts, "A Distributed Satellite Operations Testbed for Anomaly Management Experimentation," Collection of Technical Papers – AIAA 3rd "Unmanned-Unlimited" Technical Conference, Workshop, and Exhibit, Chicago, IL, September, 2004.

4. Kitts, C., "Managing Space System Anomalies Using First Principles Reasoning," To Appear, IEEE Robotics and Automation Magazine, Special Issue on Automation Sciences.