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Elastic and Rigid Tethers as Pulling Capture Technology

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Index

- About Aero Sekur
- Tether as Pulling Capture Technology
- Tether History
- Project Overview
- Design Challenges
- Rigid Tether Preliminary Design
  - Configuration & Materials
  - Stiff Webbing Materials Selection
- Elastic Tether Preliminary Design
  - Configuration & Materials
  - Elastic Rope Sizing
- Thermal Sheath Preliminary Design
  - Configuration & Materials
  - Preliminary Thermal Analyses
- Next Steps

About Aero Sekur

- Aero Sekur S.p.A. is the global provider of advanced survival equipment and systems for mission critical Aerospace & Defence applications

- Employs c. 200 people
- Operates from 3 Divisions and 3 subsidiary companies
- The 4 facilities, covering an area of c. 250.000 sq. ft, are located in Italy

  - Airborne Systems – Aero Sekur S.p.A Division
  - Defence – Aero Sekur S.p.A Division
  - Space & Technology – Aero Sekur S.p.A. Division

  - Sekur Sistemi srl (subsidiary)
  - H.A.S srl (subsidiary)
  - Sensichips (subsidiary)

Tether as Pulling Capture Technology

Tether as an system of a pulling capture technology (net, harpoon) for ADR mission

Simple mechanisms
Simple rendez-vous
Versatile
Cheaper

Complex Stack Control

Simplicity before capture

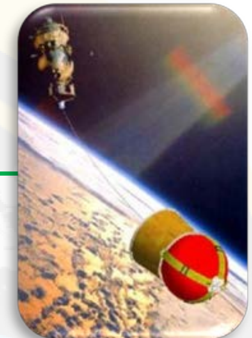
Complexity after capture

Tether History

A number of space tethers have been deployed in space missions with various degrees of success

NASA/ASI TSS-1
Included Kevlar
20 km long
Deployed to 256 mt

ESA YES
Dyneema
35 km long
Not deployed



NASA MAST
Hoytether based
1 km long
Deployed to 1 mt

1966 → 1992 → 1996 → 1997 → 2007 → 2008

NASA Gemini 11
First tether is space
30 meters long
Fully deployed

NASA/ASI TSS-1R
Included Kevlar
20,7 km long
Deployed to 19,7 km

ESA YES2
Dyneema (0,5 mm)
32 km long
Fully deployed

- Yellow: Electrodynamic
- Green: Momentum exchange & stabilization
- Red: Formation flying & pulling

Project Overview

- Project developed under a ESA Contract (ITT AO8258)
- Activities started in September 2015 and last 18 months
- Today we are approaching **TRR1** for **Material Level Tests** (planned for 1/6/2016).
- **PDR** has been held in end of February 2016

- TRP Objectives are:

1. to increase the **TRL** of the tether for ADR (primarily for the net) to **5-6** through an extensive environmental and functional test campaign.
2. To deliver **2x full-size stiff and elastic tethers** as fully functional **EM** with associated “data sheets”

Consortium

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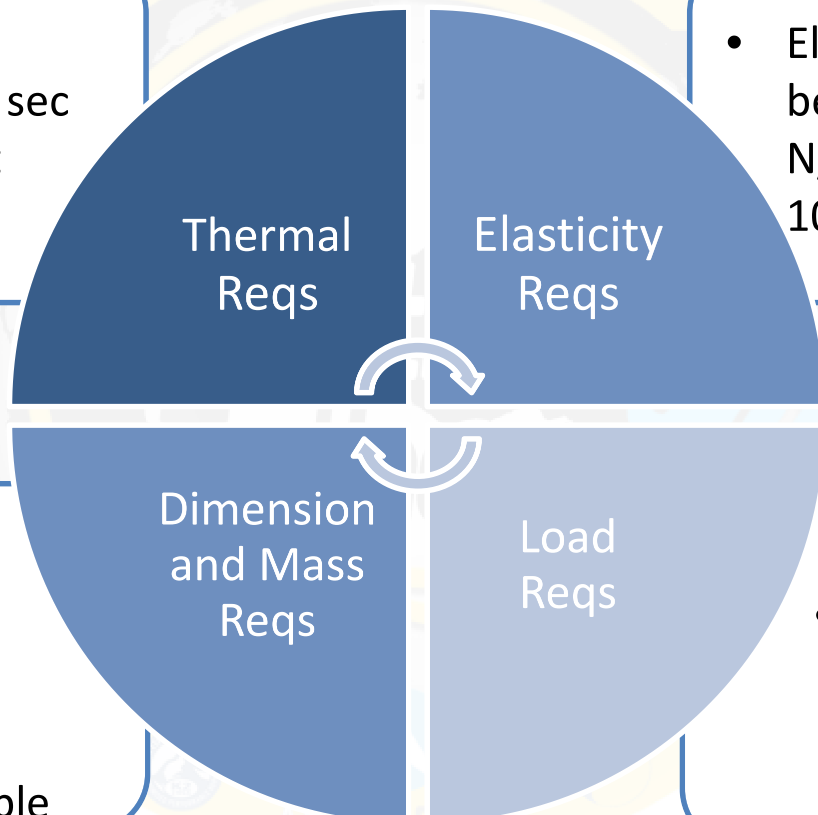
Project Overview and Design Challenges

What makes tether design (specifically elastic) a real challenge?

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

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

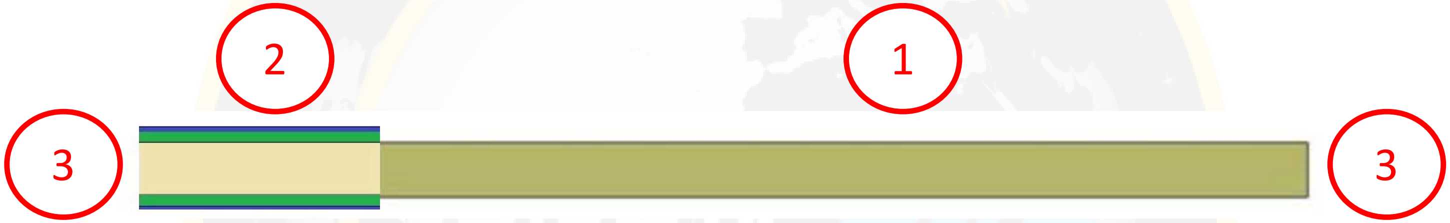


- Diam. of around 1 cm
- Section as much homogenous as possible
- As light as possible

- Peak operational load of 3800 N for 17 sec

Rigid Tether Preliminary Design Configuration & Materials

- Rigid Tether is ribbon-based and it is composed of 3 parts:
  - Stiff Webbing (1) for the whole length
  - Thermal Sheath (2) on the first 5 or 10 mt (TBC)
  - Interfaces to Net and Chaser (3)



- Stiff Webbing material candidates have been selected among the suite of **high-strength and low flexibility fibers** available in the market and with a known space heritage:
  - Dyneema
  - **Kevlar 49**
  - Technora
  - LCP Vectran
  - **PBO Zylon**

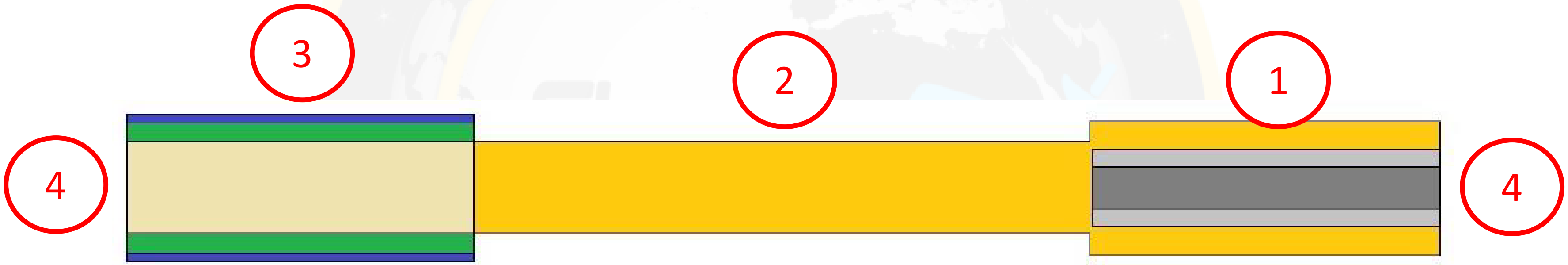
- The 2 candidates ribbons for the Stiff Webbing part have been chosen based on material-level specifications:
  - Breaking strength (**greater than 6600 N**)
  - Operative temperature (greater that 400 C)
  - Width and seamable area (between 15-38 mm)
  - Good flexibility
  - Good seamability
  - Low mass

- The minimum breaking strength values has been defined following the MoS verification approach used for textile materials with:
  - Ageing Efficiency: $\varepsilon_a = 0{,}85$
  - Temperature Efficiency: $\varepsilon_t = 0{,}9$
  - Joint Efficiency: $\varepsilon_j = 0{,}95$
  - Safety Factor: SF = 1.2
  - Margin of Safety: MoS > 0
  - Design Ultimate Load (from project specification): DUL = 4000 N
  - Material strength (from material specification or Type-A basis from test): S_m

$$MoS = \frac{S_m e_j e_t e_a}{SF\ DUL} - 1 > 0$$

Elastic Tether Preliminary Design Configuration & Materials

- Elastic Tether is rope-based (TBC) and it is composed of 4 parts:
  - o Elastic Rope (1)
  - o Rigid Rope (2)
  - o Thermal Sheath (3) on the first 5-10 mt (TBC)
  - o Interfaces to Net and Chaser (4)



- Elastic Rope part configuration is inherited from Bungee Cords
- For the Elastic Rope and Rigid Rope parts materials are the same as Stiff Webbing except the introduction of an Internal Sheath (IS) made of Nylon
- For the Elastic Core (EC) of the Elastic Rope parts several elastomers have been investigated → VMQ Silicone has been selected

Elastic Tether Preliminary Design
Elastic Rope Sizing 1/3

In order to size the Elastic Rope part matching the requirements a step-by-step **experimental approach** has been followed

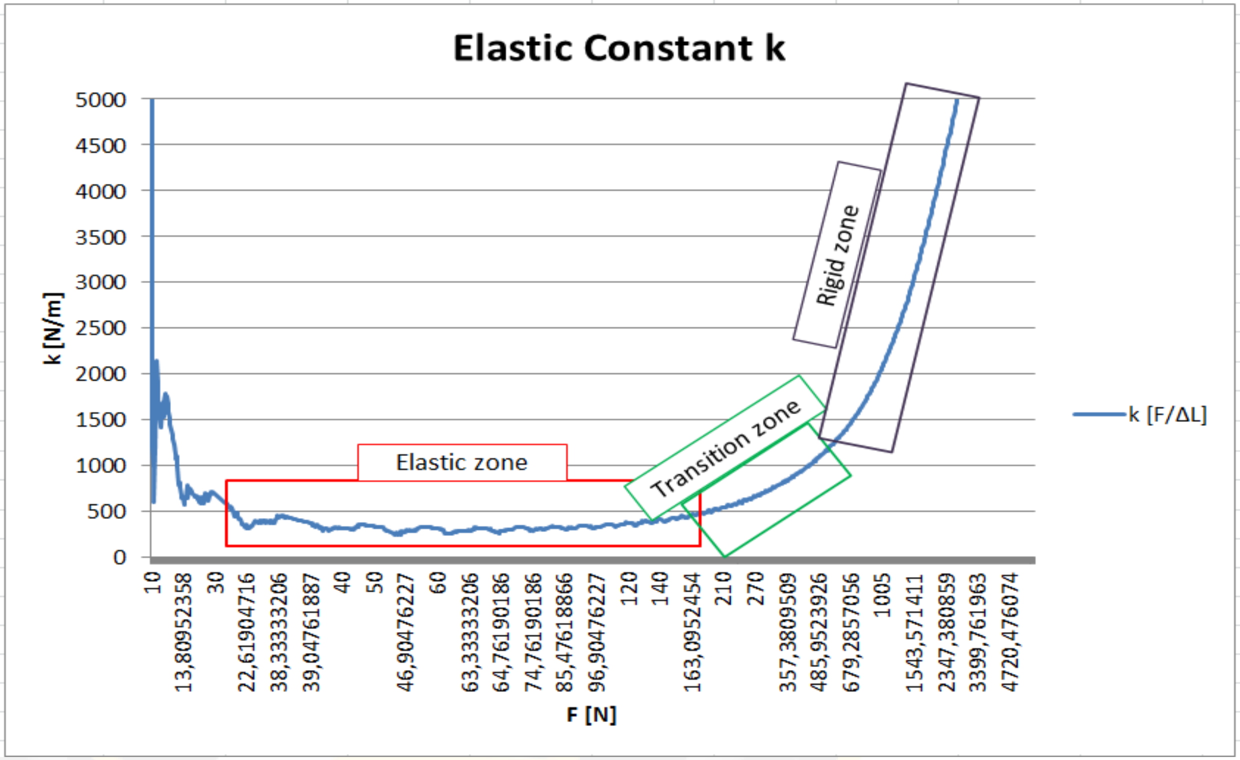
Prototype I

- 1 External Sheath (ES) made of Kevlar 950 yarn
- 1 Internal Sheath (IS) made of Nyon Nexis Type 3210 1400 dtex yarn
- 1 Elastic Core (EC) made of 10 Elastomeric Strands of diam. 2 mm (compound **NBR 70 M332**) pre-tensioned at 100%
- Diameter D of 1 cm and Area A of 0,79 cm^2
- Length L of 1 mt

Elastic Tether Preliminary Design
Elastic Rope Sizing 2/3

For the Elastic zone:

- E = 5,49 MPa
- k = 431 N/m



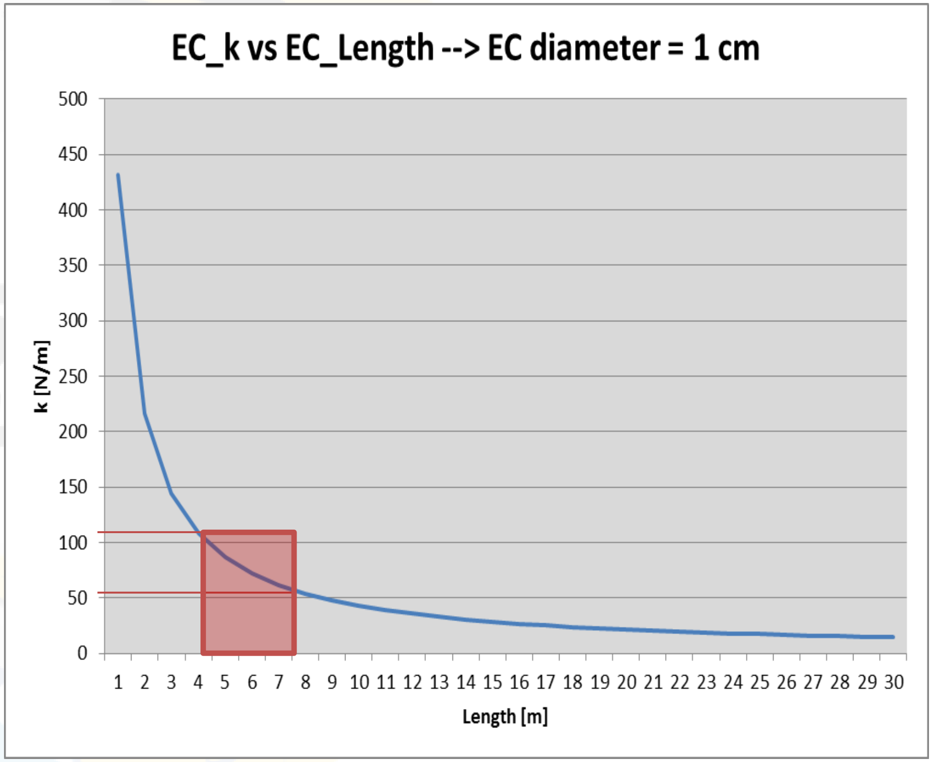
- Elastic behavior is compliant to what is requested.
  - o elastic zone is acceptable
  - o transition zone can be smoother
  - o rigid zone is oversized
- IS and ES are physically oversized. They shall be better tailored with respect to EC

Elastic Constant k requirement can be obtained according to:

$$k = \frac{EA}{L_0}$$

So towards the final design of the EC:

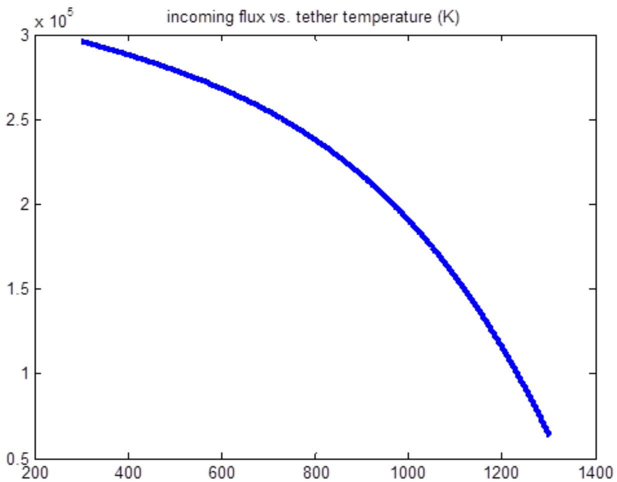
- A is planned to be maintained around 1 cm in diameter
- E will be updated following the final selected compound for the EC
- L_0 will be then selected according to the formula above

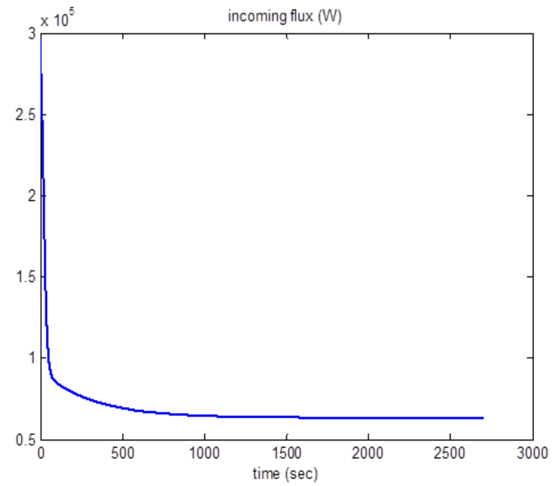


For the compound used for the initial prototype activities in order to obtain a k between 50 and 100 N/m a **L_0 between 4 and 8 mt** shall be selected

Thermal Requirement E.1

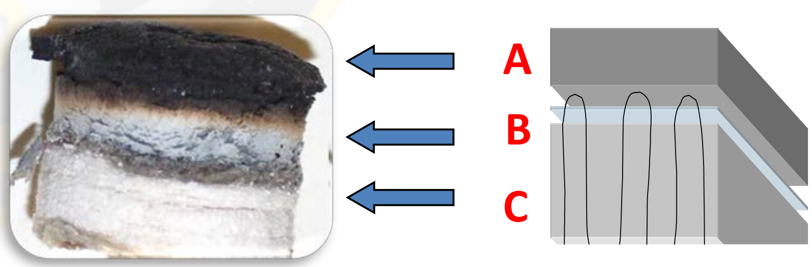
The first 5 meters of the tether extension from the chaser satellite interface shall support a maximum initial heat flux of 300 kW/m^2 (considered as radiating power)





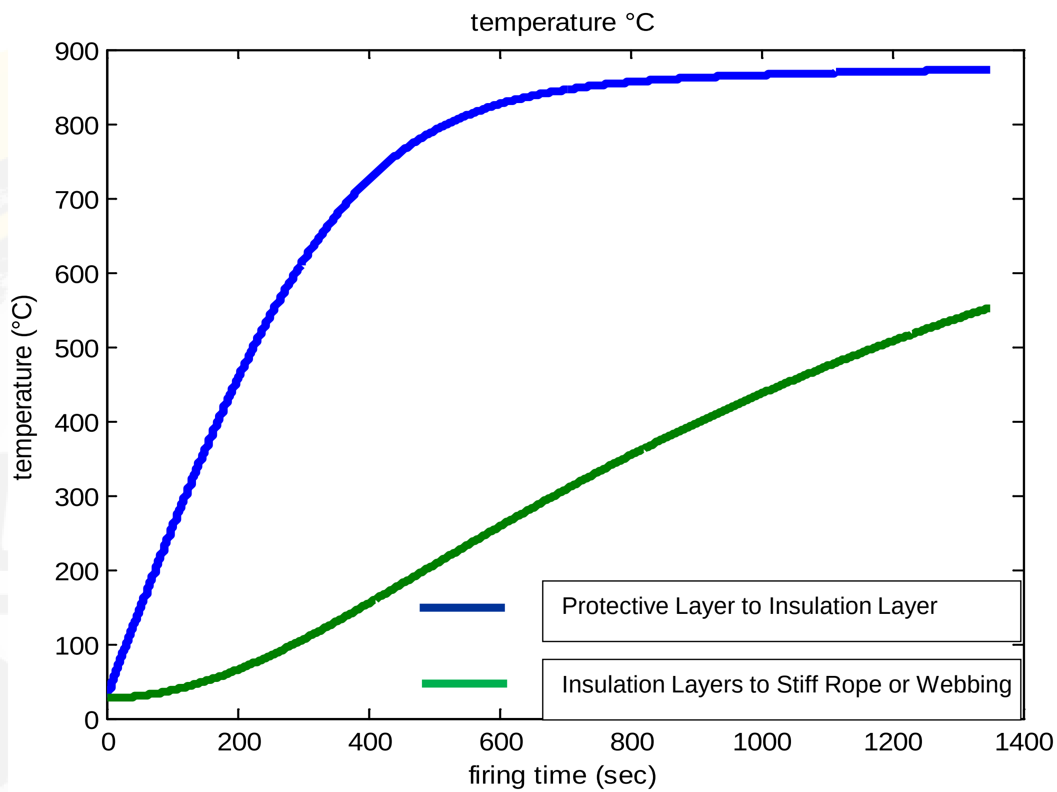
A preliminary thermal analysis has been performed considering:

- Configuration (inherited from SPEM)
  - ~~A: Ablative Layer~~
  - B: Thermal Protection Layer (Nextel)
  - C: Thermal Insulation Layer (Allumina or Silica Felt)



The analysis consider:

- An equivalent radiative and convective model
- A thickness of 15 mm of the material for the Thermal Sheath insulation layer



Outcomes:

- Selected Thermal Sheath configuration allows PBO Zylon (max. 482 C) usage
- Kevlar usage (max. 400 C) is → second iteration with proper model may lower temperature at Insulation Layer to Stiff Rope or Webbing
- VMQ Elastomer (max. 200 C) constituting the EC of the elastic tether shall be far from first 10 mt

Next Steps

Next activities in TRP **"Elastic Tether Design and Dynamic Testing"**

Between TRR1 and PTR1:

- Execution of Material Level Tests (materials for all the parts)
- Finalization of prototype activities for the Elastic Rope sizing
- Identification of the Test Models for the Sub-Assembly and Assembly Level Tests

Between PTR1 and CDR:

- Prototype activities for the study of the Thermal Sheath configuration and integration
- Second Iteration of the Thermal Analyses
- Finalization of the design for both the tethers (elastic and rigid):
  - Final Concept and Materials Trade-off
  - Product / Drawing Tree
  - Mass Budget
  - Sizing and Manufacturing Drawings (also for Test Models)
  - Manufacturing and Integration Procedures (also foe Test Models)

CDR is planned for the 28/09/2016

Thanks for the attention!