DOI: 10.13009/EUCASS2023-368
Aerospace Europe Conference 2023 – 10TH EUCASS – 9TH CEAS

BFS an atmospheric reentry kit to bring NANOSAT Payloads « Back From Space »,

*Stephane HEINRICH**, Isaac MULLENDA**, Xavier MARTIN**, Karine HEINRICH**, Arthur HUMBERT*,*
***e.NOVA Aerospace, 11 avenue Maurice Chevalier, Pépinières d'Entreprise, F-06150 Cannes la Bocca*
**e.NOVA Aerospace, 1 avenue d'Aix, F-31100 Toulouse*
stephane.heinrich@enova-aerospace.com & comm@enova-aerospace.com

Abstract

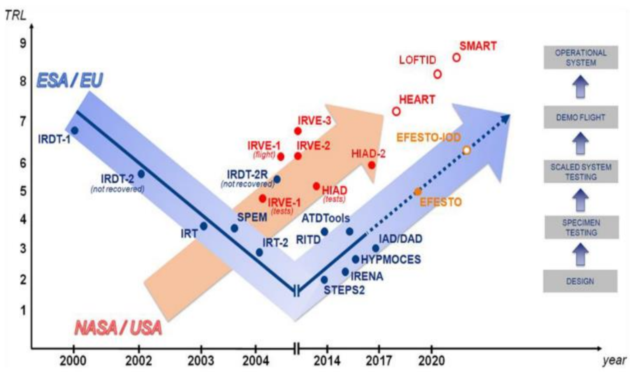
The atmospheric reentry technologies have not evolved significantly since the early days of space exploration. Mostly they were designed for manned spaceflight applications allowing humans to return safely to Earth in a capsule or shuttle-like vehicle. Those applications have all the drawbacks that return vehicles whose shapes were constrained by launch phase restrictions (cross-section of the capsule or of the heat shield under fairing, aerodynamic shape of the shuttle). The next generation of reentry systems intends to disrupt this constraint with the deployment of a larger heatshield via an inflatable or deployable heatshield composed of flexible or textile thermal protection systems. If those concepts are not completely new and have already been intended in the past more than 2 decades ago, their implementation on operational applications seems to be finally underway. (H2020 EFESTO, NASA ADEPT, …). The trends for NEWSPACE and for GREENSPACE for a more industrial and sustainable use of space have reactivated the interest in reusable systems and recovery of elements from space in a more innovative manner (in-orbit manufacturing and production, short-time recovery of experiments out of ISS resupply cargo 6-month routine.). Due to its past experience in reentry topics coming from past activities in Design for Demise in a research entity of the ALTRAN Company, the e.NOVA start-up was created by his founder to promote this legacy and top-listed this project BFS "Back from Space" as a main initial objective and initiated a consortium with industrial textile and composite developers, shape memory alloy provider, thermo-mechanical and computational fluid dynamics analysts.

This paper intends to present the state of the art on this thematic and the initial progress status of this internal project funded by French "Plan de Relance" promoting F-TPS (flexible thermal protection system) as an "Innovative Technology for NANOSAT industry".

1. State of the Art

With the explosion of the use of CubeSats, satellites have become smaller, lighter, and cheaper. This means that the instruments and experiments onboard are able to follow the same trend. Making an instrument space-ready while miniaturizing it and making it cheaper is now accessible, allowing the option to bring samples back to Earth for Newspace's actors. Consequently, the BFS was defined as an atmospheric reentry kit developed for CubeSats and Nanosats to allow them to reenter the atmosphere safely in order to deliver their payload to the ground.

Nowadays, some projects have proposed and developed similar approaches to what the BFS project is searching.



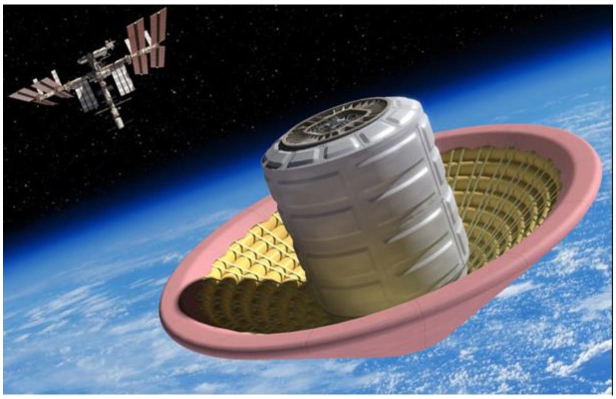


Figure 1. LOFTID Inflatable Heat Shield / Figure 2. NASA HEART concept

Historically, the IRDT based on a Russian inflatable design has been experimented in Europe with few success early 2000's . Later on, NASA initiated a lot of researches on a similar inflatable design with led to suborbital demonstration (IRVE-2,3). The upgraded design HEART[2][3] was assumed to be able to reenter an entire ISS Module

DOI: 10.13009/EUCASS2023-368

Recently the NASA LOFTID was developed and made an orbital demonstration late2022 successfully. The same device was foreseen as a reentry decelerator for the ULA next Vulcan rocket for the recovery of their propulsion module. China meanwhile made an orbital attempt during the maiden flight of the Long March-5B rocket in 2020.

Fi

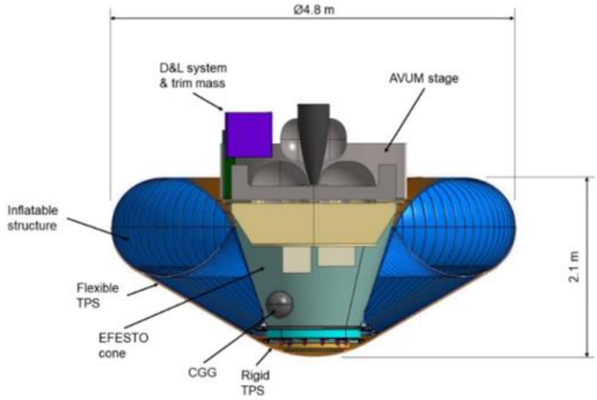


Figure 3. LOFTID Inflatable Heat Shield / Figure 4. EFESTO system configuration for Earth application

In Europe, the projects were re-initiated at ESA with LIED project for an large inflatable device for future Martian landers aimed to land heavy mass or higher Martian altitude. Later on, the EU-EFESTO was initiated and achieved in 2022 up to TRL6

The NASA ADEPT[1] program has developed and tested in suborbital a mechanically deployable re-entry vehicle system for nanosats and spacecrafts [1].This project uses a very performant F-TPS allowing to address high-energetic reentries. In Europe, several projects were found in the bibliography, but the most advanced project the Italian agency ASI project mini-IRENE which developed and tested a deployable decelerator. It is assumed that related project is going on in a stealth mode with the Leonardo Group in order to propose deployable reentry solutions up to Microsatellite size.

2. Market Study

Actual means to create a microgravity environment are pretty limited. On earth facilities can only produce few seconds (drop tube) to discontinuous minutes (parabolic flight). Even a suborbital flight can only produce few minutes of microgravity at once. Then next option is an orbital mission, with the associated difficulty of retrieving the payload.

Easiest option is to rideshare with multiple experiments on an ISS cargo, but the return volume and mass is very limited, hence expensive. Moreover, the mission schedule is driven by the ISS needs, so you’ll need to comply with external requirements. A typical mission is minimum 6 months between first space exposure and sample return, without taking into account any waiting queue.

The idea behind BFS project is to have an autonomous reentry system for small payload in order to allow the best possible retrieving delays. Mission duration should be driven by its payload as it could lower the return-on-investment time and allow new possibilities.

To define the types of missions the BFS should be able to achieve, we need to first define what sorts of payloads could be brought back. The types of payloads can be categorized either as scientific or commercial.

For the scientific payloads, the goal of bringing them back is to offer the possibility to study the payloads on the ground, in laboratories on Earth. In some cases, a return to Earth might not be necessary as telemetry can offer enough useful data. In addition, some experimentations (such as on human physiology) are unsuited for the CubeSat format due to the volume constraints. While limiting ourselves to addressing payloads smaller than 27U for the BFS, we can still work with experiments requiring different conditions. The BFS can be mounted as rideshare on launchers, allowing it to bring the experiment where it should be (e.g. the Van Allen radiation belts), keep it there for the specified duration, and bring it back safely for analysis on the ground without human intervention. For more complex experiments that require a human, the BFS offers the possibility to transport payloads from the ISS to the ground on demand, as opposed to the current cargo spacecraft that fly only every six months.

The commercial payloads, as opposed to the scientific ones, represent the products of in-orbit manufacturing. While this market is still in development, it will likely play a major role in the industry of the future for specific, high quality, and high added-value products. Some of these products can be 3D printed organs for medical purposes or high-quality optical fibers.

DOI: 10.13009/EUCASS2023-368

To be viable and offer a long-term service, the economic aspect and business model of the BFS need to be studied. As discussed earlier, the field of applications is large but the question of going into orbit has to be considered before we can look at coming back. For this aspect of the payloads life, e.NOVA discussed a collaboration with Nanoracks to offer "early returns" services to their clients. This offer would interest at least 1/3 of Nanoracks' clients, as it gives them the ability to refurbish their experiments quicker, pay for less time on the ISS, and in consequence fly more often. Such types of missions would launch from the ISS's Bishop module at an estimated initial frequency of 4 flights per year. In order to be interesting for a client to use our early return solution, we have to ensure that it is cheaper for them than waiting on the ISS and paying for a spot in a regular cargo spacecraft. As such, we are focusing on making the BFS compact to save on volume and choosing the right technologies to decrease the cost. The choices and the detailed explanation for them will be explored in the following chapter.

Pharmaceutical industry is worth billions of dollars of research every year, with large portion dedicated to testing. Being able to develop new drugs in space will improve success rates and delays at a fraction of the cos due to accelerated and multidirectional growth and offered by microgravity. SpacePharma, a company founded in 2012 is a pioneer in in-orbit manufacturing and aiming for an orbital deposit in LEO with a need of one payload return every month. Space Pharma already flew several experiments in the ISS and in an autonomous way on Cubesats. Space Pharma and several equivalent companies intends to develop technologies in orbit taking benefits of acceleration process offered by microgravity for vaccines, molecules and organs and tissues 3Dprinted in orbit. The achievement of low cost access to space may revolutionize this industry and the need of capability to ferry stuff up and down.

3. Development Implementation

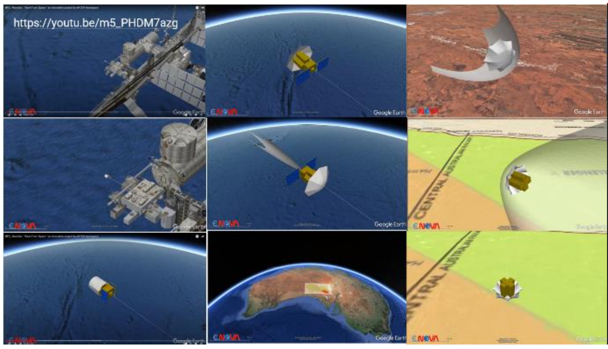
Back in 2019, e.NOVA was created with the reuse of ALTRAN Research space debris legacy and success stories on reentry safety and design for demise techniques. This leads to identify main e.NOVA internal projects: A S/W development to reuse tools for mission and reentry analysis to help emerging NEWSPACE with tools and related resources. A H/W development combining innovative reentry techniques for NEWSPACE applications in the Cubesat and Nanosat size and market , the so-called BFS " Back From Space " Project" as an atmospheric deployable reentry kit to recover payloads form orbit. Development went through multiple phases. The first one was mostly focused on flexible thermal protection system. The next year, a consortium was built around the e.NOVA company with NITREXO_Ireland, prime contractor as a numerical calculation and design office and plasma wind tunnel testing at CIRA_Italy and French textile material and process laboratory IFTH_France [5]. This consortium was created in order to bid on ESA ITT 10307 related to development and qualification of textile aerothermal shell in the ESA LIED project: a large inflatable Martian decelerator. The same year, despite the non-success at this bid the consortium was reactivated several times to investigate initiatives on similar funded activities. The same year was also initiated the cooperation with ISAE-SupAero Master students and the study was initiated on all aspects related to the systems in the scope of cubesat application of 3U size. In 2021 the project evolved enough to be presented at CNES's R&T and Call for Proposals on French funding "Plan de Relance" initiated after Covid-19 pandemic and related to in-orbit demo and validation initiatives. Due to number of experiments proposed in the space French industry, building a fully French consortium for this unique and specific application was very hard.
The next year the company answered a call for proposal related to the same "Plan de Relance" funding but focused on innovative technologies for Nanosat. The technology promoted was the flexible textile aerothermal protection need to achieve an inflatable or deployable aero shield. At a second bid, with enlarged consortium teaming IFTH_FR (textile material and process laboraty) , RTech (Hypersonic Computed Fluid Dynamics expert) CNRS-Icare (Plasma wind tunnel test facility) the consortium was awarded by a contract allowing to kick-oof the project late 2022.
This comforted e.NOVA in the submission of this project to the 2022-23 BPI Call for Proposals for In-Orbit Servicing, which could lead to initiate a design phase during one year up to an In Orbit Demonstration-In Orbit Validation of the concept in the next 2-3 years.
The outcomes of this submission is expected in 2023Q2.

4. Mission Challenges

The main objectives of the mission is to achieve a controlled reentry of the vehicle and target a landing zone. The scenario baselined was to recover the payload such as experienced for extraterrestrial samples recovery on remote areas such as Woomera or Utah test range with a non controlled vehicle. The first challenge faced within the project was the study of the re-entry trajectory and the assessment of the reachable landing accuracy. The influence of the different parameters on the final velocity will also be studied, as it will be a key driver of the touchdown system design. The scenario is based on an unguided descent from the surroundings of the International Space Station (ISS) or NEWSPACE usual orbits (<550km) down to the ground. A Keplerian trajectory serves as a first approach. Nevertheless, it is essential to take into account the effect of the atmosphere. To this end, the internal eNOVA software

DOI: 10.13009/EUCASS2023-368

has been used to simulate the atmospheric reentry. This S/W was mostly calibrated with respect to DEBRISK reentry S/W from CNES (Centre National d'Etudes Spatiales) [6]. Google Earth Pro [7] and MATLAB-like VBA Excel worksheets are used internally to pre-post process the results. Later on , the calculations will be performed on ASTOS S/W as it was successfully experienced in several trial periods.



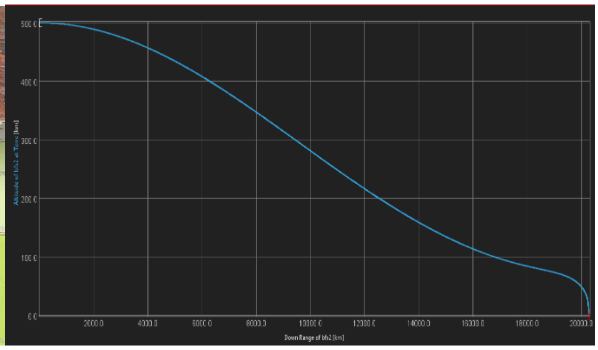
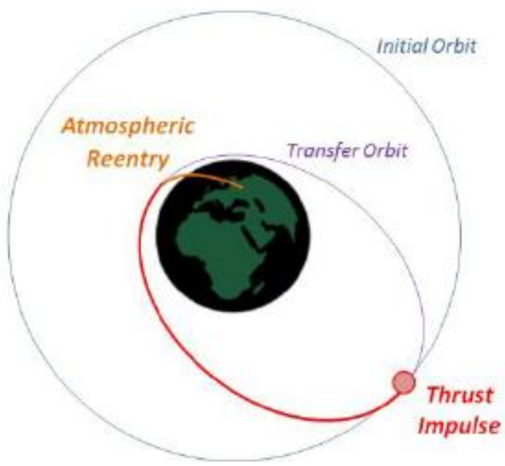


Figure 5. BFS Mission with In Orbit Servicing Tug / Figure 6. ASTOS S/W Downrange prediction

The reference is now a spacecraft with 25 kg of mass. Several parameters will take part of the final landing accuracy budget. Namely, it can be advance that the ballistic coefficient of the device will be a key driver. In addition, the heating rate must be handled in such a way that the maximum temperatures of the different materials composing the descent device are not reached. Another important factor is the initial velocity; the objective is to avoid the need of a high energy deorbit burn. A tradeoff was made between a steep reentry that provides accurate landing but generates an unmanageable heat flux for flexible thermal protection, and a much softer reentry that goes easier on thermal protection but can be much harder to predict reentry length due to atmospheric uncertainties. We now aim for a 75km periapsis which guarantees a direct reentry with reasonable margin of error on a 100 square km landing zone. The trajectory to reach a good nominal landing path was determined by iterating with the argument of the perigee and launch window in DEBRISK. As a result, the following orbit parameters were established for a hollow sphere of 25 kg and 50 cm of diameter. The material is considered ideal and without ablation.

An investigation has been performed on landing budget accuracy with all toleranced parameters acting in the downrange accuracy . This led to require a delta V accuracy much less than 0.1m/s with regard to the overall delta <150m/s is a challenge. This is only possible with a very accurate deorbit burn .This will probably require to think about a compensating device such as on-board monitoring and retro-acting in real time to ensure the requested accuracy.



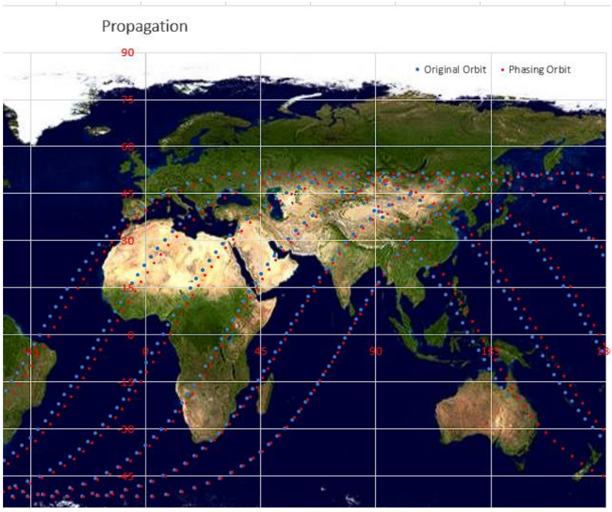


Figure 6. Reentry Manoeuvre / Figure 7. Orbit phasing tracks vs initial ground track

Then we also face another challenge, the burn must be done in a reasonable time as orbits below 200 km are very instable, we must be able to deorbit in one orbit a soon as we go beneath that limit. Using a 1N propulsion module on a 25kg spacecraft means the manoeuvre to bring periapsis to 75km from 200km takes 15 minutes, which correspond roughly to 1/6 of its orbit, which mean absolutely no margin of error, with continuous thrust. Having 2N propulsion

DOI: 10.13009/EUCASS2023-368

divides by more than two the burn duration, as efficiency is higher with shorter burns, and add redundancy. As a phasing sequence will probably be necessary in order to have a quick reentry, Periapsis won't necessary be at 200 km prior to reentry burn, so it's important to be able to re-enter from ISS orbit in one go. With a 4N propulsion system, last burn would last between 3mn45s and 10mn which is acceptable. We had an RFI/RFQ with space propulsion providers Dawn Aerospace, and their 4U CubeDrive module could fit our need in terms of thrust and fuel capacity with still a remaining issue, their engine can't fire more than 10 seconds at once due to overheating. Issue they are currently trying to solve.
Upscaling our model to a 25kg payload, hence a 50kg spacecraft would be limited by fuel capacity and single burn capability. We could still upscale propulsion though, using a 20N single thruster to perform reentry burn that would last from 1m30s to 4mn, but with even more overheating issues, and lower cold gas precision.

Given the orbit and landing site, waiting for trajectory to naturally intercept it can take weeks. To reduce waiting time, it is possible to go on a transfer orbit designed to intercept the landing area in few hours, up to one day. A minimum of two impulses are necessary for such operation, the first maneuver will aim to lower the perigee, thus changing the orbital period, and therefore the speed at which the earth "scrolls under" the trajectory. After multiple orbits, the difference adds up and allows to make up several hundred km of distance. In order to maximize fuel savings, we chose to only "go down", thus phasing eastward. Rising Apoapsis would increase orbital cycle, allowing the ground track to go west compared to original orbit, but this will be "lost fuel" for reentry, as well as increasing reentry speed, hence heat. By lowering periapsis down to 200km, we can catch up with the next orbit's ground track in about one day. In the worst case scenario, any target within inclination range could be reached in less than two days (One day of phasing, and one day to have the closest orbit).

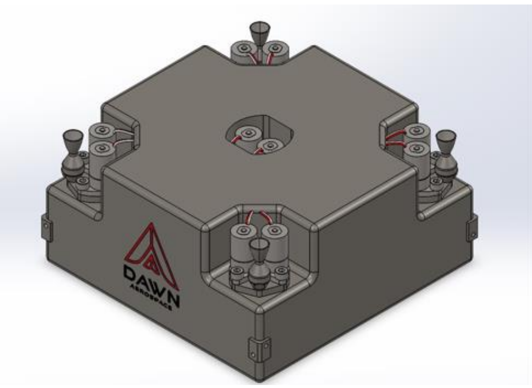


Figure 8. DAWN CubeSatPropulsion Module / Figure 9. DAWN CubeDrive Propulsion Module /

With few calculations, it's possible to determine where the last burn should occur for an ideal reentry and match the phasing burn at the same orbital point. That way the phasing orbit is "half way" through reentry orbit, both the phasing and reentry burn are made at the same position and in the same direction and we don't waste any delta-V for this maneuver.

As long as the landing area's latitude is below orbit's inclination, there is no inclination change necessary, and reentry can be made on an ascending or descending orbit, probably driven by safe areas around landing site. If the reentry corridor can't match with the trajectory, or if the landing site latitude is outside orbit's range, a first maneuver is necessary to adjust inclination, which can be very Delta-V costly.

Last phase of reentry is determined by simulations using softwares like Debrisk, Astos or Drama for the reentry arc. The first position of our simulation corresponds to the last thrust impulse, at the apoapsis. By using reentry time, downrange and knowing the reentry orbital period, we are able to simulate keplerian parameters of this last orbit, thus which orbit to aim to reach our target. We still don't take into account any drift due to J2 during the phasing period. We simplify our calculations by using initial orbit drift, this could be corrected with few iterations.

5. BFS Concept & Familly

"Back From Space" BFS is a name we use for multiple concepts and products, centered around the same goal, bring payload back from space. The first objective is to validate the concept of technology, and mainly the flexible thermal protection system. For this purpose, an IOD-IOV using a 3U cubesat was designed around a student concept in 2020.

DOI: 10.13009/EUCASS2023-368

This first approach was to design an adaptable reentry kit for nanosats in order to extend mission capabilities of this kind of satellites.
This scale of satellites, hence economically attractive, causes a lot of drawbacks, the propulsion and AOCS needed for precision landing have a great impact on payload size, and some components must have been separated prior to reentry. Upscaling to a 16U satellite would leave more room for the reentry systems and payload. It would ensure better chances of retrieving the complete system which is much more interesting for every actor of the consortium. With a 16U system, the payload would be around 6U and allow additional containment options for delicate payload, like biopharmaceutical that needs a low temperature during its entire life cycle. That allows to attract a wider range of customer and have an overall much complete validation for the entire system.

BFS GEOMETRY			27U		16Ud		16Us		3U	
Half Angle Cone	°	a	60	60	60	60	60	60	60	60
Nb RIBs	(-)	Nb	8	8	8	8	8	8	8	8
Length RIBs	m	l	0.3	0.4	0.4	0.4	0.45	0.45	0.2	0.3
Dome Diameter	m	Ds	0.50	0.50	0.20	0.20	0.25	0.25	0.10	0.10
Radius Dome (Top)	mm	Rs	250	250	100	100	125	125	50	50
Curvature Dome	mm	rd	500	500	200	200	250	250	100	100
Height Dome	mm	h	66.987	66.987	26.795	26.795	33.494	33.494	13.397	13.397
Total Surface	m²	S_Dome	0.210	0.210	0.034	0.034	0.053	0.053	0.008	0.008
Cross-section	m²	Sc_Dome	0.196	0.196	0.031	0.031	0.049	0.049	0.008	0.008
Radius Cone (Base)	mm	Rb	510	596	446	446	515	515	223	310
Surface Cone Face	m^2	S_cone	0.658	0.658	0.658	0.658	0.658	0.658	0.658	0.658
Half Angle Face	°	b	19.35	19.35	19.35	19.35	19.35	19.35	19.35	19.35
BFS CAPABILITY										
Total Surface	m^2	St	0.869	0.869	0.692	0.692	0.711	0.711	0.667	0.667
Cross-section	m^2	Sc	0.735	1.006	0.564	0.564	0.749	0.749	0.141	0.271
BFS Diameter (base)	m	Db	1.02	1.19	0.89	0.89	1.03	1.03	0.45	0.62
Balistic Coefficient	kg/m²	Cb	25	25	25	25	25	25	25	25
DragCoefficient	(-)	Cd	1.28	1.28	1.28	1.5	1.28	1.5	1.28	1.28
Reentry Mass	kg	M	23.5	32.2	18.0	21.1	24.0	28.1	4.5	8.7

Figure 9. BFS family scenario

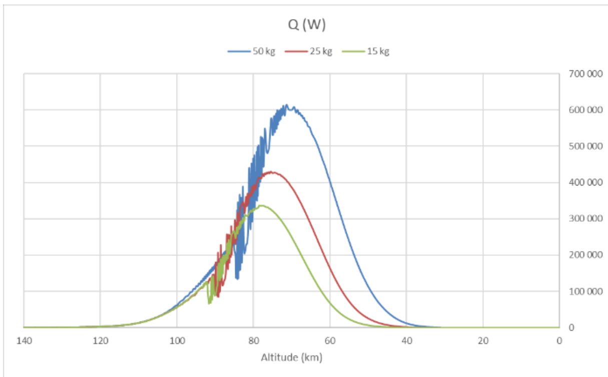
A further step into BFS project, is to increase payload return capability would be to have a 15-27U/50kg nanosat payload, and a separation post reentry boost.

6. BFS F-TPS and Aerothermodynamics

The Thermal protection system (TPS) is based on F-TPS Flexible thermal protection such as implemented on deployable and inflatable projects previously presented in the state of the art. Defining , selecting and dimensioning tis element is a key technological block for such a Project. Late 2022, eNOVA was awarded by CNES contract to a fund from French "Plan de Relance" on innovative technologies for NANOSAT. This event allowed to initiate the BFS Project with a consortium composed of : IFTH_FR[5] (textile material and process laboratory), RTech[8] (Hypersonic Computed Fluid Dynamics expert) CNRS-Icare (Plasma wind tunnel test facility)
The first step in such a study is to assess the aero thermodynamical effect of the reentry trajectory on the thermal protection of the vehicle. This was imitated by e.NOVA through a bibliographic review on state of the art and its experience in reentry calculation software. Consequently, a max flux specification of 400kW/m² aiming to be

DOI: 10.13009/EUCASS2023-368

compatible of most oxide ceramics F-TPS as highlighted in the state of the art. This led to consider a low ballistic coefficient between 25 kg/m² at assuming a drag coefficient around 1.3 for a conical shape of 60°.



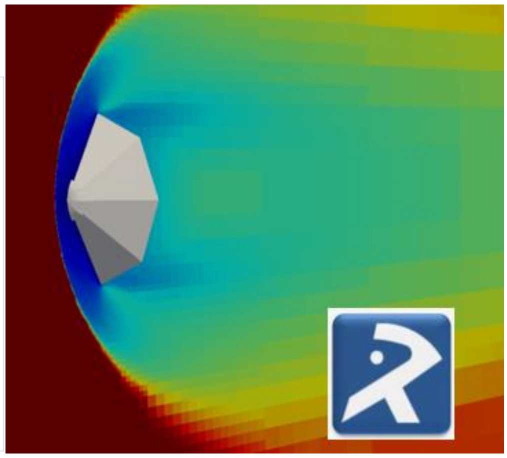
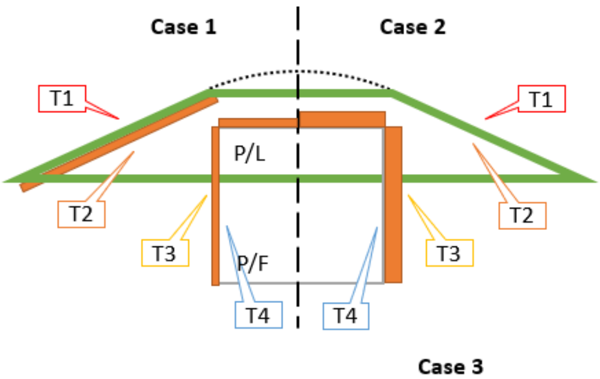


Figure 10. Flux intensity on F-TPS versus reentry mass / Figure 11. Temperature and F-TPS scenarios

Those assumptions were confirmed by RTech CFD partner in the first runs of activity. They used their own development software PAMPERO, MISTRAL and BLIZZARD.
Those flux and temperature profiles were injected in a 1D thermal calculation to assess the performance of the F-TPS on different scenario on implementation of internal insulation material.

1. Isolation on the F-TPS
2. Isolation on the P/L
3. Mix of both



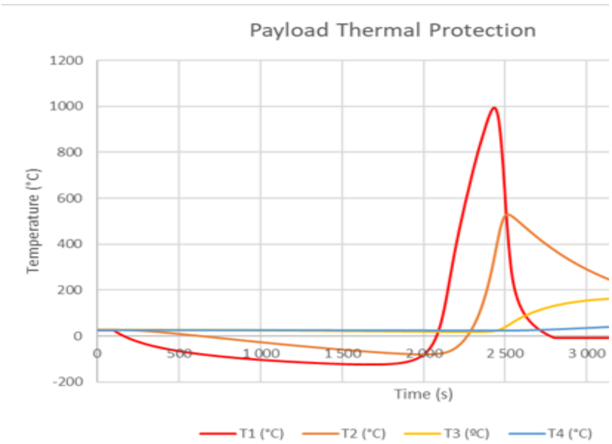


Figure 12. F-TPS scenarios / Figure 13. Temperature repartition during reentry

Later on , those raw calculation based on radiative view factor and conduction of the materials will be upgraded through 3D scad numerical simulation using 3D Experience suite of Solidworks. In parallel, RTech partner will be able to simulate with thermos-dynamical on meshed CAD design the details of selected thermal design. The initial calculation

DOI: 10.13009/EUCASS2023-368

demonstrated the need of 6-12mm of high-performance insulating felts in order to obtain the thermal performance requirement.

600°C on high-T° metallic parts (Ribs)
200°C on low parts (External P/L)
50-100°C (internal P/L)

The next step of the projects is to procure the materials for thermal protection system. If insulating material are pretty easy to procure at moderate industrial cost , the procurement for aerothermal textile is definitively not such easy and accessible for industrial and low-cost approach as required by newspace application.
e.NOVA raised an overview of F-TPS reference as used in the state of the art , and a complete overview of what is available on the market. This listing overview was raised on both external aerothermal textile material (1rst layer) and internal insulating felt material (2rst layer)

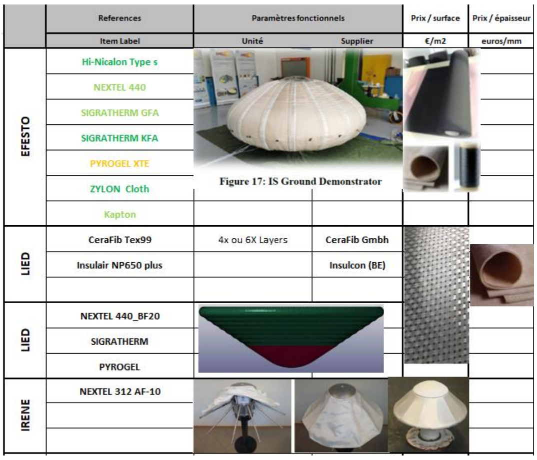


Figure 14.F-TPS Shield State of the Art / Figure 15. CNRS-ICARE Plasma wind tunnel test

The performance of the fiber materials in temperature can be summarized as below :
Oxide Ceramics

- Silica Glass <1000°
- Silica Oxide (St Gobain Quartzel)<1200°C
- Alumina Oxide (3M NEXTEL)<1400°C
- Mix of Silica / Alumina oxide (3M NEXTEL)

Zyrcon, Cerium, Yttrium oxide (rare metals)

Composite Ceramics

- Silicon Carbide (Nicalon)
- C/C (Carbon/.Carbon)

The outcomes of this market survey demonstrated the few cooperation of US providers to get availability and support for tests characterization procurement. By chance European providers are more customer-oriented and could access most of the US References. Unfortunately, the cost aspect (>1000Euros/m²) remains far from objectives required by newspace application (<250Euros/m²). After deep investigation, some experience of producing oxide ceramics testile have been found in Europe , but production is currently stopped expecting a restart not before 2024. The most promising sources is based in DITF research, a German research laboratory having forwarded its technology to Saint Gobain France for later production of oxide ceramics with a production objective in few years. St Gobain is currently

DOI: 10.13009/EUCASS2023-368

already addressing production of Quartzel (silica oxide) as main material for RF transparency for aircraft radar nose cone or electromagnetic guided missile.
Alternative to US material references can be found in most of the case in equivalent refences of Japan suppliers or providers , they will be carefully evaluated in the course of the project.
Those further characterization sequences are planned for mechanical testing in temperature and for processes assembly (weaving , sewing) at IFTH laboratory and in CNRS-ICARE aerothermal plasma wind tunnel facility PHEDRA (Soufflerie à Plasma Hors Equilibre De Rentrées Atmosphériques).
The initial results of mechanical testing demonstrated a good behaviour of NEXTEL[36] or NEXTEL-Alternative material in temperature tested up to 1400°C. But Quartzel (or full silica oxide) demonstrated a high performance decrease at those temperatures .

Zyrcon and pyrogel material were discarded from the selection due to quick "erosion" when manipulated offering an unacceptable particle contamination for a space application.

The activities on those characterization are still on going

7. BFS Mechanical Part

The BFS concept is aimed as a kit able to fit most of applications. Its design shall be adaptable to all scenarios. It is then composed of the following elements:

Rigid Dome :
- Adaptable to the application

F-TPS :
- Mostly generic from 3U-16U-27U

Structural Frame (generic)
- Front & rear frame (if needed)
- Damping bar (or device)

Deployment & support mechanism (generic)
- Ribs
- Struts

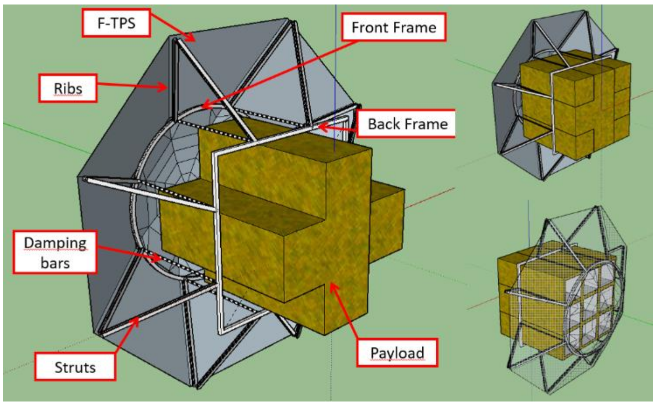


Figure 16. BFS Structural frames concept

Design options are investigated in order to curve the F-TPS external diameter in order to smooth the aerothermal flux and close the aft part of conical shape in order to avoid back aero flux and increase drag coefficient in order to get heavier payload with the design.
The system is composed of a front dome and trenched canvas to complete the deceleration cone. Eight ribs are articulated from the cone base to form a cone, or more exactly an octagonal pyramid. The structure is completed with struts that unfolds and holds the bottom of the ribs, forming a general shape of a 120° blunted cone.
This design has the advantage of being simple, robust and unreversible. It is also reasonably light weighed. Its main disadvantage is that it encapsulates the payload, meaning we must find a way to provide electric power from an external source. However, this drawback can become an advantage when speaking of thermal protection, as this allows an additional thermal protection on the back of the system, given we manage to dissipate remaining heat with radiation.

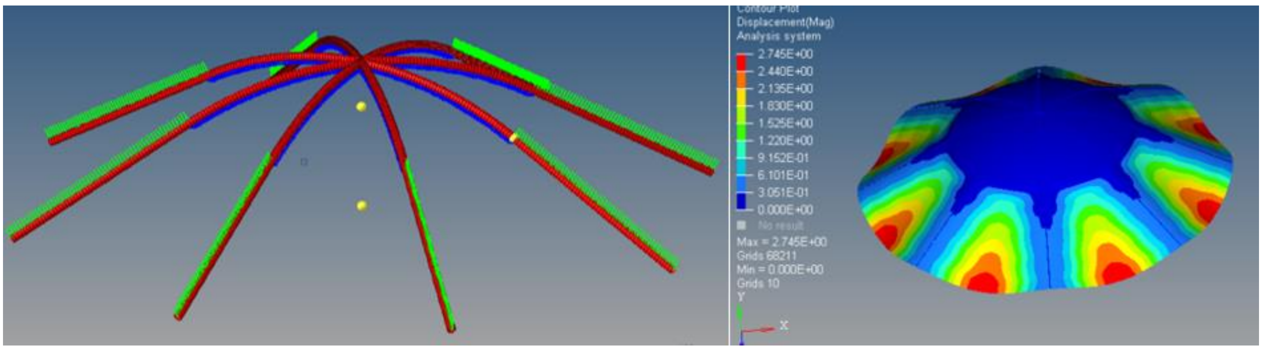


Figure 17. FEM Analysis on Ribs & F-TPS under Max dynamic pressure

DOI: 10.13009/EUCASS2023-368

Those back struts also provides lesser rib deflexion during reentry. Eventhough those might occur after the heating peak, we need to have the F-TPS as tight as possible to avoid heat concentration as much as possible.
Having this heat peak preceding the dynamic pressure peak can be interesting in some applications. Using Shape Memory Alloys to lock some mechanism, or use temperature to increase pressure into inflatable ribs, hence resistance are options to consider.

8. BFS Deployable & Landing Systems

The two options are investigated to deploy the F-TPS which are mechanical and inflatable options. For our first approach we decided to go with mechanical deployment as it seems much easier than dealing with pressurised components and related systems in such tiny environment, and the weight gain wasn't guaranteed on such a small scale (3U). Nevertheless, having an inflatable design opens possibilities, especially when speaking of sea landing, due to floatability. With the upscaling of the model there may be a change of strategy concerning structure, but for now we focused on mechanical deployment.
The deployment mechanism is today baselined on an electro-thermo activated SMA hinge (Shape memory alloy provided by NIMESIS[4] Partner). It is assumed the device could be activated in case of electrical failure. The device is help by a deployable struts powered by a folded carpentier blade aimed to deploy and install the 2 semi strut bars in order to withstand the dynamic pressure and release the deflexion of the rib beam.

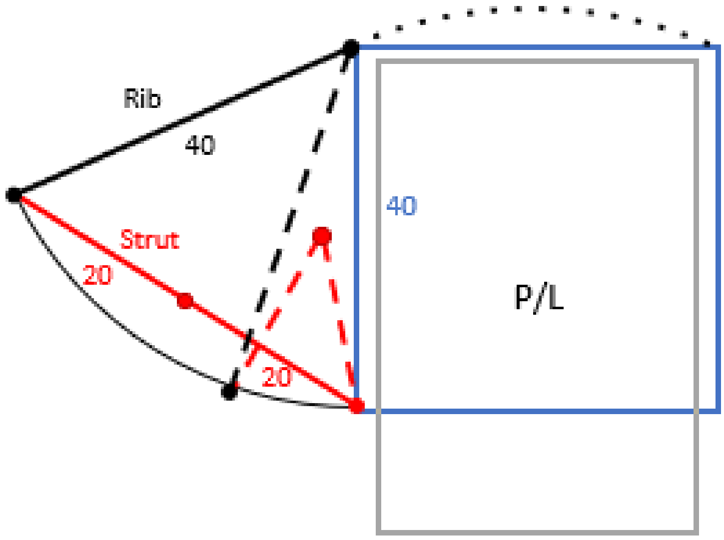


Figure 17. BFS deployment and support mechanism / Figure 19. Safety parasail and parachute

9. BFS Electronic Unit

The aim of this unit is to provide the following tasks:

- Environment Recordings (P°,T°)
- Dynamic Recordings (Accelerations and rates)
- Data Storage
- Data Transmission (RF SATCOM)
- Radio RF beaon (Recovery purpose)
- On-Board Computer
- Battery Pack (6-12h autonomy)
- Power Management

The following task addressed was to treat the preliminary design of a payload module for a In-Orbit Demonstration / In-Orbit Validation (IOD/IOV) mission. The objective is that this module must collect data during a first re-entry of the BFS device that can serve to validate the concept and to improve further design iterations with real data from the descent. In particular, pressure and temperature measurements are desired to be collected, together with monitoring the position and velocity of the spacecraft during the descent trajectory. 3-axis linear accelerations and the three angular accelerations would be interesting information as well. All the data is to be sent to ground via IRIDIUM link. These requirements, divided into mission requirements (MR), physical requirements (PR), and auxiliary requirements (AR),

DOI: 10.13009/EUCASS2023-368

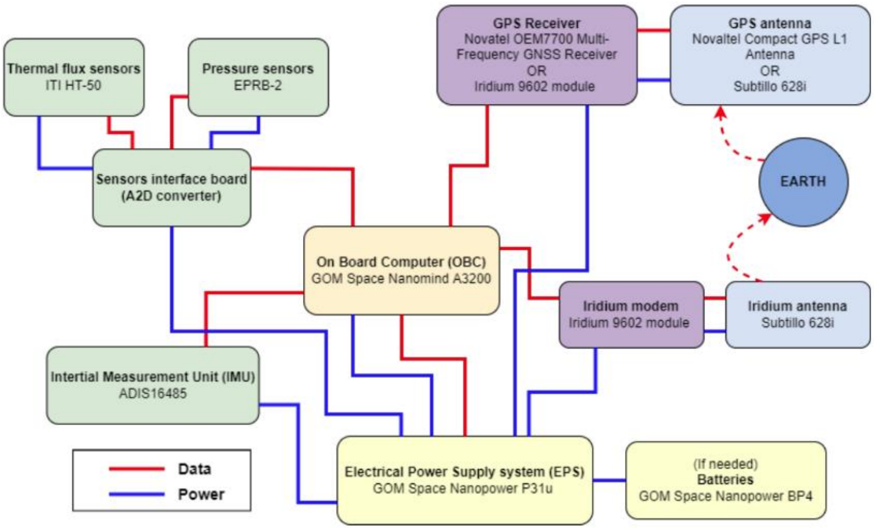


Figure 20. BFS Avionics schem

Having defined the preliminary set of requirements for the payload module and design solutions for them, hardware choices were made to address them. The choices are presented in Table hereafter, the selection of the components were in fact mostly reused from the previous experiment assembled at ISAE SupAero and flew as the EntrySat Cubesat (that unfortunately was operational only 2 weeks).

Req.	Hardware	Manufacturer	Ref.
MR1	Temperature and thermal flux meters	Instrumental Thermal Instrument (ITI) Company	[18]
MR2	EPRB-2 miniature pressure transducer	Althen Sensors	[19]
MR3	ADIS16485 Tactical Grade Six Degrees of Freedom MEMS Inertial Sensor	Analog Devices	[20]
wMR4.1	Subtillo 628i - Iridium/GPS Super Low Profile Antenna	Iridium	[21]
MR4.2	OEM7600 Dual-Frequency GNSS Receiver	Novatel	[22]
MR5.1	Subtillo 628i - Iridium/GPS Super Low Profile Antenna	Iridium	[21]
MR5.2	Iridium 9602 modem	Iridium	[23]
AR1	Nanomind A3200 OBC	GomSpace	[24]
AR2	Nanopower P31u Electrical Power Supply System	GomSpace	[25]

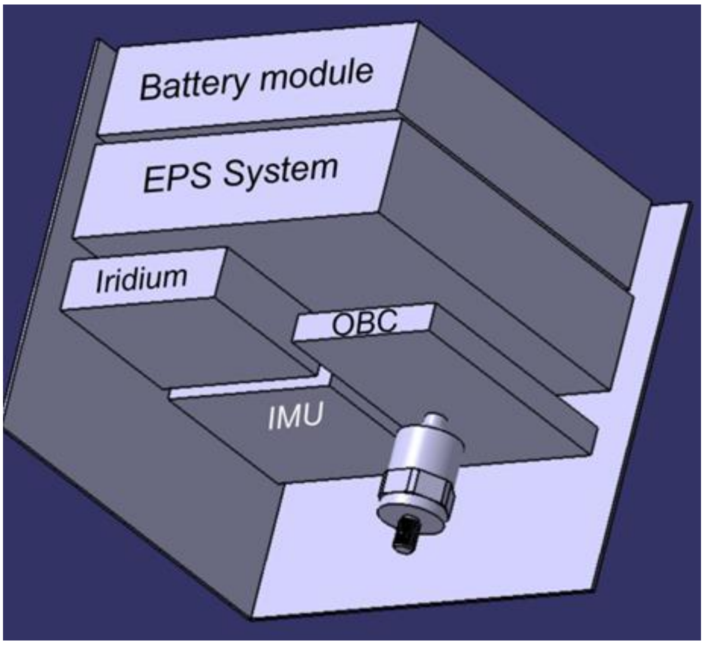


Figure 21. BFS Electronic Components (preliminary) Figure 22. BFS CAD Arrangement for Electronic unit

Finally, a draft of CAD model was developed to verify that all these components would fit in the 1U module that is allocated for them. The result of this quick arrangement can be seen hereafter.

In fact, all components seem to fit in 1U payload module. However, some other points would need to be taken into account. For instance, the harness with all the cables of the components needs to be integrated in the device.

DOI: 10.13009/EUCASS2023-368

10. Roadmap

Through the various studies conducted, we managed to define the different requirements and aspects for possible DEMO missions:

- DEMO of the BFS Kit (3-4U size).
- DEMO of a BFS Mission (12-16U size)
- DEMO of a P/L BFS IOS (15-27U size)

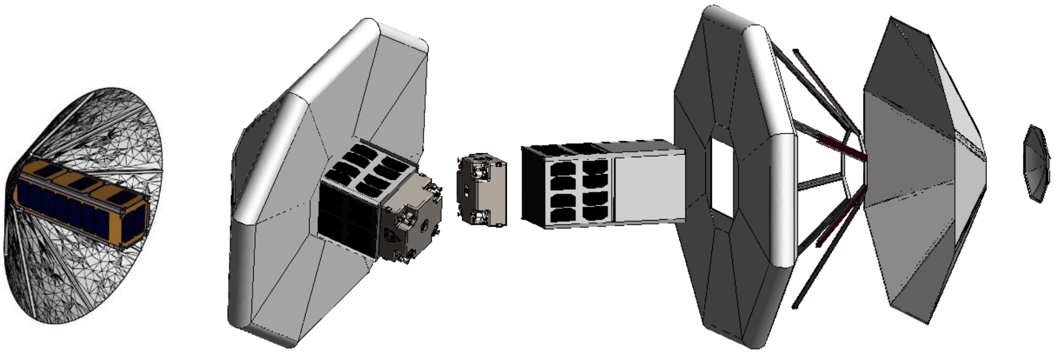


Figure 23: Exploded view of BFS Mission Demo (12-16U) / Figure 24: BFS Kit Demos (3-4U) & Mission Demo (12-16U)

The IOS (In Orbit Servicing) mission intends to recover a P/L after separation of a satellite platform or servicing vehicle able to conduct reentry burns and get back to orbital deposit for refueling. It is also investigated the capability to be launched without a P/M (Propulsion Module) using vehicle able to a controlled reentry vehicle: an upper stage after deorbit burn or a dedicated space tug such as D.ORBIT ION Module (aimed to for controlled reentry at disposal) The modularity of our elements allow to address a large range of applications promoted by current developments and operators foreseen in the NEWSPACE Market

The recent kick-off of the BFS F-TPS study comforted e.NOVA in the submission of the BFS project to the 2022-2023 BPI Call for Proposals, related to In-Orbit Servicing with Nanosat provider Endurosat_FR.
This selection was under a RFI Process (Request for information) sent to many European platform providers such as U-Space [33], Hemeria [34], Nanoavionics [35], and Endurosat [36] , GOMSPACE , SITAEL

This funding can allow to study a BFS mission design for 1 year with a PDR-CDR and a 2–3-years project to prepare an IOD-IOV mission with added partners such as Space Pharma as a potential maiden customer and equipment and integration partners such as COMAT_FR and MECANO.ID_FR in Toulouse.

The goal of the BFS concept is later to design a standard payload module in order to be able to bring back either 5 or 9 CubeSats or one bigger payload. Different contacts have been established with companies specializing in different areas such as EXOLAUNCH for separation rings and dispenser and Dawn Aerospace [32] is considered for propulsion modules.
With some small changes to its design, the BFS could also serve as a Space Tug or a Space Lab before returning to Earth and bringing its payloads back. The technology investigated in the F-TPS allow now to consider high energetic reentry missions to get extra-terrestrial sample containers the capability to reenter our atmosphere.

DOI: 10.13009/EUCASS2023-368

ACKNOWLEDGEMENT

The author aims to thank its partners for their contribution in the BFS F-TPS project and CNES delegates in the supervision and follow-on of this activity. The related contract n° 220646/00 was awarded by CNES French space agency in the scope of "Plan de Relance" initiated by French "Ministère de l'Economie , des Finances et de la Relance".

References

[1] Alan M. Cassell, Brandon P. Smith, Paul F. Wercinski, Shakib M. Ghassemieh, Kenneth E. Hibbard, Adam P. Nelessen, and James A. Cutts. ADEPT, A Mechanically Deployable Re-Entry Vehicle System, enabling interplanetary cubesat and small satellite missions. 32nd Annual AIAA/USU. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4077&context=smallsat, 2018.

[2] Davide Bonetti1, Gabriele De Zaiacomo, Ingrid Dietlein, Burkard Esser, Giuseppe Guidotti, Alberto Fedele, Jean-Luc Verant, Ysolde Prevereaud, Giovanni Gambacciani, Giulia Bimbi, Giuseppe Governale, and Nicole Viola. EUROPEAN FLEXIBLE HEAT SHIELDS: ADVANCED TPS DESIGN AND TESTS FOR FUTURE IN-ORBIT DEMONSTRATION. FAR2019. http://www.efesto-project.eu/content/download/219/1242/version/1/file/FAR2019_EFESTO_paper_DEIMOS_Bonetti_public.pdf, 2019.

[3] National Aeronautics and Space Administration (NASA). Hypersonic Inflatable Aerodynamic Decelerator (HIAD). NASA Facts. https://gameon.nasa.gov/gcd/wp-content/uploads/sites/58/2017/04/FS_HIAD_FINAL_170403.pdf, July 2017.

[4] https://www.nimesis.com/fr/accueil/

[5] https://www.ifth.org/

[6] Centre national d'études spatiales. DEBRISK. Software, 2013.

[7] Google. Google Earth Pro 7.3. Software, July 2020.

[8] Matlab. Matlab R2020b. Software, 2020.

[9] Python TM. Python 3.8.3. Software. https://docs.python.org/3.8/, May 2020.

[10] Benchmark Space Systems. Starling CubeSat Warm Gas Thruster datasheet. Available online. https://www.benchmarkspacesystems.com/products/propulsion# starling-datasheet.

[11] CUA Aerospace. CubeSat High Impulse Propulsion System (CHIPS) datasheet. Available online. 48 https://cuaerospace.com/products-services/space-propulsion-systems/ cubesat-high-impulse-propulsion-chips, October 2019.

[12] VACCO. Propulsion Unit for CubeSats (PUC) datasheet. Available online. https://cubesat-propulsion.com/wp-content/uploads/2016/03/ 11044000-01_PUC_2019update.pdf.

[13] NanoAvionics. CubeSat Propulsion System EPSS datasheet. Available online. https://nanoavionics.com/cubesat-components/cubesat-propulsion-system-epss/.

[14] Benchmark Space Systems. BGT-X5 Green Monopropellant Thruster datasheet. Available online. http://www.busek.com/index_htm_files/70008517E.pdf.

[15] ENPULSION Spacecraft Technology. ENPULSION NANO datasheet. Available online. https://www.enpulsion.com/wp-content/uploads/ENP2018-001. G-ENPULSION-NANO-Product-Overview.pdf.

[16] Hyperion Technologies. PM200 Propulsion Module datasheet. Available online. https://hyperiontechnologies.nl/wp-content/uploads/2019/11/HT_PM200. pdf, 2019.

[17] Morpheus Space. NanoFEEP datasheet. Available online. https://www.morpheus-space.com/static/MSWeb/documents/M-Space% 20Products.pdf.

DOI: 10.13009/EUCASS2023-368

[18] Inc. International Thermal Instrument Company. HT-50 Thermal Flux Meter – High Temperature. Online. https://thermalinstrumentcompany.com/products/heatfluxtransducers/ ht-50thermalfluxmeter, 2022.
[19] Althen Sensors and Controls. EPRB-2 Miniature Pressure Transducer. Online. https://www.althensensors.com/sensors/pressure-sensors/ miniature-pressure-sensors/4629/eprb-2-miniature-pressure-transducer/, 2022.
[20] Analog Devices. ADIS16485 - Tactical Grade Six Degrees of Freedom MEMS Inertial Sensor. Online. https://www.analog.com/en/products/adis16485.html#product-overview, 2022.
[21] Iridium. Subtillo Mini 628i. Online. https://www.iridium.com/products/multiband-subtillo-mini-628i/, 2022.
[22] Hexagon Novatel. OEM7600 Dual-Frequency GNSS Receiver. Online. https://novatel.com/products/receivers/gnss-gps-receiver-boards/ oem7600, 2022.
[23] Iridium. Iridium 9602 Module. Online. https://www.iridium.com/products/iridium-9602/, 2022.
[24] GomSpace. NanoMind A3200 - Versatile On-board Computer for Cube, Nano and Microsat missions. Online. https://gomspace.com/shop/subsystems/command-and-data-handling/ nanomind-a3200.aspx, 2022.
[25] GomSpace. NanoPower P31u - Electrical Power Supply system for small nanosatellites. Online. https://gomspace.com/shop/subsystems/power/nanopower-p31u.aspx, 2022.
[26] 3M Advanced Materials Division. 3m Nextel Ceramic Fibers and Textiles Technical Reference Guide. 3M Website. https://multimedia.3m.com/mws/media/1327055O/ 3m-nextel-technical-reference-guide.pdf, October 2021.
[27] Engineering ToolBox. Metals - Specific Heats. Online. https://www.engineeringtoolbox.com/specific-heat-metals-d_152.html, 2003.
James Fesmire. Standardization in cryogenic insulation systems testing