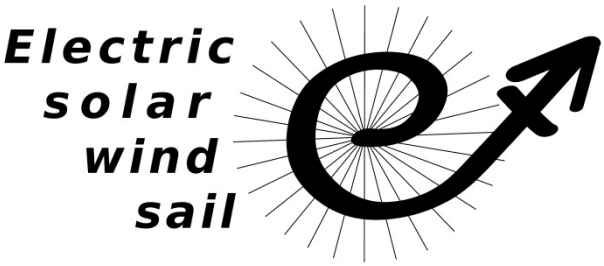

ESAIL D3.1.1
Requirement specifications of the tether test reels

Work Package: **WP 3.1**

Version: **Version 1.0**

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1	0	30 May 2011	All	Initial issue	Rosta

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List of Acronym and Abbreviation

DLR	German Aerospace Center (Deutsches Zentrum für Luft und Raumfahrt)
ESAIL	Electric Sail
PTA	Preliminary Test Assembly
EU	European Union
FP-7	Seventh Framework Program
WP	Work Package

Reference Documents

[RD01]	Reeling test plan, WP 31, D3.1.2., Issue 1, Revision 0

1. Scope of this Document

This document defines constrains and requirements for the unreeling tests of the main tether, the so called “Heytether” [RD01]. This document is a deliverable item of the EU-FP7 funded Esail-Project. Furthermore it describes the tether reel concepts for the unreeling tests and the assembly to accomplish the reeling tests.

2. Tether Test Reel Concepts

To investigate the different ways of unreeling the Tether, different possibilities were developed and analyzed to find the most promising concept to be realized for unreeling tests. In the following the individual concepts are described and evaluated.

2.1. *Folded Tether Concepts*

Concepts with folded tethers figured out to be not possible to realize due to the fragility of the tether. The minimal bending radius of the tether material is 18 mm, this shows that a folded version would permanently deform, weaken or even damage the tether. This would show up in damaging the tether wires itself or the welding points from the auxiliary wires on the main wires could break. Therefore the analysis of these concepts was not continued.
The Folding concept is not applicable to the fragile design of the tether.

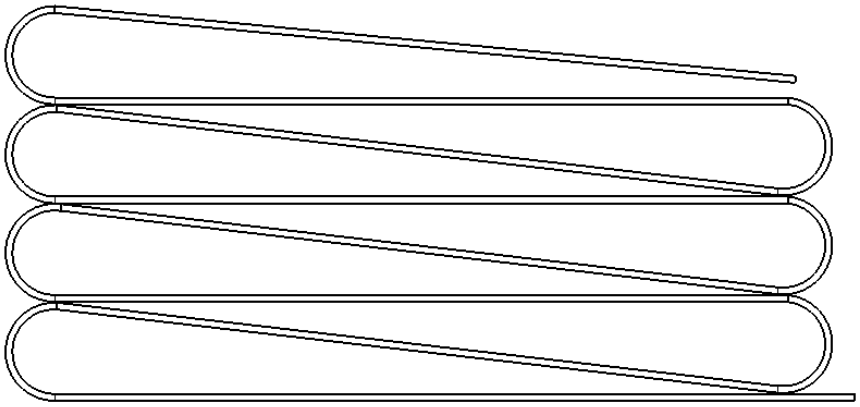

Figure 1: Folded tether concept

2.2. *Reeling Tether Concept with Flat Contact Surface*

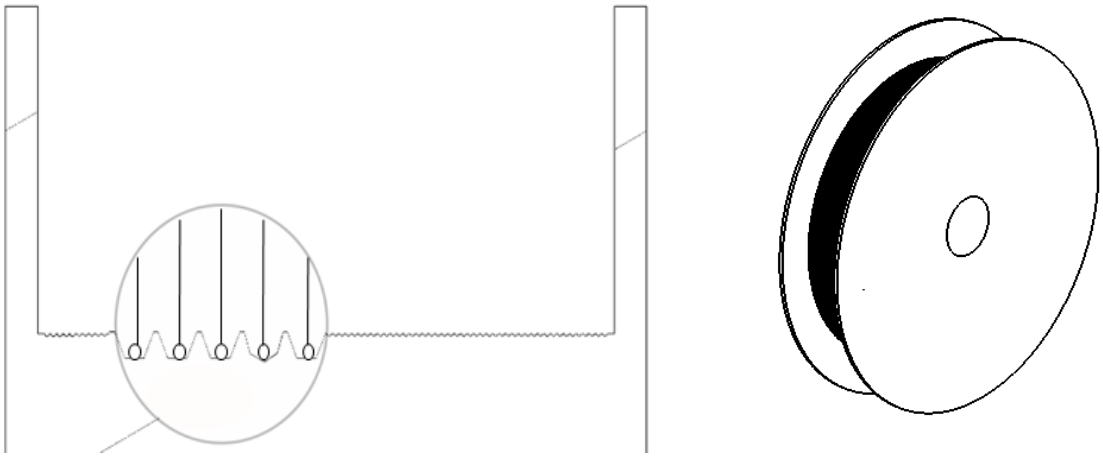

Figure 2: Flat contact surface concept

In this concept the Heytether is reeled layer by layer, side by side. The tether touching contact surface is modified with small grooves in a helix shape for guiding the tether, therefore no additional mechanism is needed. The design of this reel is similar to a commercial used cable reel. The advantage of the concept is the simpleness of the reel and the simple guidance system unreeling. Furthermore the grooves keeps the main wire in its position and avoid therefore the jamming between the main wires A disadvantage in this concept is that the position of the auxiliary wire loops is not defined in each position and therefore the possibility to jam and causing damage on the Heytether exist. Further the high manufacturing complexity is also a disadvantage.

Advantage	Disadvantage
Guidance of the Tether Tether layers side by side Avoid jam of the main wires	Difficult tether guidance manufacturing Auxiliary wires loops could jam in to each other

2.3. *Reeling Tether Concept with Inclined Contact Surface*

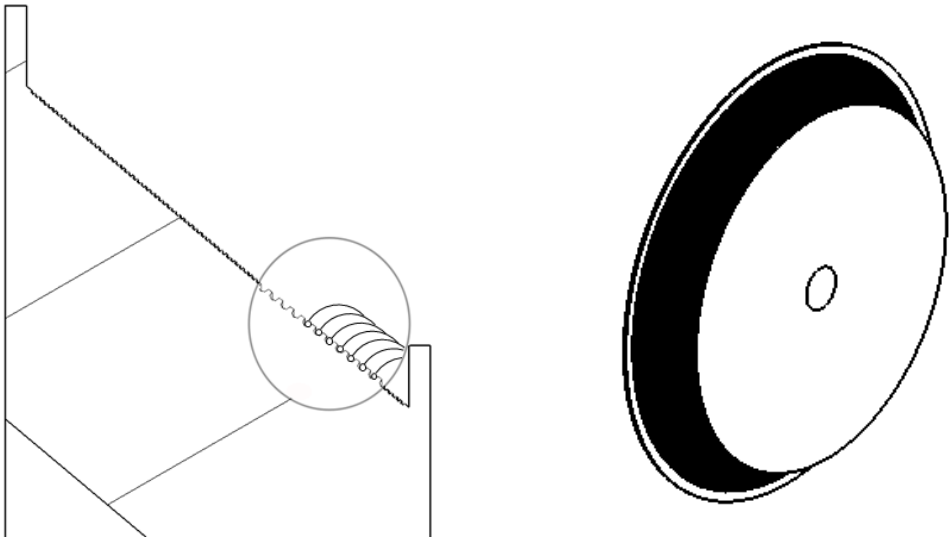

Figure 3: Inclined contact surface concept

This reel concept is characterized by an inclined tether contact surface. Like the concept described before the contact surface is modified with a groove for guiding the tether. As a result of the inclined contact surface, it is guaranteed in every case that the supreme auxiliary wire loop falls on top of the individual lower layer. Thus it is avoided that the layers could jam. Figure 2 shows the configuration of the layers, laying on top of each other. In this configuration, the bigger diameter of the cylinder shaped reel has to be oriented into downward direction during launch. The advantage of this concept is that the inclined running surface avoids jamming of the auxiliary wire loops. In addition to that, the grooves guide the tethers and additional mechanisms can be avoided. The disadvantage of this concept is the disproportional high manufacturing complexity of the reel due to the inclined running surface and the groove for the tether guidance.

Advantage	Disadvantage
Guidance of the tether	Difficult tether guidance manufacturing
Tether layers side by side	Complex Reel manufacturing
	Straighten the tether perpendicular

2.4. *Reeling Tether Concept with lay down Tethers*

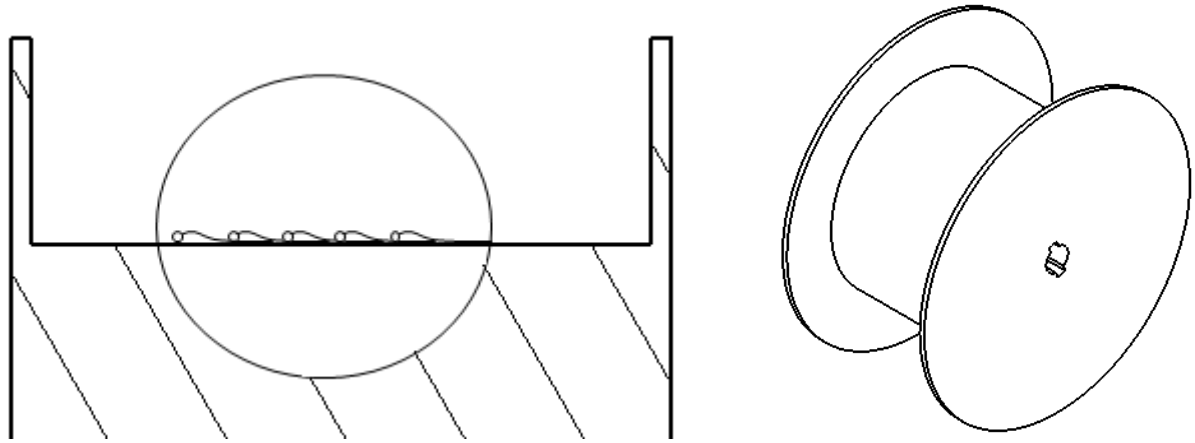

Figure 4: Lay down tether concept

For this Concept the auxiliary tether loops lay down on the contact surface. Therefore the width of the contact surface needs to be augmented. In this concept the reels contact surface is plane without any guiding profile machined on the tether contact surface. The down laid tethers require a defined distance between two main wires of the tether. This distance is mandatory to avoid strong bending on the auxiliary wire loops, which could result in outrunning the stress capacity of the welding points as well as the stress capacity of the auxiliary wire itself. The advantage is that the reel has a simple design and that the auxiliary tether loops can lay on the contact surface and might not be straighten perpendicular to the contact surface. In addition to that, the reeling on the reel is very simple and reliable. The disadvantage is the additional needed tether guidance system for reeling the tether during manufacturing process or at upreeling after each test run. The tether must be stacked above each other; this requires a very careful and smooth reeling process during manufacturing.

Advantage	Disadvantage
Heytether lay on the running surface Simple reel design Due to the distance between the main Heytether the bending force is low	Additional Heytether guidance needed

2.5. *Reeling Tether Concept with Stacked Tether*

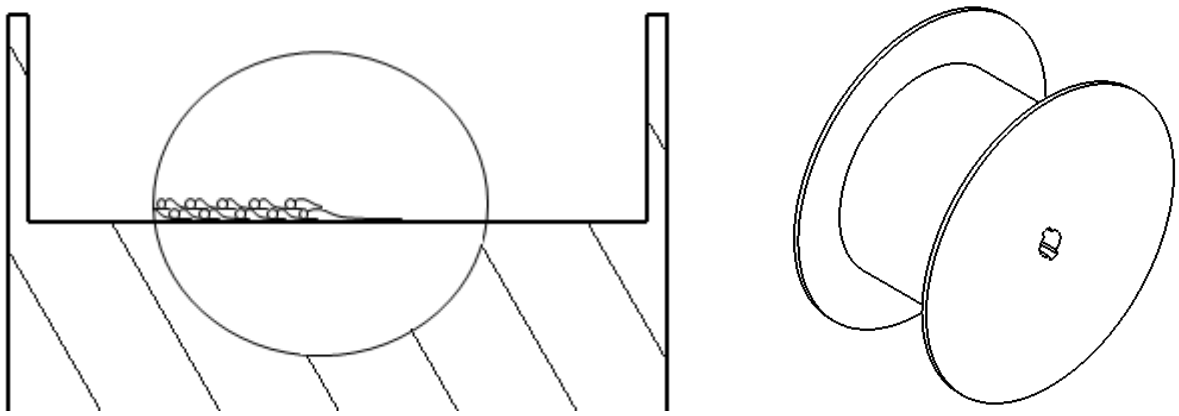

Figure 5: Stacked tether concept

In this concept the wheel design is similar to the down laid tether concept. The only exemption is the required reel width. The tether reeling is different in this concept.
The tether is reeled up side by side and as soon as the whole space on the contact surface is filled, the tether will be stacked above each other. In this case only the tether of the former layer defines where the next layer is positioned. The advantage in this configuration is the simple reel design and that additional tether guidance obsolete. The disadvantage is that the tether can damaged each other by stacking above or beside each other, as well as the welding points of the auxiliary wire loops could get harmed due to high bending forces. Furthermore on one edge of the reel side wall the auxiliary wire loops are bended extremely when more Heytether layers are stacked above each other and the weighting force stresses the auxiliary wires.

Advantage	Disadvantage
Heytether lay on the running surface Simple reel design No Additional Heytether guidance needed	Auxiliary tether loops could jam in to each other

2.6. *Reeling Tether Concept Rounded Edge Reel*

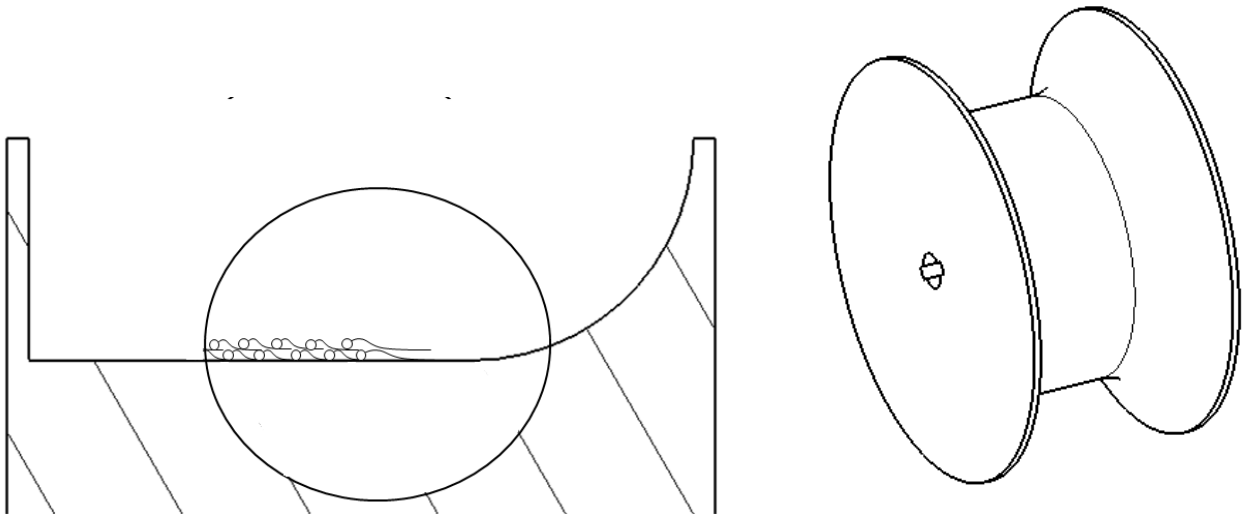

Figure 6: Rounded edge concept

This concept is a further development of the staked tether concept. This development results in a rounded reel side edge. The way how the Heytether is reeled up to the reel is the same as in the stacked tether concept. The advantage is again the simple reel design and the not necessary tether guidance. And with the new rounded edge the bending of the auxiliary tether loops will be reduced or even totally avoided. The only disadvantage is that the manufacturing complexity of the reel is slightly increased.

Advantage	Disadvantage
Heytether lay on the running surface Simple reel design No Additional Heytether guidance needed	Moderate difficult Reel manufacturing

3. Concept evaluation

To choose a reel concept for implementation of tests, all introduced concepts were evaluated. The criteria for evaluation of the design are the following:

- Jam of the Heytether:
  This refers to the jamming risk of the described concept during the unreeling procedure.
  The worst case originates if the Heytether is reeled up without guidance and caused by this effect the Heytether will become stacked above each other. Through the groove in the tether running surfaces stacking of layers will be avoided and the possibility of damaging and jamming of the Heytether is decreased. With an additionally inclined running surface the best rated solution related to safe deployment can be realized.
- Guidance of the Heytether:
  This criteria deal with the guidance of the Heytether. The best case is that the tether will be guided passively e.g.: with a groove, the worst case requires an additional external guidance mechanism for reeling the tether.
- Complexity of the manufacturing:
  In this case the complexity of the reel manufacturing is evaluated. The worst case for the manufacturing is an inclined running surface equipped with a groove. Accordingly the best case is a flat running surface without any groove.

The following Table valued the different designs of the reel after the following system:

Best case	Good case	Neutral case	Bade case	Worst case
++	+	0	-	--

	Concept 1 (flat)	**Concept 2 (inclined)**	**Concept 3 (lay down)**	**Concept 4 (stacked)**	**Concept 5 (round edge)**
Jam of the Heytether	+	++	0	-	0
Guidance of the Heytether	+	+	0	+	+
Complexity of the manufactiuring	-	--	++	++	+

To have the possibility to investigate in different unreeling problems the best rated concept, concept 3 and 5, are selected for the test implementation. But thus that the concept 4 has the same reel design as concept 3 additionally the concept 4 is implemented also for a test reel. With this three different reel designs it is possible to investigate in many different tether reeling configurations. For this reason the influence of the tether damaging during unreeling can be detected in many cases.

4. Test Setup

4.1. *Tether Test Reels*

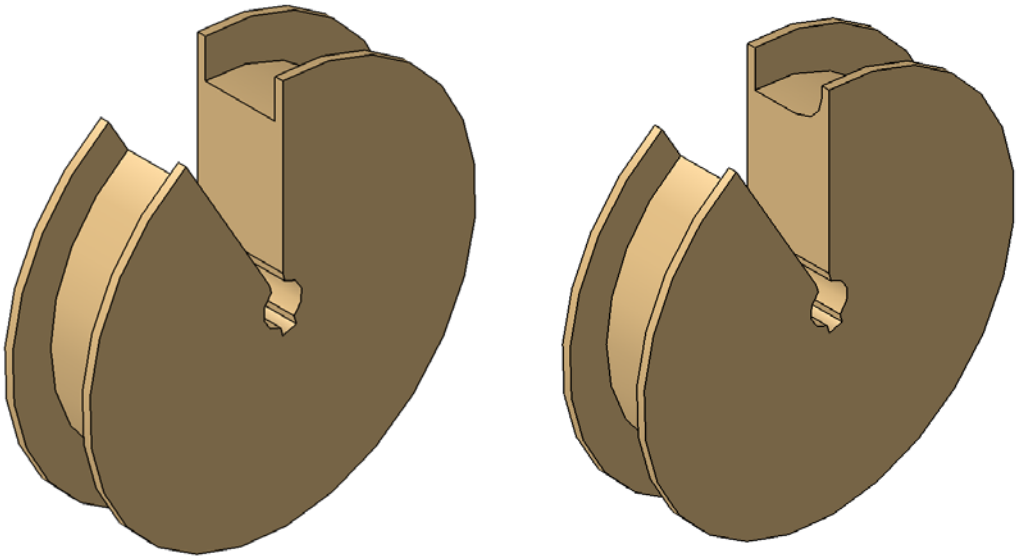

Figure 7: Cut through, isometric, views of the Concept 4 (left) and concept 5 (right) reels in the 10 m test tether version.

For the reeling tests, two different diameters of reels are going to be realized. The smaller version, which can handle the current tether samples of 10 m, is used to verify the reeling concepts, described in chapter 2. The big diameter reel shall be close to the final main tether reel design and was designed with the input from the preliminary unreeling tests, executed with the 10 m tether reel and the PTA.

The 10 m tether reel is used to investigate the tether unreeling behaviour of the concept 4. This kind of reels has a contact surface width of 9 mm based in the first design of the Heytether with an auxiliary loop high of 9 mm. This version will be used to investigate the reeling behaviour in case of many stacked layers.].

The rounded edge reel represents a modification of the 10 m tether reel and represents the concept 5. This reel has two different designed side walls. The reel has a sharp defined transition from the contact surface to the sidewall. The opposite site has a smooth shaped transition. The rounded side is implemented in the reel design to avoid the deflection of the auxiliary loops. This deflection is caused by the stacked main tether in this transition area. At the reeling process, the tether is reeled up on the sharp edged transition, with its auxiliary wire loops pointing towards the rounded side of the reel. This reel allows investigating in the tether behaviour in the transition area as well as if a rounded transition could help avoiding to damage the tether.

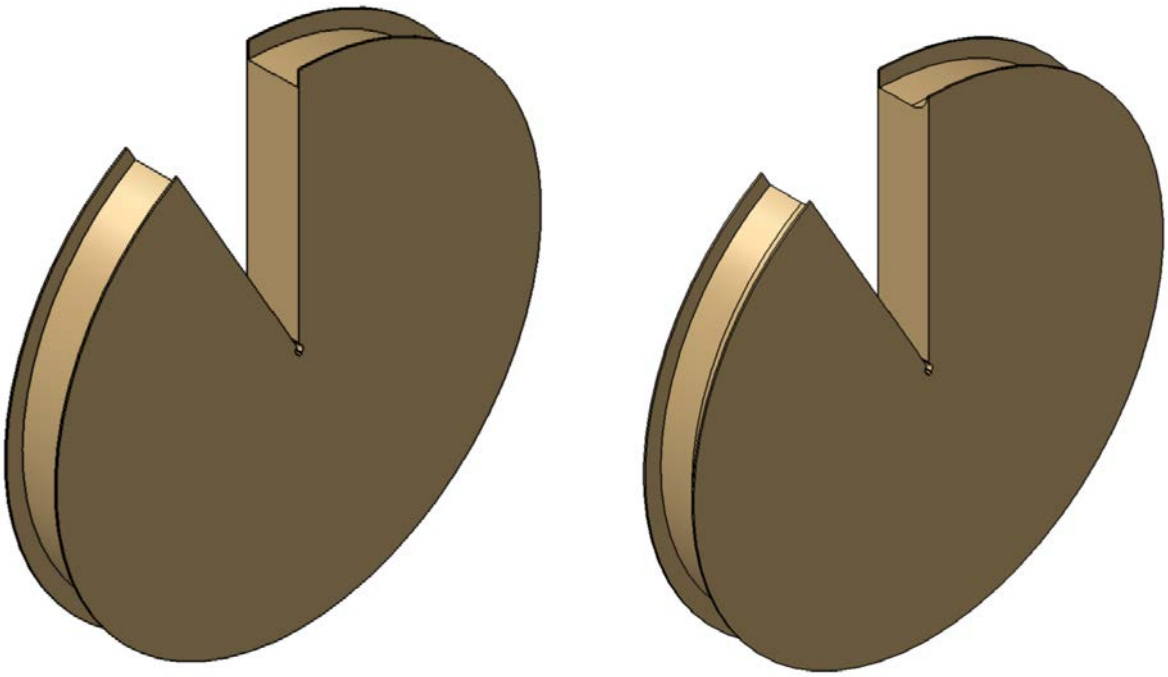

Figure 8: Wide Reel with the contact surface width for the modified tether in the concept 4 (left) and concept 5 representing version

Due to the design change of the main tether, (from Hoytether to Heytether) the auxiliary loops became a new height of 20 mm. Therefore the tether reel had to be adapted to the new loop height. To reduce the damaging possibility of the stacked tethers, a distance of 0.5 mm between two main tethers was foreseen. Due to this modification the new width of the tether running surface is 30 mm. With this dimension it is possible to place nearly 20 layers of the main tether side by side before the next stack of layer begins. With this tether reel it is possible to investigate if the distance between the tether layers influence the unreeling behaviour in that way that damage on the tethers can be avoided.

5. Constraints

The following constrains describe design characteristics or results that should be provide for the design implementation of the test reel and or the test configuration.

Number	Description	Reference
CS-311-01	The tether length for the test is 10 m.	Tether manufacture
CS-311-02	Two different tether loop high, 10 mm and 20 mm, shall be tested.	Tether manufacture
CS-311-03	The used tether end mass shall be the same for every test run.	RF-1
CS-311-04	The thermal influence in the test facility shall be low	RF-1
CS-311-05	The reel geometry and material should be realistic to the main tether reel.	RF-6

6. Requirements

The requirements for the unreeling tests can be split in the following three classifications.

6.1. *System Requirements*

This part describes the requirements which are usable for the whole system.

Number	Description	Reference
SR-311-01	The unreeling speed of the Heytether shall be measured.	RF-5
SR-311-02	The deployed length of the Heytether shall be measured.	RF-5

6.2. *Functional Requirements*

The functional requirements describe the performance of the system.

Number	Description	Reference
FR-311-01	Retraction of the Heytether shall be possible.	RF-4
FR-311-02	The minimal unreeling speed shall be 3 mm/s.	RF-1
FR-311-03	It should be possible to unreel the Heytether of 10 m.	RF-2
FR-311-04	The unreeling of the tether shall be repeatable.	RF-1

6.3. *Operational Requirements*

These requirements describe the operability of the system.

Number	Description	Reference
OR-311-01	The unreeling speed shall be the same for every test run in a single campaign.	RF-1
OR-311-02	The mounting height of the PTA should allow a full deployment of the test tether.	RF-2
OR-311-03	The unreeling speed should be regulated.	RF-3
OR-311-04	The unreeling tests should be documented on video.	
OR-311-05	The pull force on the tether should be simulated by gravity force.	

References:

RF-1 The reproducing of the same conditions in every test run is required for the unreeling tests, to demonstrate the reliability of the tether unreeling.

RF-2 To be able to test the unreeling behaviour of the full deployed tether, the full length should be unreeled.

RF-3 To investigate in the tether behaviour during different unreeling speeds, the motor should have the possibility to change the rotation speed.

RF-4 During the tests it should be investigate in different numbers of stacked layer on the reel. Therefore the motor should be capable to reel up the tether.

RF-5 Measurement of the different tether conditions during the test.

RF-6 Esail Document Part B: Description of Work