Flight Results from the GeneSat-1 Biological Microsatellite Mission

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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. To execute this mission, the GeneSat-1 satellite was launched on December 16, 2006 from Wallops Flight Facility as a secondary payload off of a Minotaur launch vehicle. During the first week of operation, the core biological growth test was successfully executed, and by the end of the first month of operation all primary science and engineering test objectives had been successfully performed. In its current phase of operation, a variety of secondary technology characterizations tests are being performed, and a wide range of educational, training, and public outreach programs are being supported. This paper reviews the GeneSat-1 mission system, discusses the government-industry-university teaming approach, and presents flight results pertaining to the primary scientific and engineering experiments.

INTRODUCTION

Over the past three 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.

Program Objectives

As a technology demonstration program, the specific objectives of the GeneSat-1 mission are to[1,2]:

1) Develop, design, assemble, and test a flight-ready autonomous technology demonstration platform that employs advanced sensors to exploit cellular or microscopic organisms in a small form factor.
2) Demonstrate the capability of accommodating multiple technologies including fluorescent imaging of single proteins using green fluorescent protein (GFP) techniques.
3) Quantitatively detect levels of GFP expressed in living cultures (*E. coli*) as a means of evaluating technologies targeted at assessing human Exploration risks.
4) 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.

This vision implies a heavy reliance on miniaturized optical systems, microelectronics, microfluidic systems, and computer-based technologies. The intent of this mission is for it to serve as the first step in the development of biologically based sensors for human exploration, including biosentinels for use on the surface of other planets as occupational health sensors. The long-term programmatic objective is to develop a space system platform and mission team capable of executing follow-on missions that explore other sensor types such as imaging and polymerase chain reaction (PCR) DNA amplification techniques.

Driving Requirements and Challenges

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, programmatic and cost constraints limited the size of the vehicle to a triple-CubeSat class vehicle measuring approximately 10 cm x 10 cm x 30 cm and weighing under 5 kg. Second, the payload required regulation 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.

Third, the viable shelf life of the biology drove design elements relating to launch preparation and ground handling. Fourth, 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 for primary command and telemetry operations, and a Mission Operations Center.

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 18-meter antenna on the ground. An amateur band beacon downlink is used to support the mission's education/outreach program with external operators able to submit their telemetry for inclusion in a publicly available mission database. Communications between the communication stations and the MOC is conducted via a secure Internet-link using a data streaming architecture for realtime operations.

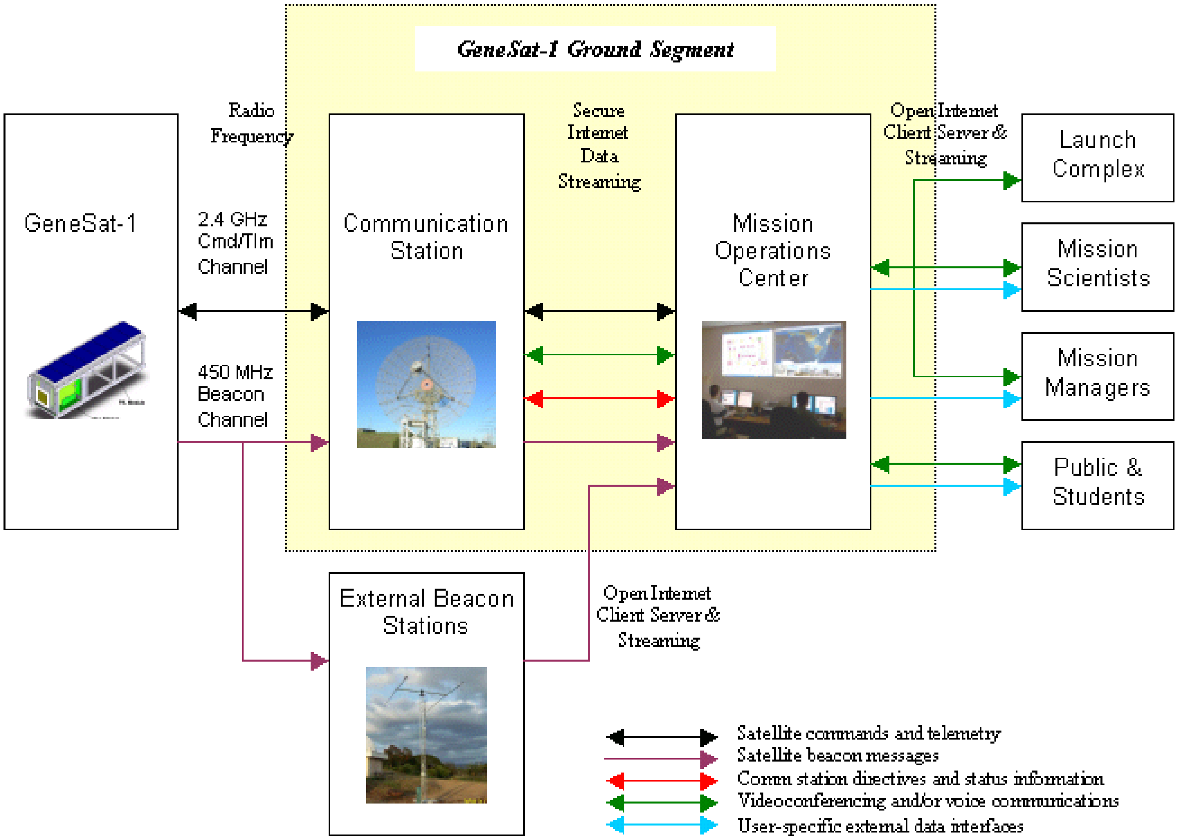


Figure 1: The GeneSat-1 Space System

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 340mm and weighs about 3.5 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 "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.[3] 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.

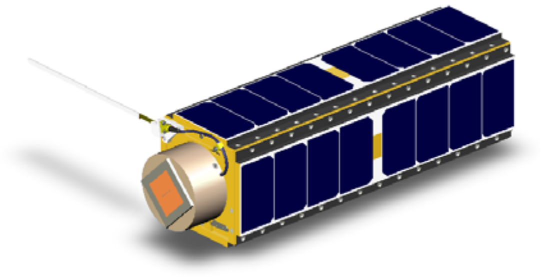


Figure 2: The GeneSat-1 Satellite

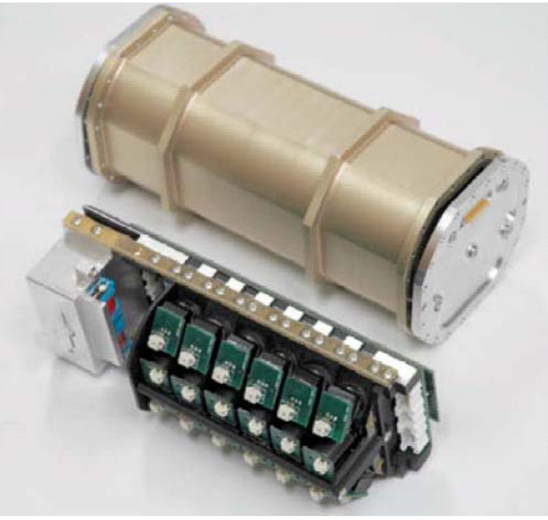


Figure 3: The GeneSat-1 Payload Module

Figure 4: The GeneSat Payload Microwell Plate

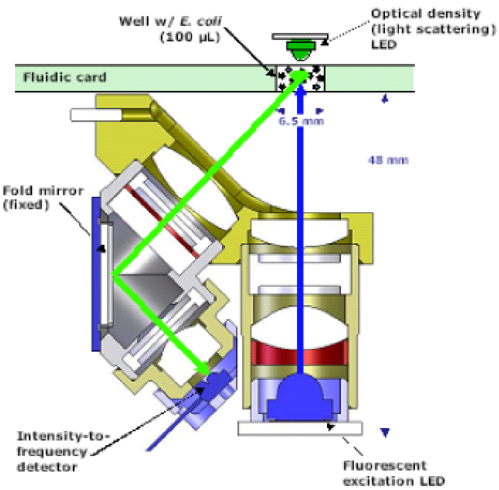


Figure 5: The Payload Optical Detector System

Launch Adaptor

The Cal Poly Picosatellite Orbital Developers (P-POD) is a simple device designed to release picosatellites into space. Depicted in Figure 6, the P-POD mounts to the launch vehicle, encapsulates the picosatellites during launch in order to protect primary payloads, and ejects the picosatellites upon receipt 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 one or more CubeSat-class satellites out of the box once the door opens.

The standard P-POD design was delivered by the Cal Poly team and then modified by NASA Ames in order to accommodate a custom structural configuration used on the GeneSat-1 vehicle. As seen in Figure 2, a cylindrical extension was made to one end of the satellite in order to accommodate an amateur radio beacon in support of the mission's education/outreach program. Because of the limited volume, this equipment was placed outside of the standard CubeSat form factor. The cylindrical projection was configured to fit within the P-POD's helical ejection spring; in supporting this, modifications to the P-POD pusher plate assembly were made.

The second P-POD modification was the installation of an NEA release mechanism for opening the door; this was motivated due to thermal loading concerns in the launch environment.

Primary Communications Station

The GeneSat-1 space system uses a dedicated station with an 18-meter parabolic antenna for primary command and telemetry communication operations. The station is a facility owned and operated by SRI International and located on land leased from Stanford University. SCU students refurbished the station to support the mission. This work included installing a new mesh appropriate for 2.4 GHz communications and working with SRI personnel to upgrade components, troubleshoot functionality, and procedurally refine the methods of operation.

The facility's antenna is driven by a programmed track antenna pointing system. The dish, shown in Figure 7, provides the more than 40 dBi needed to close the link with the satellite transceiver. Mounted to the antenna's tripod is a multi-beam feed supporting communications on the 2.4 GHz channel as well as the 437.1 MHz beacon receive channel. A minimum elevation angle of 10° was adopted to ensure non-interference with local receivers.

Figure 6: P-POD Fit Check

Figure 7: Primary Communication Station

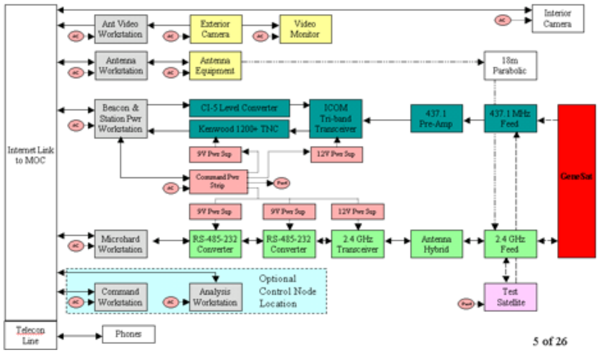


Figure 8: Communication Station Component Diagram

Additional communications equipment specific to the GeneSat-1 mission includes transceivers, data processing components and workstations, power control equipment, and an independent antenna tracking console. Figure 8 depicts a component block diagram for the station.

Beacon Receive Stations

A significant portion of the GeneSat-1 mission's education/outreach program involved participation in the mission through direct reception of the spacecraft's beacon signal. Designed to be received by a standard OSCAR-class amateur radio station, this signal periodically broadcast satellite telemetry, allowing external participants to conduct performance analyses, follow the progress of the biology experiment, etc.

External operators were encouraged to submit their received telemetry to the GeneSat-1 team through a simple web site that returned a QSL card to operators. This telemetry, which was maintained separately from the primary GeneSat-1 databases, has been made available to a variety of external experimenters and educators.

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 via encrypted communications through the public Internet, as depicted in Figure 9. Data is streamed between distributed applications through a suite of network bus software that includes drivers and interfaces for the wide variety of hardware and software components that exist within the command and data handling architecture.

The network bus uses the commercially available Creare DataTurbine Ring Buffered Network Bus server. This server had been used extensively by the SCU team in a wide variety of realtime robotic control applications, thereby allowing the development team to exploit existing designs and software.[4] Significant testing of this system has been performed to characterize communication (latency, packet loss, etc.) between remote control segment facilities; as shown in Figure 10, this latency is typically under 200 msec, which easily meets the near-realtime requirements of the GeneSat-1 mission.

Control Nodes and Mission Operations Centers

Command and telemetry operations are performed through the use of satellite control software that allows the operations team to remotely operate the GeneSat-1 vehicle. Although a Control Node can operate from any location with an Internet connection, programmatic security and configuration control requirements have led to the use of four Control Node locations: the Multi-Mission Operations Center (MMOC) at NASA Ames Research Center, the SCU Robotic Control Center

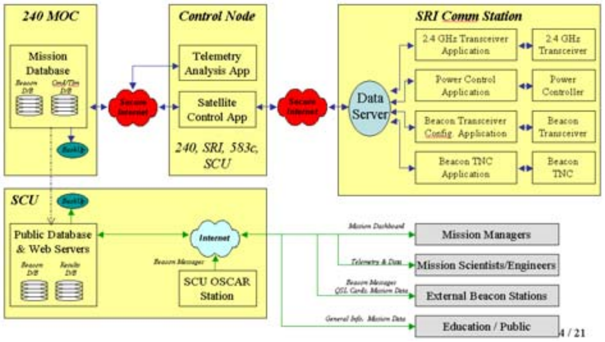


Figure 9: Mission Operations Center

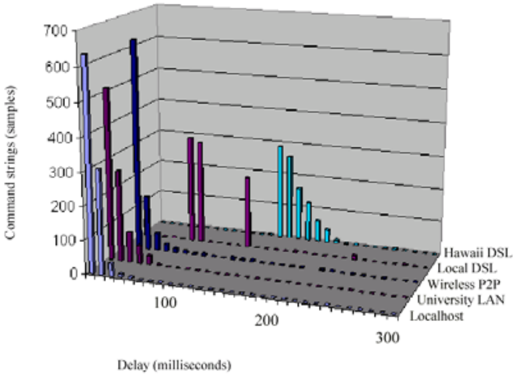


Figure 10: Ground Network Latency

Figure 11: Operations at the NASA Ames MMOC

Figure 12: Operations from the SCU MOC

located in the NASA Research Park in Moffett Field, the GeneSat-1 operations development and training laboratory on the SCU campus, and within the SRI communication station.

During launch and early orbit operations, Control Node operations were run from the SRI station; this allowed the entire mission operations team to work from one location, thereby improving teamwork during this phase of tight coupling between tracking, telemetry and commanding operations.

After routine tracking was established, the Ames MMOC, shown in Figure 11, served as the primary Control Node during the balance of GeneSat-1's primary operations phase. After approximately two months of on-orbit operations, all primary mission objectives had been met, and control of the mission was turned over to SCU for student education and research experimentation. At this point, the SCU operations centers, one of which is shown in Figure 12, were routinely put into use as Control Nodes.

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.[5,6] Figure 13 shows a typical telemetry display used for routine command verification and state of health analysis.

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.

FLIGHT OPERATIONS

On December 16, 2006, Genesat-1 was successfully launched as a secondary payload on a Minotaur launch vehicle from Wallops Flight Facility. The launch, shown in Figure 14, placed the satellite into its expected orbit, a 40° inclined circular orbit with a 410 km altitude.

Mission operations proceeded rapidly, with beacon reception established within the first orbit and successful 2.4 GHz command channel communications established on the second day of operations. Initial telemetry analyses showed a vehicle health state so positive that the primary biological experiment was initiated after about only two days in orbit. Over the course of the next four days, the experiment was autonomously executed. During this time, the mission

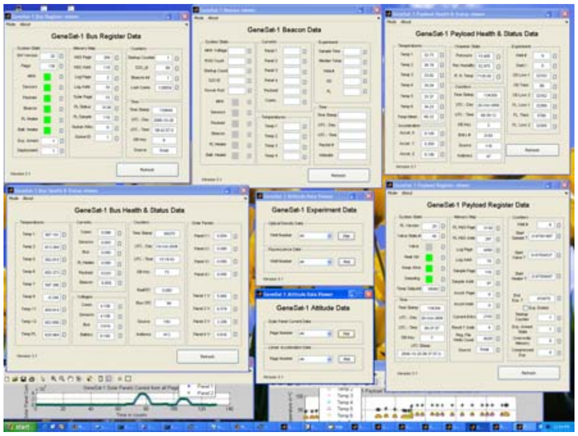


Figure 13: MATLAB-based Telemetry Display

Figure 14: GeneSat-1 Launch from WFF

Table 1: Primary Operational Milestones

Dec 16, 2006 0400 PST	Successful Minotaur launch from WFF
Dec 16, 2006 0420 PST	Deployment of GeneSat-1 from P-POD
Dec 16, 2006 0530 PST	Beacon first received
Dec 17, 2006 0400 PST	2.4 GHz command & telemetry communications established
Dec 18, 2006 0500 PST	GeneSat biological experiment initiated
Dec 22, 2006 0535 PST	96-hour biological experiment complete and baseline data retrieved
Dec 22, 2006 0635 PST	Baseline science data disseminated to complete mission team
Jan 17, 2007 1700 PST	All primary mission criteria successfully completed
Feb 21, 2007 1430 PST	Operational control of satellite handed over to SCU for training and research
Fall 2007	Expected de-orbit

operations team monitored the progress of the experiment and retrieved experimental data that was being stored on-board the spacecraft. By the conclusion of the 96-hour experiment, a complete baseline profile of science data had been retrieved and delivered to the science team for initial analysis. This baseline profile provided data at a sample period of approximately 2 hours, a resolution finer than standard ground-based acquisition for this type of experiment, but a resolution that was only about 1/8 of the available stored data.

Over the course of the following three weeks, additional science data was retrieved and more thorough analysis of spacecraft health and performance was accomplished. After approximately one month of on-orbit operations, all primary mission procedures had been executed, and all associated flight data had been retrieved, thereby constituting mission success. Over the course of the second month of operations, secondary analyses were conducted, additional technical experiments were performed, and new student mission operations crew members were trained and certified. On February 21, 2007, after approximately two months of on-orbit operations, NASA transferred control authority of the mission to their SCU partner such that the satellite could be operated for the purposes of supporting student education and engineering research experiments. Table 1 provides a summary of the primary GeneSat-1 operational milestones.

Biological Results

The GeneSat-1 biological experiment involved the assessment of E. coli. metabolism as a function of microgravity through the use of GFP experimental protocols. Several integrated bioreactors have been previously flown on manned space vehicles to study biological phenomena[7-9]; however, these systems have required a human operator to initiate the experiment, record data, collects samples for analysis, and/or prepare (freeze/fix) samples for return to Earth.[10]

In contrast, once initiated by ground command, the GeneSat-1 payload automatically executed the experimental protocol, to include establishing a temperature-controlled environment, activating the specimens through the supply of nutrients, tracking cell growth and gene expression via the optical measurement of light scattering and fluorescence.

Figures 15 and 16 show the 96-hour curves of optical density and fluorescence during the primary growth phase of the E. coli specimens. The optical density curve measures the bulk growth of the specimens, thereby allowing the fluorescence data to be normalized as a function of bacteria population. Wells 10 and 11 are controls and exhibit no growth. Significant differences in growth rates among the live wells is explained in part by the use of different strains of the bacteria. With respect to fluorescence, increases over the lifetime of the bacteria with different transient responses explained in part by the use of different strains.

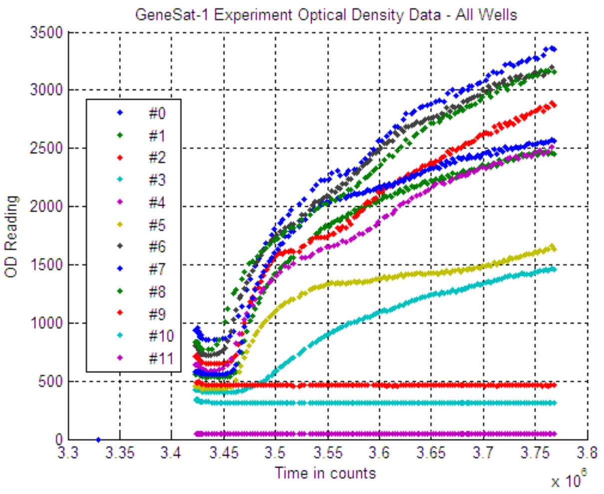


Figure 15: 96-hour Optical Density

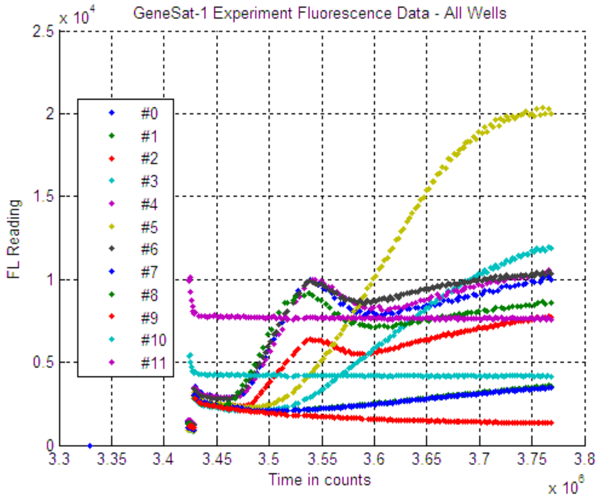


Figure 16: 96-hour Fluorescence

Overall, the science experiment produced results consistent with previously conducted experiments and within the expectations of the science team. Given GeneSat-1's primary objective as a technology demonstrator (rather than to discover new metabolism patterns for E. coli. in microgravity), this consistency has played a significant role in verifying the ability of the GeneSat-1 payload technology to properly function.

Satellite Performance

Significant effort was invested in characterizing the performance of the satellite's subsystems given the desire to verify the design and to investigate technologies for use on future missions. Figures 17-22 present a variety of satellite telemetry that was instrumental in performing these analyses.

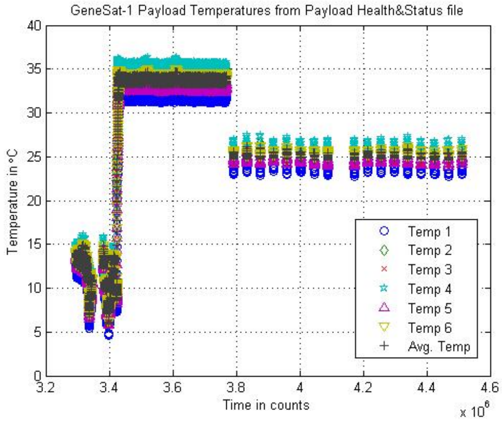


Figure 17: Payload Temperature Profile

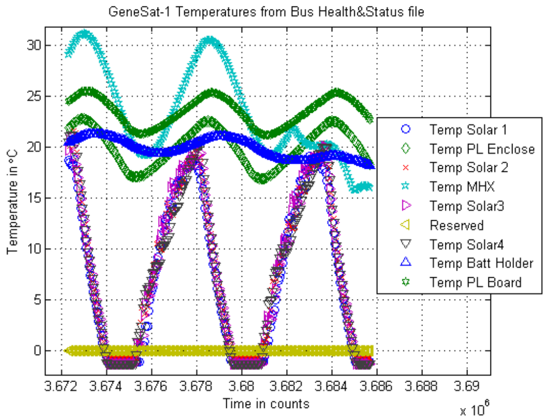


Figure 18: Satellite Temperature Profile

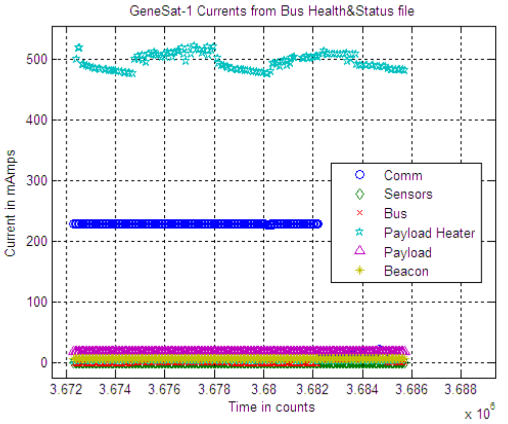


Figure 19: Satellite Power Consumption Profile

One particular study involved characterizing the ability of the satellite to maintain payload temperature, a critical concern given the biological experiment. Figure 17 shows the temperature profile for the six temperature sensors distributed across the payload well-plate. Prior to initiation of the experiment, the payload naturally stabilized in a range of approximately 5-15 °C which was sufficient for survival prior to biological activation. During the primary 96-hour experiment, the payload temperature was controlled to achieve a mean temperature of 34 °C; as seen in the Figure, this was successfully achieved. Figure 18 shows the temperature profile throughout the satellite during a portion of this phase, giving an indication of the heat dissipation throughout the spacecraft. Finally, Figure 19 shows the power draw required to achieve the 34 °C set-point. Clearly, at around 500 mA, the duty-cycled heater power constituted the most significant power load for the primary phase of the mission; this equated to approximately 60% of the power demand. While this was not unexpected, it certainly highlights the criticality of the temperature control requirement for biological payloads as well as the challenge this can present for small spacecraft missions.

Another important performance characterization involved the evaluation of the Microhard MHX-2400 2.4 GHz communications transceiver, a COTS component that was used with no modification for space flight. The selection of this component provided many benefits for the spacecraft design to include its ISM-band operation, cost, compact size, configuration flexibility, output power, data encoding and encryption, etc. However, its selection presented many concerns regarding its performance in the space environment, the need for a high gain ground antenna, the need for precision antenna tracking, the impact of satellite orientation given the directionality of the on-board antenna, the impact of delay and Doppler shift, the presence of elevated noise levels, etc.

Significant ground test was performed to verify performance and to reduce risk, and assessment of the link performance on-orbit has been a continuing task of the operations team.[11] Figure 20 depicts the link margin for a series of satellite contacts as a function of ground antenna azimuth and elevation. This fairly typical performance indicates an oscillatory characteristic of the link's performance that dominates link parameters such as space and atmospheric losses. Figure 21 reinforces this view, showing the time history of link margin for a single contact. An obvious explanation for this variation was oscillatory pointing errors caused by the satellite's spin; indeed, this affect had been anticipated by the design and operations teams and was a focus of data collection during the assessment of satellite performance. Figure 22 shows the current profile from two of the vehicle's body-mounted solar arrays. These curves clearly indicate the satellite's spin, and they lead to an estimate of approximately 40 seconds for the period of spin about the minor axis. This period is consistent with the observed variation in link margin.

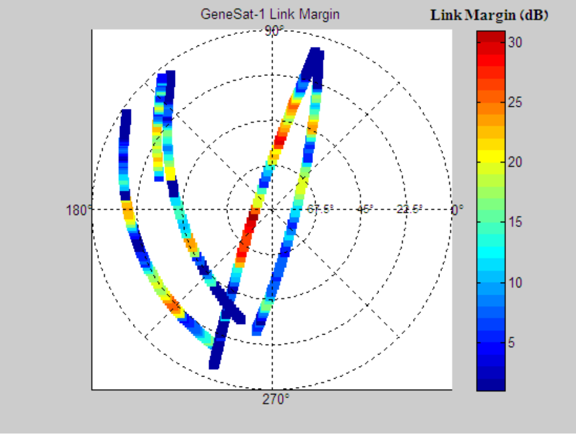


Figure 20: Link Margin Contact Profiles

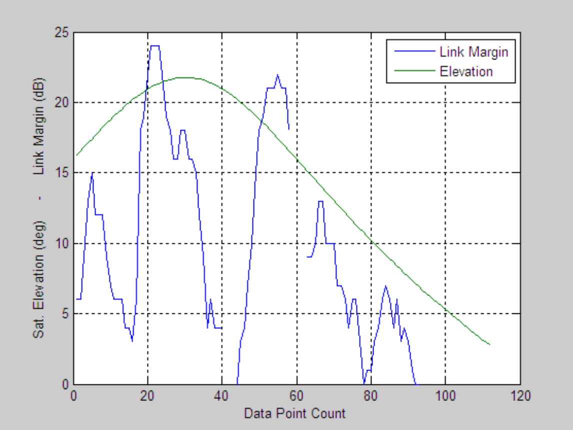


Figure 21: Link Margin Time History for a Contact

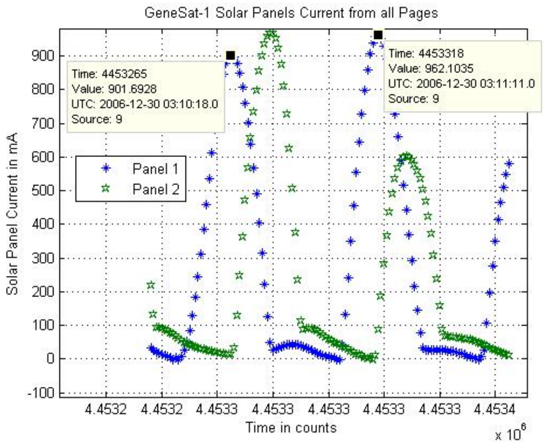


Figure 22: Link Margin Time History for a Contact

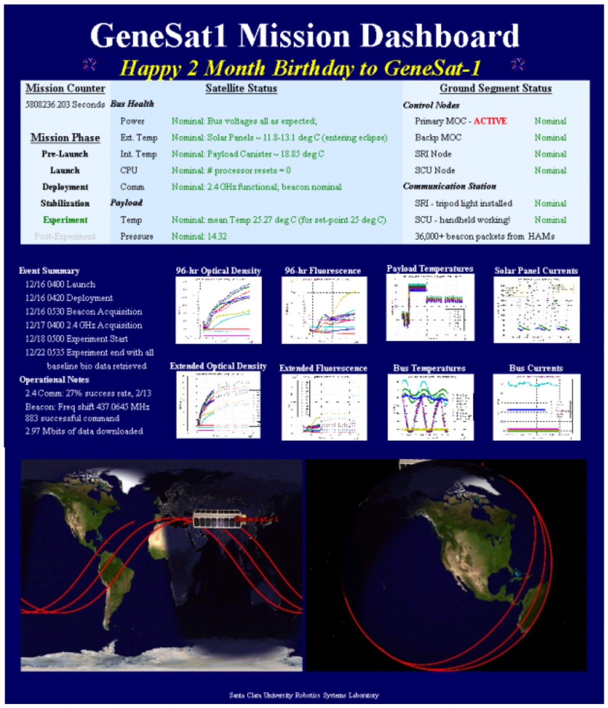
Data Dissemination

The fundamental use of the Internet for realtime command and telemetry operations influenced the nature of the general dissemination of mission operations data. An on-line contact log was typically filled out in near-realtime. Detailed telemetry analyses relating to the results of contact procedures were automatically generated via Matlab at the conclusion of each pass and posted to an on-line data products directory, providing mission scientists and engineers access to the spectrum of data products – from raw telemetry to high-level performance analyses – within minutes of the conclusion of each contact.

Post-pass logging also included updates to a web-based "mission dashboard," shown in Figure 23, which summarized mission progress, satellite health, and science results. This page proved to be enormously popular, resulting in more than 18,000 hits during the first two days of the biology experiment.

Education and Outreach

The GeneSat-1 management team demonstrated a compelling interest in providing an exciting and meaningful education and outreach program as part of the mission. Perhaps the most educationally beneficial aspect of this program was the integral involvement in dozens of students in the design, development, test and operation of the mission. By involving universities as


GeneSat1 Mission Dashboard

Happy 2 Month Birthday to GeneSat-1

Mission Counter
5808236.203 Seconds

Mission Phase
Pre-Launch
Launch
Deployment
Stabilization
Experiment
Post-Experiment

Satellite Status
Bus Health
Power: Nominal: Bus voltages all as expected;
Ext. Temp: Nominal: Solar Panels ~ 11.8-13.1 deg C (entering eclipse)
Int. Temp: Nominal: Payload Canister ~ 18.85 deg C
CPU: Nominal: # processor resets = 0
Comm: Nominal: 2.4 GHz functional; beacon nominal
Payload
Temp: Nominal: mean Temp 25.27 deg C (for set-point 25 deg C)
Pressure: Nominal: 14.32

Ground Segment Status
Control Nodes
Primary MOC - ACTIVE: Nominal
Backp MOC: Nominal
SRI Node: Nominal
SCU Node: Nominal
Communication Station
SRI - tripod light installed: Nominal
SCU - handheld working!: Nominal
36,000+ beacon packets from HAMs

Event Summary
12/16 0400 Launch
12/16 0420 Deployment
12/16 0530 Beacon Acquisition
12/17 0400 2.4 GHz Acquisition
12/18 0500 Experiment Start
12/22 0535 Experiment end with all baseline bio data retrieved

Operational Notes
2.4 Comm: 27% success rate, 2/13
Beacon: Freq shift 437.0645 MHz
883 successful command
2.97 Mbits of data downloaded

Figure 23: The Web-based Mission Dashboard

partners on the mission team, this program provided incredible opportunities for more than 50 students. These students ranged from freshman to Ph.D. candidates, and they were directly exposed to – and often responsible for - a wide range of emerging technologies, the interdisciplinary nature of engineering, the processes used in project management and systems engineering, the wide-ranging nature of different lifecycle phases, and the real-world challenges of accomplishing a challenging task with constrained resources. In addition to providing hands-on activities in university design courses, student members of the mission operations team were trained and certified as part of a satellite operations laboratory. Furthermore, student involvement also resulted in several undergraduate senior design thesis projects, a Masters thesis in advanced health management techniques, and several student design and research papers that have been widely published and presented in peer-reviewed venues.[12,13]

The involvement of the amateur radio community also proved to be quite popular given the availability of the beacon transmissions and the data necessary to decode telemetry and analyze satellite performance. In the first 24 hours alone, more than 1600 packets of beacon telemetry were collected by amateur radio operators and submitted to the GeneSat-1 MOC; this was about 5 times the amount of data collected by the mission operations team during this same period. By the end of the first two months of operation, more than 40,000 packets had been received and submitted by more than 50 distinct operators in more than a dozen countries throughout the world.

Finally, the GeneSat-1 team has supported a wide variety of outreach support to K-12 and public audiences through exhibits, classroom visits and other interactions that has engaged more than 1,000 participants to date. As one example, high school students in Pennsylvania are analyzing GeneSat-1 telemetry as part of class lessons in physics and math. As another example, the design of the amateur radio QSL card, shown in Figure 24, was the result of a artistic competition among middle school students

THE MISSION TEAM

The core of the GeneSat-1 mission team consists of staff scientists and engineers within the NASA Ames Research Center's Small Spacecraft Office and 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.

NASA Ames Research Center - Air Force Det 12 - CREST

Michael L. Miller: 2 Fred Burr Road, PO Box 39, Philipsburg, Montana 59858
mlmiller@intellus.us • Altitude: Perigee 410 Km, Apogee 412 Km • Location of Transmitter: GeneSat - 1 Spacecraft

Call Sign: KE7EGC
Frequency: 437.075 MHz FM

Design by Max Burkhardt, Age 12, Kirby High School, Santa Cruz, CA

Mode: Beacon AX-25 Protocol 1200 BPS, 1 Real-Time Data Packet/5 Seconds, See genesat1.org To Decode - Inclination: 40 - Period: 90 minutes - Ground Control and Point of Contact: CREST - Website: www.crestnrp.org/genesat1

Wallops Flight Facility - Mid-Atlantic Regional Spaceport (MARS)

Stanford University - Cal Poly, San Luis Obispo

Digital Sciences Corp - Santa Clara University

Figure 24: QSL Card for Amateur Radio Operators

- Stanford University's National Center for Space Biological Technologies (NCSBT) contributes significant expertise regarding the development of biological instrumentation suitable for space flight.
- The California Polytechnic State University (CalPoly) at San Luis Obispo provided its unique P-POD launch ejection system, which was adapted by the Ames team in order to accommodate the custom configuration of the GeneSat-1 spacecraft.
- 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 students also provided functional test services prior to launch and contributed 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 a program management and administrative support partner.

Overall, the integrated mission team demonstrated a complementary blend of expertise capable of meeting the unique challenges of bringing the GeneSat-1 mission to flight.

SUMMARY AND CONCLUSIONS

Launched in December 2006, the GeneSat-1 mission has successfully met all mission objectives, providing an important contribution to the development of research-quality instrumentation for *in situ* biological research and processing. As the first such free-flying satellite-based genetic analysis experiment, its design is providing significant insight into the appropriate application of small satellite technologies for enabling high-performance space-borne laboratories.

In exploring 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.

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