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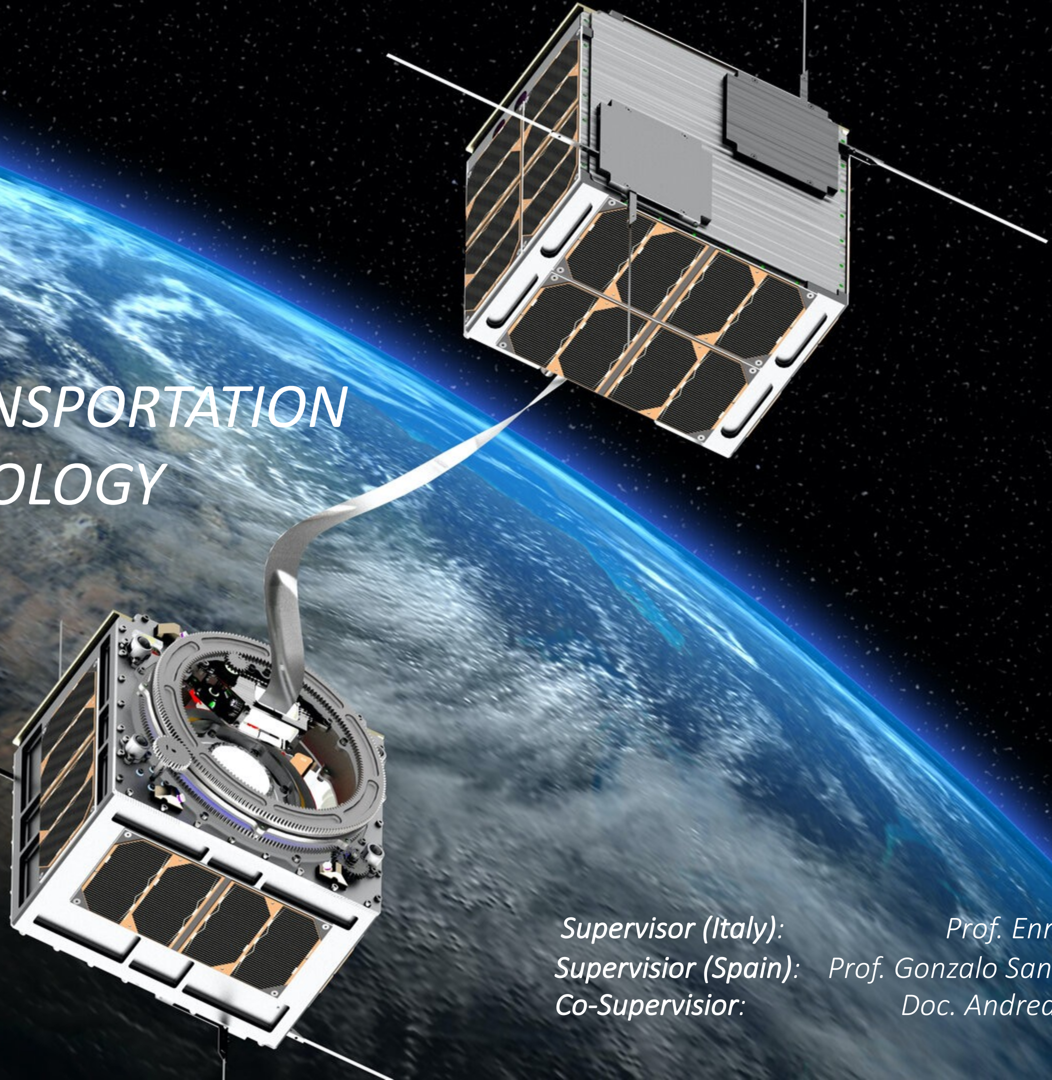
GREEN IN-SPACE TRANSPORTATION WITH TETHER TECHNOLOGY



Doctoral Meeting
Admission to the Third Year
5th – 6th of September 2022

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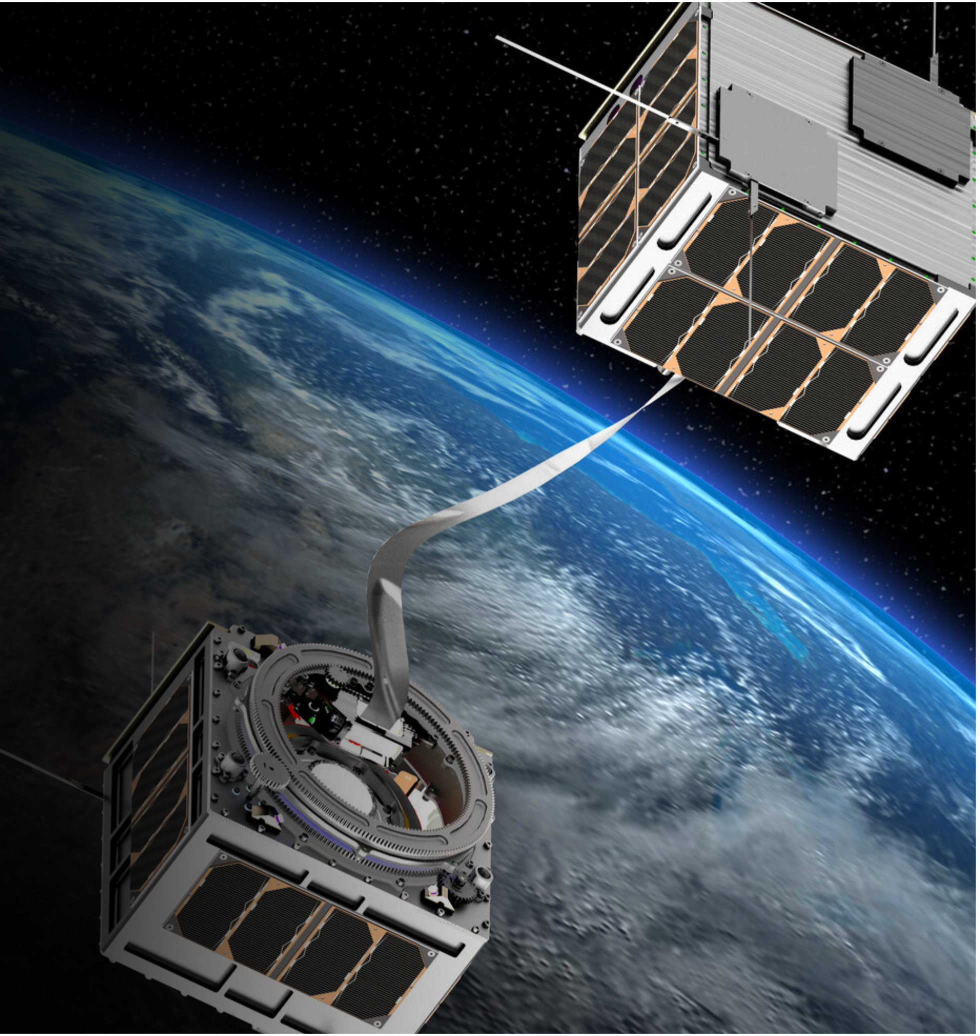


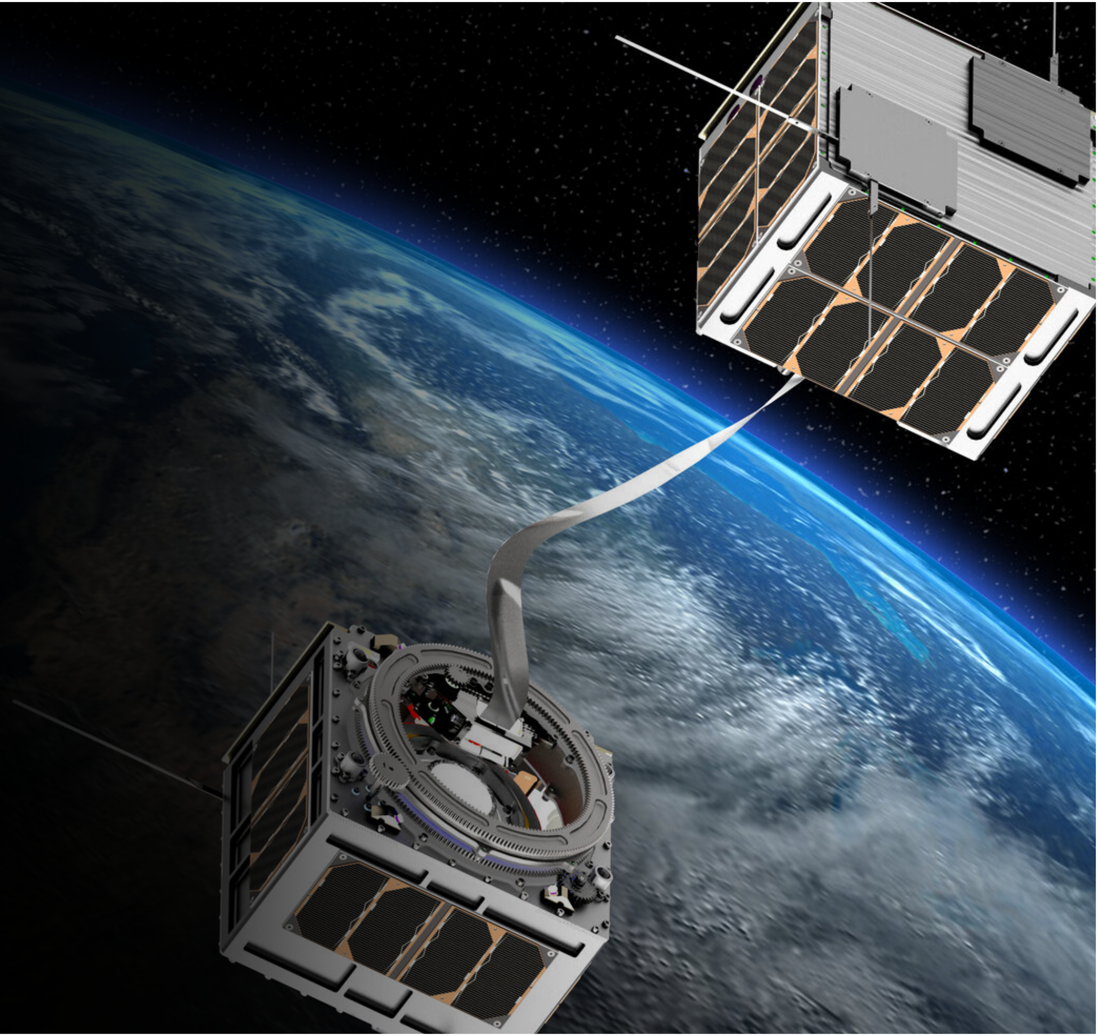
OVERVIEW

- *Space tethers*
- *Research project Goal*
- *International Programs*
- *Achieved Goals*

1. *ET PACK Program*
   - *1.1 Spool and Spooling Machine*
   - *1.2 Tape Mechanical Properties*
   - *1.3 Deployer Functional tests*

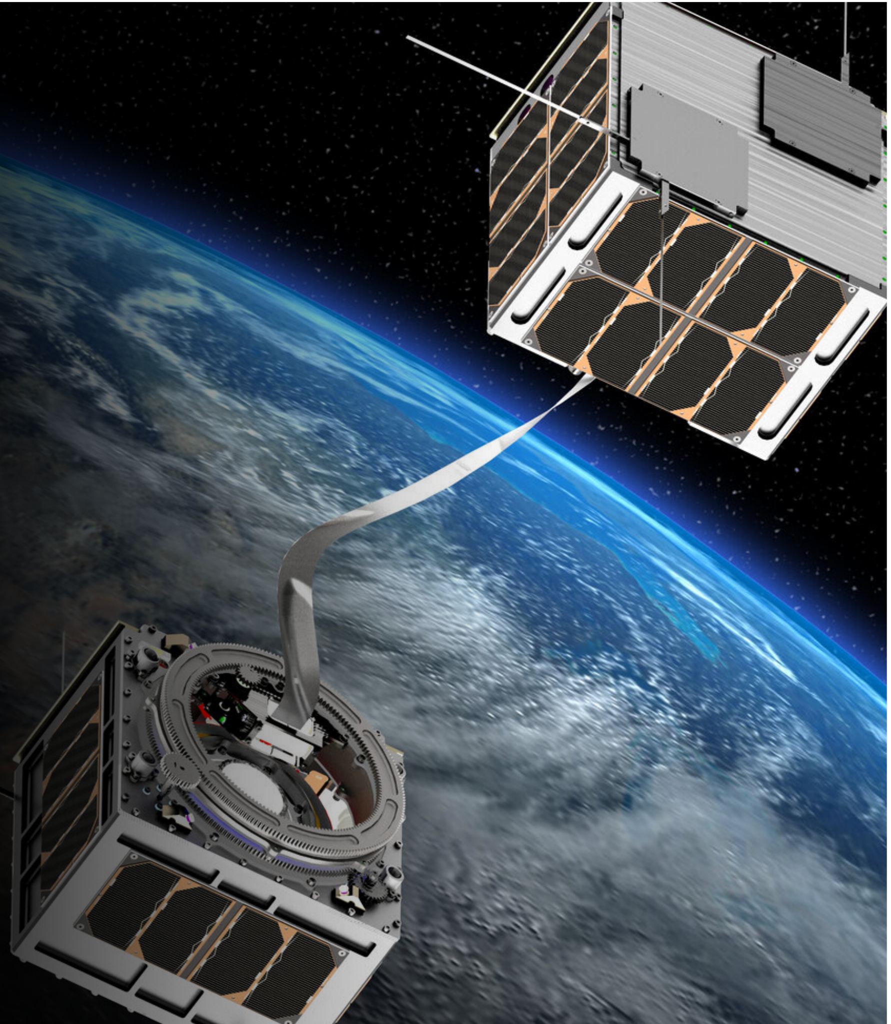
2. *Iperdrone.1 Program*
   - *2.1 Baseline Design*
   - *2.2 Control Law*

- *Future Developments*
- *Pubblications*



SPACE TETHERS

- *A Tethered Satellite is coupled by a long cable to another mass or spacecraft.*
- *Tethers can be Inert or Electrodynamic*
- *Tethered satellites provide propellant-free propulsion.*



What kind of missions a Tether System can be used for?

- De-orbiting end of life satellites
- Re-boosting LEO satellites
- Re-entering payload from space

RESEARCH PROJECT GOAL

Demonstrate different configurations of Tether Systems to:

1. overcome the limitations of rocket propulsions,
2. enable new classes of missions currently unaffordable or infeasible,
3. significantly advance the tether technology towards an operational level,
4. establish a deeper understanding of critical processes and technologies for improving Tether Systems in the future.

INTERNATIONAL PROGRAMS

- ET PACK

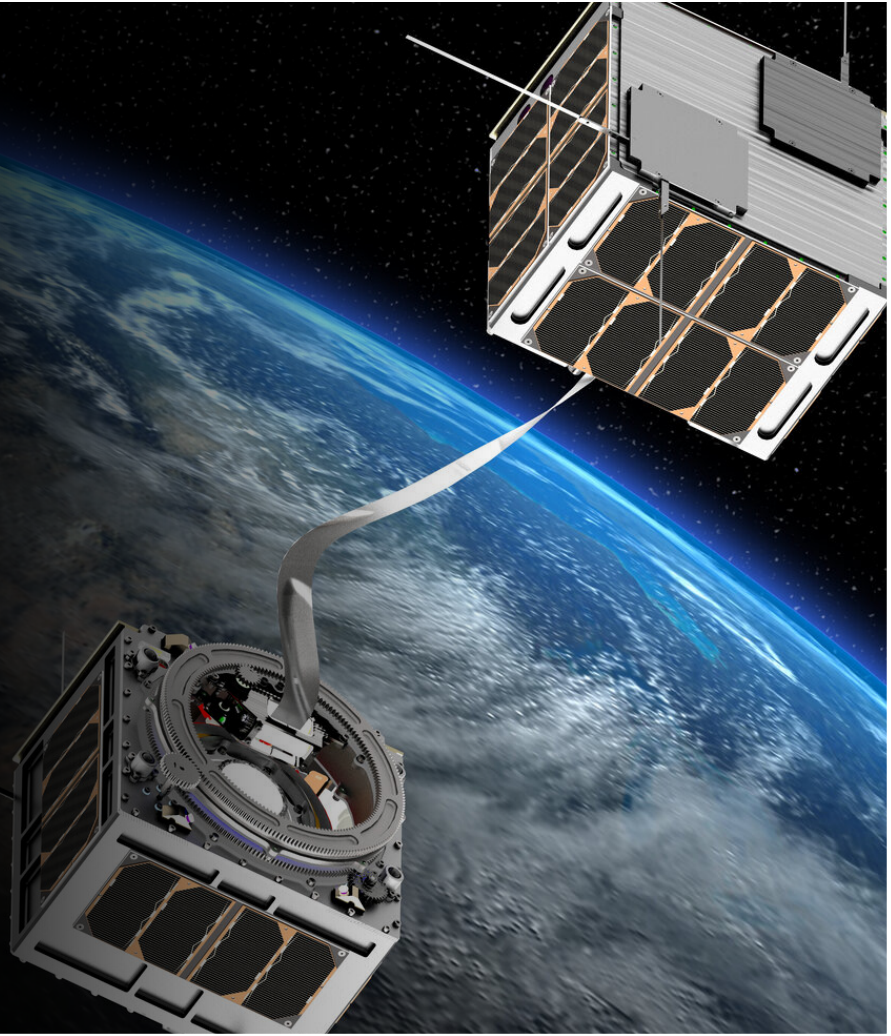
Design, development and tests of a propellant-free Electrodynamic Tether Kit to be mounted on satellites prior to launch and to be deployed at the end of the satellite operational life.

- IPERDRONE.1

Design and development of a Small Space Deployment Inert Tether System for de-orbiting a space drone (reentry capsule) with a minimum impact on the space environment from the International Space Station (ISS)

- INTERNET IN SPACE

Development of a new technology based on the use of an Electrodynamic Tether System for reboosting satellites in LEO orbits and for the compensation of the Aerodynamic Drag



ACHIEVED GOALS

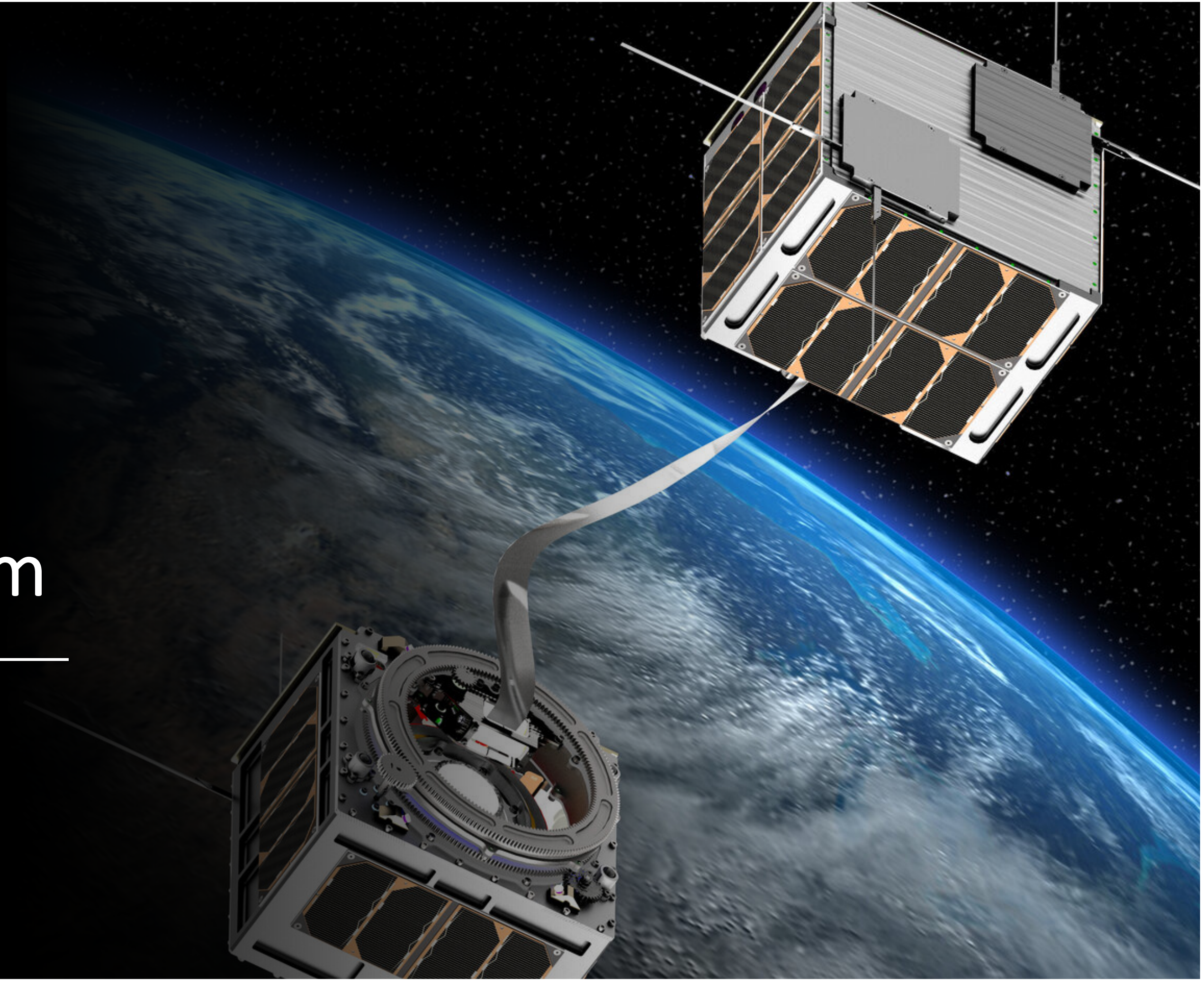
ET PACK Program

- Detailed Deployer Design: a) Spool design, b) Tape Mechanical properties definition, c) Internal components design;
- Checking of the deployer functionality through deployment functional tests

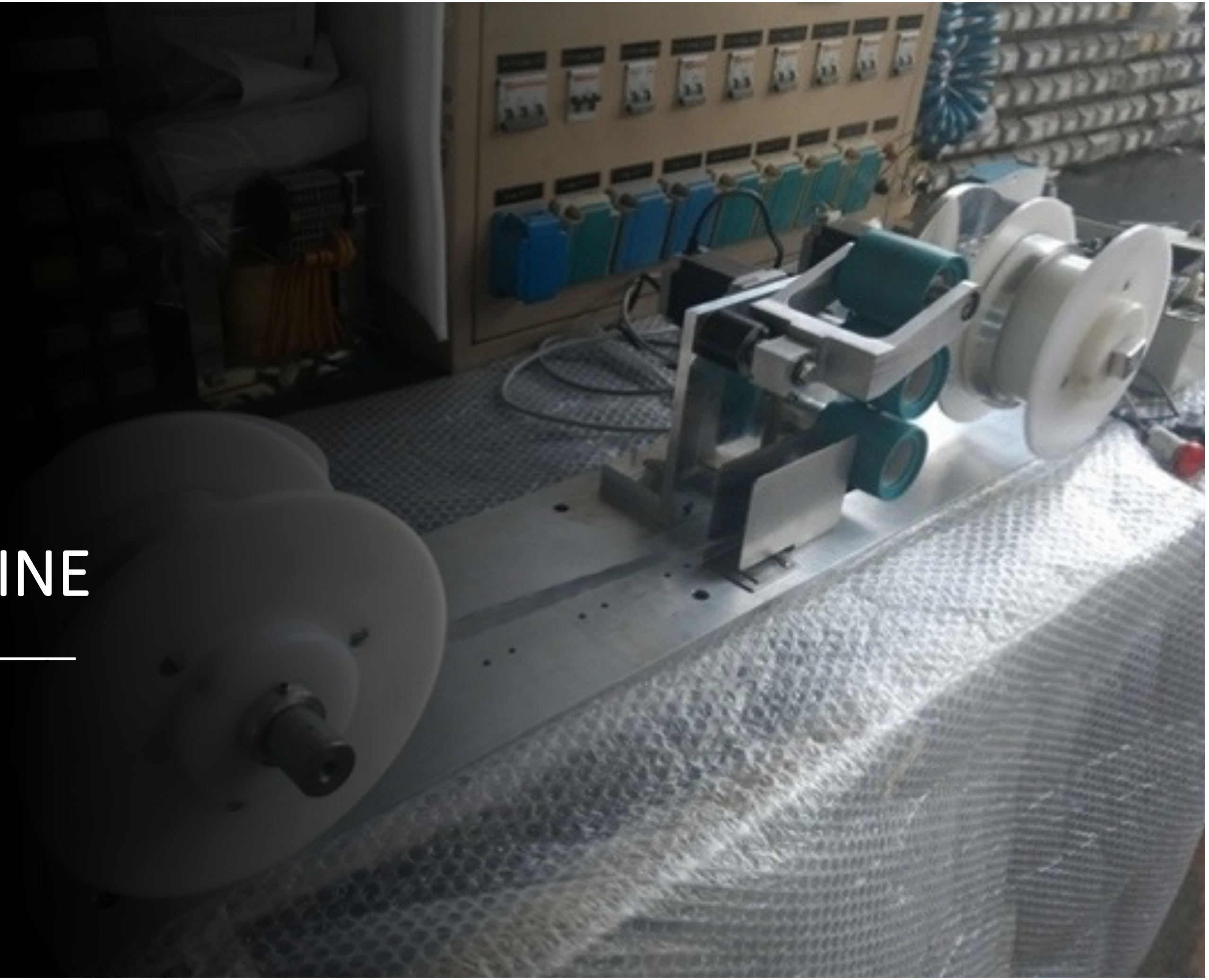
IPERDRONE.1 Program

- Tethered drone deployment analysis, respecting ISS safety requirements and phase-A design
- S/W design: developing control laws for tracking the deployment reference trajectory, in order to satisfy the required ΔV for initiating de-orbiting

ET PACK Program



SPOOL AND SPOOLING MACHINE



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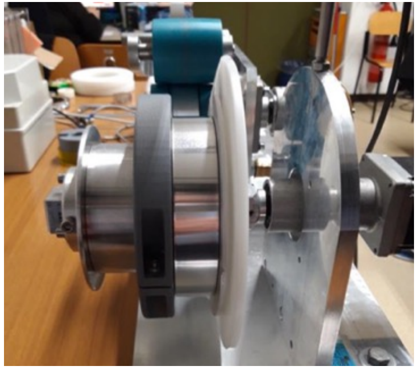
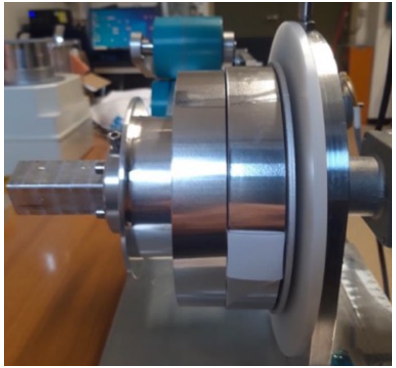
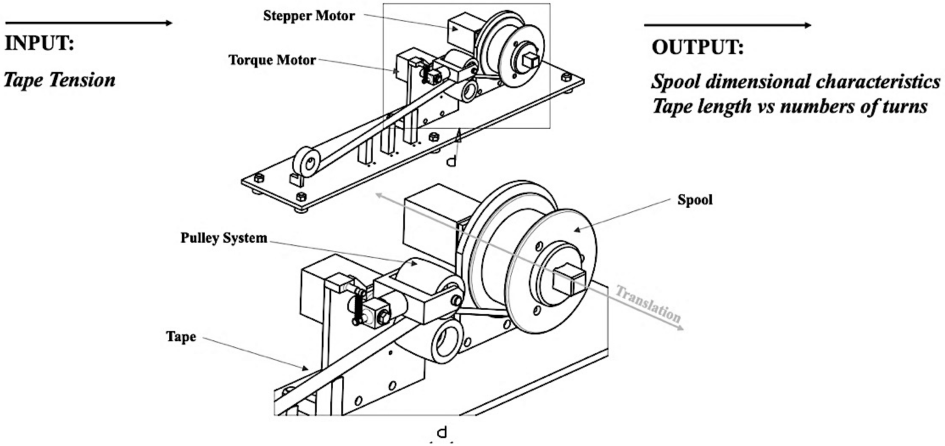
DESIGN

SPOOL AND SPOOLING MACHINE

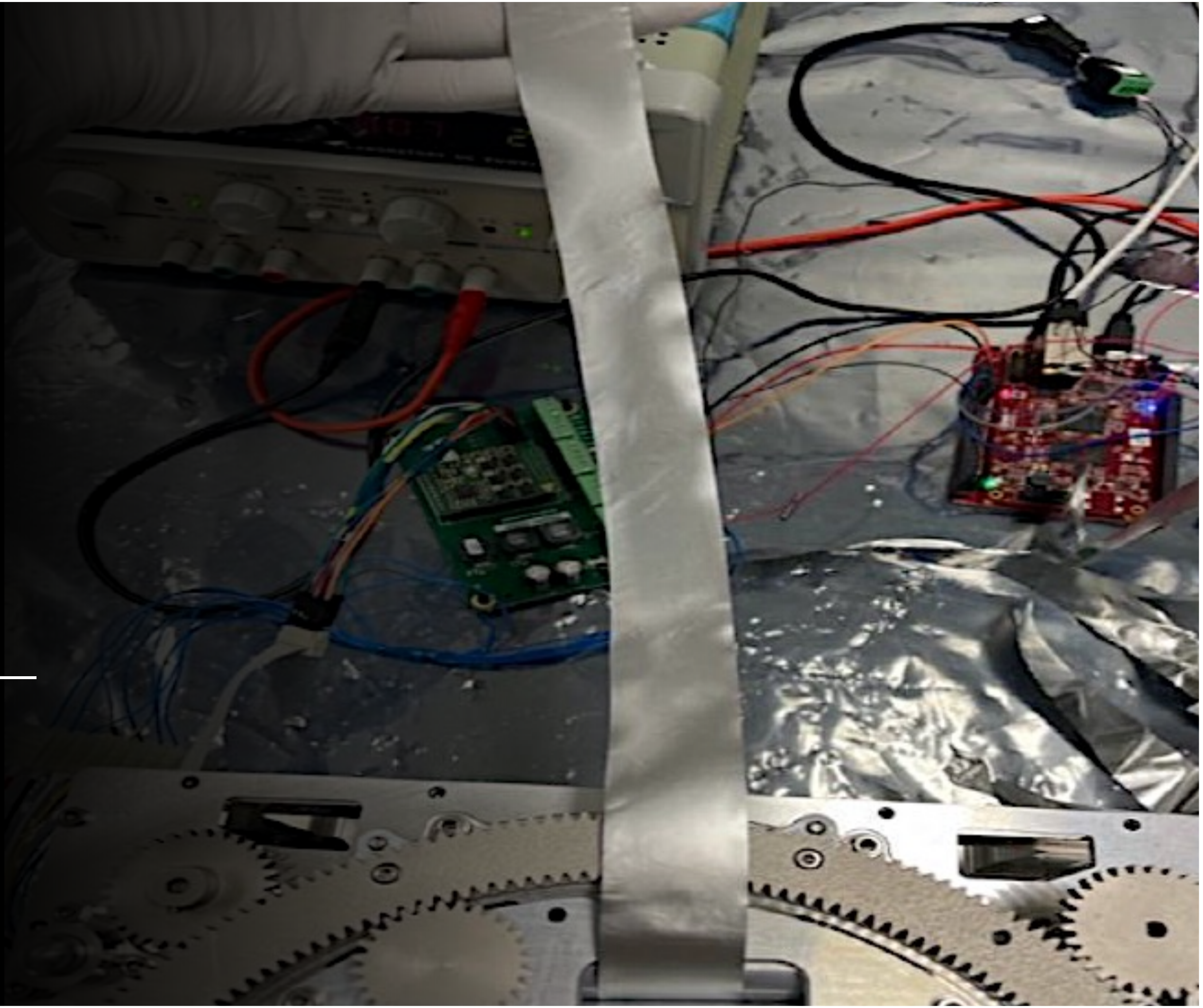




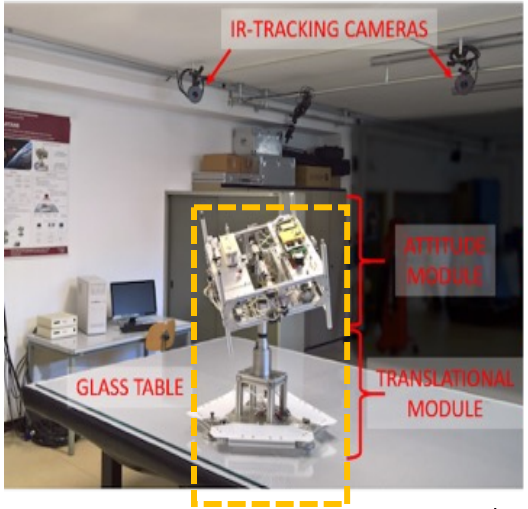


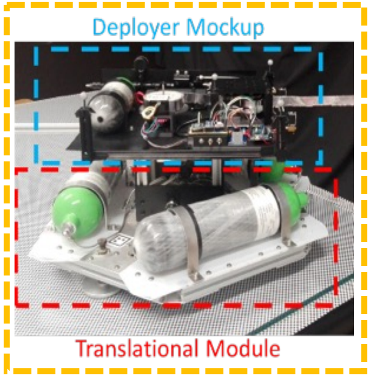
- **Spool:** Investigation of the spool design in term of spool type and dimensions according to the volume available in the deorbiting kit. The trade off analysis led to the selection of a stationary spool with 3 stacked coils and parallel spooling
- **Spooling Machine:** the machine controls the tether tension, gives the relationship between the tether length and the number of tape turns . The spooling machine is accurate in maintaining the tape tension and in keeping the coils aligned. It computes accurately (within 1%) the spooled tape length using the encoder of the stepper motor and the coil diameter measured by the laser sensor.

TAPE MECHANICAL PROPERTIES



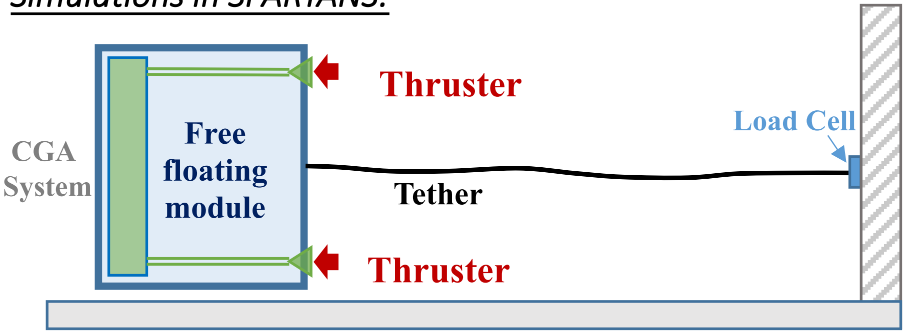
TAPE MECHANICAL PROPERTIES





SPARTANS Facility

Simulations in SPARTANS:

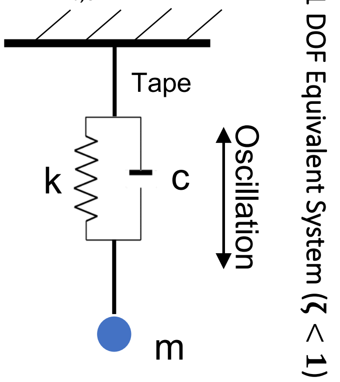


Setup

Tests:

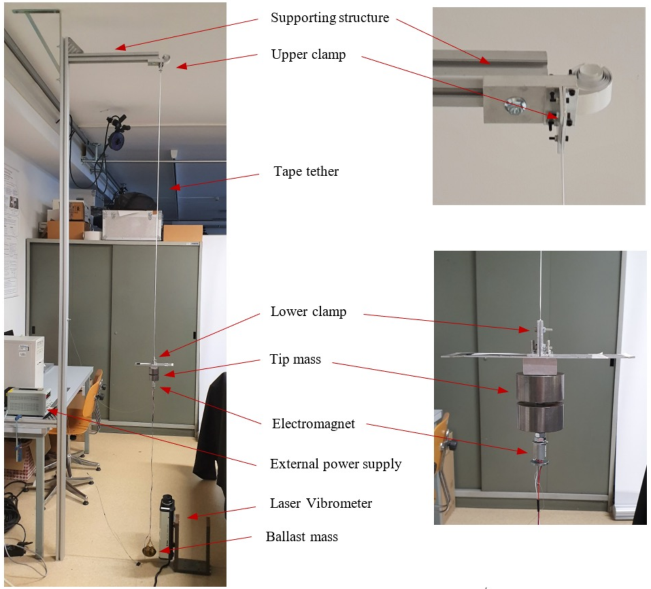
The tether with the Tip Mass attached to the free end was modelled as:
1 Degree of Freedom (DOF) 2nd order underdamped system ($\zeta < 1$) with:

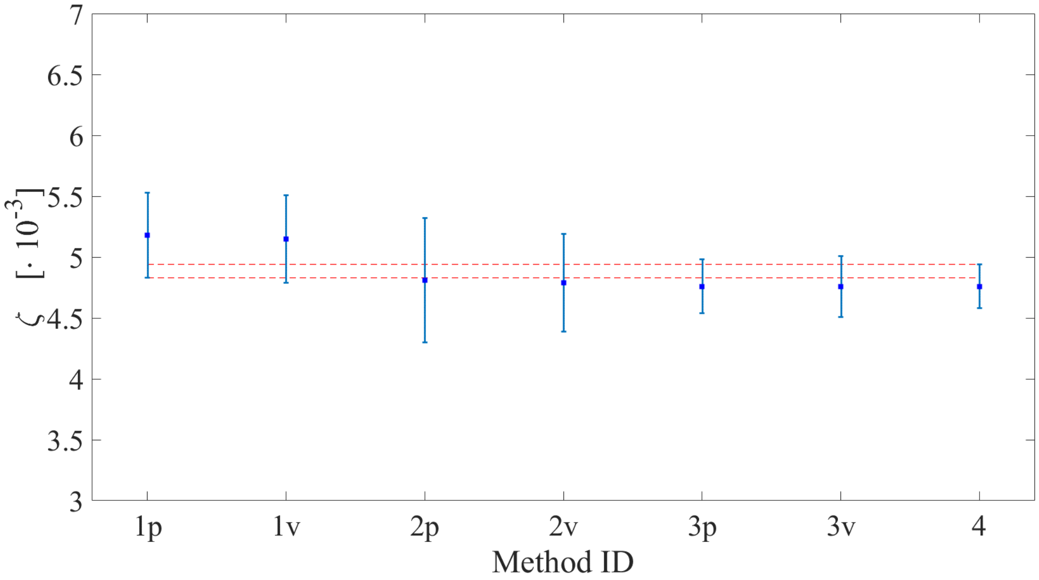
- *initial displacement with respect to the equilibrium position:* $x_{l,0}$
- *null initial velocity:* $\dot{x}_{l,0}$



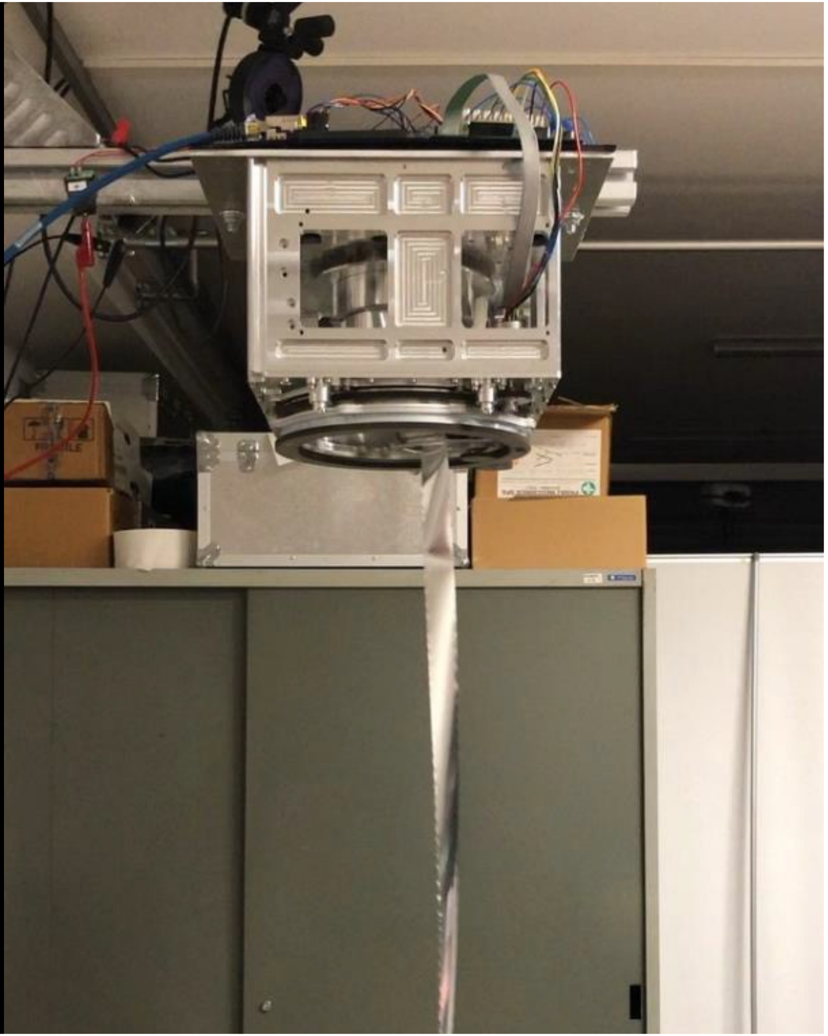
DAMPING COEFFICIENT
UNCERTAINTY ANALYSIS

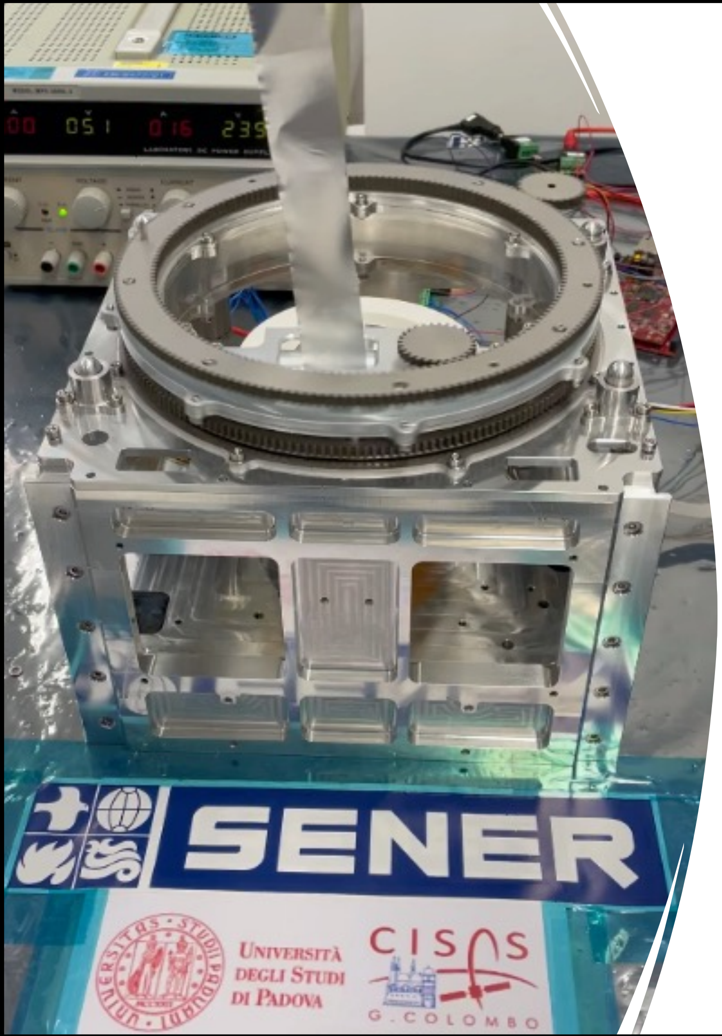
	Method	*ID*	*Damping Ratio* $\bar{\zeta}$ [$\cdot \mathbf{10^{-3}}$]	*Extended Uncertainty (95%)*
1°	Non-linear regression on peaks (p) and valleys (v) envelop	1p	5.18	0.35
		1v	5.15	0.36
2°	Logarithmic decrement on peaks (p) and valleys (v)	2p	4.81	0.51
		2v	4.79	0.40
3°	Linear regression on peaks (p) and valleys (v) envelop	3p	4.76	0.22
		3v	4.76	0.25





ET PACK DEPLOYER: FUNCTIONAL TESTS





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TESTS

- Deployment tests are meant for checking the ability of the DM prototype and its pulleys system to deploy smoothly different sections of tape made of 40-µm-thick bare Aluminum and 50-µm PEEK.
- We conducted a number of deployment tests on representative tape lengths to evaluate the system functionality and in particular to check the performance with regards to the following points:

1. Specific Deployment Velocities
2. Transition between the Aluminium and Peek sections of tape
3. Velocity ramp up from zero to 500 RPM of orbitator motor.

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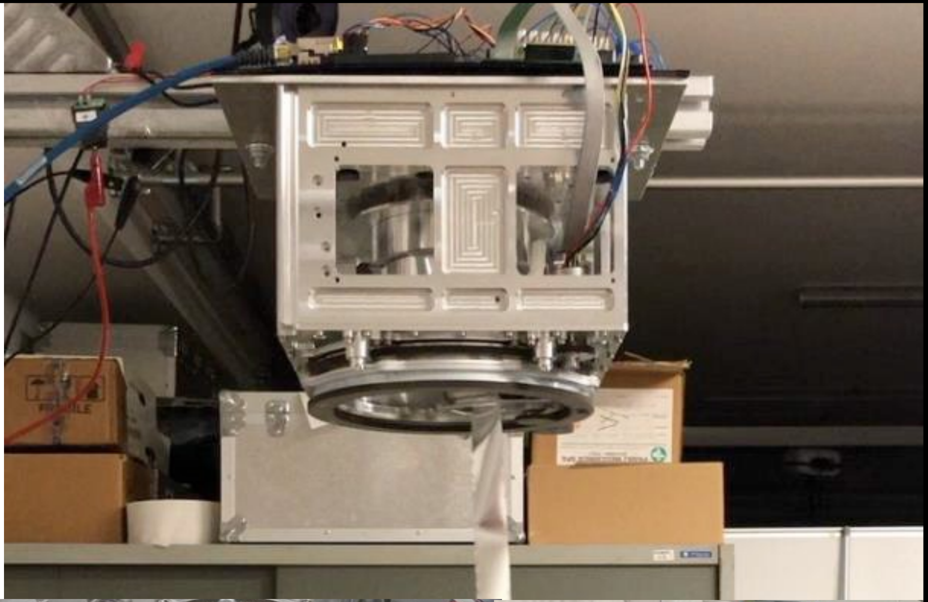
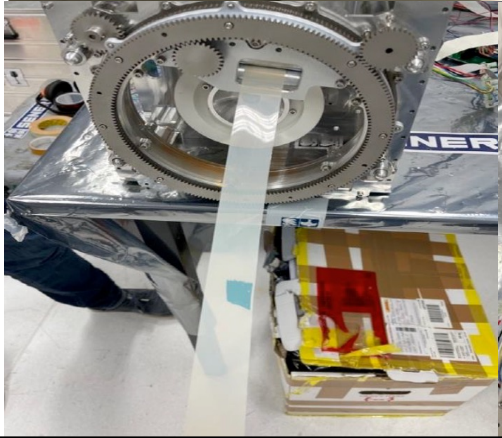
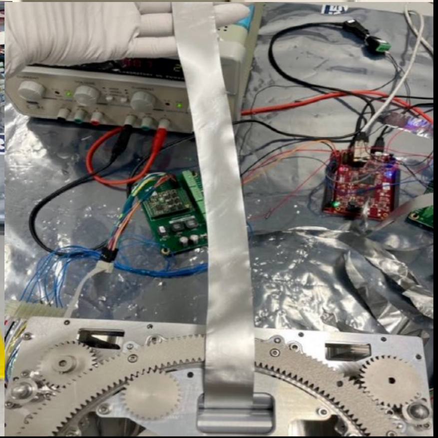
TEST OF SPECIFIC VELOCITIES

- Tapes were tested at speeds corresponding to the maximum, prevalent, and minimum values of the deployment profiles.
- Table summarizes the values used for the tests, i.e., the orbitator motor rotational speed and the exit velocity of the tape.

Velocity	*Motor velocity*	*Linear Tape velocity*	*Note*
Min	*30*	*0.024*	*Small vel. flutuations*
Prevalent	*80*	*0.064*	*Smooth and stable*
Max	*550*	*0.44*	*Smooth and stable*







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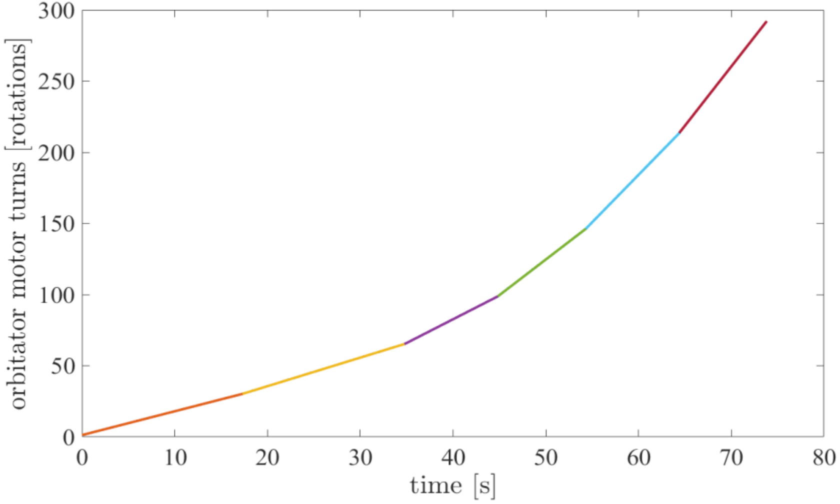
TRANSITION BETWEEN TAPE MATERIALS

- Peek and Aluminium joined together (with glue)
- Test conducted at a prevalence velocity of 80 rpm to test the change in tape thickness is from 50 µm to 40 µm
- These tests proved that there are no issues related to the transition between the two materials;
- The drive pulleys can handle the transition without any problem



Commanded rotational velocity compared to the actual velocity	*Imposed angular velocity [rpm]*	*Measured angular velocity [rpm] (99,7% confidence level)*
1	100	100,4 ± _0,1
2	120	120,3 ± _0,1
3	200	199,9 ± _0,2
4	300	300,2 ± _0,2
5	400	400,2 ± _0,3
6	500	499,6 ± _0,1

RAMP-UP

- The velocity ramp-up test is representative of the initial phase of deployment.
- The test was done up to a rotational velocity of the drive motor of 500 RPM that corresponds to a tape exit velocity of 0.4 m/s for an outer diameter of the coil of 110 mm.
- The test was carried out following a piece-wise velocity profile in order to observe the behaviour at different speeds.
- The rotational speed of the orbitator motor commanded during the test and measured by the motor encoder is shown in the table.

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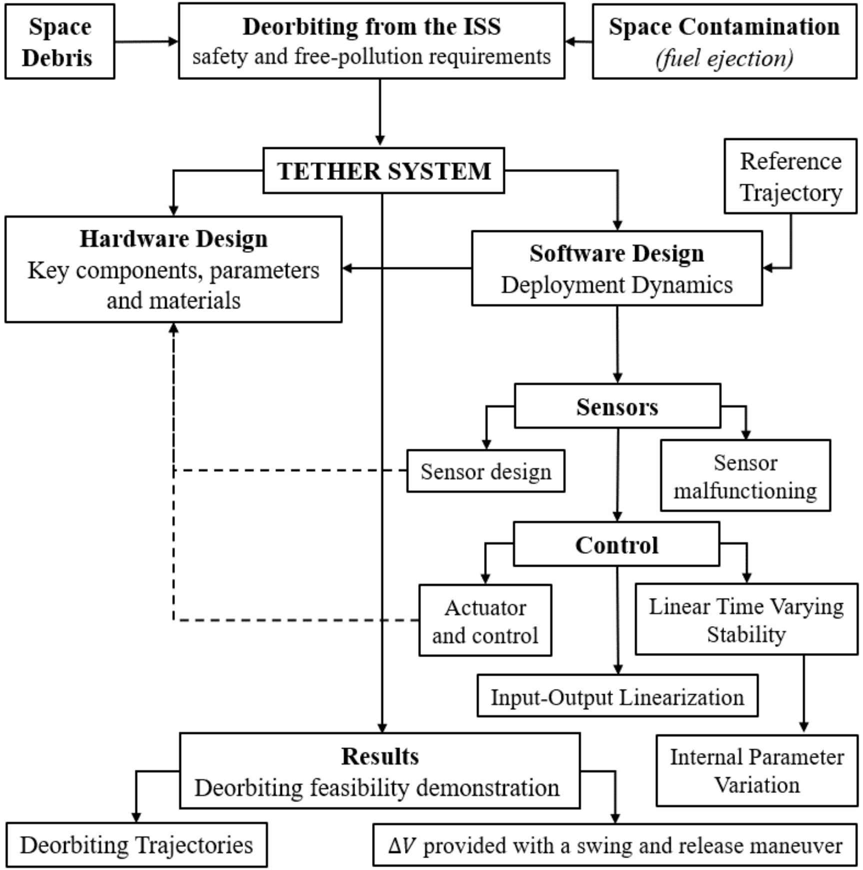
DEPLOYER FUNCTIONAL TESTS
RESULTS

IPERDRONE.1

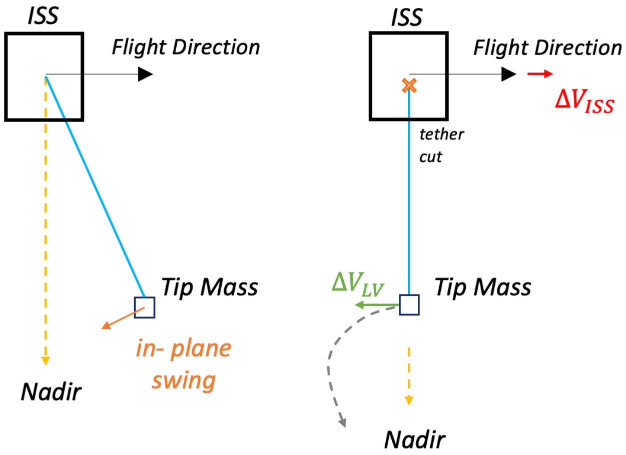
BASELINE DESIGN

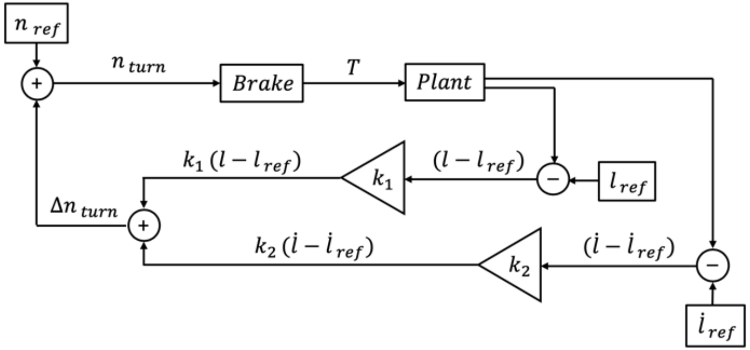
- The aim of IPERDRONE.1 mission is the development and the validation of key technologies able to provide a safe and controlled re-entry of a payload from the ISS.
- These technologies involve an adequate combination of propulsion systems:
    1. A de-orbit inert tether system, for the initial critical phase close to the ISS,
    2. A classic chemical propulsion system for the final re-entry.
- This deorbiting strategy give the possibility to operate with two different concepts, one passive (Tether System) and one active (Chemical Propulsion System).

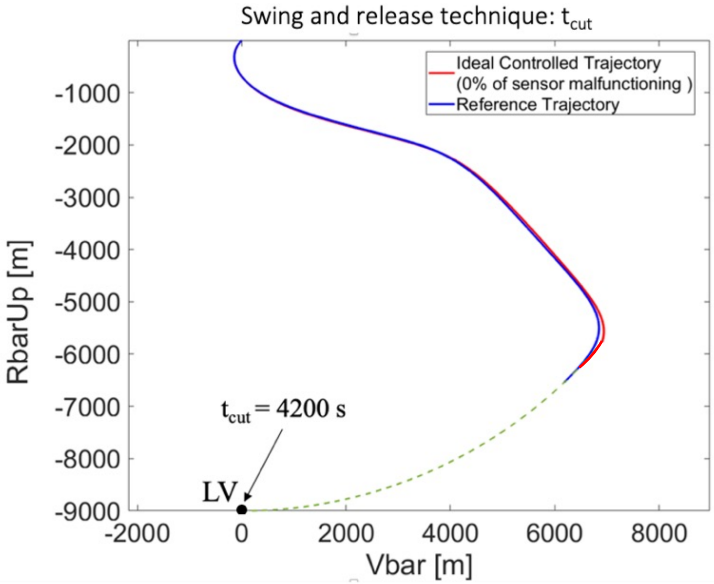


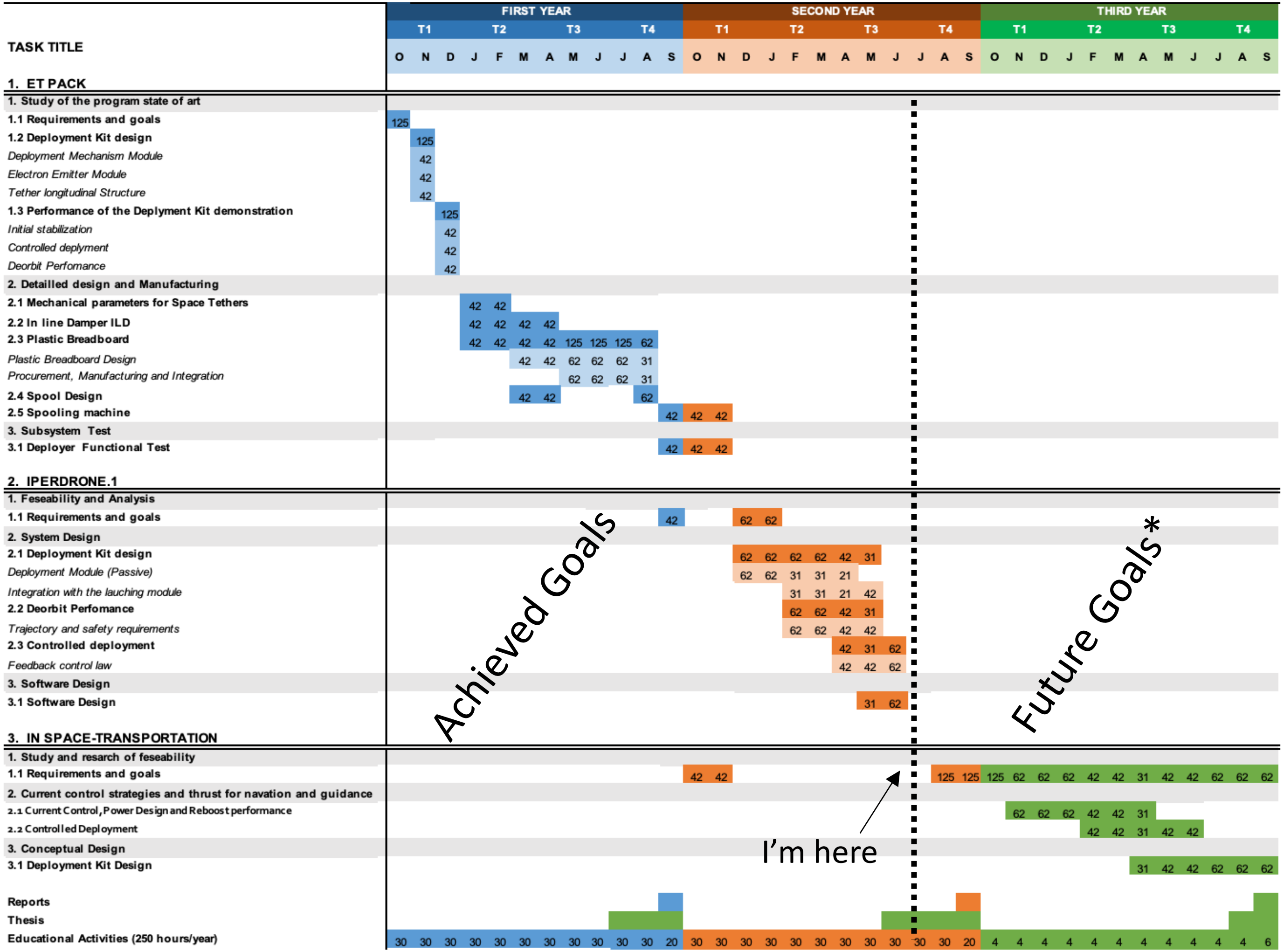
CONTROL LAW

- *Based on the swing and release technique*









*Future Research Project Goals

INTERNET IN SPACE

- Development of current control strategies and therefore thrust for navigation and guidance of satellites maintained in their original orbit by Electrodynamic Tether Systems
- Developing a mass-efficient system that can generate the desired thrust for applications of great future interest such as LEO satellite constellations

PUBLICATIONS

[1] *Brunello A., Valmorbida A., Lorenzini E., Cantoni S., De Stefano Fumo M., Fedele A.,Gardi R., Votta R., (2020), Deorbiting small satellites from the ISS using a tether system, (2021), CEAS Space Journal, 13, 10.1007/s12567-020-00337-1.*

[2] *Sarego G., Olivieri L., Valmorbida A., Brunello A., Lorenzini E., Castellani L., Urgoiti E., Ortega A., Motta G., Sanchez-Arriaga, G., (2021), Deployment requirements for deorbiting electrodynamic tether technology, (2021), CEAS Space Journal. 10.1007/s12567-021-00349-5.*

[3] *Brunello A., Valmorbida A., Lorenzini E., Cantoni S., De Stefano Fumo M., Fedele A.,Gardi R., Votta R., (2020), Tethered Satellite-Controlled Re-Entry Dynamics From the International Space Station, (2021), IEEE Journal on Miniaturization for Air and Space Systems. PP. 1-1. 10.1109/JMASS.2020.3046182.*

[4] *Valmorbida A., Olivieri L., Brunello A., Sarego G., Sànchez-Arriaga G., Lorenzini E., (2021) Enabling Technologies Validation For Deorbiting Devices Using Electrodynamic Tethers, (2021), 72nd International Astronautical Congress 2021, Conference Proceedings.*

[5] *Valmorbida A., Olivieri L., Sarego G., Brunello A., Vertuani D., Lorenzini E.,(2021), Experimental Validation of a Deployment Mechanism for Tape-tethered Satellites*, (2021), *IEEE International Workshop on Metrology for Aerospace, Proseedings of the virtual conference*.

[6] *Brunello A., Olivieri L., Sarego G., Valmorbida A., Lungavia E., Lorenzini E., (2021), Space Tethers: Parameters Reconstruction and Tests, (2021, IEEE International Workshop on Metrology for Aerospace, Proseedings of the virtual conference*

[7] *Valmorbida A., Brunello A., Olivieri L., Sarego G., Lion L., Pertile M., Lorenzini, (2021), Experimental Determination of Mechanical Characteristics of Tapes for Space Applications, (2021), Forum Internazionale delle Misure, Taromina, 15-19 September 2021, Conference Proceedings.*

[8] *Olivieri L., Brunello A., Sarego G., Valmorbida A., Lorenzini E.C, An in-line damper for tethers-in-space oscillations dissipation, (2021) Acta Astronautica, 189, pp. 559 – 566, DOI: 10.1016/j.actaastro.2021.09.012*

[9] *Sarego G., Bellio E., Caon A., Valmorbida A., Olivieri L., Brunello A., Colombatti G., Lorenzini E.C., Retrieval Strategies for Tethered Satellites, (2021) Proceedings of the International Astronautical Congress, IAC.*

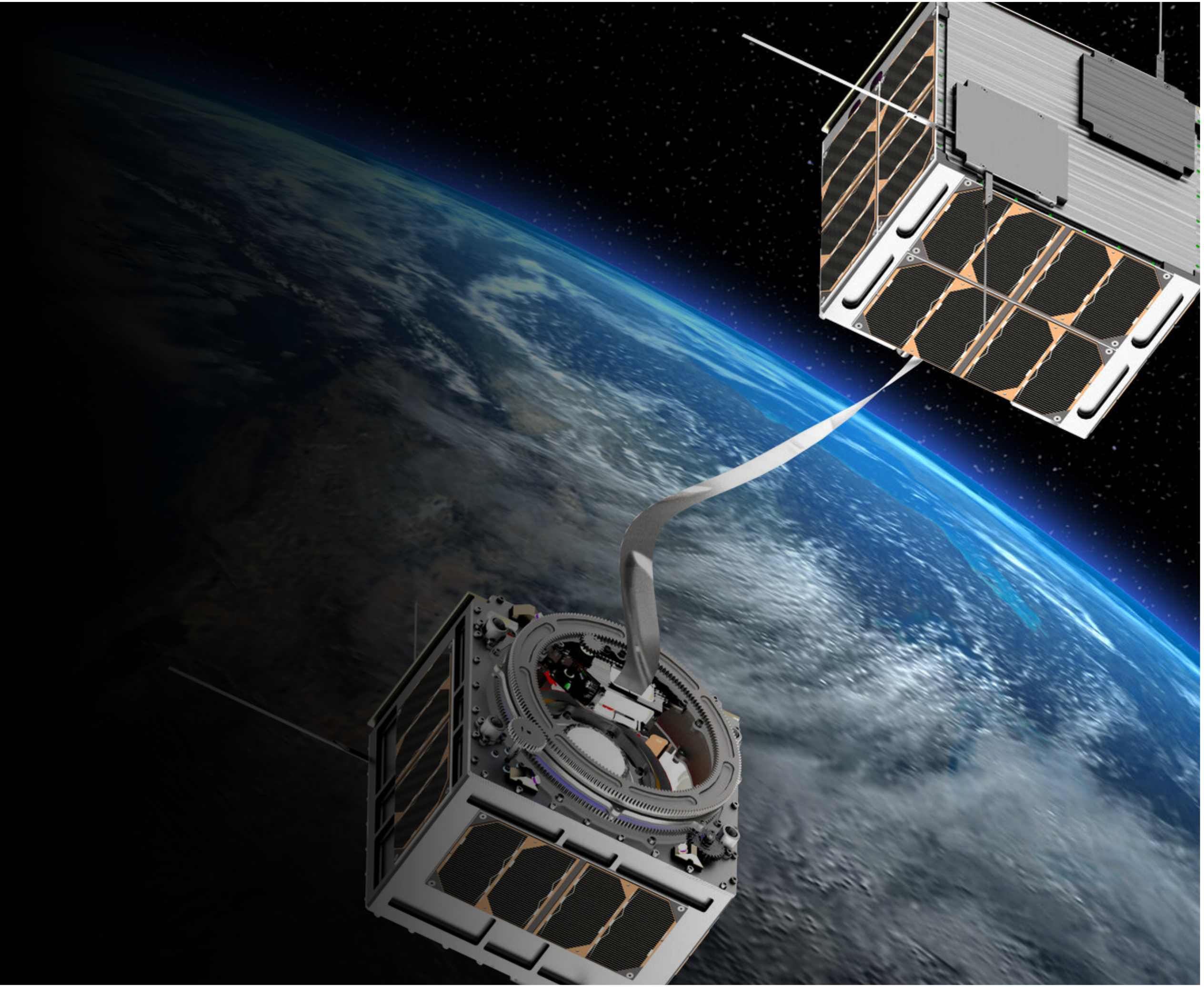
[10] *Sarego G., Olivieri L., Brunello A., Colombatti G., Valmorbida A., Lorenzini E.C., Sánchez-Arriaga G., Impact risk assessment of deorbiting strategies in low earth orbits, (2021) Accelerating Space Commerce, Exploration, and New Discovery conference, ASCEND 2021, art. no. AIAA 2021-4243, DOI: 10.2514/6.2021-4243*

[11] *Tarabini Castellani L., García González S., Ortega A., Madrid S., Lorenzini E.C., Olivieri L., Sarego G., Brunello A., Valmorbida A., Tajmar M., Drobny C., Wulfkuehler J.-P., Nerger R., Wätzig K., Shahsavani S., Sánchez-Arriaga G., Deorbit kit demonstration mission, (2022) Journal of Space Safety Engineering, DOI: 10.1016/j.jsse.2022.01.004.*

[12] *A. Valmorbida, L. Olivieri , A. Brunello , G. Sarego , G. Sánchez-Arriagac and E. C. Lorenzini, Validation of enabling technologies for deorbiting devices based on electrodynamic tethers, (2021), 72nd IAC Dubai, Extended version for Acta astronautica, On Review.*

[13] *A.Valmorbida, A. Brunello, L. Olivieri, S. Fortuna, G. Sarego, M. Pertile, E.C. Lorenzini, Measurement of mechanical characteristics of tape tethers for space applications, (2022), Accepted Paper for presentation at MetroAerospace2022.*

[14] *A. Brunello, S. Garcia -Gonzalez, A. Valmorbida, G. Sarego, L.Olivieri, S. Fortuna, E. C. Lorenzini, Deployment Functional Tests Of An Electrodynamic Tape For Space Debris Mitigation, (2022), Accepted Paper for presentation at IAC2022*



THANK YOU!