TETHERS AS PULLING CAPTURE TECHNOLOGY FOR E.DEORBIT AND NET/HARPOON-BASED ADR MISSIONS

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ABSTRACT

Tether systems have been used in space for various scopes since the beginning of the space era. They have been investigated as electrodynamics power generators or motors, momentum exchange and orbital stabilization assets or formation flying connection and pulling ropes. In the most recent years, in the context of ESA (European Space Agency) Clean Space Initiative and general interest in space debris removal missions, they have been included as one of the key technologies for capturing and de-orbiting large space target debris by pulling them. Tether would act as a flexible link, elastic or rigid, between the chaser spacecraft and its capture system, consisting, for instance, in a harpoon or a net. Tether elasticity is an important element to take into account for the controllability of the stack. On one side, a high elasticity tether leads to a simpler control problem and a better shocks reduction. On the other hand it may include the presence of a potential resonance with sloshing and an increased risk of collision after the de-orbit burn.

In the ESA TRP (Technology Research Program) study titled Elastic Tether Design and Dynamic Testing, Aero Sekur, with its local partners Aviospace and Gottifredi Maffioli, is currently studying and developing both a rigid and a highly elastic tether. Main objectives of the TRP are two; first to increase the TRL of the tether for ADR (Active Debris Removal) missions to 5-6 through an extensive environmental and functional test campaign at both material and assembly levels. Second to deliver two full-size (100 meters long) rigid and elastic tethers as fully functional Engineering Model (EM) with associated datasheets tabulating nominal and extreme values for parameters providing also a clear view of the design parameters-performances dependencies for the future CE (Concurrent Engineering) assessments to be done at system and mission levels. The on-going TRP is related to the activities for the e.Deorbit mission, now in Phase B1, and it reflects the ESA implementation plan of technologies required for Active Debris Removal (ADR) missions.

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The current paper describes the activities performed so far in the study, meaning until the development tests at assembly level on tethers scaled models, and the relevant results obtained. Main requirements (thermal about heat fluxes, chemical about thrusters plume impingements, physical about elastic constant and performance about load conditions) are presented. Relations with the common use ground-based products, as the “shock cords”, are also underlined. Then the configuration and final design, presented at CDR (Critical Design Review), of both the tether systems is shown, together with the description and the properties, obtained after dedicated tests, of the candidate materials for all the system parts. The related technological and manufacturing processes (braiding and seaming) for both the types of tethers are also included in the text. Moreover the first scaled models produced for the Development Tests at assembly level will be depicted and the first test results shown. In conclusion an overview of the planned activities until the final wrap-up will be presented.

1 INTRODUCTION

Among all the possible options to be exploited for the capture of a large orbital debris in space, a consistent number of them relies on the presence of a tether or a cable. Such an element allows to maintain the link between the chaser and the target until the re-entry phase. The main concepts of capture system based on this technology are the net and the harpoon. Both of them uses a tether for the solidarization of the de-orbiting stack. The tether has to work under a pulling load with the thrusters for the deorbiting burns positioned on the same side of the target debris and capture system.

In the introduction a general view of tethers history with a major focus on the capture utilization and specifically for the ESA e.Deorbit mission will be provided.

1.1 Tethers History

Since the beginning of the space era tethers have been studied by the main national agencies, institutions and industries for several applications.

The 3 main applications of tether are:

- Electrodynamics tethers
- Momentum exchange and stabilization tethers
- Formation flying and pulling tethers

The application we are considering in this work is the third one. Of course depending on what and how the tether has to perform the design of the system can be different. Beside the development studies on this type of space technology, several missions has been carried out and we mention hereafter some of them [RD3], [RD11].

- **1966** – NASA Gemini 11 Mission – First tether in space, 30 meters long for electrodynamics and formation flying scopes. It was fully deployed.

Figure 1: NASA Gemini 11 Mission – Tether deployment

- **1992 -** NASA/ASI TSS-1 Mission – 20 km long tether for electrodynamics and momentum exchange scopes. It included Kevlar as constituting material and it was deployed only up to 256 meters.

Figure 2: NASA/ASI TSS-1 Mission – Tether deployment

- **1996** – NASA/ASI TSS-1R Mission – 20.7 km long tether for electrodynamics scopes. It included Kevlar as constituting material and it was deployed up to 19.7 km.

- **1997** – ESA YES Mission – 35 km long tether for momentum exchange experiment. It included Dyneema as constituting material. The tether has not been deployed [RD4].

Figure 3: ESA YES Mission – Tether deployment

- **2007** – ESA YES2 Mission – 32 km long tether for momentum exchange experiments. It included Dyneema as constituting material. It was fully deployed [RD4].

- **2008** – NASA MAST Mission – 1 km long Hoytether type of configuration for momentum exchange and formation flying applications. It was deployed up to 1 mt [RD12].

The history of tethers in space clearly shows that the deployment and the dynamic behaviour of such an element is not as trivial as though. The harsh thermal environment and the microgravity aspects overall play an important role in the success of the mission. One of the lesson learnt from the various mission failure or partial success is to not underestimate the design, sizing and specifically the materials selection of such an element. Moreover also the mechanism that can be present for a correct unspooling shall not be ignored.

1.2 Tethers as Pulling Capture Technology

A net or harpoon with a tether as pulling capture technology for an active debris removal mission [RD13] presents several advantages, but also some disadvantages that, for completeness, need to be listed.

The advantages are the following:

- Simple mechanisms
- Simple rendez-vous
- Versatile
- Cheaper

The disadvantages are the following:

- Complex stack control

So the pulling option for an orbital debris removal mission can be defined as a relatively simple operation before capture and a more complex management of the orbital stack after capture.

1.3 Elastic Tether for e.Deorbit Mission

In the ESA TRP (Technology Research Program) study titled Elastic Tether Design and Dynamic Testing, Aero Sekur, with its local partners Aviospace and Gottifredi Maffioli, is currently studying and developing both a rigid and a highly elastic tether. The TRP is related to the activities for the e.Deorbit mission, now in Phase B1 [RD5], [RD6], [RD7], [RD9] and [RD10], and it reflects the ESA implementation plan of technologies required for Active Debris Removal (ADR) missions [RD8].

2 MAIN REQUIREMENTS AND DESIGN CHALLENGES

The design of a full scale tether for a pulling of an orbital debris and specifically for the ESA e.Deorbit mission is based on a detailed list of requirements defined in [RD15].

The main requirements are resumed hereafter:

- Thermal Requirements
    - Heat flux of 300 kW/m^2 for 1350 sec for the first 5 mt
    - Flexibility

- Elasticity Requirements
    - Elastic constant between 50 and 100 N/m over a length of 100 mt

- Dimension and Mass Requirements
    - Diameter of around 1 cm
    - Section as much homogenous as possible
    - As light as possible

- Load Requirements
    - Peak operational load of 3800 N for 17 sec

These requirements are partially in conflict among them, which is an aspect that makes the tether design a real challenge.

3 TETHERS DESIGN

The design of the 2 types of tether has been performed taking into account all the requirements as defined in [RD15] and all the status of the art on tethers design [RD1], [RD2] and [RD3]. The current paragraph will synthetically describe their configuration. For major information on the 2 type of tethers design please refer to [RD16].

3.1 Rigid Tether

The rigid tether is a ribbon-based tether composed of 2 parts:

- Stiff Part (indicated with 1 in Figure 4) for the whole length with loop interfaces with EST seams
- Thermal Part (indicated with 2 in Figure 4) on the first 17 meters with TUB and TER seams

Figure 4: Rigid Tether – Development Model R-COM-SCA#2

The EST seam is the seam at the extremity of the tether, the TUB seam is the seam that close the external layer of the Thermal Part in a tubular. The TER seam is the seam that connects the Thermal Part to the Stiff Part.

For the Stiff Part several high-strength and low flexibility fibers available in the market and with a known space heritage have been evaluated. At the end a Kevlar webbing 25 mm wide capable of withstanding 7750 N (BOL) has been selected.

For the Thermal Part several materials have been evaluated (metals, ceramics and ablative). At the end the designed protection system is:

- An internal layer of 15mm Silica webbing (indicated with 1 in Figure 5)
- An external layer of 3M Nextel fabric (indicated with 2 in Figure 5)

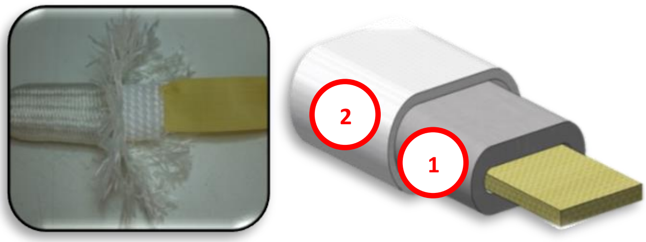


Figure 5: Thermal Part Configuration

3.2 Elastic Tether

The elastic tether is a rope-based tether and it is composed of 3 parts:

- Elastic Part (indicated with 1 in Figure 6) for 3 meters
- Stiff Part (indicated with 2 in Figure 6) for around with loop interfaces with EST seams
- Thermal Part (indicated with 3 in Figure 6) on the first 17 meters with TUB and TER seams

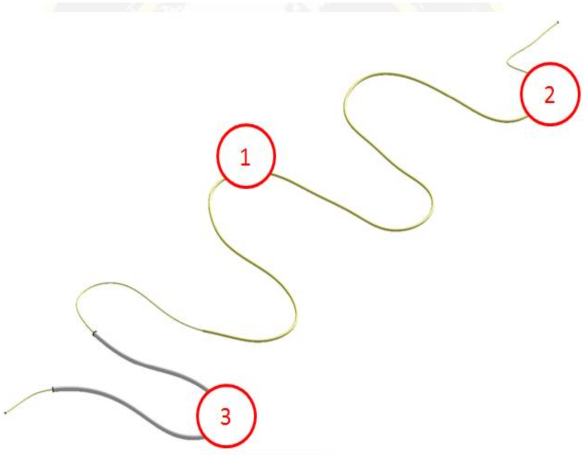


Figure 6: Elastic Tether – Configuration

EST, TUB and TER seams are the same as defined for the rigid tether in order to exploit similarity as much as possible.

Elastic Part configuration is inherited from Bungee Cords. It is composed of:

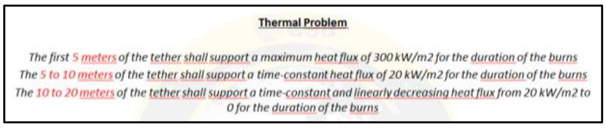
- External Sheath (ES) made of Kevlar yarn
- Internal Sheath (IS) made of Nylon yarn
- Elastic Core (EC) made of Silicone-VMQ strands

Stiff Part is constituted of Kevlar yarn and it represents the continuation of the External Sheath. The stiff part is able to withstand a load of 7000 N (BOL).

Thermal Part is identical to Rigid Tether corresponding one.

4 THERMAL ANALYSES

In the frame of the design of the Elastic and Rigid Tether, a key driver is set by the environmental requirements applicable for the mission. Specifically, a tether-based capture with a flexible link implies that the tether is pulled, and so the chaser's thrusters shall be oriented in such a way that their plumes may generate impingement on the tether itself. This effect has been quantified in previous studies ([5], [6], [7] and [10]) and following requirements for the heat flux limits have been generated accordingly:



Thermal Problem

The first 5 meters of the tether shall support a maximum heat flux of 300 kW/m2 for the duration of the burns
The 5 to 10 meters of the tether shall support a time-constant heat flux of 20 kW/m2 for the duration of the burns
The 10 to 20 meters of the tether shall support a time-constant and linearly decreasing heat flux from 20 kW/m2 to 0 for the duration of the burns

Figure 7: heat flux profile requirements

For these requirements, a verification approach including both analyses and testing is pursued. In particular during the design phase a campaign of thermal analyses was performed with the goal to preliminary evaluate the compliance of the design under development with the requirements, and to support the design consolidation and optimization by:

- Support the material level trade-offs (A2 vs. A3, C2 vs. C3)
- Evaluate admissible reduction of thickness for the thermal protection layers

The thermal solvers adopted for this activity are:

- SOLIDWORKS Simulation 2015
- SOLIDWORKS® Simulation is a design analysis system fully integrated with SOLIDWORKS.

Tool parameters used in present activity:

- Solver: Intel direct sparse
- MESH: Linear tetrahedral element generated from an automatic algorithm.

Successively materials specifications have been fed into the thermal models. Where the specifications were not available from the manufacturers, they have been derived experimentally via material-level tests performed in the first phase of the study

Table 1: Material properties

Mat ID	Mat name	α, ε	Thermal Conductivity	Bulk Density	Specific heat	Allowable temperature
		[- , -]	[W / m K]	[Kg / m3]	[J / Kg + K]	[°C]
A2	WEBBING KEVLAR MIL-T-87130 TYPE VI CL.5 mm 25	0.04, 095	0.040	621	1138 @RT 1750 @340°C	+360
A3	WEBBING 100% PBO Zylon BC mm 25x1	0.04, 095	0.041	728	945 @RT 1620 @340°C	+460
C1	FABRIC 3M Nextel 312 (AF40)	0.14, 095	0.108 @93°C 0.187 @760 °C	866	250	>800
C3	WEBBING Silica FIBERSIL		0.0113	442	998 @RT 1110 @340°C	>1000
C2	WEBBING Silica ALUTEX		0.0178	349	1000 @RT 1160 @340°C	>1000

The key assumptions taken for the implementation of the analyses are described hereafter:

1. Tether diameter is negligible with respect to Tether length.
2. All materials have low thermal conductivity (they are all good thermal insulators).
3. Heat exchange in the length direction can be assumed negligible.
4. Due to the above, and the axial symmetry of the tether, there is no need to model the entire length of the tether, while it is adequate to model only slices of the tether on the most interesting points.
5. Thermal Contact Resistance value is assumed 0.02 K m2 / W for all contacts. This value is typical (see following figures) for ceramic sheet, webbings, fabric and so on. Sensitivity analyses performed showed that this assumption is quite conservative (e.g. higher values will improve the thermal protection performance).

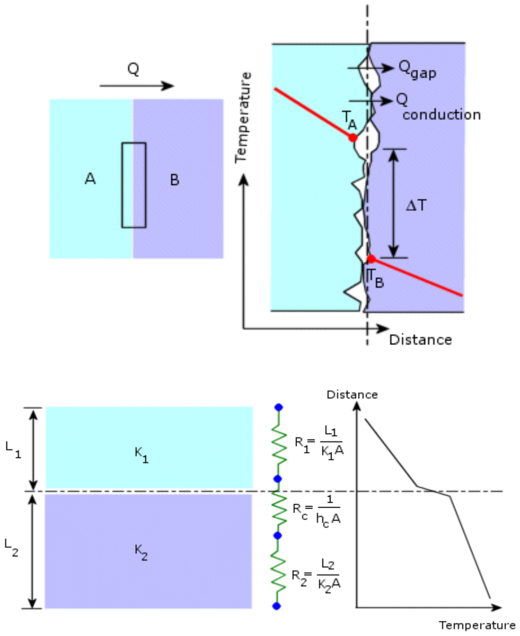


Figure 8: Thermal contact resistance mathematical model

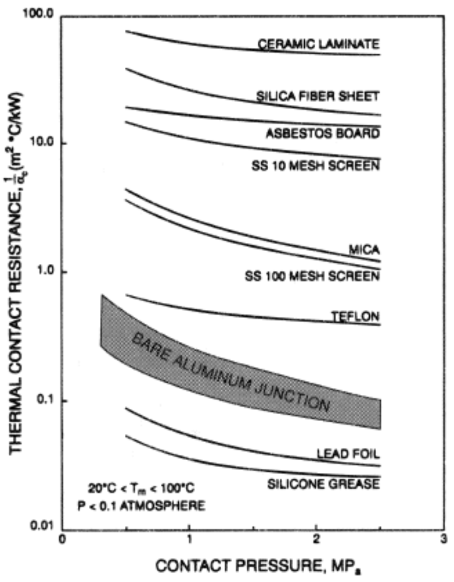


Figure 9: TCR typical value vs. contact pressure

6. During the manufacturing process the layers are pressed on each other with respect to the nominal configuration, and the thickness of each cable section is slightly shrunk (a shrinkage of 5% so each radial dimension is reduced at 95% of its nominal thickness). The mass of each layer of course doesn't change, so this is took into account in the models to have the exact mass (bulk density is increased).
7. Tether configuration is summarized by the following figure:

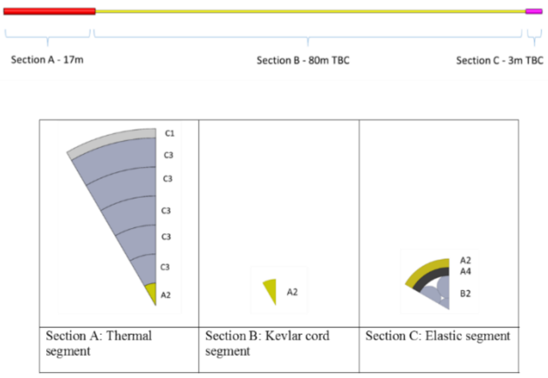


Figure 10 - Tether model configuration

8. The heat flux according to requirements is assumed with the following profile over time and over tether length (x = 0 is the interface between the tether and the chaser)

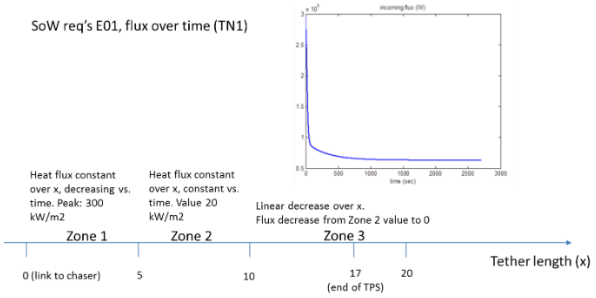


Figure 11: Heat flux profile

The hot thermal cycle is characterized from a sequence of 3 steps:

- H1: A stationary condition with a heat flux from : Solar + IR + Albedo

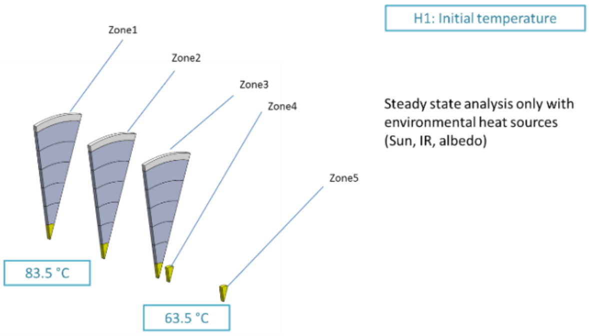


Figure 12: H1 stationary condition before thrusters' burn

- H2: A transitory condition of 1350s. A heating ramp with a heat flux from : Thrust impingement + Solar + IR + Albedo

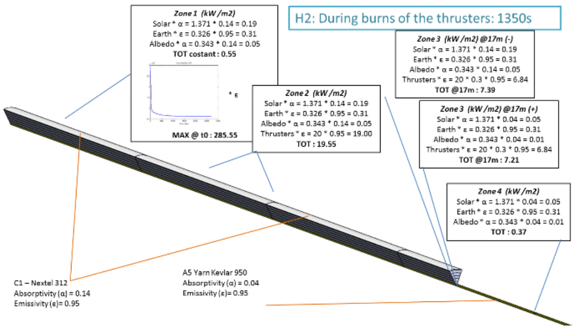


Figure 13: H2 transitory condition during thrusters' burn

- H3: A transitory condition until the stationary condition (some hours). A cooling ramp with a heat flux to : Solar + IR + Albedo

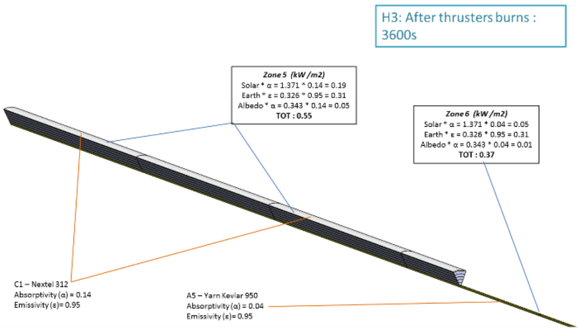


Figure 14: H3 transitory condition after thrusters' burn

The major results in the case of elastic tether are summarized hereafter:

- H1: steady state temperature on the Kevlar-Silica interface of 83 °C
- H2: Temperature on the Kevlar core reaches its plateau after approximately 100 seconds. Peak temperature on Nextel external sheath: 813 °C. Temperature on the TPS is still increasing at the end of the firing (1350 s)

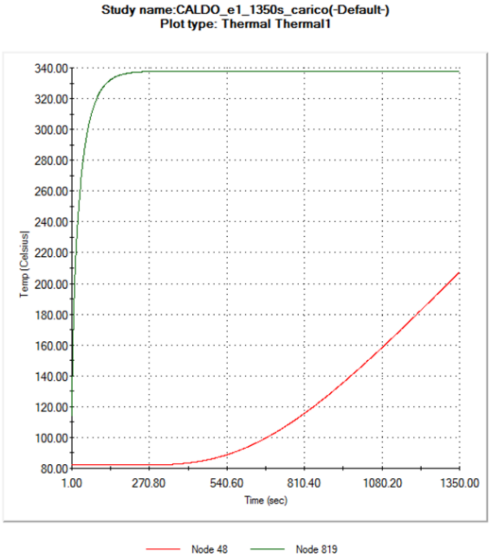


Figure 15: H2 major results

- H3: Temperature on the interface btw. TPS and core reaches its maximum (344°C) after 1200 seconds after the end of the firing. Temperature after the end of TPS goes down to 63°C approx. 400 s after the end of firing

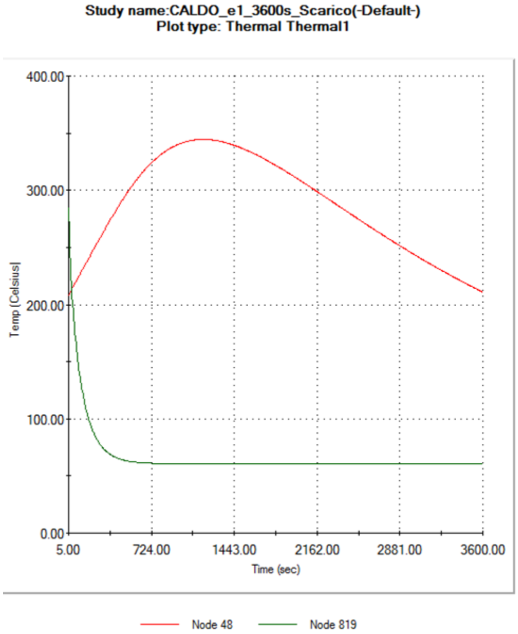


Figure 16: H3 major results

The following conclusions can be drawn from the results of the analyses:

- The analyses campaign allowed to support the consolidation of the design, with respect to sizing of the thermal protection of the tether and selection of the most appropriate materials where trade-offs were still open
- The consolidated design of both elastic and rigid tether is compliant with environmental requirements set by TRP SOW and [15]
- Analyses showed that peak temperatures reached by the core elements of the tether are below their admissible temperatures (which are already set with a 200°C margin on the decomposition temperatures determined by tests)

Sensitivity analyses performed showed the robustness of the analyses with respect to assumed parameters.

5 ASSEMBLY-LEVEL DEVELOPMENT TESTS

The tests related to the assembly-level development phase have been carried out on 3 scaled models, one for the rigid tether and two for the elastic one. Table 2 describes the 3 codes and referred description. The need to have 2 configurations for the scaled elastic tether models is related to the fact that an E-COM-SCA test must be conducted under customized procedure, which takes into account high elongations, not applicable at this level.

Code	Description
R-COM-SCA	Complete rigid tether (thermal + mechanical parts) with mechanical interfaces at reduced but representative scale
E-MEC-SCA	Partial elastic tether (mechanical parts) with mechanical interfaces at reduced but representative scale
E-THE-SCA	Partial elastic tether (thermal parts) with mechanical interfaces at reduced but representative scale

Table 2- Models description

Code →	A-BBB-CCC
A	E: Elastic tether
	R: Rigid tether
BBB	COM: complete tether
	MEC: partial tether (mechanical part)
	THE: partial tether (thermal part)
CCC	SCA: reduced but representative scale model
	FUL*: full scale model (deliverable EM)
#N	#N: Sample serial number

Table 3- Codification

**FUL models not realised for development phase*

The tests results will allow to understand the thermal and mechanical part matched tensile behavior, taking into account all the critical joints.

Results from development tests aims to deeply describe both the elastic and rigid complex system at BOL and EOL. The ageing for the EOL conditions follows the thermal constraints treated in paragraph 4.

5.1 Test Matrix

The Assembly Level Test Campaign Matrix (see Table 5) at development phase allow to have a general overview on the tests and therefore to manage the test:

- Test objective and adopted standard
- Facility
- Requirements which must be satisfied
- Specimens number

5.2 Test Description

The assembly-level development tests are conceived as a first step to validate the design of the tethers, before completing the verification of the compliance with requirements.

TEN01 and TEN02 tests are performed with the following purposes, to be verified respectively in Beginning-of Life conditions and End-of Life conditions (i.e. after the tether has been aged in space environment with applicable thermal loads, also due to thrusters plume impingement, and vacuum conditions)

- To characterize and validate the overall elastic behavior and stiffness vs. elongation feature of the tether DM
- To determine and verify experimentally the breaking load of the tether DM, particularly to evaluate the strength of the seams.
- To determine and verify experimentally the maximum elongation at rupture of the tether DM, in order to refine and update, if necessary, the design of the tether test models before the qualification tests phase

Due to the length of the specimen and their expected elongation, most common tensile machines for purposes of material characterization are not suitable (typical maximum length achieved by the specimen under load is less than 1 meter).

CSMT laboratory of CAI in Padova is identified as appropriate, having the following specifications Main specifications of the tool:

- Maximum length of the specimen under load conditions: 2.60 m
- Maximum applicable force: 30000 N
- Maximum velocity of the actuator: 0,53 m/min, compatible with FED STD 191 Method 6015 (applicable for ribbons, prescribing 152 mm/min).
- Achieved output: Trends Force vs time and Elongation vs Time

Additional test equipment:

- A video-camera to be able to record the test execution. Required frame rate: 2 fps minimum
- Markers are added along the specimen so that permanent deformation and creep effect can be measured during (via video recorded) and after the test (by measurement on the specimen)
- The tool is equipped with a graduate scale (resolution 1 mm) so that movement of the markers can be tracked on the video recorded

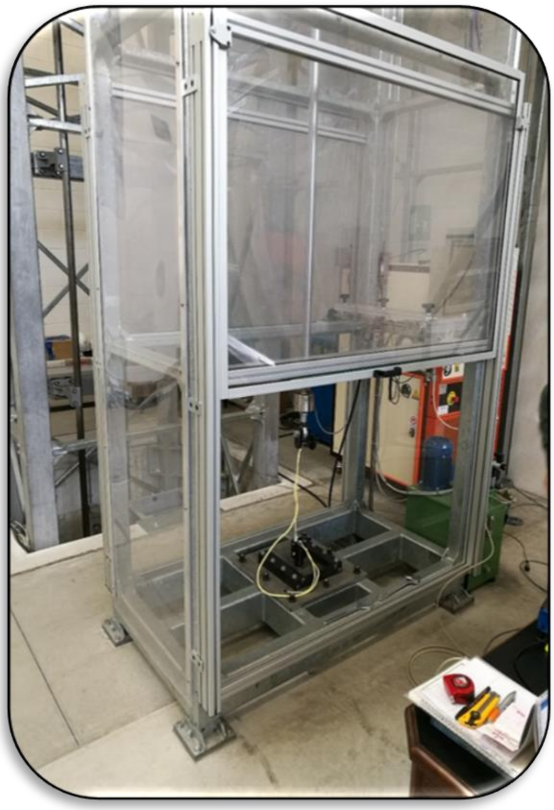


Figure 17. Tensile machine adopted for TEN01 and TEN02 tests

The specimen to be tested in EOL conditions have to be aged by applications of a thermal-vacuum load sequence (Thermal Vacuum Ageing, TVA in the following), with the following purposes:

- to verify the capability of the tether models to withstand the thermal environment due to thrusters plume impingement, which will require to use this step as an ageing procedure before the execution of tensile test in EOL conditions (TEN02)
- to validate the design of the thermal protection layers of the tether (i.e. to verify that the operational heat flux will not generate temperatures exceeding the operational limits of the materials)
- Estimated temperatures (to be validated by the test): up to 1500 °C on the outer surface of the external layer (made by Nextel) and will drop down to 360°C on the boundary between thermal protection and inner core (made by Kevlar)

Due to the estimated temperature range, most common thermal vacuum machines are not suitable (typical TV chambers have a maximum temperature of 200 – 250 °C).

AAC test house equipment for combined high-temperature vacuum testing is identified as suitable (LVC, Large Vacuum-Chamber).

TV chamber can host a cylindrical induction heater where the tether thermal protected segment is fitted. The unprotected segments can lay outside the heater volume and do not require any specific thermal protection, as the temperature of the chamber, outside the heater will not exceed 120 °C (within the operational limit of Kevlar).

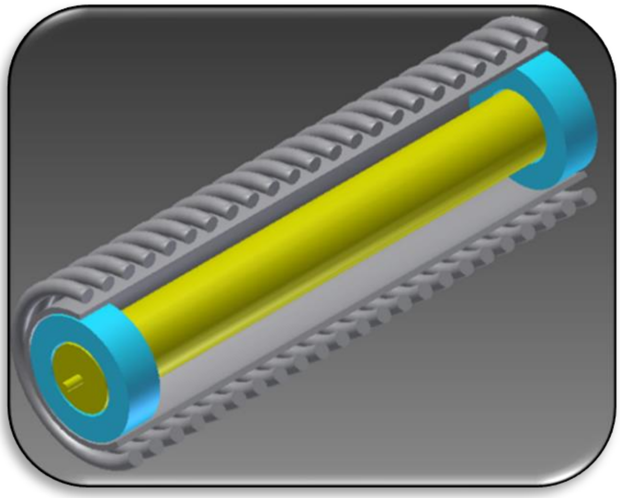


Figure 18. Cylindrical induction heater configuration

The chamber is equipped with a pyrometer and can allow K type thermocouples inside the test article to be plugged with the Data Acquisition System. The thermocouples are located on the interfaces between layers of different materials in the thermal protection.

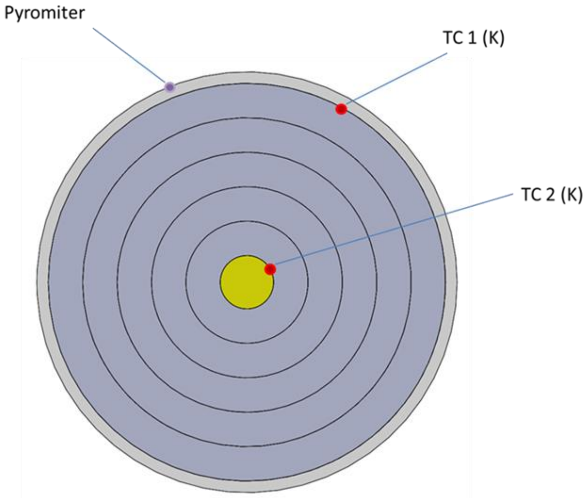


Figure 19. Location of the TCs on the tether cross-section

As there is no direct control on heat flux (the control loop includes measurements on temperature, which is directly linked to heat flux), the Heat flux profile has to be validated by means of calibration runs.

The reference heat flux (as specified by ESA and AS requirements) can be very difficult to achieve since the instantaneous peak. The goal is to reproduce a heat flux which has the same energy applied over time.

Table 4. Heat flux profiles

Theoretical heat flux profile		Actual Heat flux profile	
Time [s]	Heat flux [W/m2]	Time [s]	Heat flux [W/m2]
0	0	0	0
9,99	0	4	0
10	285600	8	251000
74	84200	10	251000
510	67100	21	251000
1360	63300	74	84200
1360+	550	510	67100
2003	550	1360	63300
2005	0	1360+	0
5003	0	5000	0

The real heat flux profile adopted will take into account of the initial thermal status of the tether (i.e. constant temperature of 82°C) which would require a very long preconditioning

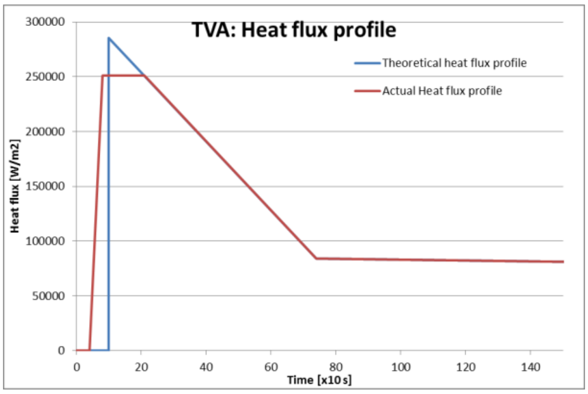


Figure 20. Heat flux profiles

The outcome of the test will be:

- Temperature measurements (via pyrometer and via thermocouples) vs. time
- Tether model «aged» ready for TEN02

5.3 Test Models Integration Process

The R-COM-SCA integration process main steps are here after summarized using images. The integration procedure is similar for both elastic and rigid tether.

Figure 21- R-COM-SCA materials before integration

All Kevlar products have been submitted to vacuum stripping treatment before the integration. All 3M Nextel have been submitted to thermal cleaning process before the integration.

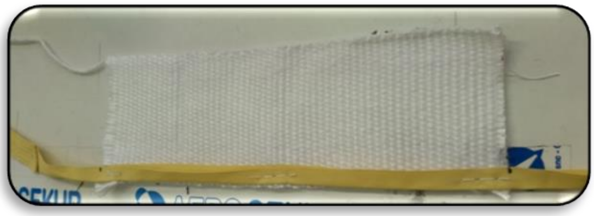


Figure 22- Silica webbing disposition before the wrapping process. Baste seams made with 3M Nextel thread avoid mutual movement

The needed quantity of silica webbing to have the 5 protective layers is reached to joint together 3 silica webbing (0.1 m height).

Figure 23- 5 silica layers as thermal insulation material before the insertion inside the 3M Nextel sleeve

Once silica webbings are wrapped, Nextel thread is used as baste seam. The pulling phase related the insertion of the silica and Kevlar inside the Nextel sleeve is a critical step where special tools (Teflon temporally sleeve) are used to minimized the friction force.

Figure 24- R-COM-SCA final model

The other seams, to avoid the relative movement of the thermal protection on the Kevlar webbing and to pack the silica layers are made with Kevlar thread.

6 NEXT STEPS

The ESA TRP “Elastic Tether Design and Dynamic Testing” activities started in September 2015. The CDR of the project has been performed in October 2016. Currently the Assembly-Level Development Tests described in paragraph 5 are on-going and they are planned to end at the beginning of June.

The next steps are:

- Assembly Level – Development Tests (April-May 2017)
    - Execution of Development Tests on scaled and partial models (TEN01 and TEN02)
    - PTR2-Dev and possible revision of the scaled and full models design

- Assembly Level – Qualification Tests (May-June-July-August 2017):
    - Manufacturing of scaled and full size models (including EM) for the Qualification Tests
    - TRR2- Qual
    - Execution of Assembly Level – Qualification Tests

- Between PTR2- Qual and Final Presentation (September-October 2017):
    - PTR2-Dev and possible final outcomes and suggestions for the tethers design
    - Preparation of Development and Qualification Plan and Final Documentation (WP8000)

Final Presentation of the work is planned for the end of November 2017 in ESTEC.

7 CONCLUSIONS

Tethers usage in space has a history of more than 60 years for a wide set of scopes ranging from electrodynamics to momentum exchange and formation flying.

In the last 3 years, in the context of the ESA Clean Space Initiative, the tether has been defined as one of the crucial technologies for a harpoon or net capture system for an active debris removal mission

Within a ESA TRP work Aero Sekur is designing, manufacturing and qualifying up to TRL 5-6 through the realization of an EM the tether for the ESA e.Deorbit mission having the scope to capture and dispose Envisat by 2024.

Both an elastic and a rigid tether have been designed with the support of dedicated material tests and thermal analyses. Then through several development models all the main functionalities, according to requirements, have been assessed. At the end of the work 2 EM for each type of tether will be available for all the performances qualifications and for following testing, if needed in order to additionally increase the technology TRL. Moreover a design parametric tool for both the type tether is planned to be created in order to support the e.Deorbit and any other ADR mission CE system-level design efforts.

8 ABBREVIATIONS AND ACRONYMS

The abbreviation and acronyms present in the paper are the following:

ADR	Active Debris Removal
AS	Aero Sekur
ASI	Agenzia Spaziale Italiana
AVS	Aviospace
BOL	Beginning Of Life
CAI- CSMT	Comitato Alpino Italiano - Centro Studi Materiali e Tecnologie
CDR	Critical Design Review
CE	Concurrent Engineering
DE	Development Model
EM	Engineering Model
EOL	End Of Life
ESA	European Space Agency
GM	Gottifredi Maffioli
PTR	Post Test Review
SOW	Statement Of Work
TC	Thermocouple
TCR	Thermal Contact Resistance

TRL	Technology Readiness Level
TRP	Technology Research Program
TRR	Technology Readiness Review
TSS	Tethered Space System
TV(A/C)	Thermal-Vacuum (Ageing/Chamber)
WP	Work Package

9 REFERENCES

All the paper references are included in the current chapter.

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Assembly Level Tests Matrix - Development		Objectives	Test Standard	Test ID	Requirement	**Rigid (R)**		**Elastic (E)**		**Number of Tests**
						Test Model	Number of Specimens	Test Model	Number of Specimens	
Mechanical Tests	Tensile Test BOL	Strength --> E, k Elongation --> E, k Note: up to rupture	Dedicated Procedure	TEN01	T-13 T-15 T-18 P-01 P-02	COM-SCA-#1	3,00	MEC-SCA-#1 THE-SCA-#1	6,00	9,00
	Tensile Test EOL after Heat Flux (Heat Flux according to req. E.1 and E.2 for 1350 sec)	Strength --> E, k Elongation --> E, k Note: up to rupture Characterization of: - Mass	Dedicated Procedure	TEN02	T-13 T-15 T-18 P-01 P-02	COM-SCA-#2	3,00	THE-SCA-#2	3,00	6,00
				Total Number		-	6,00	-	9,00	15,00

Table 5- Assembly Level Tests Matrix - Development phase