

Space hardware for plant samples

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Abstract

This document aims to study previous and upcoming space missions that involved biological samples to understand the hardware, procedures and aspects needed for such a mission. Additionally this document serves as a technical bridge and will attempt to break down some of the engineering aspects for other disciplines, as well as recommend feasibility and attempt to realise aspects of a proposed similar mission by the Plants for Space center.

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Mission idea

To test the specimen in a space environment, Plants for Space wishes to transport a sample along with test equipment into a microgravity environment. To do this, supporting hardware will be needed (covered later in this document). The sample is expected to be a genetically modified piece of moss ([Physcomitrella patens](#)) that is to express a designed response to a specified stimuli. These are yet to be decided but some early ideas are temperature change for stimuli and colour change, growth or chemical production as possible responses. The exact mechanisms will need to be simple, lightweight and ideally using hardware that will be aboard the mission already.

The mission would involve a sample being stored aboard a card that contains all necessary life support, monitoring and testing systems. This could then be adapted to suit a variety of mission delivery systems (cubesat/smallsat, ISS mission).

Previous missions

This list is not exhaustive and will mostly focus on plant based biological samples, but bacteria and bioscience experiments will be listed for completeness.

BioSentinel 2022

6U CubeSat that explored the effects of deep space radiation on yeast cells. Sat was launched aboard Artemis-1, and ventured into orbit beyond the moon. Yeast cells failed to grow, which the team determined was a result of extended storage pre-mission. [1], [2]

The mission made use of multiple microfluidics cards to perform tests and activate the dried yeast.

Advanced automation was developed, such as a yeast card being activated if a solar flare was detected, to monitor the effects of high space radiation.

Scientific payloads were first validated onboard the ISS.

Read more - [NASA Article](#)

GeneSat-1 2006

GeneSat-1 was Ames' NASA's first fully automated, self contained biological experiment on a satellite of its size. It tested for gene expression in microscopic organisms using Green Fluorescent Protein. [3]

Read more - [eoPortal](#)

PharmaSat 2009

PharmaSat built upon the technology of GeneSat-1, reusing many of the microfluidics and optic systems to test yeast resistance to antifungal agents.

Read more - [NASA publication](#)

O/OREAOS 2010

O/OREAOS (Organism/Organic Exposure to Orbital Stresses) was the third small satellite developed by Ames following GeneSat-1 and PharmaSat, designed to measure how well microorganisms adapt and react to the stresses of space, and the stability of organic molecules in space.

Read more - [eoPortal](#)

SporeSat 2014

SporeSat was another Ames lab biological sample mission that aimed to investigate the effects of microgravity on spores of the fern *Ceratopteris richardii*. The experiment sought to measure calcium ions as these are used in the gravity sensing mechanisms of the plant.

The mission used three lab-on-a-chip devices (coined “bioCDs” by the team) that sensed calcium signalling in real time. These sensors and samples were contained in spinning containers that mimicked various gravity levels.

Read more [eoPortal](#)

EcAMSat 2017

EcAMSat (E. coli AntiMicrobial Satellite) housed an experiment that tested the antibiotic resistance of bacteria in space. The experiment used two strains of E. coli, one wild strain and another genetically edited strain that was missing the stress response.

Read more - [NASA](#)

AstroBio CubeSat (ABCS)

AstroBio is a 3U cubesat that to test an automatic lab on a chip technology within the van-allen belt (a region of high radiation near earth). The tests will evaluate the functionality of the device (delivery of reagents, mixing of chemicals, detection of emitted photons, electronics, data storage and transmission) and the stability of chemicals and biomolecules in space conditions.

Read more - [AstroBio CubeSat](#)

ISS

VEGGIE-1, 2 & 3. APH (Advanced Plant Habitat) are all missions involving plants being grown aboard the ISS. Plants grown include romaine lettuce, Chinese cabbage and Mizuna mustard.

EuCROPIS 2018

EuCROPIS aimed to study the feasibility of growing plants (specifically tomatoes) in a closed loop system (turning urine into fertilizer and then into food) under different gravity conditions (simulated lunar and martian gravity). The system contained an extensive sensing suite, having multiple cameras to record growth, chemical sensors to record plant related compounds (ammonium, nitrite, nitrate, pH, chloride, sodium and potassium), RAMIS (RAdiation Measurement In Space), humidity, temperature, and a mRNA Expression analysis system to analyse how the microgravity altered various gene expressions. [4]

Read more - [Deutsches Zentrum für Luft- und Raumfahrt](#)

Chang’e 4 “biosphere”

Chang’e 4 was a lunar lander mission that deployed multiple payloads onto the far side of the moon. Among these payloads was a canister containing seeds for cotton, potato, rapeseed, *Arabidopsis thaliana*, as well as fruitfly larvae and yeast. The aim was that these organisms would act in synergy and produce/consume oxygen/CO₂ for each other. The biosphere was a partial success, with sprouting recorded of the cotton, but a failure of the heating system meant it wasn’t able to survive the lunar night. [5]

Read more - [The Planetary Society](#)

SpaceMoss

SpaceMoss is an ongoing project from the university of Copenhagen to introduce genes into moss for a long duration mission to mars. So far “anti-freeze” genes from a spruce budworm and Resveratrol bioproduction have been implemented.

https://2015.igem.org/Team:UNIK_Copenhagen/Description

Outline of hardware

Temperature control

Temperatures in a space environment are determined by a number of factors and can vary across a wide range, as well as change in a short time period. For a cubesat in LEO its period would be from 90 to 120 minutes, with it being in sunlight half the time and earth occlusion the other half. Mass of the satellite also plays a large role in thermal balance, as larger craft will take longer to heat up/cool down, and will therefore have a more stable temperature. Due to these factors it is difficult to claim certain temperature ranges experienced by a satellite, however we can compare similar craft in orbits we are targeting. MinXSS-1 (2016) made their estimated and recorded temperature ranges publicly available [6], for their 3U cubesat in an equatorial low earth orbit. The most central electronics (motherboard, power systems) experienced a temperature range from -1°C to $+40^{\circ}\text{C}$, where as systems with a higher thermal mass (batteries) experienced only $+10^{\circ}\text{C}$ to $+21^{\circ}\text{C}$.

Spacecraft typically contain an assortment of temperature critical components. Lithium-ion batteries for example will reduce in effectiveness and eventually stop working in colder environments, and so will often come with heating systems to keep them within their operational range (0°C to 45°C for best performance). Some subsystems (i.e. high end optics or scientific equipment) are the opposite, and need very low temperatures. These systems make use of radiators and in some extreme cases will use technology such as heat pumps to achieve localised very low temperatures.

The sample itself will ideally be kept around room temperature (24°C to 26°C), with stability of the temperature being ideal for the comfort of the moss.

Heating

Considering that this mission will aim for smaller mission platforms, heating will likely be required, however with insulation and the relatively forgiving temperature point, this should be very simple to achieve. A simple resistive heater placed near the sample with a controller should suffice.

As the sample will want a tight temperature range as well as an adjustment to the temperature being a likely stimuli, the controller will likely be more advanced, such as a PID loop. This would allow the flight computer or other controller to adjust the temperature set point according to a mission profile.

Cooling

Cooling may be needed, depending on the survival/comfort range of the sample. Once more details are known about mission (satellite size, target orbit, insulation) thermal simulations can be run and cooling requirements can be reassessed. Due to relaxed cooling needs compared to other space systems (such as very low temperature optics) increasing cooling capabilities should be as simple as increasing thermal emissivity (though the use of radiators or type of coating). In an extreme case active systems such as peltier modules may be used, as these are low cost, simple solutions to cooling needs.

A concern raised early on in discussions was the transport of the sample, as waiting stages of the sample (such as in the fairing before launch) could be prone to overheating. Additionally accidental triggering of the stimuli want to be avoided, so it should be made sure that the temperature should go above a threshold unless specifically desired.

Atmospheric control

The sample will want an atmosphere that mimics that of earths to maintain healthy condition, supplying gasses such as CO_2 and Oxygen. These will be consumed over the duration of the

mission, however variables such as rate of consumption, ideal mixture, and pressure are all unknown and will need testing. Ideally the sample can survive on a small volume of atmosphere long enough to run the mission.

Additionally depending on the mission launch provider, more testing/validation will need to be done as well as certification to launch a pressurised container. This will likely be a significant cost factor in the project.

Vibration

During the launch of a mission, the payload can experience large vibrational loads (can be upwards of 10g). The attachment of the sample within its container needs to be able to withstand these high vibrations.

And early idea floated was using a thick layer of agar, similar to the kind used in petri dishes, however testing would be needed to determine if this would be good for the sample.

Another idea could be to grow the moss sample into a porous substrate to more securely anchor it down.

Additionally, dampening can be used and measures can be taken to isolate the sample/payload from the vibrations of the launch.

Sensing

Sensing is a critical part of the mission, as this will be how results will be obtained and mission success/failure is determined from results gathered. Many forms of sensing exist, however selecting a specific method will be about finding an intersection between feasibility of engineering of both biological and technical.

Imaging

Imaging with some sort of camera will likely be a high priority, even aside from it being used as a sensing tool. A camera allows for a great deal of diagnostics to be done, such as verifying sample conditions. It also will be desirable for more marketing/publication reasons, as a cool picture of an experiment can speak a thousand words.

Small lightweight cameras have greatly developed thanks to smartphones, and the camera will likely be inside the pressurised container, making it simpler to find a suitable model. The main challenge will be selecting something with a short focal length, as we will need to keep the assembly compact, and will want the camera as close to the sample as possible. Perhaps a macro lens or some sort of microscope like camera may want to be used to allow for observation of the structure of the moss/resolving fine details.

Additionally with one of the detection methods proposed being fluorescence, the camera would also need an accompanying UV illuminator.

Lab on a chip? or other chemical detection

Lab on a chip technology has developed greatly, and has been used before in biological space missions due to its lightweight, advanced sensing capabilities. Often paired with microfluidics, these systems are capable of performing advanced procedures that would typically take a much larger laboratory setup.

This being said, early on into the project it was decided microfluidics would be avoided, due to complexity and lack of experience with the technology from most of the team.

Additional sensing capabilities?

Additional non-critical sensors will likely be integrated into the mission, increasing data collected from the mission. Sensing capabilities such as radiation dosage, internal atmospheric conditions, and any easy to integrate sensors.

How this mission could be achieved

The mission would be realised with the options being between a small-sat (a standardised format such as a CubeSat, or multi-mission shared sat) or mission being hosted aboard the ISS. Ideally the hardware design is mission agnostic, as both options face similar constraints, mainly independence/automation (satellite cant be interacted with once launched and very high labor cost upon the ISS), however ISS may have easier constraints for atmosphere.

The main focus on development will be the payload system, as we will be handing off responsibility of other systems to whatever host platform is chosen. Finding and working with a suitable platform (for example a ready made CubeSat system designed to host a payload) will be a priority to realise launching this project.

Early on development will likely focus on building on-ground systems/tools to assist the biology focused branches of this project, to gather data and experience on life support systems, as well as build the system in parts.

The method of transport for the mission is also yet to be decided, but is almost guaranteed to be some sort of ride-share with other missions.

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