Proposal for a CubeSat probe constellation to map Titan's atmosphere

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In this paper, we propose the design of a mission to investigate Titan. The core part of the mission are the CAPOs (Cubesat Atmospheric PrObe) which are 2U CubeSats that will be used as probes to collect data while they are descending Titan's atmosphere. In the paper, we present the design of the CAPOs and the design and build of a CAPO prototype, using easily available components. The scope of the CAPOs is to measure relevant scientific data of Titan's atmosphere, for this purpose they will have a set of sensors to measure parameters such as: Temperature; Atmospheric pressure; Methane; Carbon dioxide; High energy particles; Ultraviolet light; Magnetic field. All of these need their location to be determined. In order to do that, we propose the use of NAVSATs (NAVigation SATellites). We will discuss their design and requirements. We also propose the user requirements and the overall design of some subsystems of the MOTHER (Master Orbiter for Titan atmospHEric Research), which is the satellite that will be orbiting Titan and will dispense both the CAPOs and the NAVSATs. Once the NAVSATs are deployed, they will get in the desired orbit to be able to transmit navigational system to the CAPOs. Once the CAPOs are deployed (one by one) they will start the descent trough Titan's atmosphere while measuring all the parameters.

I. Introduction

The Cassini-Huygens mission was one of the most important solar system space explorations missions of all time, we learned so many things about Saturn and Titan, specially from the second one, that we could have never imagined. We passed from seeing an orange sphere, here on Earth, to discovering one of the most Earth-like space objects in our solar system. Cassini was able to take radar images of Titan, and it mapped the first global topographic map, [1]. Huygens collected data from the atmosphere and took pictures of the terrain, [2]. But there are still some uncertainties of how this Earth-like moon is, and its atmospherical characteristics and processes/cycles.

In order to study these unknowns, an attractive way to do it would be by using a constellation of CubeSat probes to map Titan's atmosphere, with a set of important sensors.

II. Scientific relevance

Titan is the only known "world" other than Earth that contains liquid (methane) on its surface. It also has an atmosphere 50% denser than Earth's, made up mainly of molecular nitrogen (N_2) which makes up approximately 95% of the atmosphere and methane (CH_4), which makes up approximately 5%. The UV light and the energetic particles break up the CH_4 molecules and by combining with N_2 they create other organic materials ([3]). This makes the moon of Saturn an ideal place for the search for life and the understanding of the beginning of life on Earth. The fact that the Cassini-Huygens mission discovered that there is a layer of liquid water under the surface further favours this project/mission.

The search and investigation of Titan is a crucial step both for understanding the beginnings of life and for possible future human missions of research or colonisation ([4], [5]).

III. Mission concept and overall design

The whole mission will be composed of the MOTHER (Master Orbiter for Titan atmospHEric Research), which will carry, as a payload, other satellites that will be deployed with the purpose of a positioning system, named NAVSATs, and all the CubeSat probes, named CAPOs (Cubesat Atmospheric PrObe).

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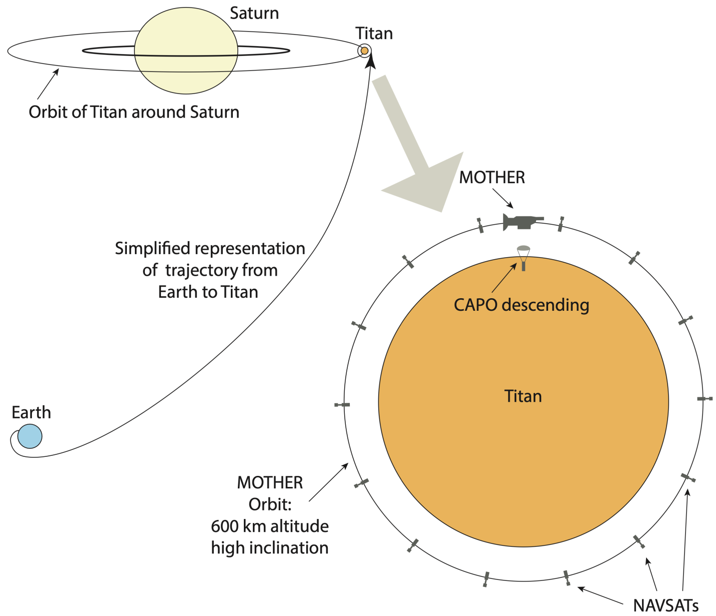


Fig. 2 System diagram. Shows the Mission concept and its main components.

The CAPOs will carry the sensors that will be measuring the atmospheric characteristics of the Titan atmosphere. They will be descending from the MOTHER satellite to the Titan surface while taking measurements. The position knowledge of these CAPOs will be achieved by means of a positioning system built by a series of NAVSATs that will also be deployed from the MOTHER satellite, and will continue orbiting Titan in the same way as the MOTHER satellite will.

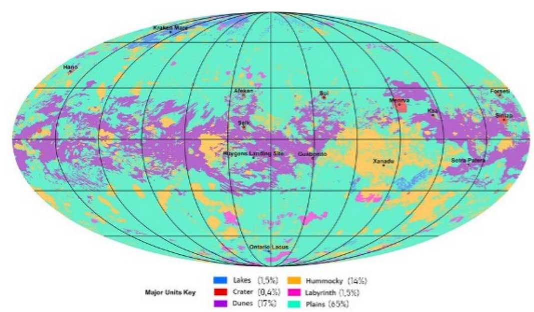


Fig. 1 Global map of Titan's major geomorphological units (after [6].

Titan has no magnetic field, so it has no natural shield against energetic charged particles ([7]). The interactions of atmospheric methane and nitrogen with solar UV, the solar magnetic field and galactic cosmic rays have been explored by several science groups ([8]). So, measuring energetic particles and their energy during the probe descent would be useful ([9]).

A. Trajectory, launch, and rocket requirements

Out of the several possible trajectories to reach the Saturn satellite, Titan, we define the one that minimises the travel time and the required Δv (which is the change in velocity needed to achieve the mission, an important characteristic of propulsion systems, including launch rockets). The trajectories are extracted from [10]. The chosen one will take off in Jan-19-2030, which will need a Δv of 6.86 km/s, and will reach Titan on Feb-10-2038. If there were any launch delay, the mission could change its launch date since there are other launch windows, as shown in figure 3).

As explained in section III.E we will use an approximation of the Cassini-Huygens mass to present the possible launchers. Cassini/Huygens was launched on a Titan IVB rocket in 1997. It was the only civil launch of a Titan IVB, and they went out of production in 2005. Other heavy launch vehicles have also been retired, but luckily new ones are being introduced. Of those available now or in the near future, there are Ariane-6 A64 (Europe), Falcon Heavy (USA) and Space Launch System, SLS (USA). There are also some in Russia, China, etc. There are new heavy launchers in the pipeline, that will be ready in the future, like Starship from SpaceX.

None of the User Manuals for the 3 launchers mentioned above give the performance for an injection orbit to Saturn, but they do for injection to the Moon or Mars. The delta-v for Lunar transfer is about 3.1 km/s, and for Mars transfer it is about 4.5 km/s. For a Transfer orbit to Saturn, the required Δv is about 6.5 km/s, so the performances can be roughly scaled by these numbers.

Ariane-6 A64: 8.6 tonnes for Lunar transfer, so roughly 4 tonnes to Saturn.

Falcon Heavy: 16.8 tonnes for Mars transfer, so roughly 11 tonnes to Saturn.

SLS: 27 tonnes for Lunar transfer, so roughly 12 tonnes to Saturn.

So, although Ariane-6 is unlikely to have enough performance, it is likely to be upgraded over the coming years. The two available USA launchers have more than enough performance.

Figure 4 shows the proposed trajectory to reach Titan. This is the same as the trajectory to reach Saturn, because Titan is in orbit around Saturn.

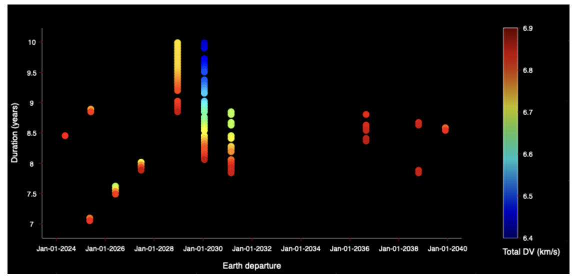


Fig. 3 Possible launch dates, from Earth to Saturn.

B. Satellite orbit

There is a presence of an atmospheric region around Titan, that can be divided into a denser region, Alt ≤ 600.0 km, and a less dense region, 600.0 km < Alt ≤ 1300.0 km ([11]. We will then set our satellite orbit at $h = 600$ km, right above the denser region of the atmosphere. Considering the Titan mass, $M = 1.35 * 10^{23}$ kg, the Titan radius, $R = 2.57 * 10^3$ km, and the gravitation constant $G = 6.6743 * 10^{-11}(m^3 kg^{-1})/s^{-2}$, we obtain the satellite velocity at this height, using

$$v_0 = \sqrt{(GM)/(R+h)} \quad (1)$$

of 1.68 km/s.

Given this altitude and this velocity, and given that the orbital period of the satellite is determined by

$$T = 2\pi r / v_0 \quad (2)$$

being $r = R + h$, we obtain a period $T = 197$ minutes.

The implication of the satellite velocity in orbit around Titan is that the probes will need an equivalent Δv in the opposite direction (same direction, opposite sense) of the same magnitude, in order to slow down the probe (tangent velocity = 0) at the time of ejection, so that the probes' descent towards the surface of Titan rather than continue orbiting around it. At the same time, the orbital period is important at the time of defining the data link system between the probes, CAPOs, and the main satellite, where the data is stored and sent to Earth. These two aspects are described later in this paper.

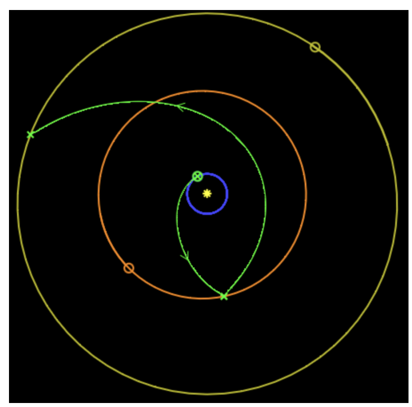


Fig. 4 Proposed trajectory, from Earth to Saturn. The blue circle (actually an ellipse but almost circular) is the Earth's orbit. The next "circle", in orange, is Jupiter's orbit. The outer yellow "circle" shows the orbit of Saturn. All showing the position of the respective planet at the moment of launch The green line shows the trajectory to Saturn, including a close flyby of Jupiter.

The MOTHER will need orbit maintenance, since at 600 km of altitude there is still atmosphere which will produce drag and, without orbit maintenance, the MOTHER would lose speed and eventually re-enter.

We propose to use a polar orbit. We propose two options for the CAPOs deployment configuration: (a) Deploy the CAPOs homogeneously, equally distributed by all Titan's atmosphere and surface; or (b) Deploy a larger number of CAPOs over some specific locations (lakes, seas or other sites of interest). For both of the proposals, the CAPOs could be deployed either over a long period of time (less frequently and therefore more distance between probes) or over a short period of time (more frequently and less distance between probes), depending on whether we prioritise to study the atmospheric evolution with time or with space.

C. NAVSATs configuration and orbits

The NAVSATs are the satellites (CubeSats) orbiting Titan that give the possibility of knowing the position of the CAPOs. Also, by analysing the signals received from the CAPOs, the NAVSATs might gather information about the density structure of the atmosphere. They add value to the mission because the scope is to create a profile of Titan's atmosphere. This could be possible using the CAPOs alone, but by knowing their position, using the NAVSATs, we can create the profile with higher accuracy, and we will be able to determine with more precision if there are, or not, atmospheric changes due to the terrain, the latitude or the longitude.

These NAVSATs are not the core component of the mission, though, they are an option that would improve the profile data of Titan's atmosphere. If it turns out, in more advanced phases of the project, that NAVSATs are not feasible, this would not affect the core part of the mission: the CAPOs could calculate their altitude by knowing the atmospheric pressure.

Alternatively, standard satellites systems for receiving and transmitting telemetry data (called transponder) include a so called ranging function, which can give range and range rate from the ground station. This function is not normally available in low-cost transponders. By implementing this functionality, it could be possible to get relative range and range rate while in contact with the MOTHER.

Here we propose the NAVSAT concept (see figure 6) and the requirements.

The NAVSATs need to be in the same orbit as the MOTHER, but with separations so that they are evenly distributed around the orbit. In order to do that, we'll use a Hohmann transfer ([12]) back to the initial orbit.

The NAVSATs will produce a retrograde impulse using a propulsion system, which will change the orbit into an elliptical one. The orbit period will get smaller and after the desired number of orbits the NAVSATs will use a prograde impulse with the same magnitude (assuming no drag, otherwise, the impulse will need to be slightly larger to compensate this drag) and will get back into the same orbit with an along orbit separation from the MOTHER depending on the number of revolutions in the elliptical orbit (see figure 5).

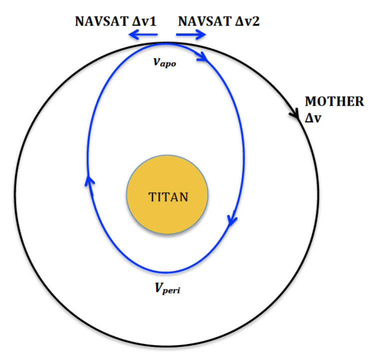


Fig. 5 NAVSATs Hohmann transfer orbit diagram

D. Challenges of the NAVSATs design

It is very important to know precisely where the NAVSATs are. With GPS, Galileo, or other terrestrial positioning systems, the position of the satellites is based on "fiducial reference stations", which do not exist in Titan. The NAVSATs position could refer to the MOTHER, whose orbit could potentially be determined by measuring the Doppler-shift of its telemetry on Earth, using star trackers and timings of stars being occulted by Titan and other objects in the Saturn system etc. The problem is that most of the NAVSATs are hidden from the MOTHER, this could be solved by communicating within the NAVSATs in a "chain" mode so that any NAVSAT could communicate with the mother indirectly. The NAVSATs would communicate with each other, transferring the messages to the ones that are closer to the MOTHER. This would cause that the closest NAVSATs would have to deal with a lot of data. A potential solution to know the NAVSATs position would be by dropping a series of beacons onto the surface of Titan. This would be rather like the DORIS system, but with the drawback that their initial positions would be unknown. They could eventually be worked out if MOTHER is also equipped with a "DORIS" receiver, and assuming its orbit could be worked out as mentioned above. MOTHER could then downlink the determined station positions to the stations, who could then encode them in their own uplink, like DORIS does ([13]). The other problem is that it would need these beacons to have a power source enough to last the mission lifetime. But this would add a complexity to the mission which might not be needed. Whilst theoretically possible, this is all quite a major undertaking (i.e. autonomously installing both a GPS-like and DORIS-like on a far-away world). Another option would be to inject one or more data-relay satellites into a higher orbit. Again it's potentially feasible but adding even more layers of complexity for the sole purpose of enabling a GPS-like service to the landers. It would of course add to the complexity of the NAVSATs too, as they would need a 2-way comms with the data-relay and potentially a steerable antenna.

A further hard requirement for the "GPS" systems is that they need a perfectly synchronised time signals, thus all the NAVSATs would need atomic clocks. Quartz-based clocks would not have the required stability and could not be cross-checked. Of course this is feasible, but the compatibility of an atomic clock with a CubeSat is yet to be determined.

The thermal control of the NAVSATs should not be very complex: the incoming solar radiation (and albedo from Titan) is rather low. The internal power dissipation is also low (see III.D.1). With effective external isolation, it should be manageable.

The attitude control could be done using 3-axis control, but that needs sensors and actuators (and power and mass). At its simplest it could be done with a star tracker and a set of reaction wheels, but these need power. A potential alternative is gravity-gradient stabilisation, but this needs more study: deployment length, rigidity, control of oscillations, etc. [14]

1. NAVSAT power system

The NAVSAT's would need long-term power. This almost certainly means nuclear. Fortunately, ESA is developing its own small nuclear sources (RHUs and RTGs) which might be able to fit the job. Probably by 2030, the proposed time of launch, these will be available and will take about 1U or less of space. There are being other investigations and developments in micro RTGs ([15], [16], [17], [18]).

The same would be true for any power need of a DORIS-like beacon.

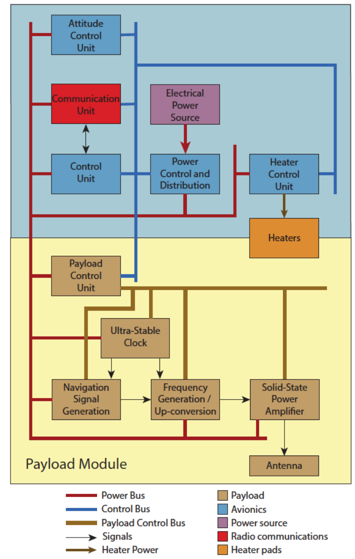


Fig. 6 NAVSAT block diagram.

E. MOTHER design

The design of the MOTHER spacecraft itself is not the subject of this paper. Instead, it addresses the mission to be performed by landers in the context of a more general mission to Titan, where we refer to the Titan-orbiting spacecraft as MOTHER. As it is not the subject of the paper, it is not described in detail; only the requirements relevant to the lander experiment are described. Therefore, MOTHER's mass is unknown. A reference mass can be the mass of the Cassini/Huygens spacecraft, which was about 5.7 tonnes at launch.

This mission benefits from using standardised CubeSats. We propose to use a CubeSat dispenser to eject both the CAPOs and the NAVSATs, like the EXOpod ([19]) or like the DSD ([20]), but for 200U for the CAPOs (100 CAPOs, 2-Units each) and 42U for the NAVSATs (14 NAVSATs, 3-Units each).

For the MOTHER power supply we assume the use of a Radioisotope Thermoelectric Generator, or RTG, because this power system can generate a continuous flux of electricity uninterruptedly. This feature makes it more reliable than other common power system such as photovoltaic panels, which can suffer damage from environmental conditions and also, for the Titan mission case, would not be very efficient since the amount of sunlight that arrives at Titan is very low ([21]).

There has been only one interplanetary mission that powered using solar panels: Juno, and it went to Jupiter, which is much closer to the Sun than Saturn.

IV. CAPO and prototype design

The CAPO is a 2U CubeSat composed by 1U of propulsion and 1U of payload. Its purpose is to collect relevant scientific data while it descends on Titan's atmosphere. There are different benefits of using the standard of a CubeSat, some of the most important are the dimensions, for the ejection system see III.E, and the availability of standardised components.

The CAPOs have to measure the local parameters of interest: none of them can only be measured on the MOTHER or the NAVSATs. The atmospheric pressure, the temperature, the CH_4, the UV light, the CO_2 and the VOC, and their variations with height, are parameters that can be measured only in the atmosphere. It is also interesting to measure the change in flux of UV and electromagnetic particles while descending through the atmosphere.

A. Propulsion systems for CubeSats

The design of propulsion systems for satellites, or spacecrafts, has been intensively researched all over the years ([22]). Several technologies have been used in space since the beginning of the space race. However, the propulsion system for very small satellites (nano or pico satellites) is yet to be improved. Several teams around the world are working on them. A review of the CubeSat propulsion systems is provided in ([17], being the proposed three main categories: Cold-gas, Hot-gas (similar to an ABM (Apogee Boost Motors) or a solid fuel booster) and Electric propulsion systems.

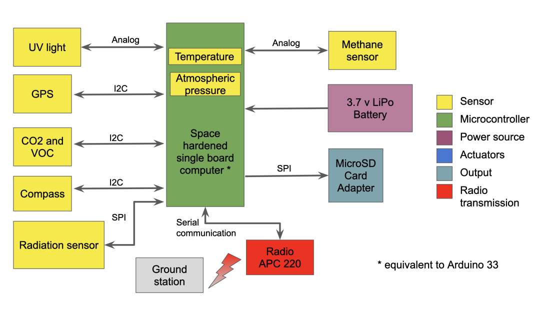


Fig. 7 CubeSat block and connexions diagram.

For our particular needs, which imply a high Δv to slow down the horizontal velocity of the CubeSat, but not a particular requirement on fine control, the optimum propulsion system is the Hot-Gas. The Hot-Gas is the most compact thruster, with low energetic needs to operate.

This propulsion system provided, in 2018 by ATK company, a thrust of about 170 N, can provide a Δv of 1.3 km/s, and has a specific impulse of 250 s. This technology is rapidly improving, and we are expecting an improvement of 40-50% in the next 8 years, allowing a Δv of 1.7 to 1.9 km/s in 2030.

With this high impulse, if the centre of mass of the CAPOs is not completely aligned with the ejecting nozzle, there will be some tumbling, with the result of the Δv would be in many directions, resulting in completely ineffective thrust. To solve this, the CAPOs need to spin around the thrust axis. This will be started just before deployment while they are still under the control of the MOTHER. It will be done using a reaction wheel inside and the MOTHER as a power source. Then they would be deployed, while they keep spinning, and they would ignite and produce the thrust. After the impulse is finished, they could stop spinning while using the energy from an electromagnetic braking of the reaction wheel to charge the battery.

This would cause a small angle momentum transfer to the MOTHER that could be easily absorbed by the MOTHER's own attitude control system (reaction wheels).

B. CAPO probes descending flights

The "descending flight" of the CAPO probes towards the Titan surface are very critical. This is the time when the measurements will be acquired, so the core part of the mission. The time of descending will be determined by the density of the atmosphere and the shape and mass of the CAPOs, which, in turn, determines the terminal velocity.

Using data from [23] we have calculated the approximate velocity at which the CAPOs would descend and the time that it would take for the CAPOs to reach Titan's surface. To do this, first we have calculated the terminal velocity (v_T) of the CAPOs for each interval (given by the data). Once we know the terminal velocity of each interval, we have calculated, using a step-wise process, the instantaneous velocities for each interval. With this, we have calculated the approximate v(t) and h(t) per interval, and finally, the total descend time, using equations (3), (4), and (5):

$$v(t) = v_T \tanh(\frac{g}{v_T} t) \tag{3}$$

$$h(t) = h_0 - v_0(t - t_0) - 1/2(g - \frac{C_D \rho A}{2m} v^2)(t - t_0)^2 \tag{4}$$

being the acceleration

$$a = g - \frac{C_D \rho A}{2m} v^2 \tag{5}$$

where g is Titan's gravity, v_T is the terminal velocity, h_0 is the initial height at 600 km, v_0 the initial descending velocity (zero in this case), C_D is the drag coefficient, ρ the air density, t_0 the initial time, a is the acceleration, and A the cross-section area.

This descending time is a function of the area exposed to the atmosphere or Cross-section Area, so we will design this area to fulfil our requirements.

If the descending velocity is too high, we would acquire fewer measurements (the sensors have a limited acquisition frequency). Also, the landing at a high velocity is not convenient as it could damage the CAPOs, making it more difficult for them to continue functioning after landing in order to send all the captured data to the MOTHER during its visibility (in the following orbit, for example).

The parameter to adjust to control the descend velocity is the cross-section area. We have included a deployable flap system. The flaps would be square plates, originally alongside four faces of the cube, which move through 90°

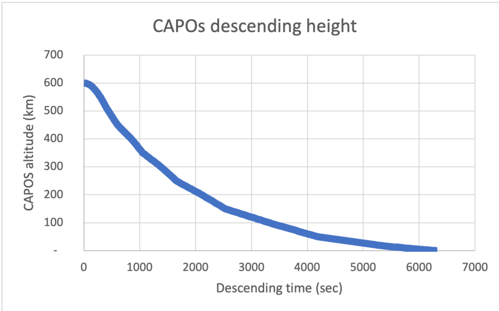


Fig. 9 Graph of the calculated altitude vs time.

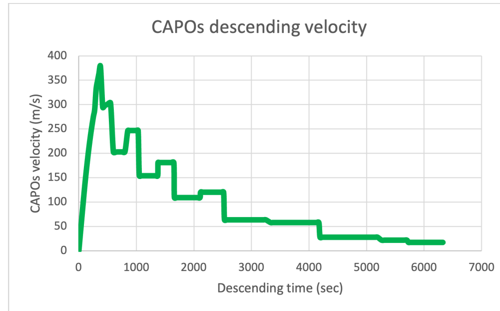


Fig. 10 Graph of the calculated descend velocity.

when deployed (see figure 8). We have therefore designed the area such that the total descending time is enough for the sensors to acquire the data and the landing velocity is small enough not to damage the CAPOs.

We propose to use four 10 cm^2 flaps that are deployed when the CAPOs start descending. They increase the cross-sectional area by 5 (up to 50 cm^2), and this reduces the descent velocity. With this system, the velocity at the landing is reduced down to less than 14 m/s, and the total descend time is about 105 minutes. Given an orbit time of about 197 minutes, this implies that the CAPOs will send the data from the initial measurements to the MOTHER during the same orbit in which the CAPO has been deployed, and the rest of the data, for most of the descending time, at the next MOTHER orbit. Given that the rotation period of Titan is much larger than the orbit period of the MOTHER, the CAPOs will still be well in visibility of the MOTHER during at the following orbit after having been deployed. This is important to optimise the CAPOs battery dimension.

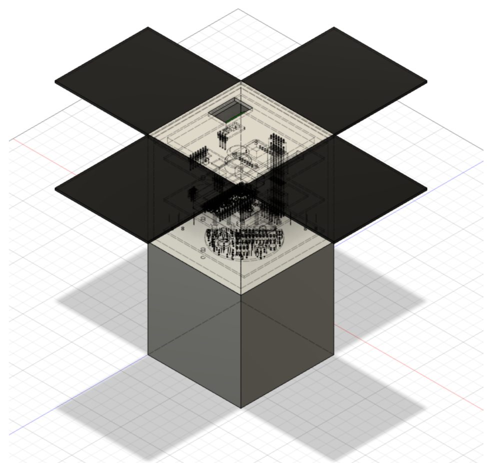


Fig. 8 Representation of the CAPO while descending. The white cube is the payload (what we have prototyped), the grey cube is the propulsion unit and the black plates are the deployable flaps.

C. Electronics design

The CAPO will use a set of sensors to collect the data. It will also have a power source, a central computer, a communication system and a navigation system. The CAPOs would need to use a space hardened single board computer, and to have all the electronic components space hardened and radiation tolerant avionics. The requirements for the CAPOs are in **??**. It is beyond the scope of this paper to design a CAPO using space hardened components. We have investigated feasibility by building a prototype using easily available parts. This section mostly discuses the prototype.

For the prototype, since it's tested on Earth, the CAPO prototype is based on an Arduino. We also use it for the prototype because of its benefits compared to other microcontroller boards. It is affordable, very user-friendly, and also very small and lightweight. For the CAPO design and prototype, we use an Arduino nano sense BLE 33, which also has temperature and atmospheric pressure sensors.

The most efficient way to organise the CAPO sensors and modules is by using a set of PCBs, each one with different modules in it. We have distributed all the modules in 3 PCB, shown in the table 1.

The CAPO prototype also has a Geiger counter (radiation sensor), we have based our design in a commercial one, that has been optimised to fulfil our needs. [24] The Geiger tube detects energetic particles and gamma rays. It does not distinguish between them, and it does not measure their energy, which is needed for the CAPO probes ([25]). For the prototype, the Geiger tube is sufficient to represent a more sophisticated sensor.

D. Energy supply

For the CAPO prototype, we use a 1S (3.7 V) 1100 mAh LiPo battery. We use it because it can give sufficient power for all prototype sensors while being commercially available, it has a low price, it's small and lightweight. For the

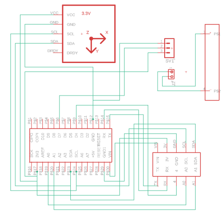
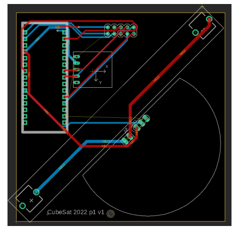
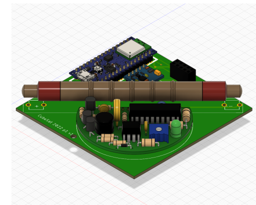
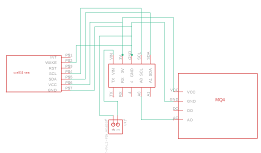
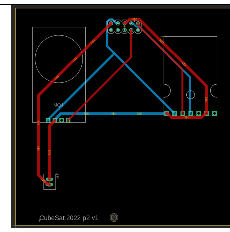
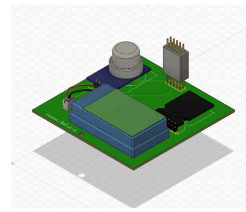
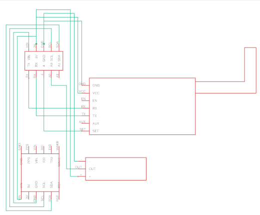
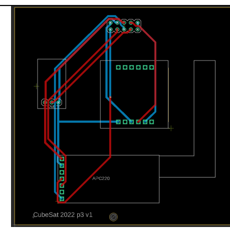
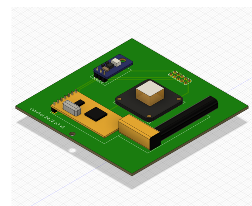
PCB list			
Description	**Schematic**	**Board**	**3D model**
1st PCB, includes the Arduino, the Geiger counter, the compass and the SD card adapter (not in the Board)			
2nd PCB, includes the MQ4 sensor, CO_2 and TVOC sensor and 1S 1100 mAh LiPo battery.			
3rd PCB, includes radio module, GPS and UV light sensor			

Table 1 List of PCBs developed for the CAPO prototype.

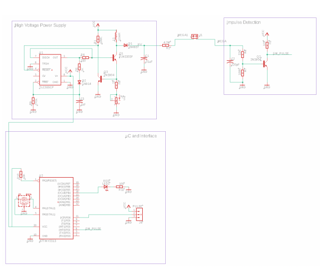
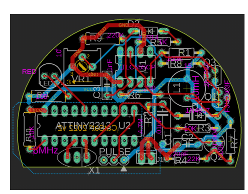
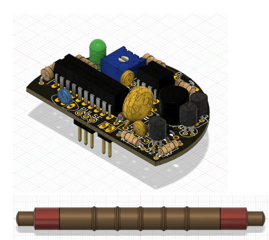
Sensor PCB			
Description	**Schematic**	**Board**	**3D model**
The Geiger counter is able to detect gamma and beta radiation. For the "real mission" CAPOs we propose to use an energetic particle detector since these are the ones that makes the CH_4 and N_2 mix and create other organic compounds (see II). The sensor consists of a microprocessor and interface system, a high voltage power supply system to the tube, a GM Tube, and an impulse detection system.			

Table 2 Geiger counter sensor PCB used in the CAPO prototype.

real CAPO, we propose to use a similar solution based on batteries, because it is the best option compared to other common power sources. Solar panels are not a viable option, since only about 1% of the sunlight that gets on Earth arrives at Titan's surface [21] [26]. Wind turbines would be another option, but they use much more space and have to be deployed and work on a very cold environment, which would makes them have dubious reliability. They also do not provide much power. We propose to charge the batteries of the final CAPOs before deployment using the power from the MOTHER's RTG.

The CAPOs which go to Titan could also use other type of batteries if more power is needed, for example they could use Li-Ion batteries.

V. CubeSat prototype implementation

We have designed the schematics and ordered them to build the 3 PCBs of the CAPO prototype, and the PCB for the Geiger counter sensor, assembled the modules and components, and fit them into a 1U CubeSat 3D-printed cube.

A photograph of the real prototype is shown in figure 11.

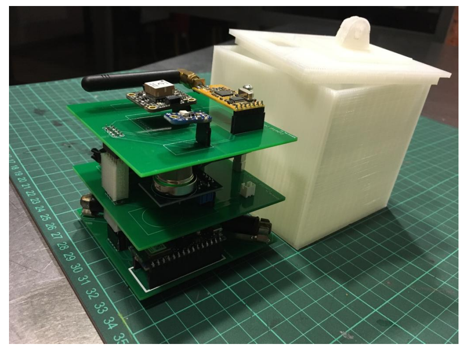


Fig. 11 Photograph of the real CAPO prototype. The 3D-printed Cube includes a piece to attach the prototype to a drone.

VI. Ground Station

We developed a ground station (using Xojo SW) for the CAPO prototype set of sensors, in order to visualise the data and control the prototype in real time. For the real mission, the data would be extensively analysed (see VII, but a real-time visualiser would be necessary for the control station, in order to visually monitor that all subsystems are correctly functioning.

The ground station has three functionalities:

- It receives the data from the prototype, and it stores the data.
- It visualises all the data (using graphs).
- It is capable of sending telecommands to the prototype.

An image of the built ground station display is shown in figure 12.

VII. Testing and Validation

The CAPO prototype was tested in order to ensure the proper functionality of its payload (all sensors), the central unit, the data transmission, and the ground station.

We followed a series of tests in order to demonstrate that the prototype that we built functions as it should. During the building process, we tested each system and sub-system isolated. Once the CAPO prototype was built, we tested all the subsystems together, including the ground station. We created a "simulated" scenario of what the descent would be. We carried it out by attaching the CAPO prototype on top of a drone. We took the prototype up to roughly 500 m of altitude (lifted by the drone) and we performed a free fall like test while collecting measurements. The data was received and visualised in the ground station of section VI in real time. We also checked and proved that the telecommand was properly working.

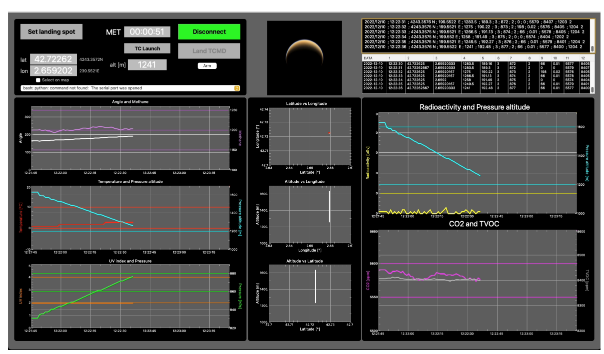


Fig. 12 Print out of the ground station displaying the acquired data (see real time acquisition video here).

All the sensors functioned well, and we were able to measure all the parameters while the CAPO prototype was descending. The results were displayed in the ground station and can be seen in figure 12.

VIII. Conclusion

A mission to explore Titan's atmosphere has been designed. The mission consists of a MOTHER satellite that will orbit around Titan, which will embark as a payload a number of CAPO CubeSats with atmospheric sensors, that will descend through Titan's atmosphere towards Titan's surface. The mission also includes a constellation of NAVSATs for the positioning of the measurements taken during the descent. The mission is planned to be launched in 2030 and will reach Titan in 2038. It will provide extremely interesting scientific measurements that will complete the understanding of one of the most Earth-like space objects in our solar system, initially provided by the Cassini-Huygens mission during the period from 2004 to 2017. The overall mission is described, together with each of the space objects involved. Moreover, a prototype of the probes, CAPOs, that shall be acquiring the atmospheric measurements and landing in Titan's surface, is built and tested, and the results of the prototype test are also shown. The scientific benefits of the proposed mission are presented. Some critical points and challenges are discussed, and in some cases solutions are proposed.

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