1222 · 2022
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UNIVERSITÀ DEGLI STUDI DI PADOVA

Green in-space transportation with tether technology

Alice Brunello - 36th Cycle

Supervisor: Prof. Enrico Lorenzini
Co-Supervisior: Dott. Andrea Valmorbida
Spanish Co-Supervisior: Prof. Gonzalo Sanchez Arriaga

Admission to II year - Settembre 8-9, 2021

1. Research Project Focus

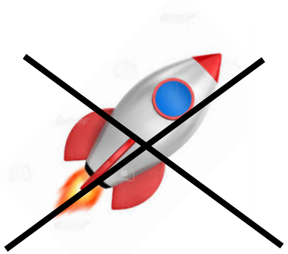
Analyze different configurations of Tether Systems to:

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

2. Research Project Goal

Demonstrate the capability of the tether technology to:

- provide robust, safe, propellant-less propulsion
  (both as de-orbiting and orbit-raising device)

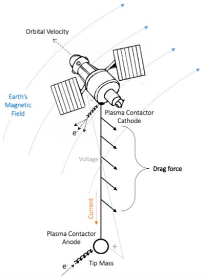


- fully characterize the performance of an integrated tether propulsion system

Introduction: INTERNATIONAL PROJECT

1. ET PACK

E.T PACK



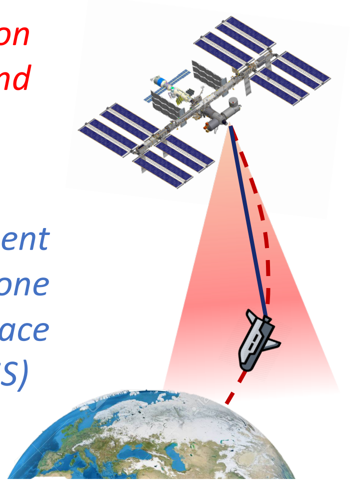
Design, development and tests of a propellant-free Electrodynamic Tether Kit prototype to be mounted on satellites prior to launch and to be deployed at the end of the satellite operational life

2. IPERDRONE.1

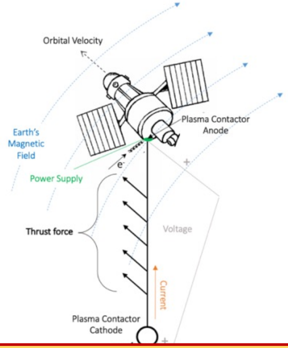
ASI Agenzia Spaziale Italiana

CIRA Centro Italiano Ricerche Aerospaziali

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)



3. INTERNET IN SPACE



Study 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

1. *Mechanical Parameters for Space Tethers*
2. *In Line Damper (ILD) Design*
3. *3D - printed Breadboard Design*
4. *Spool Design*

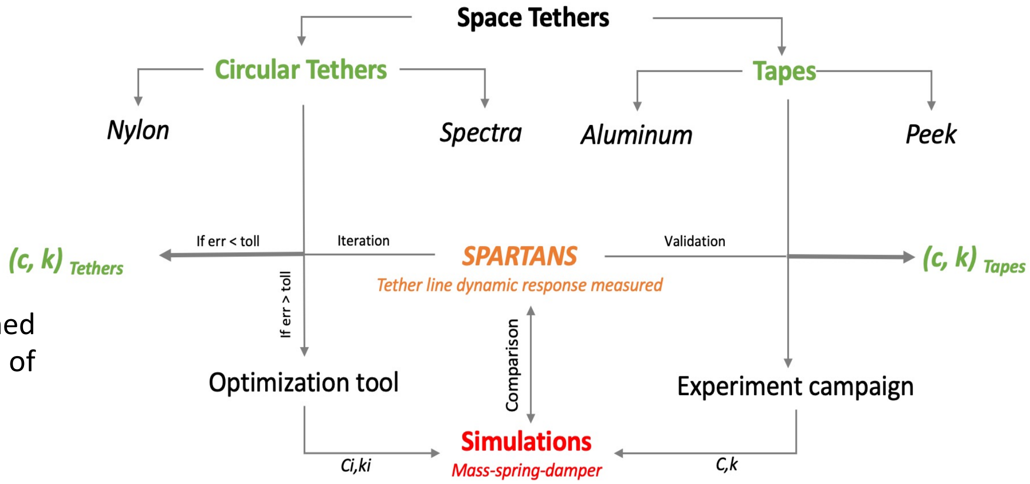
1. *Mechanical Parameters for Space Tethers*

Determination of Mechanical Parameters for Space Tethers : Damping and Stiffness coefficients

A. Brunello et al.,
"*Space tethers: parameters reconstruction and Tests*",
Metrology for Aerospace 2021

The paper illustrates the characterization of tether materials to find valid solutions for future space tether missions.

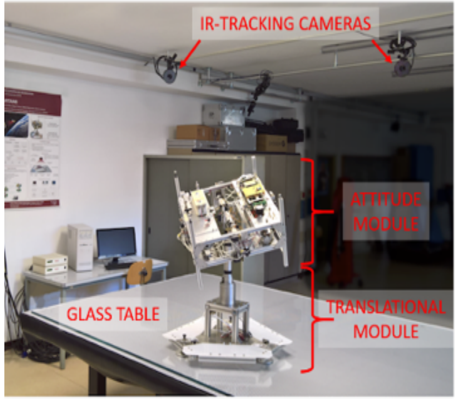
Elastic characteristics and damping coefficients were determined through a campaign of experiments and the measurement of tether-line dynamic responses.



Another Article will be presented at the "Forum Internazionale delle Misure 2021" :
"*Experimental Determination of Mechanical Characteristic of tape for Space Applications*"

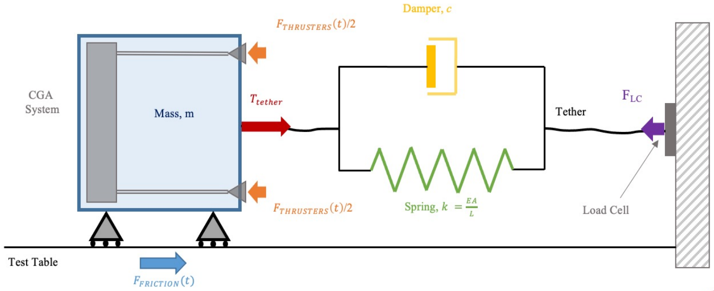
1. Mechanical Parameters for Space Tethers

- SPARTANS Facility



- H/W in the loop simulations

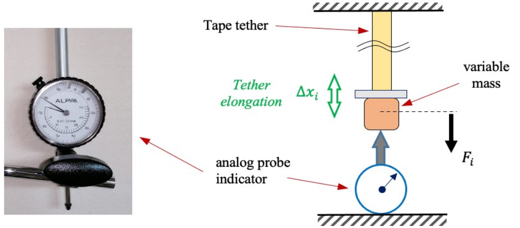
Mass-Spring-Damper equivalent System



Experimental Campaign for Tapes

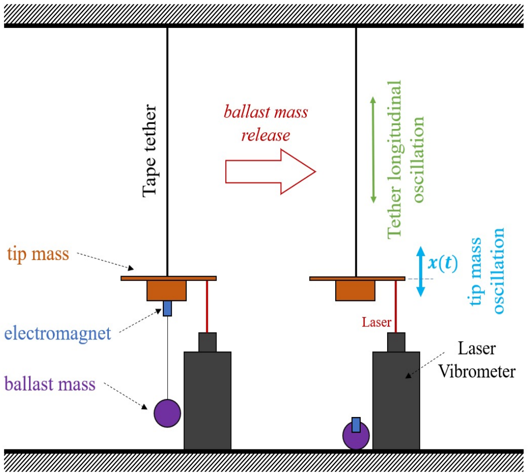
1. Young Modulus Determination

Tape elongations for different loading conditions using an Extensimeter

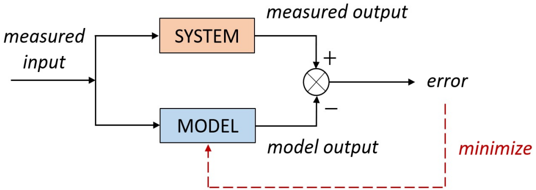


2. Damping Coefficient

A Laser vibrometer was used to determine the damping coeffcient c through the determination of the logaritmic decrement $\delta(t)$ of the time response spectrum.



Optimization Tool for Circular Tethers

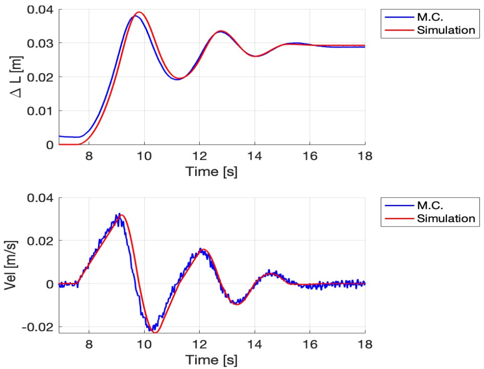


1. Mechanical Parameters for Space Tethers: RESULTS

1. Nylon

$k = 167.6\ 4 N/m$
$c = 8\ Ns/m$

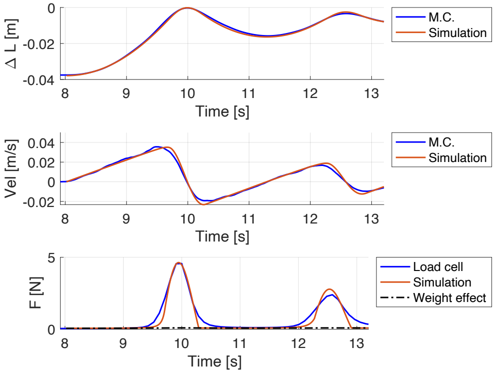
All discrepancies between experiments and simulations are related to the residual friction effects between the translation module and the test table.



2. SPECTRA[TM]

$k = 753\ N/m$
$c = 35\ Ns/m$

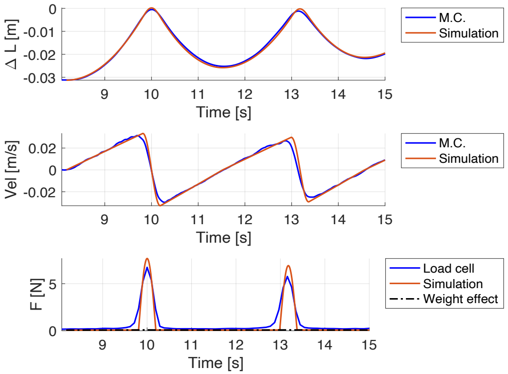
Due to the high value of the damping coefficient the braided structed seems to be more efficient in damping oscillations.



3. PEEK

$k = 18190.91\ N/m$
$c = 0.37\ Ns/m$

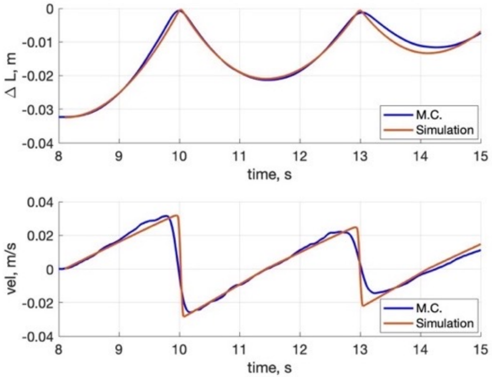
Discrepancies between experiments and simulation are very small; the proposed system is representative for verifying the PEEK tape mechanical parameters and its performance for tethered applications.



4. Aluminum

$k = 24734.25\ N/m$
$c = 48.16\ Ns/m$

Discrepancies between experiments and simulation are related to the higher stiffness of the investigated sample, that is comparable with the experimental setup equivalent stiffness. Different phenomena are present and the model implemented in the simulations is only partially representative.



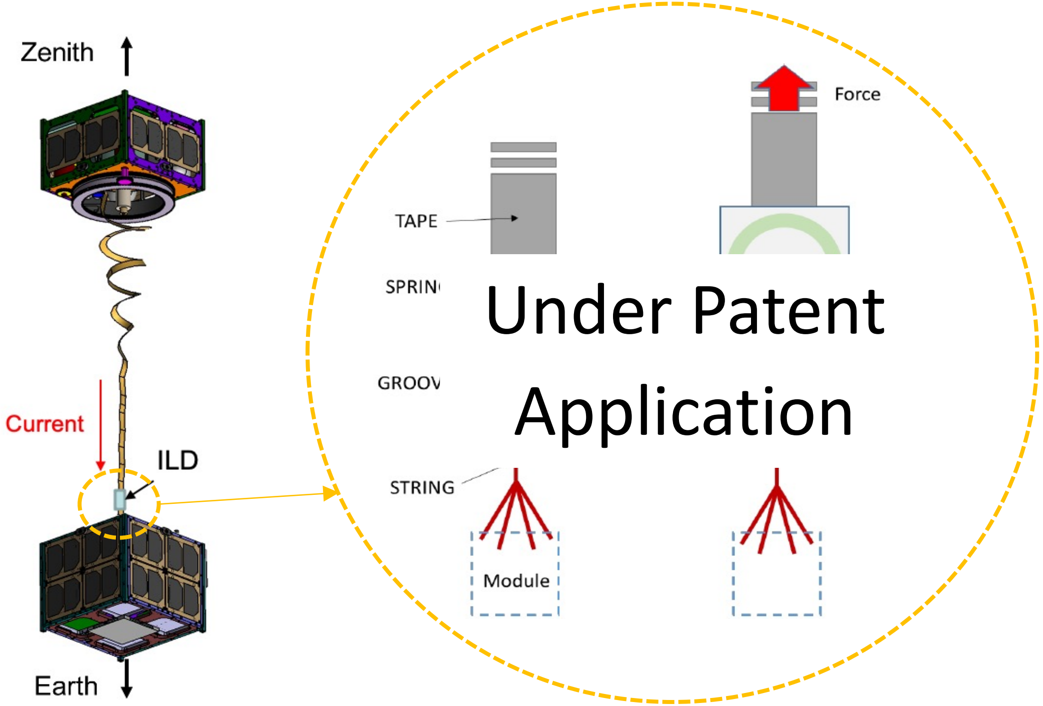
2. In Line Damper (ILD) Design

Contribution to the design and manufacturing of an In-Line-Damper for damping tether oscillations and reducing loads that are transmitted to the bottom module during the deployment phase

The ILD will be used to damp tether oscillations that can affect the deployer maneuver and the deployment trajectory and optimize performance of the mechanism in the deorbiting system.

- The ILD must guarantee:
  1. Electrical continuity
  2. Mechanical continuity

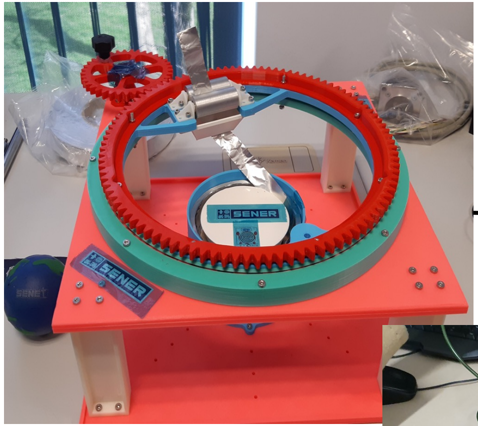
- The ILD must be miniaturized



3. 3D-printed Breadboard Design

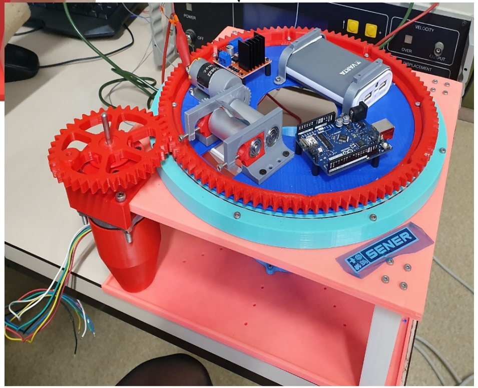
Breadboard Design and Manufacturing

- The BreadBoard is representative of the ET PACK Deployer in dimensions and volume.
- The structure is made of a 3D printing material (P430ABS)
- Plastic Breadboard Design include:
  - ✓ Hardware (structure, pulley mechanism, motors, sensors)
  - ✓ Software (Current control, motors Syncronization)
  - ✓ Determination of the best option for the tape extraction method for unwinding the inside tape spool
  - ✓ Identifications/solutions of critical aspects;



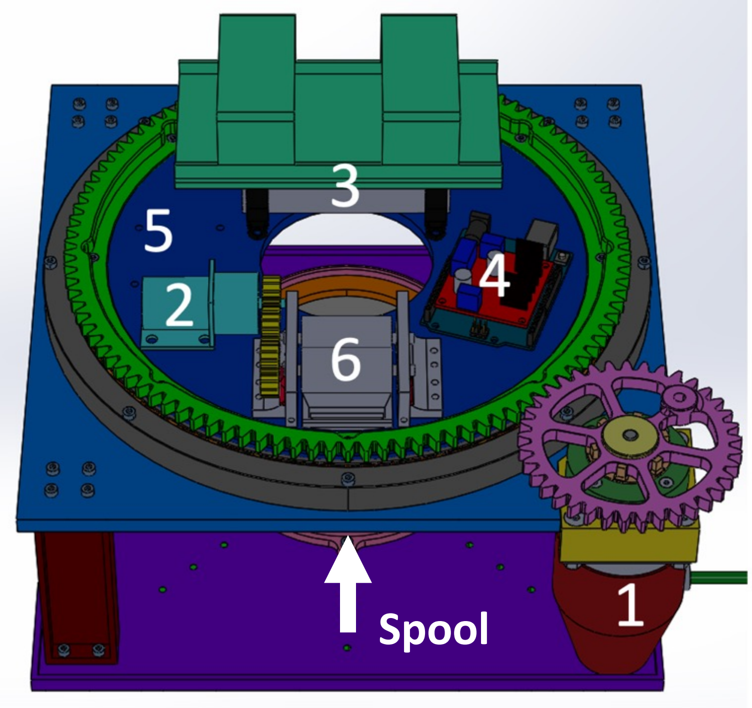
Operated Manually

Motorized



3. 3D-printed Breadboard Design

Breadboard Design and Manufacturing: Motorization

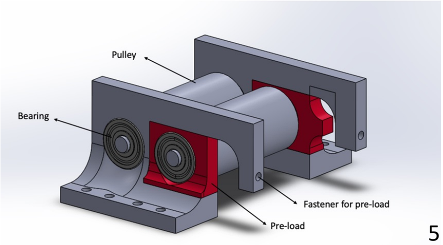


1. Stepper motor
2. Torque motor
3. Power Units
4. On-board data/commands handling
5. Support Plate
6. Pulleys Mechanism

1

2

3



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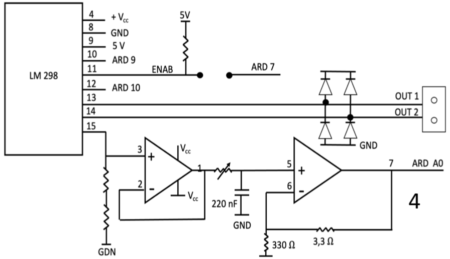

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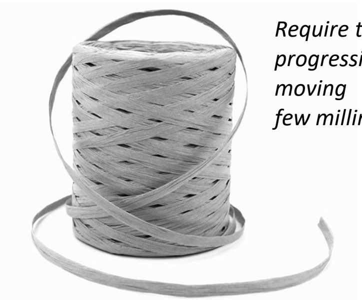
4. Spool Design

Tape Spool definition: shape and winding method

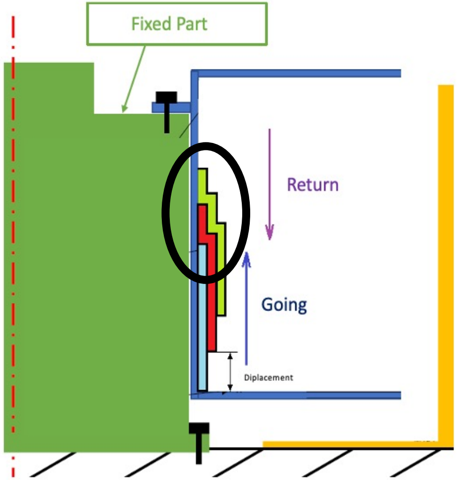


Require the tape to be progressively wound moving axially by a few millimeters

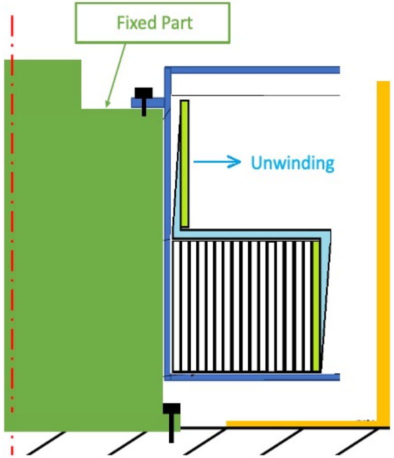
- ✓ Compact
- ✓ Resistant to launch load
- ✓ Safe
- X Big volume
- X Edge demaging

Type of Winding

«Staggered Spool»



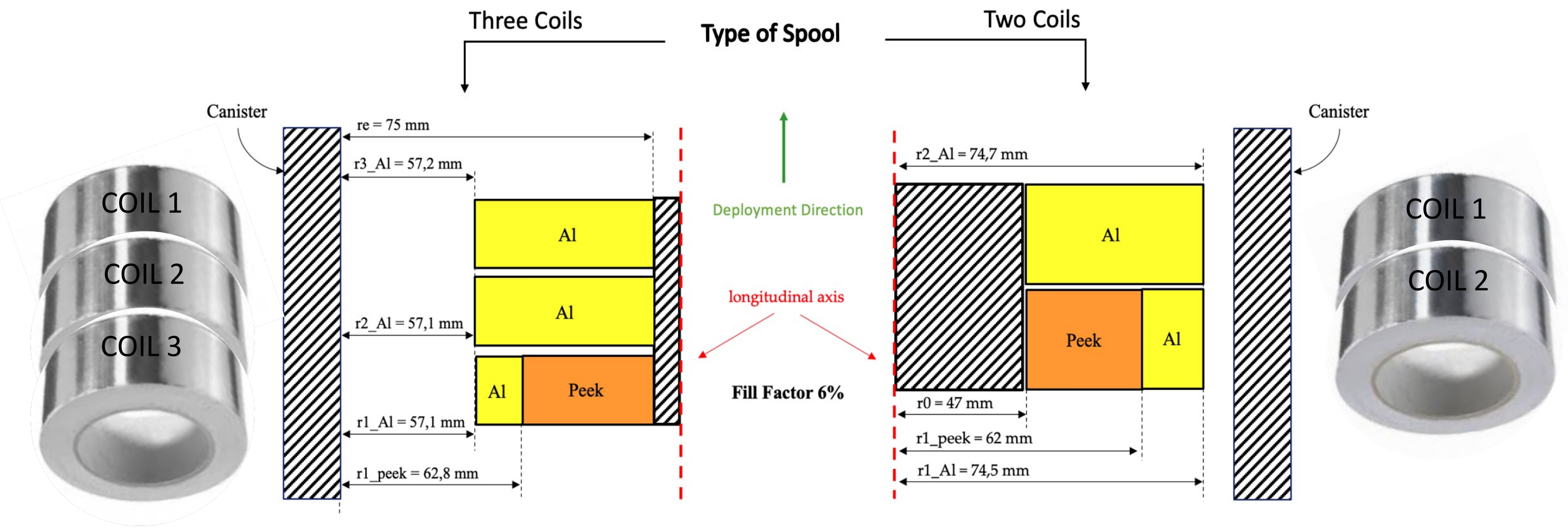
With Coils



Simpliest way to wrap a ribbon

- ✓ Compact with the desire level of tension
- ✓ Low Volume
- ✓ No edge demaging along the tether length
- X Need folds to pass from one coil to the next

Parallel Spool dimensions: Number of Coils



Necessity of future tests in order to verify the best solution

Università degli Studi di Padova

Schedule and Future Goals

		FIRST YEAR												SECOND YEAR												THIRD YEAR											
		T1			T2			T3			T4			T1			T2			T3			T4			T1			T2			T3			T4		
TASK TITLE	% OF TASK COMPLETE	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
ET PACK																																					
1. Study of the program state of art																																					
1.1 Requirements and goals	100%	125																																			
1.2 Deployment Kit design	100%		125																																		
Deployment Mechanism Module	100%		42																																		
Electron Emitter Module	100%		42																																		
Tether longitudinal Structure	100%		42																																		
1.3 Performance of the Deplyment Kit demonstration	100%			125																																	
Initial stabilization	100%			42																																	
Controlled deplyment	100%			42																																	
Deorbit Perfomance	100%			42																																	
2. Detailed design and Manufacturing																																					
2.1 Mechanical parameters for Space Tethers	100%				42	42																															
2.2 In line Damper ILD	100%				42	42	42	42																													
2.3 Plastic Breadboard	80%				42	42	42	42	125	125	125	62																									
Plastic Breadboard Design	100%						42	42	62	62	62	31																									
Procurement, Manufacturing and Integration	80%								62	62	62	31																									
2.4 Spool Design	80%						42	42				62																									
2.5 Spooling machine	0%												42	42	42																						
3. Subsystem Test																																					
3.1 Deployer Functional Test	0%												42	42	42																						
IPERDRONE.1																																					
1. Feseability and Analysis																																					
1.1 Requirements and goals	0%												42			62	62	62																			
2. System Design																																					
2.1 Deployment Kit design	0%															62	62	62	62	62	42	42															
Deployment Module (Passive)	0%															62	62	62	31	31																	
Integration with the lauching module	0%																		31	31	42	42															
2.2 Deorbit Perfomance	0%																		62	62	42	42															
Trajectory and safety requirements	0%																		62	62	42	42															
2.3 Controlled deployment	0%																				42	42	125	42	42												
Feedback control law	0%																				42	42	125	42	42												
3. Software Design																																					
3.1 Software Design	0%																							42	42												
IN SPACE-TRANSPORTATION																																					
1. Study and resarch of feseability																																					
1.1 Requirements and goals	0%													42	42									42	42	125	62	62	62	42	42	31	42	42	62	62	62
2. Current control strategies and thrust for navation and guidance																																					
2.1 Current Control, Power Design and Reboost performance	0%																										62	62	62	42	42	31					
2.2 Controlled Deployment	0%																													42	42	31	42	42			
3. Conceptual Design																																					
3.1 Deployment Kit Design	0%																															31	42	42	62	62	62
Reports	30%																																				
Thesis	0%																																				
Educational Activities (250 hours/year)	40%	30	30	30	30	30	30	30	30	30	30	30	20	30	30	30	30	30	30	30	30	30	30	30	20	4	4	4	4	4	4	4	4	4	4	4	6

Achieved Goals

Future Goals*

I'm here

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*Future Research Project Goals

1. ET PACK
- Spooling Machine Design
- Functional test executions for validating the correct functioning of the deployer prototype

2. IPERDRONE.1
- 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

3. 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****, 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****,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****, IEEE Journal on Miniaturization for Air and Space Systems. PP. 1-1. 10.1109/JMASS.2020.3046182.*

[4] *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, Proceedings of the virtual conference.*

[5] *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, Proceedings of the virtual conference*

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

[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,*** *Forum internazionale delle misure 2021, Accepted for presentation.*

Thank you for the attention!

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