The O/OREOS Mission – Astrobiology in Low Earth Orbit

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Abstract. The O/OREOS (Organism/Organic Exposure to Orbital Stresses) nanosatellite is the first science demonstration spacecraft and flight mission of the NASA Astrobiology Small-Payloads Program (ASP). O/OREOS was launched successfully on November 19, 2010, to a high-inclination (72°), 650-km Earth orbit aboard a US Air Force Minotaur IV rocket from Kodiak, Alaska. O/OREOS consists of 3 conjoined cubesat (each 1000 cm^3) modules: (i) a control bus, (ii) the Space Environment Survivability of Living Organisms (SESLO) experiment, and (iii) the Space Environment Viability of Organics (SEVO) experiment. Among the innovative aspects of the O/OREOS mission are a real-time analysis of the photostability of organics and biomarkers and the collection of data on the survival and metabolic activity for micro-organisms at 3 times during the 6-month mission. We will report on the spacecraft characteristics, payload capabilities and first operational phase of the O/OREOS mission. The science and technology rationale of O/OREOS supports NASA's scientific exploration program by investigating the local space environment as well as space biology relevant to Moon and Mars missions. It also serves as precursor for experiments on small satellites, the International Space Station (ISS), future free-flyers and lunar surface exposure facilities.

Keywords: Astrobiology, Cubesats, Low cost mission, Spectroscopy, Space biology, O/OREOS, SEVO, SESLO

1. Introduction

The NASA Astrobiology Small Payloads Program (ASP), founded in 2008, enables the development of astrobiology payloads that can be accommodated on small satellites and free-flyers in low Earth orbit (LEO) and beyond. A key goal of the ASP program is testing and optimizing payloads that address fundamental astrobiology science and technology objectives. The program envisages delivery to a variety of orbital destinations (e.g., LEO, L1, lunar orbit) and aims ultimately to supply miniaturized payloads for surface missions (platforms, landers, rovers) that operate on the surface of the Moon, Mars and near-Earth objects (NEOs), including sample return missions [1].

O/OREOS is a triple cubesat developed to undertake a 6-month technology-demonstration mission in LEO (~ 650 km). The spacecraft has two independent science payloads, each hosted in a separate 10 cm^3 cube; see Figure 1. O/OREOS' two payloads monitor how exposure to space radiation and microgravity perturb biology and organic molecules, see official NASA Website: http://www.nasa.gov/mission_pages/smallsats/ooreos/main/index.html

Each payload addresses a key astrobiologically focused goal:
(1) Measure the survival, growth and metabolism of two different microorganisms using *in-situ* colorimetry. The *biological payload* known as SESLO (Space Environment Survival of Living Organisms), tests how microorganisms survive and adapt to the stresses of the space environment, including microgravity and ionizing radiation. These results can contribute to our understanding of the environmental limits of life and address many aspects of life sciences as well as planetary protection. **(2)** Measure the changes induced in molecules and biomarkers using ultraviolet and visible spectroscopy. The *organic payload*, known as SEVO (Space Envrionment Viability of Organics), monitors the stability of biomarkers and organic molecules exposed to space radiation. SEVO space data will allow us to investigate the life cycle of those molecules, which is highly relevant to a better understanding of carbon chemistry in space environments.

O/OREOS addresses several research avenues that provide important insights into astrobiology: organic chemistry in space; extraterrestrial delivery processes; the adaptation of life to the space environment; planetary protection; space exploration; and *in-situ* monitoring technology.

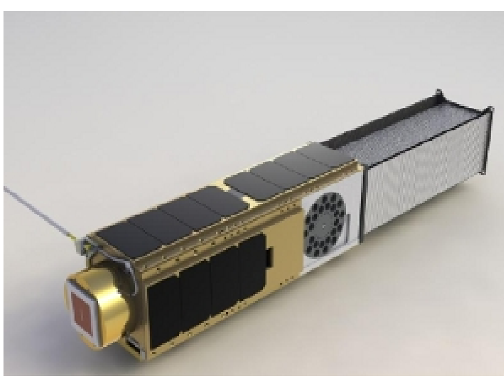

Figure 1. A solid model of the O/OREOS triple-cubesat with its de-orbit mechanism deployed.

Further, O/OREOS measurements provide, for the first time, a real-time analysis of the photostability of organic molecules and biomarkers while demonstrating some of the opportunities available for small satellites in astrobiology/chemical space research programs.

2. Spacecraft characteristics

O/OREOS was built on a heritage of previous successful cubesat missions, such as GeneSat and PharmaSat, and benefited from other experiments flown previously in LEO along with exposure facilities on the International Space Station (ISS). The spacecraft bus and mechanical configuration, as well as the SESLO payload, have heritage derived from GeneSat-1 (4.4 kg) and PharmaSat (5.1 kg), triple cubesats that launched aboard Minotaur I rockets as secondary payloads in 2006 and 2009, respectively, and were deployed in LEO at 420 – 450 km.

GeneSat-1, a technology demonstration, measured diffuse fluorescence and light scattering to monitor gene expression and organism population in two strains of *E. coli* in culture. PharmaSat, a science experiment, utilized 3-color absorbance measurements to characterize the dose response of *S. cerevisiae* to the antifungal drug voriconazole. The experiments lasted approximately 4 days; results were telemetered to the Santa Clara ground station. Both payloads and their spacecraft included sensors, thermal control, software, mechanical, power, communications, and other subsystems that were the basis in part for the O/OREOS spacecraft, bus, and its SESLO payload.

Figure 2. The successful launch of O/OREOS as one of eight secondary payloads (STPSat2, FASTRAC-A, FASTRAC-B, FalconSat5, FASTSat-HSV01, RAX, O/OREOS, NanoSail-D2) on November 19, 2010 with Minotaur IV HAPS from the Airforce Base Kodiak, Alaska.

The SEVO payload has heritage from the EXPOSE facilities hosted on the outside of the ISS, particularly its sample cells, which were modeled after the *Organic* experiment on EXPOSE-R. The SEVO UV-visible spectrometer has heritage from the similar Lunar Crater Observation and Sensing Satellite LCROSS UV-visible spectrometer.

O/OREOS was launched successfully as one of eight secondary payloads on November 19, 2010 with a Minotaur IV HAPS from Kodiak Launch Complex, Alaska (USAF STP S26); see Figure 2. The Minotaur IV rocket included a Hydrazine Auxiliary Propulsion System (HAPS) to take the vehicle to a secondary orbit. Minotaur IV rockets incorporate a standard 92-inch fairing from the Taurus booster and are capable of boosting payloads more than 1,750 kg into orbit.

The O/OREOS spacecraft is equipped with a passive attitude control system that utilizes multiple permanent magnets to orient its "patch" antenna (see Figure 3) toward ground stations when above the northern hemisphere, along with magnetic hysteresis rods that dampen rotational or nutational ("wobbling") energy. The satellite rotation along the z-axis was measured to be approximately 7 rpm near the start of the mission and it subsequently slowed to ~ 1 rpm. At the beginning of the mission, the satellite underwent significant nutation, or "coning", about its center of mass, which was manifested as, and measured via, characteristic variations in the electrical currents from the four body-mounted solar panels (Figure 3).

The spacecraft utilizes two radios, one a UHF transmit-only "beacon" to assist in locating the spacecraft and to enable amateur radio operators around the world to track a number of spacecraft, payload, and mission parameters as O/OREOS passes overhead. To date nearly 100,000 packets of data have been submitted by amateur operators from 22 countries to the mission website, http://ooreos.engr.scu.edu/dashboard.htm.

Science data and two-way communications for command and control utilize the S-band radio, which transmits and receives using conventional 2.4-GHz WiFi technology, *via* a 5 x 5 cm patch antenna (Figure 3; also see Section 4 below).

O/OREOS is the first science nanosatellite to operate above the thermosphere; its physical characteristics would result in a time to orbital decay of about 66 years. To meet NASA and UN orbital debris management requirements (decay < 25 years after end of mission), O/OREOS includes a self deploying "NanoKite" that increases its surface area by over 50% but adds only a few percent to its mass, resulting in an estimated time to de-orbit of 22 years. When the satellite is stowed inside the PPOD (Poly Picosat Orbital Deployer) for transport, launch, and flight, the collapsed NanoKite adds < 2 cm to the length of the spacecraft; upon orbital deployment, its interior coiled spring extends it to ~ 20 cm as the satellite exits the PPOD.

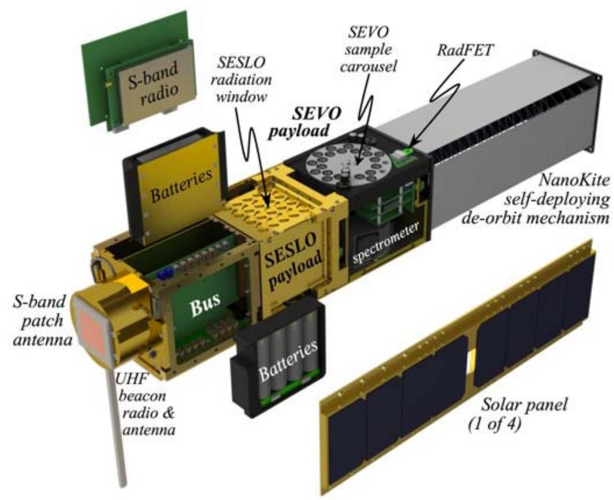

Figure 3. The O/OREOS spacecraft showing key components, the bus and two payload cubes, and the NanoKite de-orbit mechanism that will help O/OREOS's orbit decay from 650 km in ~ 22 years.

3. O/OREOS Dual Payloads

The SESLO experiment characterizes the growth, activity, health and ability of microorganisms to adapt to the stresses of the space environment; see Figure 4. The experiment is hermetically sealed in a containment vessel at one atmosphere and contains two types of microbes: *Bacillus subtilis* and *Halorubrum chaoviatoris*, each as wild-type and mutant strains; they were launched in a dry state.

The SESLO payload consists of three "bioblock" modules, each including twelve 75-µL sample wells; see Figure 4. Groups of 6 wells are connected by microfluidic channels and a solenoid-activated valve to one of two reservoirs containing germination/growth medium for one of the microorganisms. In each subset of six wells, three wells are devoted to the wild-type strain and three to the mutant.

Absorbance through each 2.8 mm (diameter) x 12 mm well was monitored using 3-color LED illumination (470, 525, and 615 nm) at one end of the well and an intensity-to-frequency detector at the other end. Prior to spacecraft integration and flight, the cells were dried onto the walls of the microwells and the bioblocks were sealed using gas-permeable membrane. The growth medium for *Bacillus subtilis* included the viability dye Alamar blue, a redox-based metabolism indicator that changes color from blue to pink as a consequence of cellular metabolic activity. The *Halorubrum chaoviatoris* medium did not contain Alamar blue, but this organism generates carotene as it grows, resulting in the appearance of a pale orange color. SESLO organism growth experiments in space were conducted at three time points relative to the launch date (2 weeks, 3 months, and 6 months) by filling the 12 dry wells in one bioblock with growth medium. First data were retrieved 2 weeks after launch [2].

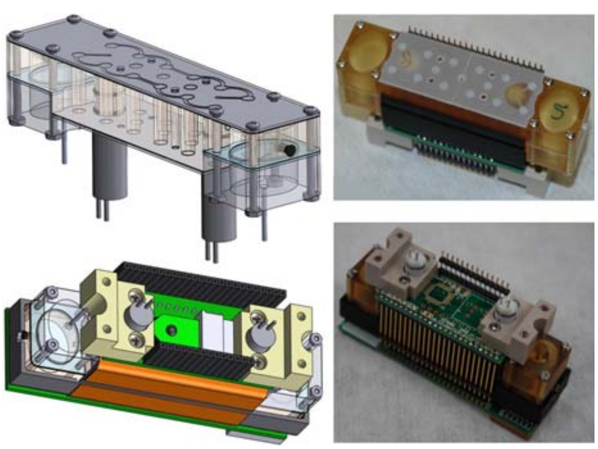

Figure 4. Four different views (solid model at left, photographs at right) of one of three bioblocks included in the SESLO payload. The two valves protrude down from the block (upper left); reservoirs are the elliptical structures at both ends of the block; heater is orange and RadFET is a black dot near the center of the bottom left depiction.

The SEVO experiment tests the survival and photostability of organics in the outer space environment: radiation is attenuated only by a 1.5-mm-thick MgF_2 window upon which the samples are supported in thin-film form. Molecules from four different molecular classes (a polycyclic aromatic hydrocarbon, an amino acid, a quinone and a metalloporphyrin) were selected for flight based on their astrobiological and exobiological relevance. The SEVO payload consists of a miniaturized UV-visible-NIR spectrometer and a 24-sample carousel that hosts hermetically sealed cells; see Figure 5. Integral optics enables the use of the Sun as the light source. After passing through a given organic film, light is routed via optical fiber to the spectrometer. The spectrometer provides 1–2 nm spectral resolution, and covers the wavelength range 200 – 1000 nm; a single spectrum is acquired in 100 ms by the CCD. Multiple spectral acquisitions of full spectra are averaged to improve signal-to-noise ratios.

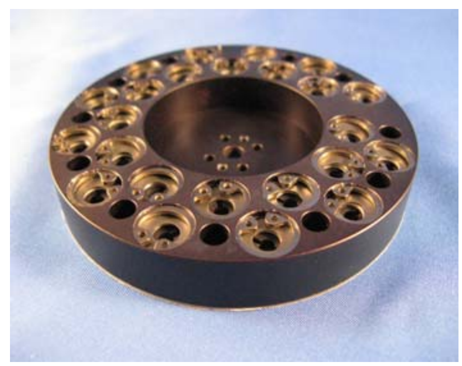

Figure 5. The SEVO sample carousel holds 24 sample cells designed to expose organic thin films to both the full solar electromagnetic spectrum and the ionizing particle radiation of space. To measure the spectrum of a sample, the carousel, driven by a stepper motor, rotates the sample cell over an assembly of collection optics that focuses the transmitted light into an all-silica optical fiber which terminates into the compact UV/VIS spectrometer.

SEVO requires baffled solar intensity sensors (adjacent to the sample carousel) to provide simple Sun-pointing information due to O/OREOS' lack of active attitude control. When the SEVO instrument rotates through an angle at which solar intensity is adequate to record a UV-Vis spectrum, the spectrometer is turned on and returns spectra collected near the peak intensity for that rotation.

RadFETs (radiation-sensitive field-effect transistors) measure the total ionizing radiation dose that SEVO receives inside and outside the payload. Thermal history is monitored by integrated-circuit temperature transducers and by optical pyrometers focused on the back of the sample carousel to avoid wired connections.

Flight samples were assembled in the test-and manufacturing facility at NASA Ames Research Center; see Figure 6. Films were deposited by vacuum sublimation onto MgF_2 windows. One of four "microenvironments" was hermetically sealed into each cell along with the organic film: pure Ar (analogous to space vacuum for chemical reaction purposes); Ar and a thin (a few nm) SiO_2 layer contacting the organic film (a mineral-like surface); Ar + CO_2 + O_2 with 200 nm of Al_2O_3 on the inside of the MgF_2 window to block deep UV (a planetary gaseous environment); or Ar + controlled relative humidity (also with 200 nm of Al_2O_3 to protect the MgF_2 from humidity).

Before flight integration with the satellite, both payloads and the bus were put through a number of environmental tests including shock, vibration, and operation in a space-like thermal-and-vacuum environment. Additionally, various mission simulations were conducted to characterize the software, experiment sequence, and payload measurement performance [3].

Figure 6. The O/OREOS sample-fabrication-and-test facility for the flight sample cells at NASA Ames. Contained within a glove-box, this high-vacuum thin-film deposition system includes an Ocean Optics HR400CG-UV-VIS spectrometer (200 - 1100 nm) for film characterization.

The first set of SEVO spectra from orbit was acquired within hours of deployment on 19 November 2010. During the first two weeks of the mission, SEVO spectral sets (from all 24 sample carousel positions) were acquired daily in order to observe any initial changes in the organic films. Thereafter, frequency decreased to every 2 days, the sampling period lengthening gradually to a plateau of 15 days for the final ~ 3.5 months of the mission. Over the course of the 6-month mission, the organic films were exposed to full-spectrum solar irradiation for an estimated 1500 hours, about 35% of the total time in space [4].

4. O/OREOS Operations

Science data were retrieved on a daily basis early in the mission including nights and weekends by the students and staff at the Mission Operations Center at the Robotic Systems Laboratory of Santa Clara University, using a pair of 3-m dishes on campus; see Figure 7.

Figure 7. O/OREOS Operation Center at Santa Clara University showing one of the two 3-m parabolic dish antennas used for this mission (top) and the operations console.

With an average of one – two contacts per day with ~ 5 – 15 minutes of usable data downlink capability, 6 MB total science and health-and-status data from both payloads and the bus were downlinked during the 6-month baseline mission using the S-band radio. The active participation by amateur radio operators delivered beacon packages from all over the world.

5. O/OREOS Milestones and Controls

The O/OREOS project kick-off meeting was July 2, 2008—funding began that September—and the spacecraft was delivered less than 2 years later in August 2010 for launch in November 2010. The Preliminary Design Audit was held Nov. 21, 2008; the Critical Design Audits, Feb. 25 and March 9, 2009; the Flight Readiness Review, July 29, 2010; and the Operational Readiness Review, Nov. 2, 2010.

Asynchronous ground control experiments are in progress for both science payloads. SESLO controls were executed using the flight backup instrumentation at NASA Ames Research Laboratory approximately 6 weeks after each of the spaceflight bioblock experiments was run. The SESLO ground control system was maintained inside an environmental chamber, the temperature of which was adjusted periodically to mimic the larger changes in the spaceflight SESLO system temperature on a ~ 6-week-delay basis. The SESLO ground control biological samples were prepared from the same cultures as the spaceflight samples and were loaded into bioblocks within a day or two of the loading of the flight samples.

For the SEVO ground controls, a total of 3 sample carousels in addition to the flight carousel were loaded with organic-film-containing sample cells prepared from the same vacuum deposition runs as the flight samples. One of these is maintained in the dark at all times except for periodic (~ monthly) acquisition of a UV-visible spectrum of each film to compare with the spectra returned from space; a second carousel full of samples will be exposed to a simulated solar spectrum (to the extent possible using a xenon arc source and appropriate filtering) supplemented by exposure to the 122-nm Lyman alpha line from a hydrogen lamp. Spectra will be acquired for these irradiated samples at comparable exposure times to those of the spaceflight spectra.

Full Success (TRL = 8) of the O/OREOS mission, which includes launch, successful operation of the O/OREOS-Sat payload, and delivery of collected mission data to program management, was achieved in May 2011. The last of the success criteria to be achieved was the SESLO demonstration of its third organism growth test, successfully executed after 6 months on orbit. The full success criteria specified for the SEVO payload were to measure the degradation of (bio) organic molecules in all 4 selected space environments.

Many postdocs and young engineers were involved in the development and operations of the O/OREOS satellite allowing them to contribute to important phases of a space mission from design to launch, including in-orbit operations, ground control tests and flight data analysis. Frequent press releases and public involvement of amateur radio operators worldwide have provided significant oublic outreach for the O/OREOS mission during its operation phase.

O/OREOS was built by an experienced engineering team in the NASA Ames Small Spacecraft Division. Its scientific development was achieved by an experienced science working group, with the help of Ames-based supporting postdoctoral scientists. All these factors made O/OREOS a successful and rewarding low-cost mission.

6. O/OREOS Management

The O/OREOS development activity and spaceflight mission were managed in accordance with NASA Procedural Requirements 7120.5D as a Category III, Class D Mission, providing a framework for efficiency and low cost. The project drew heavily upon the proven low-cost management approach utilized by Ames Research Center for GeneSat-1 and PharmaSat, both low-budget, high-success activities. In this structure as adapted for the O/OREOS project, the Project Scientist is responsible for science integrity and unified goals and vision; she liaised with the Program Scientist, Chief Technologist, Instrument Scientist, the members of the

Investigator Working Group (IWG), the project manager (PM), and the Mission Manager (MM). The PM is responsible for the overall technical success, supervision of engineering development and test activities, and personnel management; these duties were taken over by the MM during the spaceflight portion of the mission. The PM is also responsible and accountable for the safety, technical integrity, performance, and, along with the MM, the mission success of the project, while meeting budget and schedule commitments.

Members of the project team manage science and technical requirements, procurements, flight systems development, testing and validation, cost and schedule tracking and control, project reports and reviews, risk mitigation, launch systems interface support, and mission operations. The IWG developed the science concepts for both payloads and provided expertise and assistance with the adaptation of the science experiments to the constraints of the spaceflight payload systems. Reviews and documentation were tailored to a limited budget and schedule. Systems Engineering (SE, compliant with appropriately tailored NPR 7123.1, NASA Systems Engineering Process and Requirements), Safety and Mission Assurance (S&MA), Risk Management (RM), and Milestone Reviews were conducted per NASA NPR7120.5D and supporting NASA specifications tailored to fit budget, schedule, and the launch scenario. Detailed plans for SE, RM, and S&MA were not necessary.

Even as a Class-D mission, with the O/OREOS spacecraft flying as one of multiple secondary payloads, safety and reliability was ensured. The PM assured that the launch vehicle interfaces, any dependencies on the Primary Payload, and interfaces with the Launch Services Provider all utilized well-defined interface integration. Management e-tools and weekly/bi-weekly team and sub-team meetings via web conferencing were used to maximize project efficiency and effective communications. Tools such as PBMA (Process-Based Mission Assurance) enabled secure collaboration and communications across the team, easing the exchange of information, data, and documents.

7. Conclusion

The success of the O/OREOS mission demonstrates convincingly that cubesats are cost-effective platforms for performing science research and conducting technology demonstrations. The O/OREOS-Sat Project achieved its overall goal to utilize autonomous instrumentation and sensors for *in-situ* organism and organic specimen exposure and measurement using a free-flying nanosatellite in support of the ASP objectives.

The utility of cubesats as science research and technology development platforms is now increasingly recognized [5] and, enabled by recent advances in miniature, micro, and integrated technologies, developers are responding by offering affordable instrumentation normally developed only for larger satellites. Cubesats now can capitalize on the latest technologies to fly instruments that truly are “state of the art.” The United Nations have formally recognized the benefits small satellites provide to developing and emerging nations [6]. With the successful completion of O/OREOS, the Astrobiology Small Payloads Program anticipates future solicitations for mission concepts and new missions.

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