SMPO19Cabana-Loriaux

BeanSat - A nanosatellite for crop cultivation monitoring in milligravity

Alexis Cabana-Loriaux[a]

[a] *Institut für Luft- und Raumfahrt, Technische Universität Berlin, Marchstraße 12-14, Berlin, Germany 10587*, cabana-loriaux@campus.tu-berlin.de

Abstract

This paper gives an overview of the BeanSat cube satellite project. BeanSat is a technology demonstration mission, to be launched as part of the TUPEX-8 mission onto a free-fall trajectory.
BeanSat reuses a lot of elements from the previous TUPEX missions. It will however replace the SDR payload of the Free-Falling Unit (FFU) with a miniature permeable terrarium structure, hosting a type of field bean (*Vicia faba*) and a special compact soil. After ejection from the REXUS rocket by the Rocket-Borne Equipement (RBE), the tumbling spacecraft will keep the terrarium's temperature stable, while de-tumbling before creating the artificial gravity gradient needed for the experiment. The payload will also take pictures of itself to monitor the bio-components inside during the whole duration of mission. Once the flight is over and the FFU is recovered, an assessment of the terrarium's state will be performed to determine the permeability in pressure and temperature of the payload.
BeanSat will thus demonstrate the effectiveness and feasibility of a higher degree mission, not possible on a REXUS flight, of growing a small fruit-bearing plant in a low-earth orbit in a permeable milligravity environment for future deep space exploration missions. Academically, the projects also aims to promote space-related activities at the TU Berlin as well to improve relations between its Space engineering and Botanics departments.
Keywords: nanosatellite, growing, milligravity, cubesat

Acronyms/Abbreviations

Most of the acronyms and abbreviations used in this document are taken from the TUPEX-7 Student Experiment Documentation (SED).

1 Introduction

1.1 Motivation

Since the dawn of spaceflight, microgravity research on living organisms has been and is being conducted to better understand the processes behind their growth and to clarify the role that plays gravity in the development. Through the years, we have learned that plants highly depend on Earth's gravity to control the orientation of the stem and roots, a strategy called gravimorphogenesis [1].

The research done so far in the area has been promising. However, we have far less knowledge on the same growing techniques using a small but constant gravity vector, nearly imperceptible by humans. This milligravity environment could, in principle, have a big long-term impact on vegetative growth and other life process might operate differently under this condition. Milligravity, through a low-frequency rotational artificial gravity, could provide humans with better growing methods in space, especially for future deep space exploration.

1.2 Original idea and concept

It is proposed, in this paper, to aim for a study of the long-term effects of vegetable growth, not only in said gravity conditions, but also in a sealed, self-sustaining environment. By varying the artificial milligravity vector, as well as the lightning conditions and the temperature of the bio-components's environment, the growth of the plant would be studied in-depth. The mission would also find a way to balance between photosynthesis and respiration of the plant so as to keep a good air mix.

In a CubeSat mission, the payload would be a high-volume, permeable terrarium, in which a plant in its youth would be planted in a compacted soil. The container would be fully sealed, so that its inside pressure remain constant. As temperature control, heaters would also be featured, while its side panels would be made to minimize thermal conductivity. To monitor the plant's growth inside the hermetic greenhouse, a simple camera would be included, as well as a proper lightning for taking images, but also serving as the main light source for the photosynthesis process.

Of course, because of the long-term nature of the project, it is impossible to carry this type of payload on a REXUS flight. Therefore, for the rest of the document, an adaptation to this longer duration mission is proposed, the BeanSat mission.

2 Mission idea

The BeanSat mission is a technology demonstration mission aiming to determine the feasibility of the original aforementioned mission of longer duration. Its inclusion in a REXUS flight would study whether the original structure would sustain the LEO launch conditions or not, where mechanical and acoustical vibrations create a lot of stress. The adequateness of the terrarium to this type of stress is thus one of the main top-level goal of the mission.

Inside the structure, the bio-components (soil and bean plant) will also be included, as if they were prepared for the longer project. Their inclusion will inform of the general state of the payload after launch.

In addition to the study of the greenhouse structure, the BeanSat mission also serves to test the capability of a 1U CubeSat-sized to properly simulate the milligravity environment using the pFDAs (Pico-Fluid Dynamic Actuator).

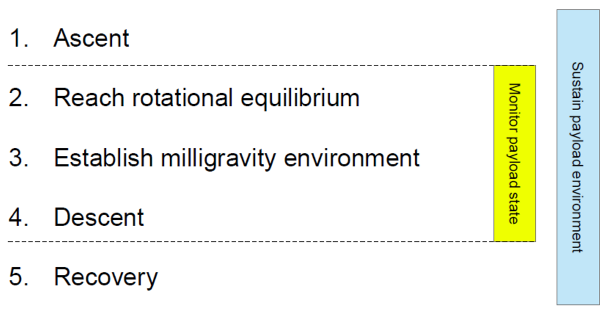
2.1 Mission objectives

In summary, the objectives of the BeanSat mission will orbit around knowledge acquisition. Here are the five main goals that would be achieved by using the TUPEX-8 mission, and including the BeanSat as a testing bench for the longer duration mission proposed before :

- **Test the terrarium structure**. As said earlier, the launch conditions and the ejection of the FFU pose a big threat to the health of the payload's structure. One of BeanSat's goal is to ensure that the vibrations of the launch vehicle don't affect the integrity of the structure or its permeability. It is very important for the structure to remain nominal during the TUPEX mission and after the recovery of the FFU. During the total duration of the mission, the environment inside the terrarium also has to remain constant, both temperature- and pressure-wise. In case one of these criterias are not met, this would inform of the non-suitability of the materials the structure was made out of and/or of the wrong fit of the structure in the CubeSat-sized FFU.
- **Experiment with the milligravity environment**. During the TUPEX-6 and TUPEX-7 missions, different types of pFDAs were used as attitude control devices for exchange of angular momentum. While the L-shaped pFDAs were used in the former, a new type of planar fluid actuator is planned to be used in the latter. The TUPEX-8 project, comprising the BeanSat payload, would use the more adequate form of pFDAs for the creation of a small artificial gravity vector, judged after the TUPEX-7 mission. The devices would be use to put the FFU in a low frequency spin to control the centrifugal force acting on the soil and the plant inside the terrarium.
- **Check the bio-components of the payload**. Again, considering the launch, ejection and de-tumbling of the FFU, these components will be vibrating a lot. With the BeanSat mission, the soil and the bean plant's health would be checked and tested after going through all these phases. Both the compacted soil and the plant's health still have to be suitable to the plant's growth after stress.
- **Ensure the ability to monitor the payload post-launch**. Within the payload's structure, a camera, as well as an sun-mimicking light will be included as monitoring devices. While serving as the main light source for the plant's photosynthesis to occur, the light will also serve to the camera as well in order for it to properly monitor the plant's growth with images during the original extended mission. BeanSat will serve to demonstrate the capability of those device inflight post-launch, and it's interaction with the bio-components who might be influencing the quality of the images.
- **Recover the FFU**. In the case of BeanSat, a smooth recovery of the Free-Falling Unit is crucial. Being able to analyze the payload's structure post-mission will allow us to better examine it, to identify potential cracking causes and to assess of its permeability.

3 Mission concept

The general BeanSat concept is very similar to its TUPEX predecessor. Here is an overview of the mission's timeline :



To fulfill the aforementioned mission objectives, the mission starts with the ascent followed by the ejection of the FFU (phase 1). It is during the phase 2 of the mission that the FFU begins its experiments. It will start by de-tumbling itself from the rotation caused by the ejection by determining its angular rate and transferring its angular momentum to the pFDAs. Then, the fluid actuators will create the low-frequency rotation needed to create the small gravity vector inside the FFU, followed by a de-saturation of them via the HISPs' (Highly-integrated side panels) magnetorquers (phase 3). During the phase 4 of descent of the FFU, this is where the parachute will deploy. Once the FFU has gently touched ground, its recovery will be performed by a team on ground, completing phase 5.

During the whole duration of the mission, the payload's permeable environment will have to be sustained, temperature- and pressure-wise. For this, the 5th phase is especially important as this will be the only way to have a clear indication of the state of the structure post-launch. As for the payload state, a monitoring during the three middle phases will be performed. This includes a proper lightning of the bio-components and taking an image every 30 seconds while the FFU is in a free fall.

4 Requirements

The mission has as well many requirements to fulfill in order to properly achieve the objectives. In annex are listed the initial requirements, in Tables 1 to 3. Here is a short summary of the most important ones:

Requirement #	Description
UR-02	Probe the inside of the terrarium twice/minute to record the state of the environment.
MR-02	The FFU shall be put in free-fall trajectory. Crucial to fulfillment of objectives.
UR-07	Recovery of the FFU. Again, crucial.
UR-11	Take a picture twice/minute, to see the state of the bio-components.

5 Project management considerations

5.1 Parallel with TUPEX-7

Given that the BeanSat mission is similar in a lot of ways to the previous TUPEX mission, it benefits a lot work that has already been done in the past. The timeline also draws a lot of comparisons. It is estimated that more or less 80% of the TUPEX-7 work packages could be reused. The majority of the changes would occur in :

- **WP1000 - FFU**. Of course, changing the SDR payload of TUPEX-7 for a terrarium brings some integration challenges. The new BeanSat payload raises the payload-to-volume ratio of the spacecraft, so a new structural design would have to be made. The secondary battery might have to be taken out for volume conservation purposes. In parallel, a new power budget would have to be unlocked to correctly supply the artificial sunlight, the camera, as well as the heaters.

- **WP6000 - Payload**. Again, a complete change of payload requires the team to put some new efforts in researching the correct materials for the terrarium. A new visible-light camera will have to be chosen, with its accompanying artificial sunlight. To keep the terrarium at a good temperature, a new set of heaters is now also required. Finally, everything regarding the bio-components (compacted soil and bean plant) will have to be thoroughly researched, as the team doesn't have experience with these kinds of material. Thus, a good communication channel will have to be set in place with the botanic department at the TU Berlin.

5.2 Schedule

Table 5 in annex shows a preliminary schedule of the mission. It is possible to see that the CDR would take place after the launch of TUPEX-7, so as to catch any big error that could occur with reused work packages. The beginning of the development for the payload has been set to start before the development of the satellite bus, because of the amount of knowledge acquisition that has to be made by the team regarding the bio-components.

6 Risk register

Table 4 in annex shows the version 1.0 of the risk register for BeanSat. Here a summery of the most important risks :

Item	Index	Description
Delivery	C3	Schedule delays with Botanics Department
Payload	B5	Loss of the bio-components after launch conditions.
EPS	A4	Failure to power every subsystem properly.
FFU	A4	Unable to recover the FFU after descent.

7 Future steps

The sections above gave an overview of the preliminary details of the BeanSat cube satellite project. To make the project a reality, the next steps would be, as per the preliminary schedule, to continue in the mission management part. As most of the team would be in a semester break until October, it would not be a good idea to kickoff the project during this time. This is why the development of the payload would happen as soon as the team is ready for the next semester. This would leave enough time to produce a prototype, so that the structures team can integrate the dummy in the design. The next big milestone would be the Preliminary Design Review (PDR), happening around the same time as the TUPEX-7 mission in 2019.

8 Conclusion

Finally, a lot of good projects have been presented in the context of the newest TUPEX-8 mission. The BeanSat mission distinguishes itself by the inclusion of bio-components inside its payload, an idea pretty far from every other project proposition. The top-level goal of the mission is the knowledge acquisition of whether or not the terrarium would be suitable for a longer duration mission, a mission where growing an actual bean plant would be attempted. In addition, because of the mostly passive activities that will happen on-board the spacecraft during the BeanSat mission, little change from the TUPEX-7 mission will have to take place regarding the past work packages. The payload-intensive schedule was also presented at the end of the paper, requiring the payload team to present the structure team a prototype of the terrarium to mitigate later integration issues.

This mission would mark a lot of points in research for food production methods in space. A small milligravity environment is maybe the solution for a sustainable and efficient method of feeding astronauts. Being able to sustain a group of people for long periods of time will enable the human race to further space exploration for years to come.

References

[1] Takahashi, H. *How do plants grow in microgravity?*. JAXA, 2003 URL: `https://global.jaxa.jp/article/special/kibo/takahashi_e.html`
[2] Paul, Anna-Lisa; Amalfitano, Claire E.; Ferl, Robert J. (2012-12-07). "Plant growth strategies are remodeled by spaceflight". BMC Plant Biology. 12: 232.
[3] Cooper, Maya; Douglas, Grace; Perchonok, Michele (2011-03-01). "Developing the NASA Food System for Long-Duration Missions". Journal of Food Science. 76(2): R40–R48.
[4] Cornell University (Last 2006). "Vegetable Growing Guide".
[5] Asphaug, Erik; Thangavelautham, Jekan;(2016-07-01). "A Cubesat Centrifuge for Long Duration Milligravity Research". NPJ Microgravity.

Annex

Table 1: **User** requirements for the BeanSat mission

Requirement #	Description	Source	Justification
UR-01	The satellite shall house a miniature greenhouse of $400 cm^3$.	User	To properly grow the plant, the greenhouse has to be big enough. This size has been set as the perfect size by the botanics department.
UR-02	The terrarium's metrics shall be probed twice per minute.	User	To provide accurate measurements of the growing speed and general health status of the plant and soil, daily monitoring is mandatory.
UR-04	The temperature of the greenhouse shall be probed twice per minute.	UR-02	Refer to UR-02.
UR-05	The FFU shall be equipped with highly-integrated side panels (HISPs)	UR-01	To fit the correct payload size, these panels are need because of their small volume. Also needed for attitude control.
UR-06	It shall be possible to control the temperature of the greenhouse.	User	To study the correlation between the temperature of the greenhouse and the growth of the plant, it must be possible to control the greenhouse's temperature in multiple increments.
UR-07	The FFU shall be recovered.	User	To properly study the effect of the launch on the soil and plant, as well as to analyze the terrarium's structure for any cracks or defect, we need to recover the free-falling spacecraft.
UR-08	The payload structure shall be totally permeable to gas.	User	The goal is to find a way to build the terrarium with certain materials in order to sustain the environment for the bio-components.
UR-09	The payload structure shall not lose energy (temperature) more than one degree every one minute.	User	The goal is to find a way to build the terrarium with certain materials in order to sustain the environment for the bio-components.
UR-10	It shall be possible to control the lightning inside the greenhouse.	User	To study the state of the payload, it must be possible to control the greenhouse's lightning conditions in multiple increments.
UR-11	It shall be possible to take pictures of inside the greenhouse.	User	To study the state of the payload, it must be possible to see it inside the terrarium.
UR-12	The humidity of the terrarium shall be probed twice per minute.	UR-02	Refer to UR-02.

Table 2: **Mission** requirements for the BeanSat mission

Requirement #	Description	Source	Justification
MR-01	The system shall fit in the 1U format according to the CubeSat international standard, for size (10x10x10cm) and weight ($\leq$1.33kg).	Launcher	To satisfy the launcher's size and weight criteria for this REXUS flight.
MR-02	The system shall be put in a free-fall trajectory for at least two minutes	User	To be able to properly conduct the de-tumbling and to create the milligravity vector for the experiment.

Table 3: **Instrument** requirements for the BeanSat mission

Requirement #	Description	Source	Justification
IR-01	The humidity probe inside the greenhouse shall have a precision of 0.5%	UR-12	To be able to finely monitor the effect of the current humidity on the plant's growth.
IR-02	The light inside the payload structure shall beam the same density and wavelength concentraiton than the Sun's	UR-10	To be able to finely monitor the effect of the current humidity on the plant's growth.
IR-03	The temperature sensor inside the greenhouse shall have a precision of 0.5°C	UR-04	To be able to finely monitor the effect of the current temperature on the plant's growth.
IR-05	The measurement of the length of the plant shall be done via a visible light camera with a precision of 1mm.	UR-11	Refer to UR-11.
IR-06	The temperature control unit inside the greenhouse shall have a granularity of 1°C with a range from 2°C to 50°C.	UR-06	To be able to finely adjust the temperature to sustain the terrarium's environment.

Table 4: Mission risks

No	Revision	Critical Item	Description	Risk index[a]		Recommendation	Countermeasures	Status
1	1.0	Spacecraft delivery	The delivery of the payload by the botanics department not on schedule.	C	3		Keep close communication with the botanics department. Make the botanists part of the schedule meetings.	open
2	1.0	Spacecraft delivery	The integration delays caused by a payload not ready to be interfaced with the entire spacecraft.	B	3	Make sure to have a final payload structure prototype while designing the spacecraft structure to mitigate integration problems.		open
3	1.0	Spacecraft delivery	Software interfacing delays with the other spacecraft's subsystems.	A	4	Re-use flight proven subsystems to reduce learning overhead		open
4	1.0	Spacecraft data gathering	Failure to properly gather data about the spacecraft's attitude and general health.	A	4			open
5	1.0	Spacecraft energy management	Failure of the EPS to gather enough energy to power every subsytem properly.	A	4	Increase budget for more solar array coverage and energy availability.		open
6	1.0	Spacecraft communication	Failure to receive/transmit data to/from the spacecraft.	B	4	Use flight-proven antennas		open
7	1.0	Payload	Loss of the bio-components after launch conditions.	B	5		Vibration testing of the whole payload's greenhouse system followed by health check.	open
8	1.0	Spacecraft	Recovery of the FFU impossible.	A	4	Make sure to learn from mistakes of past TUPEX missions.	GPS beacon added on board.	open
9	1.0	Payload data gathering	Failure of the payload's camera and light to properly image the plant.	C	2		Usage of flight-proven camera.	open
10	1.0	Cost	Failure to respect agreed on costs.	C	2	Re-use flight proven subsystems to reduce costs overhead	Thorough documentation of parts buy and personnel time schedule.	open
11	1.0	CubeSat standard compliance	Failure to comply to the CubeSat standard for size and weight.	A	5		Re-use designs from previous TUPEX missions	open

[a] See the risk index table on next page.

Figure 1: Mission risk index (Likelihood vs. Severity)

Likelihood				**Risk Index: Combination of Severity and Likelihood**	
E	Low	Medium	High	Very High	Very High
D	Low	7 Low	Medium	High	Very High
C	1,4 Very Low	5,6,9 Low	2 Low	Medium	High
B	Very Low	Very Low	Low	Low	Medium
A	Very Low	8 Very Low	Very Low	3 Very Low	Low
	1	**2**	**3**	**4**	**5**

Severity

(red)	"Red"	(yellow)	"Yellow"	(green)	"Green"

Table 5: Preliminary mission schedule

	Year	2019						2020												2021		
	Month	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
	Milestone							PDR					CDR						IPR		EAR	Launch
								Δ					Δ						Δ		Δ	
1	**Management & Documentation**																					
2	**Mission, Science & Operations**																					
3	**Satellite Bus**																					
	Structure																					
	Thermal control																					
	EPS																					
	Communications & Data handling																					
4	**QR & Tests**																					
	Unit tests																					
	Integration tests																					
5	**Payload**																					
	Hardware																					
	Contents																					