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Deorbit Kit Demonstration Mission

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Abstract

In Low Earth Orbit, it is possible to use the ambient plasma and the geomagnetic field to exchange momentum with the Earth's magnetosphere without using propellant. A device that allows an efficient momentum exchange is the electrodynamic tether (EDT), a long conductor attached to the satellite. EDT technology has been demonstrated in several past missions, being the Plasma Motor Generator mission (NASA 1993) one of the most successful. Nevertheless, it is not until today that reality has imposed a strong need and a concrete use case for developing this technology. In March 2019, the European Commission project *Electrodynamic Tether technology for PAssive Consumable-less deorbit Kit* (E.T.PACK) started the design of a new generation EDT. After completing the design phase, the consortium manufactured and is currently testing a Deorbit Kit Demonstrator (DKD) breadboard based on EDT technology. The objective of E.T.PACK is to reach Technology Readiness Level equal to 4 by 2022. The DKD is a standalone 24-kg satellite with the objective to demonstrate the performances of the improved EDT solution and validate its ultra-compact deployment system. The DKD is composed of two modules that will separate in orbit extending a 500-m long tape-like tether. The deployed bare-Aluminium tether will capture electrons from the ambient plasma passively and the circuit will be closed with the ionospheric plasma by using an active electron emitter. E.T.PACK tether will take advantage of several novelties with respect to the mission flown in the past that will allow to optimize the system volume and mass. Once successful demonstrated in orbit, the team plans to develop a suite of EDT systems capable of deorbiting satellites between 200 and 1000kg from an altitude up to 1200km in a few months. The work presents the current design status of the de-orbit kit demonstrator breadboard, the simulations of the system deorbit performances and the development approach.

Keywords: Deorbit Kit, ElectroDynamic, Tether, Propellantless, Space Debris, Orbital Servicing

Acronyms/Abbreviations

ADCS Attitude Determination and Control System
BBM BreadBoard Model
BMOM Business Model for Orbital Manoeuvring device
BETSmA Bare Electrodynamic Tether Software for mission Analysis
CAM Components and Assembly Models
cFS core Flight System
CGA Cold Gas Assembly
DKD Deorbit Kit
DKD Deorbit Kit Demonstrator
DM Deployment Mechanism
DMM Deployment Mechanism Module
E.T.PACK Electrodynamic Tether technology for Passive Consumable-less deorbit Kit
EDT ElectroDynamic Tether
EE Electron Emitter
EEM Electron Emitter Module
EPS Electrical Power System
EQM Engineering Qualification Model
FCC Federal Communications Commission
FET Future Enhancing Technologies
FLEX
FM Flight Model
HP High Pressure
IMU Inertial Measurement Unit
LEO Low Earth Orbit
LP Low Pressure
NEReA Non Explosive Release Actuator

SIM	SImulation Models
SoC	System on Chip
TRL	Technology Readiness Level

1. Introduction

The E.T.PACK consortium is designing a Deorbit Kit Demonstrator (DKD) mission to be launched in 2025. The DKD is based on the disrupting propellantless ElectroDynamic Tether (EDT) technology. This activity is currently financed with 3M€ by the European Commission under the FET-OPEN project Electrodynamic Tether technology for Passive Consumable-less deorbit Kit (E.T.PACK). E.T.PACK involves the University Carlos III of Madrid as coordinator of the project and responsible for the mission analysis, SENER in charge of the system engineering and the avionics, the University of Padova as responsible for the tether deployment mechanism validation, the TU Dresden in charge of the electron emitter and ATD and IKTS working on new material developments [1,2]. The objective of the E.T.PACK project is to develop the deorbit kit (DK) up to TRL4 by 2022. The team is currently working on securing the fundings for the following project that will focus on the DKD spacecraft qualification for flight reaching TRL8 by 2024.

Figure 1: Artistic view of the Deorbit Kit Demonstrator.

The DKD (Figure 1) has a standard 12U form factor, a mass of less than 24 kg and will be launched in a 600 km circular orbit with 51.5º inclination. It is based on bare tether [3] Technology. After deployment from the launcher, the DKD will stabilize its attitude and separate into two modules connected by 500 m of tether. The tether will be a tape of 2.5 cm width and 40µm thickness formed by a conductive aluminium tape, an inert PEEK segment, and an insulated segment. The objective of the demonstration is to deorbit in less than 100 days, whereas the natural deorbit time would be of about 15 years [4,5]. Each edge of the tether includes an independent module with its avionics and communication system. A powerful System On Chip based onboard computer using proprietary software is used to control new space radiation tolerant components. The tether is contained inside the Deployment Mechanism (DM) module that is responsible for the separation of the two parts and the extraction of the tape. Once the tether is deployed and stable along the local vertical, the Electron Emitter (EE), contained in the EE Module, is activated to eject the electrons collected by the tether. Figure 2 shows the top level overview of the DKD.

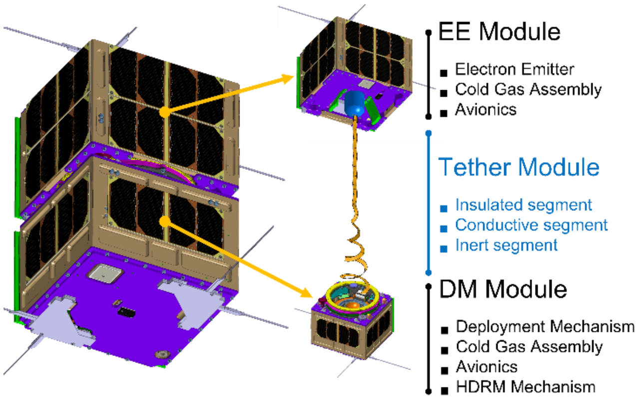

Figure 2: DKD Top Level Overview

The consortium is currently manufacturing a fully representative DKD model for demonstrating the critical mission technologies. All avionics elements of the DKD breadboard have been procured, its structure has been assembled and the first tests are ongoing.

2. Mission Objectives

The DKD mission has the objective to demonstrate in orbit the developed technologies and validate the system performances. Despite the EDT technology has been already demonstrated in space in the 90s [6,7] and there are many initiatives around the world [8,9,10], the DKD mission involves several novelties aimed at reducing the mass, volume, power consumption and cost of the device while boosting the performances and achieving full autonomy.

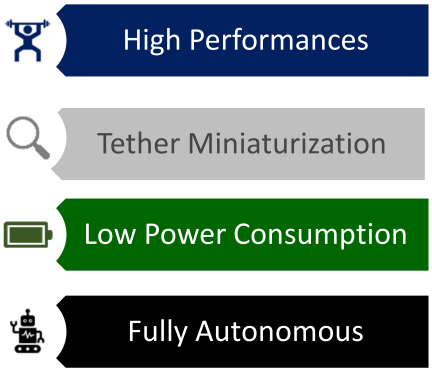

Figure 3: DKD Mission Objective.

In particular, the mission objectives can be summarised in high performances, miniaturization, low power consumption and full autonomy.

2.1 High performances

The first objective of the DKD mission is to demonstrate that is possible to deorbit from 600 km circular orbit in less than 100 days without using chemical or electrical propulsion systems. The mission will also demonstrate that is possible to turn ON and OFF the EDT that will apply an average constant force of about 5mN, sufficient to control the deorbit trajectory, thus providing collision avoidance capability.

2.2 Tether Miniaturization.

The second objective of the IOD is to push the miniaturization on the DKD components. In particular, the E.T.PACK team has developed a revolutionary system capable of storing and safely deploying a long tether segment using a very reduced volume. Despite the exhaustive test campaign foreseen on ground, the qualification of the tether deployment mechanism in the operational environment is only possible in space.

2.3 Low power consumption.

The DKD mission will demonstrate that the deorbit can be performed requiring only a limited power. While conventional electric propulsion requires hundreds to thousands of Watts and therefore large solar panels and heavy power systems, the DKD tether system will require less than 10W. This power is mainly dedicated to feed the avionics components and the active electron emitter.

2.4 Full Autonomy.

The DKD mission will be completely autonomous and nominally relying on the ground segment only for monitoring purpose. This demonstration will qualify the software to be used by the final product. Autonomy is critical to avoid any operational cost during the de-orbit phase. It is also a critical feature for commercial applications where the deorbit device should work as a lifeguard to eliminate dead spacecraft.

3. Mission Design

ElectroDynamic Tether based systems can work in LEO in any inclination and up to 1200 km altitude. Tether performances depends on orbital altitude and inclination, being optimum for low orbit and low inclination. For the demonstration mission, a medium inclination orbit and an altitude of 600 km is selected in order to guarantee a deorbit time long enough to collect a representative set of mission data. Short mission is preferred to limit the operation time and therefore the cost. Mid inclination allows to operate the mission from a Ground Station located in continental Europe.

The 24 kg of mass and the 12U Cubesat form factor allows the DKD mission to be launched as rideshare by several launchers with standard small satellite dispensers ensuring a competitive launch price [*11*]. The current baseline launcher is RFA One from Rocket Factory Augsburg. Table 1 reports the main DKD mission data.

Table 1: DKD Main mission data.

Parameter	Value
Orbit altitude:	600 km
Orbit Inclination:	51.5° circular
Spacecraft Mass	24 kg
Deorbit time	<100 days
Tether Length	500m
Average Drag	5mN
Launch Date	2025
Launcher	RFA

The 12U DKD is composed by the Deployment Mechanism Module (DMM) and the Electron Emitter Module (EEM) of about the same mass. DMM is responsible for storing and deploying the 500m of tether, while EEM task is to "turn on" the tether by emitting the electrons back to the plasma with an active emitter. Each module is completely independent, and they have their own power, communication, data handling and attitude control subsystems. Using SysML design approach, the mission is organized in five use cases, shown in Figure 4.

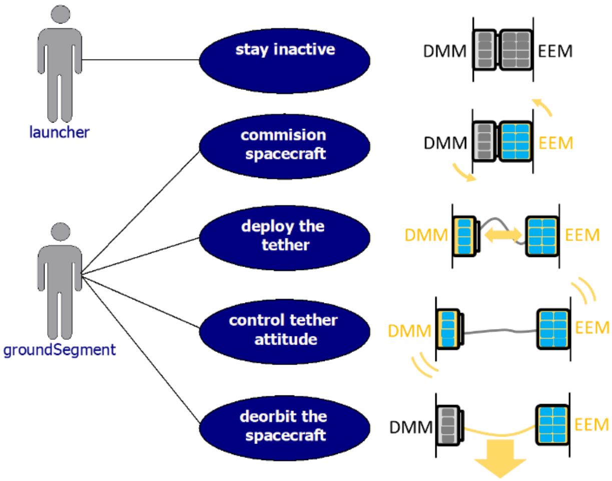

Figure 4: DKD Mission Use Cases.

3.1 Stay Inactive

The DMM and EEM modules are mounted together in a stack configuration and integrated in the launcher with the communication antennas undeployed, and the batteries fully loaded. In the first stay inactive use case the DKD modules are required to withstand transportation, the storage and the launch environment. Vibrations are a critical thread for mechanisms and in particular for tether systems to be deployed.

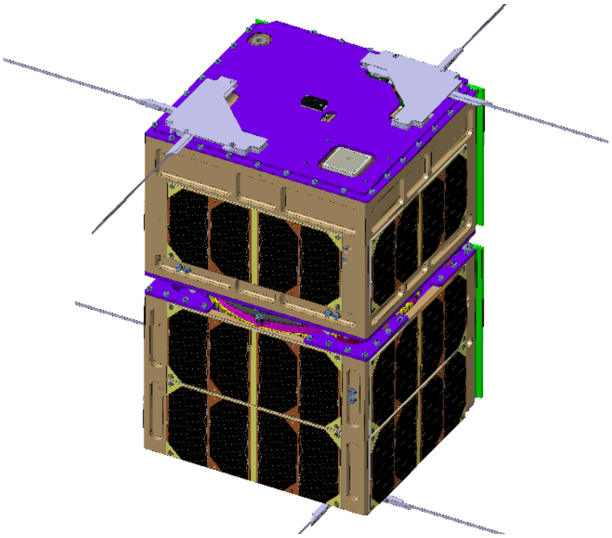

Figure 5: DKD Stack

After the deployment of the stack, the on board computers will be turned on by a kill-switch. Due to safety requirements, the modules will wait 30 minutes before deploying the antennas and activating the communication systems, meanwhile the solar panels will start loading the batteries. Using magnetic actuators, the DK will remove the stack angular momentum and acquire and maintain nadir pointing attitude.

3.2 Commission Spacecraft

The commission spacecraft use case will require a few ground station passes in order to check the systems status and calibrate parameters and correct eventual anomalies. Commissioning is mandatory for a demonstration mission, nevertheless operations will be designed to avoid any time critical activity. This will also allow to reduce the number of ground stations and therefore the operation cost.

3.3 Deploy the Tether

After completing the commissioning, the ground segment will send the telecommand to deploy the tether**.** The tether deployment will be performed autonomously by the DKD with no ground intervention and will involve both modules. EEM will acquire a 15° off nadir direction and will command cold gas thrusters to provide a smooth constant push. At the same time the DMM will trigger the separation mechanism and deploy the tether following a predefined velocity profile. The attitude of the modules will be controlled by the dedicated miniaturized Cold Gas Assembly (CGA) present on both modules. The full deployment will last 60 minutes and will end with the tether aligned along the local vertical taking advantage of the gravity gradient for stabilization. SysML has been extensively used in the design of the mission [12]. A SysML picture of the tether deployment sequence is shown in Figure 6. Tether deployment is a critical demonstration for the DKD mission.

3.4 Control Tether Attitude

After the deployment, the gravity gradient will keep the tether aligned along the local vertical in a stable configuration. Active attitude control of the DMM and EEM will prevent accidental contact between the tether and the modules removing the risk of tether wrapping and cut. In particular, the 400 m of metallic tape will experiment a considerable thermal contraction/ elongation when entering/exiting Earth eclipse, resulting in tether tension/slackness during the transition periods. Simulations have demonstrated that slackness is particularly critical since it is followed by peaks of tether tension that can cause attitude instabilities if not counteracted. An in-line damper connected to the tether will allow to absorb the tension peaks. The active attitude control of the EEM and the DMM will be performed by using magnetic actuation and moving the tether attachment location, respectively.

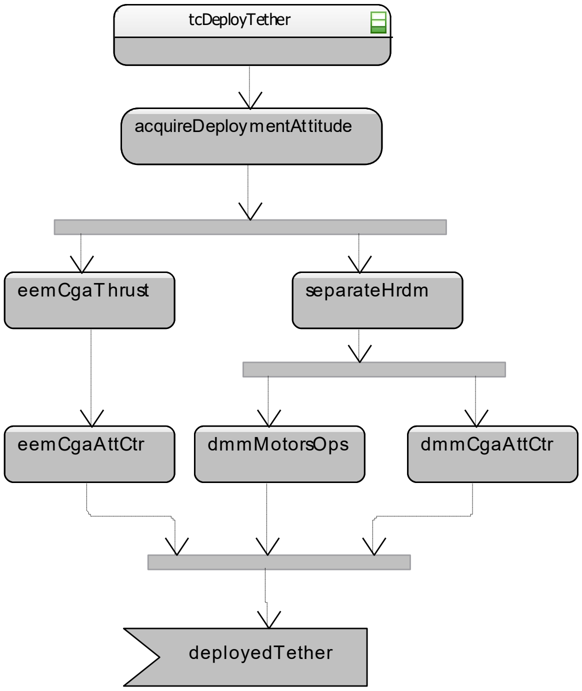

Figure 6: Use Case "deploy the tether".

3.5 Deorbit the spacecraft

Deorbit the spacecraft is the last DKD use case. The EEM will turn on a hollow cathode device that will expel the electrons collected from the ambient plasma by the bare tether segment. The generated current will interact with the Earth magnetic field producing a (drag) Lorentz force. The mission is designed to operate the hollow cathode with a 30% orbital duty cycle in order to reduce the power consumption. Plasma density in Low Earth Orbit presents a maximum in the sun direction and a minimum in the opposite direction. Therefore, the electron emitter is operated only in a +/-54° true anomaly around the sun direction.

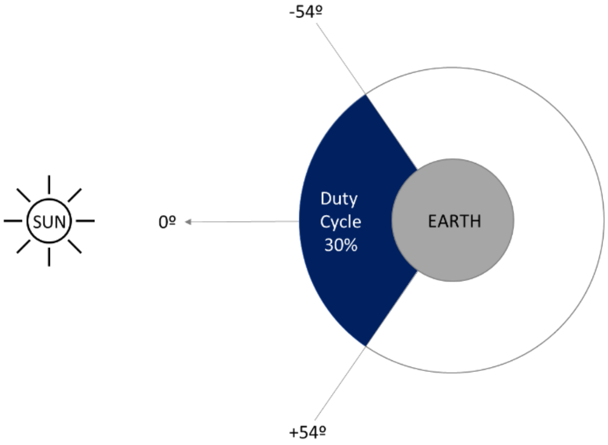

Figure 7: Deorbit Duty Cycle

4. EEM Design

The Electron Emitter Module, as indicated by the name, hosts the Electron Emitter (EE) subsystem responsible for making possible a steady electric contact between the tether and the ambient plasma. The EEM has a mass of 10,75 kg and a volume of roughly 6,8 L. It is the largest module of the DKD and the external surface is used for collecting power without the need to deploy solar panels. On average, the orbital power consumption of the module is roughly 10 W, although it varies depending on the mode of operation.

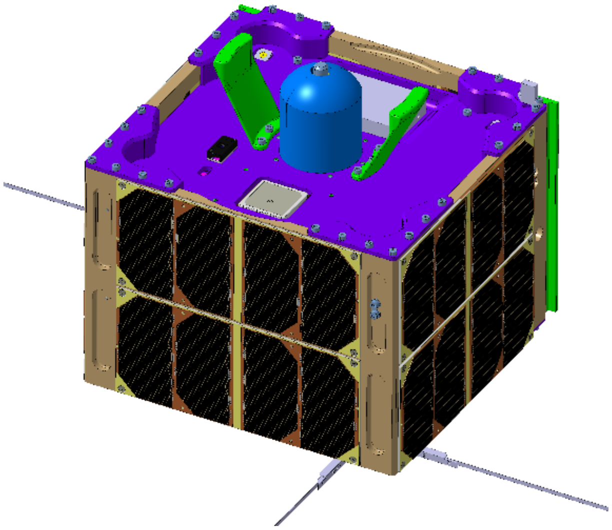

Figure 8: Electron Emitter Module

EEM subsystems includes the above mentioned EE, a Cold Gas Assembly (CGA) used for the deployment and to feed the EE, and a complete avionics suite including on board computer, power, telecommunication and ADCS. A summary of the EEM main data is shown in Table 2.

Table 2: EEM Main Data.

Parameter	Value
Mass	10,75 kg
Volume	6,8 L
Power Consumption	10 W
Main Subsystems:	Electron Emitter
	Cold Gas assembly
	Avionics

4.1 The Electron Emitter

The EE will make use of the C12A7e- low work function material and will be able to operate without heater. This breakthrough development in cathode technology will allow to operate high performance deorbit system with a very reduced power budget. The electron emitter prototype is shown in Figure 9.

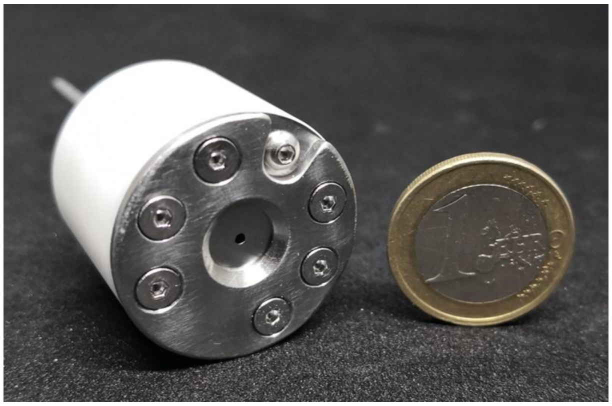

Figure 9: Electron Emitter prototype.

The electron emitter will operate at a nominal power consumption of 7,5 W and will use Krypton to generate a plasma connecting to the surrounding space environment. The noble gas will be fed to the EE by a dedicated cold gas assembly. The EE will operate in the orbital region with the highest plasma density to maximize the system efficiency. The Electron Emitter will be directly connected to the tether and operated by a dedicated electronic unit. This unit will be able not only to use power from the module's battery to ignite the cathode, but also to operate in power generation mode and load the batteries. The power harvesting operation mode is one technological experiment of the mission that could bring to very interesting results and new potential applications of the tether systems. The team is also currently working on the development of different electron emitter technology (Electron Field Emitters [13] and Thermionic Emitters) that could be combined with a bare-photovoltaic tether, also under development [14], to reduce the system mass and volume.

4.2 EEM Cold Gas Assembly

The dedicated CGA will be used during the deployment to provide the initial separation velocity to the two modules. Four micro thrusters located at the edge of the EEM will provide a constant thrust of 0.2N for 30 seconds and then will actuate to control the module's attitude during the 60 minutes of deployment. This operation will only consume a 10% of the gas stored in the tanks. The remaining gas will be used to feed the Hollow Cathode with a constant flux during the deorbit phase. The EEM CGA is divided in a high pressure (HP) side and a low pressure (LP) side, connected by a pressure reducer. In the HP side two $150cm^3$ tanks are connected to a fill-and-vent valve, an overpressure relief valve, temperature and pressure sensors and finally to a high-pressure regulator. All elements are mounted on a dedicated aluminium manifold. A second aluminium manifold hosts the LP elements including pressure and temperature sensors, overpressure relief valve, low pressure regulator and two latch valves to control the two branches: the four thrusters branch and the EE branch. Each thruster has an average thrust force of 52mN. A CGA functional engineering model, shown in Figure 10, has been developed in the framework of the project and will be qualified for space according to ESA standard in the frame of future project activities.

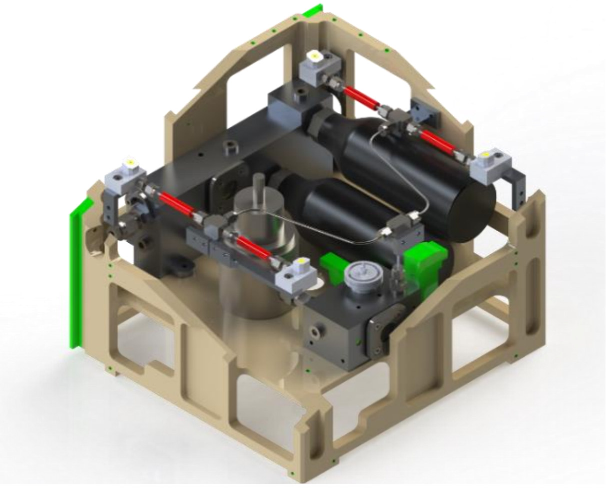

Figure 10: EEM Cold Gas Assembly

4.3 EEM Avionics

The DKD avionics are based on a powerful System On Chip (SoC) Zynq-7000 consisting on an innovative CPU plus FPGA architecture. On the software part, the core Flight System (cFS) architecture has been implemented by SENER. The architecture is based on different applications, that represent different threads running at the same time in the computer. cFS is a NASA initiative, with space heritage in different successful missions such as Morpheus, Solar Probe Plus, Mighty Eagle Lander, etc. The main advantage of cFS adoption for E.T.PACK is the availability of several space qualified software components such as the scheduler, housekeeping, memory management, etc. Furthermore, cFS allows software abstraction from the hardware thanks to several layers of software. Each layer hides its details from the other layers in such a way that the internals of a layer can be changed without affecting other layers internals. The actual software development effort is put on the E.T.PACK mission specific applications like specific sensors and actuator management and Attitude Determination and Control System (ADCS) software. In particular, the ADCS algorithms are developed in Matlab/Simulink and verified in a dedicated simulation environment. Then the ADCS software is generated by autocoding and deployed in the SoC CPU. On the hardware part, an FPGA is in charge of handling all the interfaces with the different peripherals of the module, freeing the microprocessor from software interfaces which are very time consuming. The selected sensors use different digital data interfaces including I^2C, SPI, RS-232 and CAN that are currently being implemented in the FPGA. The avionics includes a simple and robust UHF communication system, a commercial space Electrical Power System (EPS) with a 38.5Wh battery loaded by solar panels and a dedicated ADCS. ADCS receives the input from a GNSS sensor, an IMU, a set of Coarse Sun Sensors embedded in the solar panels, 2 Fine Sun Sensors and a Magnetometer. The spacecraft attitude is determined with an extended Kalman filter and controlled either by commanding three torquerods mounted on the module principal inertia axes or operating the four CGA thrusters during the deployment manoeuvre. The SoC also controls the Electron Emitter, the CGA tank valves and the thrusters used during the tether deployment. In Figure 11 a summary of all the elements of the avionics is shown.

Figure 11: EEM Avionics

DKD use exclusively magnetic actuation in the pre-deployment phase to point the spacecraft longitudinal axis 15º off from the nadir direction. Although magnetorquers can only generate a torque perpendicular to the Earth's magnetic field, they can be used to achieve a stable nadir-pointing attitude when high pointing requirements are not needed [15,16,17]. The team developed magnetic control algorithms valid for any direction contained within the orbital plane. These algorithms have been tested and successfully validated in an extensive high fidelity simulation campaign considering nominal values of errors in the attitude sensors (noise, misalignments, and scale factors), aerodynamic drag and the presence of residual magnetic dipole assumed to be known with an uncertainty inferior to 4 mAm^2. Figure 12 shows the evolution of the 321 sequence of Euler angles that relate the body frame axes with respect to the target frame. The first orbits are needed for damping the initial velocity, then the achieved pointing error is <10 degrees in each Euler angle, satisfying the mission requirements [18].

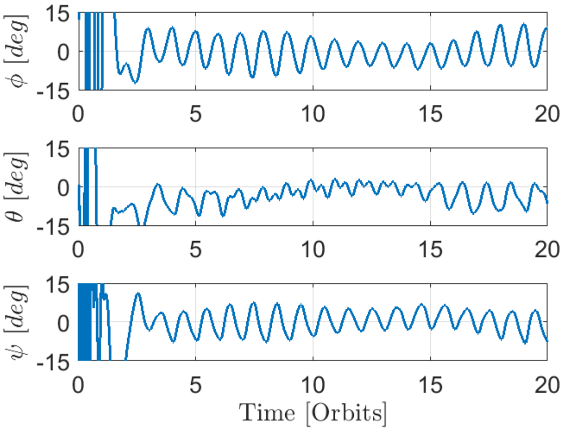

Figure 12: 321 Euler angles evolution during the pre-deployment phase with respect to the target frame.

5. DMM Design

The Deployment Mechanism Module (Figure 13) is completely built around the deployment mechanism with the only purpose of deploying safely 500 meters of tether towards Earth. The DMM has almost the same mass than the EEM but it is much more compact, being its volume 5.2 L. Its external surface is covered by solar panels used to load the battery before the deployment and for feeding the Avionics during the deorbiting. During nominal operation of the DMM, its power consumption is below 7 W.

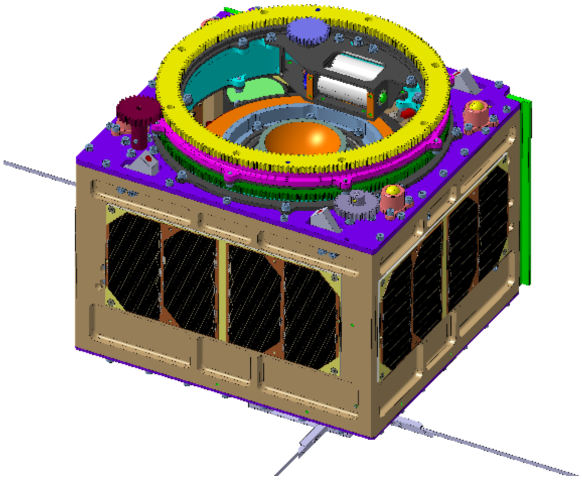

Figure 13: Deployment Mechanism Module.

The DMM systems includes the deployment mechanism (DM), a Hold Down and Release Mechanism (HDRM) to separate the two modules at due time, a Cold Gas Assembly used for controlling the attitude during the deployment manoeuvre and a complete avionics suite similar to the one previously described for the EEM module. In Table 3 the main data of the DMM is shown.

Table 3: DMM Main Data.

Parameter	Value
Mass	12,5 kg
Volume	5.2 L
Power Consumption	7 W
Main Subsystems:	Deployment Mechanism Cold Gas assembly Avionics HDRM Mechanism

5.1 The Deployment Mechanism

The DM is based on a stationary spool with a rotational extractor that deploys the tape. Two brushless motors are in charge of moving the rotational extractor and a set of pulleys that extract the tape from the spool and deploy it in the longitudinal direction of the module. The tether is extracted following a predefined releasing profile that meets the distance between each module during the deployment phase [18]. The verification of the deployment mechanism is one of the most challenging activity of the project and involves several deployment tests of few meters of tether and few deployment tests of the full 500m length. The full validation of the tether deployment will only be possible in space. High fidelity simulations will be used before the flight to cover all the deployment aspects that are not possible to test on ground.

5.2 DMM Avionics & Cold Gas Assembly

The DMM module hosts almost the same avionics than the ones described before for the EEM module (Figure 14). The main difference between the avionics is that DMM has dedicated electronics needed to command the Deployment Mechanism, while EEM has dedicated electronics to control the Electron Emitter. The rest of elements are common in both modules. This strategy simplifies the design and saves developing time.

Figure 14: DMM Avionics

The DMM Cold Gas Assembly follow the same design approach than the previously described EEM CGA. The main differences are that it uses much smaller tanks and a single branch for the 4 thrusters.

5.3 Hold Down and Release Mechanism

The HDRM selected for E.T.PACK is a SENER commercial product known with the name of NEReA (Non Explosive Release Actuator). NEReA design is based on a fusible element that releases a standard threaded screw inside a capture box. This fusible element is designed to be triggered by the same pulse that triggers a pyrotechnic element, with the added advantage of not producing any type of residue or volatile fragment. NEReA has a very short release time (less than 50 ms), very low induced shock level, is totally reliable and internally redundant. The fusible element is easily replaceable without the need to dismantle the NEReA.

6. Mission performances

The DKD performance has been addressed using BETsMA v.2 [19,20,21,22] considering a 24 kg spacecraft in a 600 km circular orbit deploying a 500 m tether with a 400 m bare Aluminium segment. The performance is estimated assuming duty cycle of 100% and 30% of the hollow cathode (Figure 15).

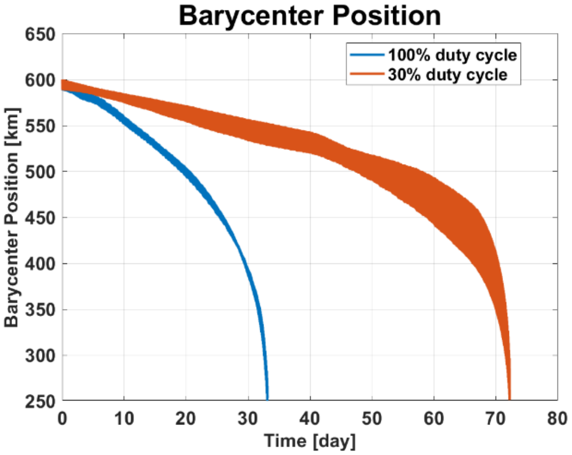

Figure 15: DKD altitude decay as a function of the duty cycle (FLEX)

The end of the deorbit is considered when the perigee reaches 250 km of altitude. With 100% duty cycle the deorbit time is 34 days and reducing the duty cycle to the 30% of the orbit the deorbit time increase to 73 days. It is interesting to observe that the performance decrease is not linearly dependent from the operation time. This is due to the fact that the cathode is active where the plasma is maximum along the orbit.

7. Development approach

The mission is developed according to the European Cooperation for Space Standardization (ECSS) standards in agreement with the international guidelines on space debris mitigation. In particular the following documents has been considered for ensuring flight approval:

- Inter-Agency Space Debris Coordination Committee (IADC). IADC Space Debris Mitigation Guidelines IADC-02-01 Revision2 March 2020.
- International Organization for Standardization (ISO) Space debris mitigation requirements (ISO 24113:2019)
- United Nations Office For Outer Space Affairs (UNOOSA), Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, adopted by the United Nations General Assembly in its Resolution A/RES/62/217 of 22 December 2007.

The E.T.PACK development and verification approach includes 5 elements: Simulation Models (SIM), Component & Assembly Models (CAM), BreadBoard Model (BBM), Engineering Qualification Model (EQM) and Flight Model (FM).

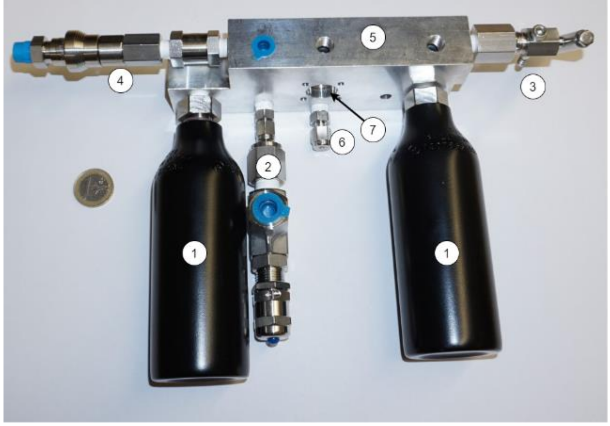

Figure 16: EEM HP Cold Gas CAM with tanks[1], relief valve[2], vent valve[3], fill valve[4], manifold[5], regulator connector[6] and pressure sensor mounting[7]

SIMs have been produced during the design activity and are continuously updated to support the incremental verification during the technology maturation process. SIM includes BETsMA, FLEX and the dynamical simulators for attitude determination and control developed by SENER using the SENERIC framework [23]. **CAMs** are the first step of verification with hardware. Whenever applicable the verification is performed at the lowest possible level on CAMs. CAM includes the CGA subassemblies like the one in Figure 16, avionics assembly, and Electron Emitter assemblies. **BBM** are flexible and adaptable to handle design changes that can occur during the early stage of the development. BBM models have been developed in the frame of E.T.PACK project. E.T.PACK BBM is the results from the integration of the breadboards of the different subsystems. Figure 17 depicts the DMM BBM integrating the DM with the control avionics.

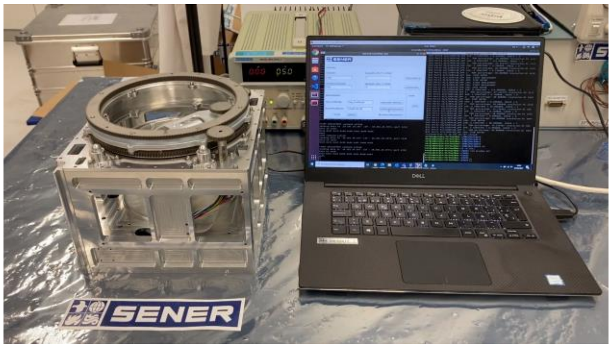

Figure 17: Deployment Mechanism Module BBM

A conventional **EQM** approach is considered mandatory due to the large number of elements under development. EQM will be used for the qualification of the DKD spacecraft. In a following project EQM will undergo full environmental qualification including mechanical vibration, thermo-vacuum cycling, radiation test, magnetic characterization, and all necessary fluidic tests. Finally, the **FM** will be built once the qualification of the DKD has been successfully completed. FM will be environmentally tested only for acceptance levels. The DKD development approach over time is depicted in Figure 18.

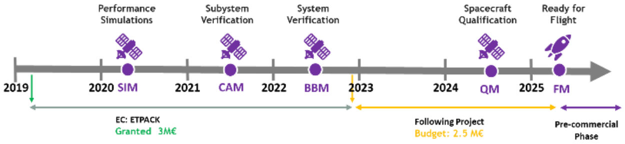

Figure 18: DKD Development Approach.

8. Deorbit Kit Applications

Over the next 10 years the demand for satellite and launch will experience a 5.7 time increase with more than 1,500 satellites to be launched every year, compared to the 260 satellites/year during the last decade.

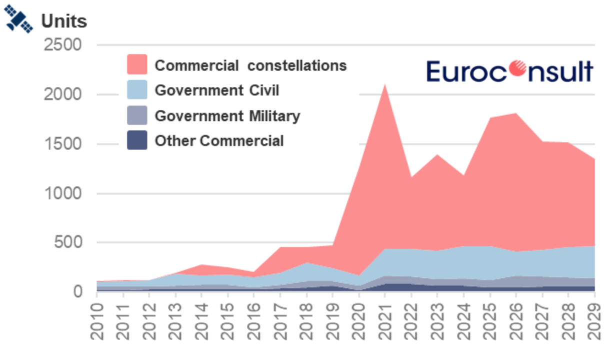

Figure 19: Satellites launch trend

According to the analysis performed by Euroconsult in the frame of the BMOM study [24], the number of addressable satellites in the 5 years from 2025 to 2029 ranges from 291 to 502 according to the assumptions. In the same period, the addressable part from launchers ranges from 570 to 1292. Launchers deorbit (Figure 18) is a very interesting use case since they can be deorbited soon after the launch reducing the requirement of radiation resistance on the avionics and therefore the overall DK cost. Satellites is also a very interesting market that could increase considerably in the future. In particular, the second largest telecommunication constellation actor, OneWeb, is deploying his constellation in very high LEO orbits around 1200km. At this altitude failing satellites do not deorbit naturally and DK would be an ideal candidate for remedy. In addition to serve the identified satellites and launcher's upper stages, EDT technology could enable the use of new orbits. In particular, station keeping via a tether in the so-called active mode can enable constellations below 400 km altitude. This Very Low Earth Orbit is starting to be an interesting option for telecommunication satellites constellations. For example, on April 2019 Starlink filed at FCC 7,518 satellites for orbits in 335 to 346 km altitude range. The DK could also boost the Satellite deorbit market by enabling single mission carrying out multiple de-orbits. Satellite deorbit market is doomed by the constrain of "single deorbiting service per servicer". In the past the cost of deorbiting has not supported any favourable business case. A light DK with a reduced mass of less than 20kg could be a game changer. If properly attached to the target spacecraft in orbit, it could take care of the deorbiting allowing a "dispenser of deorbit-kit" to provide services to several customers. Apart from the deorbiting or station keeping applications, an electrodynamic tether has the possibility of harvesting energy into the mother spacecraft. Therefore, it represents a very versatile element that could complement other sources of energy such as the solar panels in some cases.

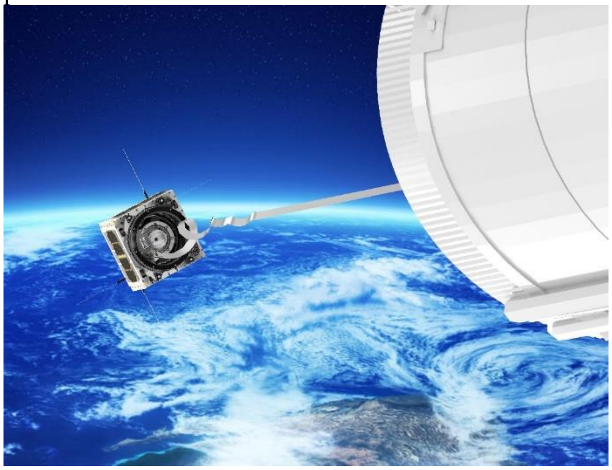

Figure 20: Artistic view of a DK deorbiting a launcher upper stage.

9. Conclusions

Nowadays, with the appearance of the mega-constellations and the new space, a deorbit system based on an electrodynamic tether could represent a game changer thanks to its reduced mass, low power consumption, high performance and its propellantless nature. The E.T.PACK consortium is designing this system and aims to validate the critical technologies in a Deorbit Kit Demonstration mission by 2025. In this paper the main mission phases have been described along with spacecraft subsystems, the validation approach and the expected performances. The spacecraft is composed by two modules that will separate in orbit to deploy a tether of 500m. One module is built around the tether deployment mechanism while the second on the electron emitter. Both modules contain off the shelf avionics connected to a new system on chip based on board computed developed by SENER. The Deorbit Kit Demonstrator will be launched in a 600km altitude orbit with an inclination of 51.5º and is expected to deorbit in less than 100 days when the natural deorbit time would be about 15 years. Once successfully demonstrated in orbit, the potential application of the future Deorbit Kit are several: Deorbit Kit can be used for deorbiting of satellites and launcher upper stages, they can be used for the orbit maintenance, they can be deployed on satellites in orbit as service kit and they can even be used to generate on-board power.

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