Electric solar wind sail

ESAIL D44.1

Final Report of Remote Unit Tether Jettison System

Work Package: **WP 4.4**

Version: **Version 1.0**

Prepared by: Tartu Observatory, Viljo Allik, Ants Agu

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Coordinating person: Pekka Janhunen, Pekka.Janhunen@fmi.fi

(List of participants:)

Participant no.	**Participant organisation**	**Abbrev.**	**Country**
1 (Coordinator)	Finnish Meteorological Institute	FMI	Finland
2	University of Helsinki	UH	Finland

3	University of Jyväskylä	UJ	Finland
4	German Aerospace Center	DLR	Germany
5	Ångström Space Technology Centre	ÅSTC	Sweden
6	Nanospace AB	Nanospace	Sweden
7	Tartu Observatory	Tartu	Estonia
8	University of Pisa	Pisa	Italy
9	Alta S.p.A.	Alta	Italy

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1. Introduction

This document describes the final design and test results of ESAIL Remote Unit (RU) tether jettison system.

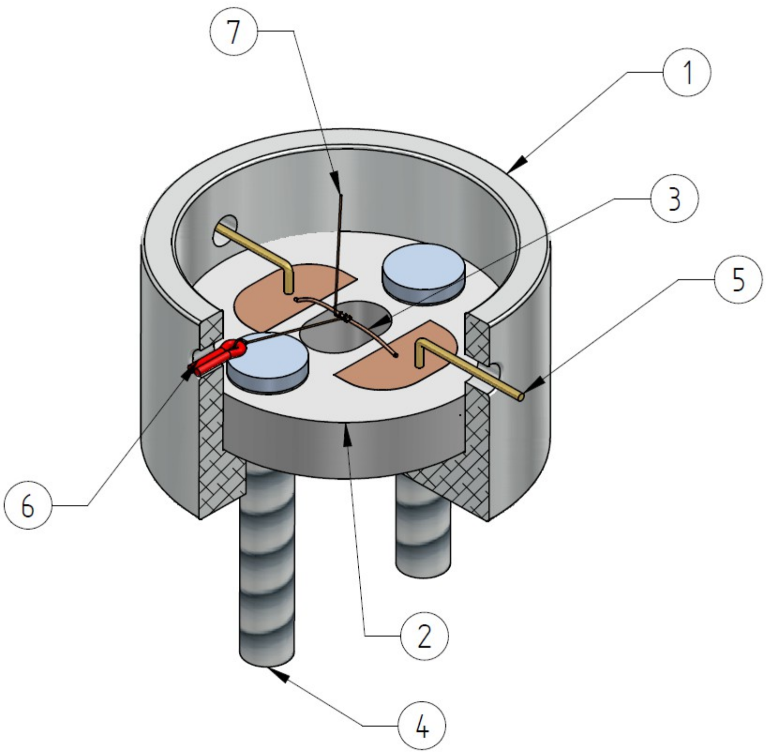
2. Overview of the development work process

During the ESAIL project execution the RU tether jettison system design requirements evolved from a system capable of providing specified incremental speed to the end mass attached to the tether moving it away from the common plane of operational tethers to a simpler approach which requires just releasing the RU end of the tether from the RU structure.

Because of that the initial spring loaded jettison design concept was abandoned and a new concept was developed. The final concept is based on melting a piece of plastic fibre attached to the end of each main tether by using resistance wire heated by electrical current.

The most important requirements for the design were reliability and minimized mass of the system. Also manufacturability and repeatability of the design were of major concern.

The final design concept is shown on figure 2.1



1 – Body of the jettison device (aluminum T6061-T6 alloy)

2 – Printed Circuit Board (PCB)

3 – Resistance wire

4 – Mounting screw

5 – Electrical connection wire

6 – Tether attachment point

7 – Tether end section (Dyneema fiber, 0.06mm diameter)

Fig. 2.1 ESAIL main tether jettison system design concept

The end section of the tether has to be made of material that can be easily melted by the heated resistance wire. The most suitable candidate of such material is Dyneema ® fiber. Dyneema ® is qualified to be used in space The recommended diameter of the fiber is in a range between 0.04 and

0.11 mm. Berkley NanoFil $_{TM}$ of 0.06mm diameter was used in the device prototype.

The body of the jettison device first prototype was manufactured by using 3D printing technology. The final prototype was manufactured by using CNC milling technology. Total of 3 final prototypes were manufactured. Two prototypes were used for local testing at Tartu Observatory and one was sent to Uppsala University for integration testing of the RU.

The PCB of the device was manufactured of FR4 material and and processed by using LPKF PCB prototyping equipment.

The photo of one of the assembled prototype devices (without connected tether) is shown on figure 2.2.

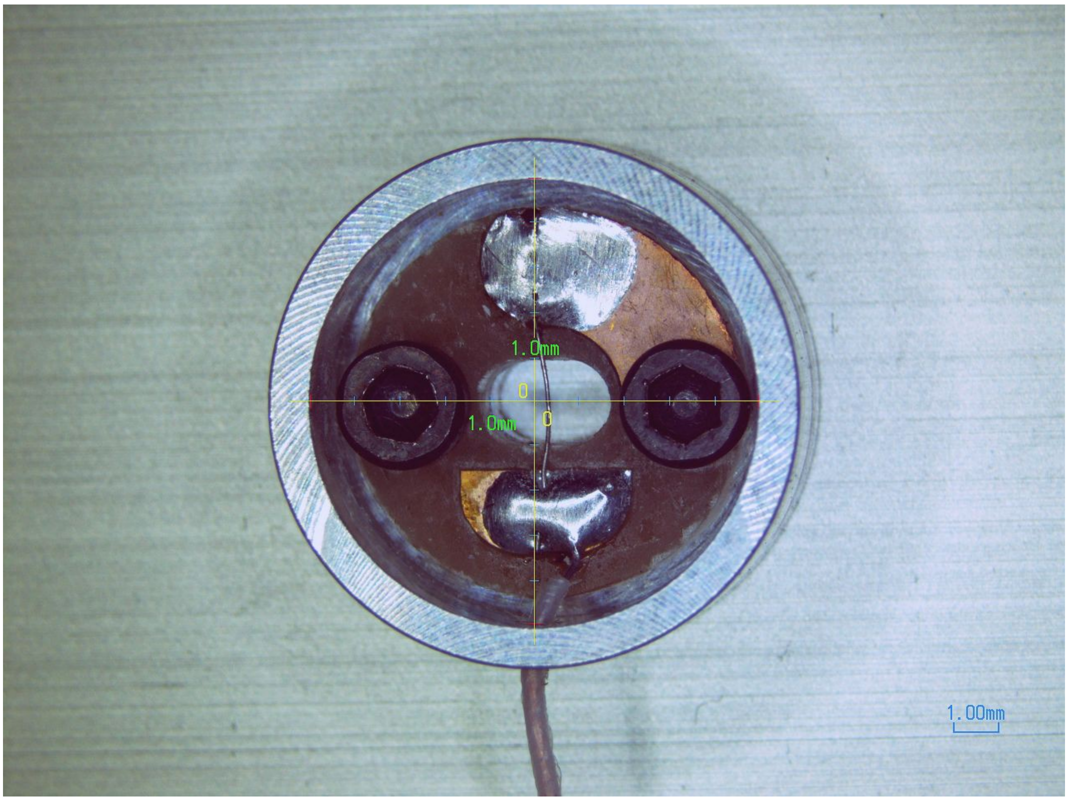


Fig. 2.2 Photo of the ESAIL main tether jettison device without tether attached

Compared to the original design concept the final prototype hatd the following changes which improved the performance and manufacturability of the device:

- One of the electrical connection wires was replaced by chassis ground connection via one of the mounting screws of the device

- The electrical PCB design was slightly changed
- The tether end point attachment was moved under one of the screw heads

The photo of the device with tether attached is shown on figure 2.3.

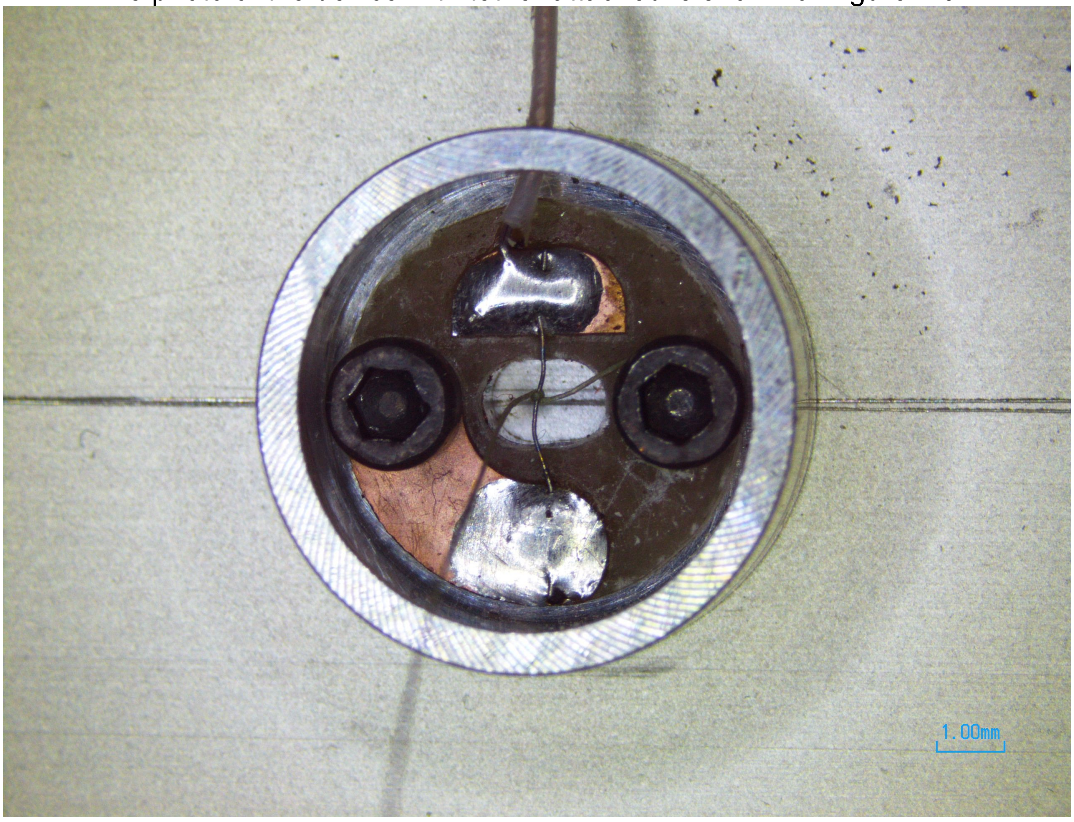


Fig. 2.3 Photo of the ESAIL main tether jettison device with tether attached

The mass of the jettison device together with mounting screws and electrical cable is about 1.6 g.

3. Testing

3.1 Tests selection

The following tests were considered relevant for the tether jettison device:

- Jettison tests at normal pressure and vacuum
- Vibration and mechanical shock tests
- Thermal vacuum tests
- Electrical tests

3.2 Tests set-up

- General test set-up

Functional tests have been performed using one of the jettison device final prototypes. To initiate jettison an adjustable DC current supply was used as electrical current source to heat up the resistance wire.

The output voltage of the power supply was set to 7.2 V according to the RU electrical power system design. The minimum electrical current level for reliable jettison function was determined experimentally and used later to perform actual tests. The actual used DC current value was close to 1 A.

The jettison tests at normal atmospheric pressure were monitored visually by test operator and recorded by a progressive scan video camera operating at 50 frames per second.

- Thermal vacuum testing

The jettison tests in vacuum conditions were performed in a small thermal vacuum chamber at Tartu Observatory.

The actual test set-up in the thermal vacuum chamber is shown on figures 3.1 and 3.2

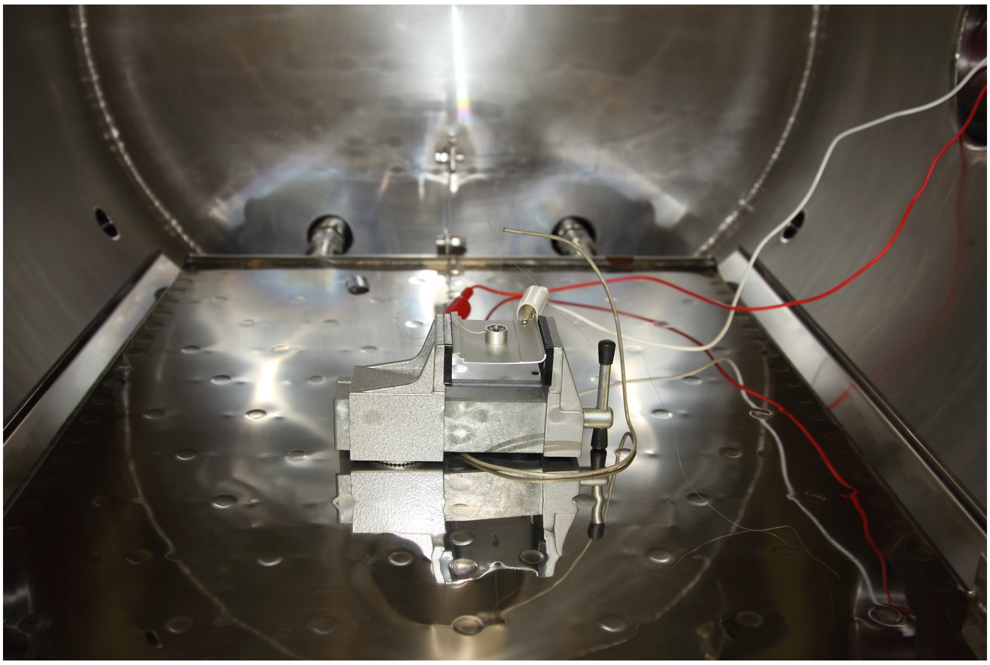


Fig. 3.1 Photo of the ESAIL main tether jettison device installed in the thermal vacuum chamber at Tartu Observatory

The jettison event was triggered in vacuum conditions at -40 deg/C and +80 deg/C by external DC voltage source. The result of the test was verified afterwards by visual inspection of the device.

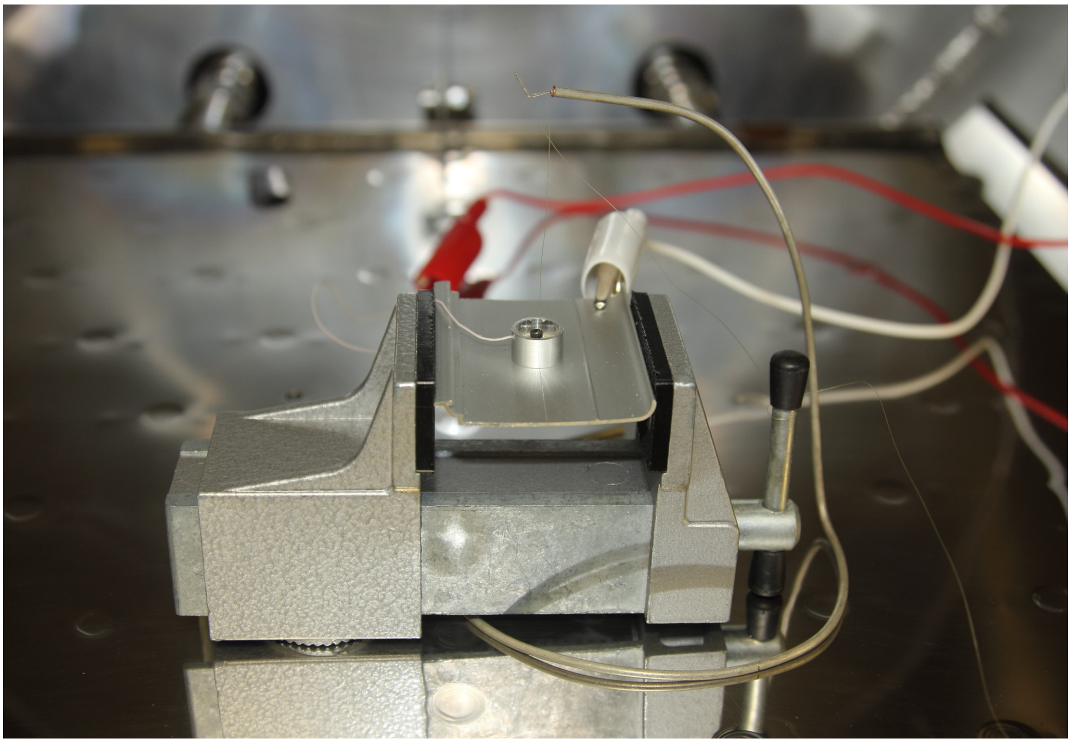


Fig. 3.2 Photo of the ESAIL main tether jettison device installed in the thermal vacuum chamber at Tartu Observatory, close-up view

- Vibration and shock testing

  Vibration and shock tests on the jettison device were performed on a small LDS V406 vibration test bench at Tartu Observatory. The device function was verified after the complete tests cycle. A careful visual inspection under stereoscopic microscope was performed to reveal eventual mechanical damage as a result of mechanical vibration and shock. The actual vibration tests set-up is shown on figure 3.3.

- Electrical testing

  Electrical tests were performed to verify the integrity of the resistance wire and its electrical connections by measuring the electrical resistance of the device during or after specific thermal vacuum or mechanical tests. Resistance measurements were done by using Fluke 287 digital multimeter.

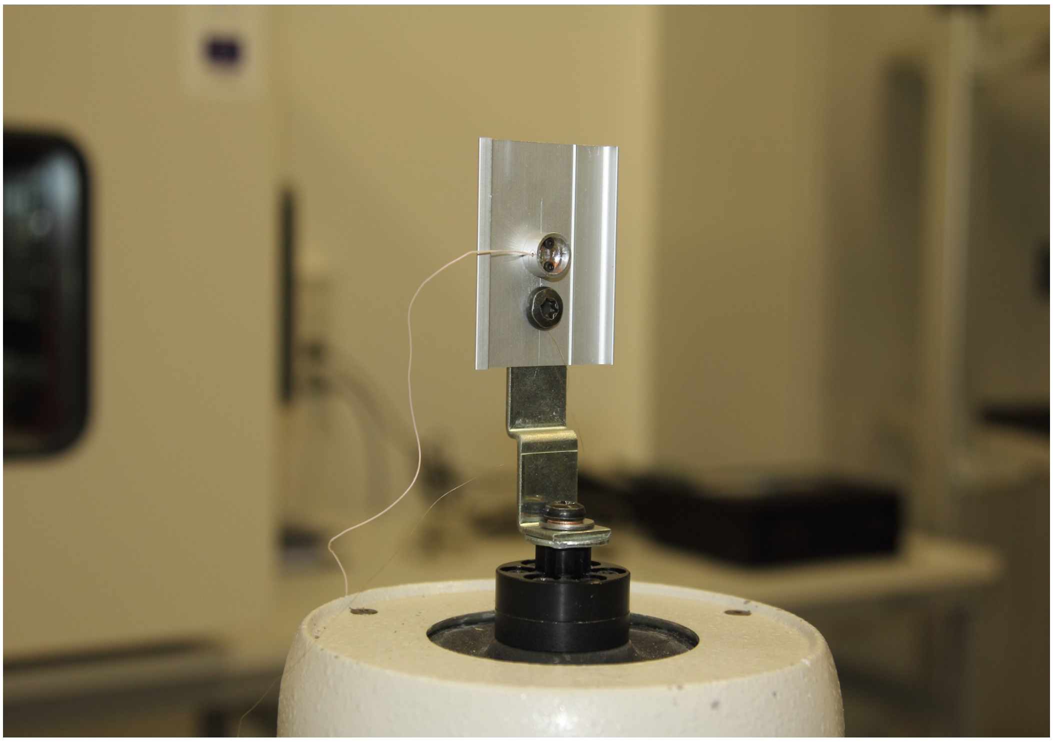


Fig. 3.3 Photo of the ESAIL main tether jettison device installed on the LDS vibration test bench at Tartu Observatory

3.3 Test results

- Functional tests

The jettison event was verified with positive result in all tests performed.

3 still frames from the captured progressive scan video recording are shown on figures 3.4 … 3.6. The typical jettison event at 1 A DC current takes about 0.5 … 1 s. The jettison event can be significantly faster at higher DC currents.

- Thermal vacuum tests

The jettison event was verified positively in all thermal vacuum tests performed at different temperatures. It was observed that in vacuum conditions somewhat (about 20...30%) lower DC current was needed to trigger reliable jettison event.

There was no significant difference in burn event duration observed at different temperatures.

- Vibration and shock tests

Vibration and shock tests were performed wit the device attached to the vibration bench in 3 different axis directions.

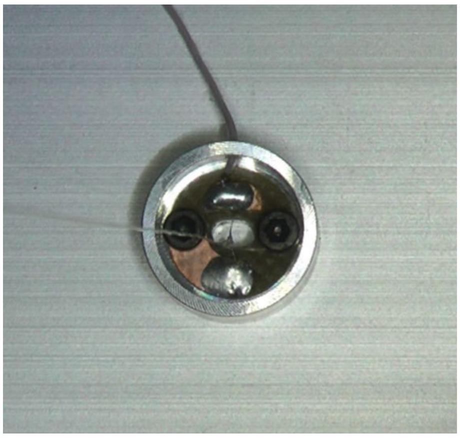


Fig. 3.4 Still frame from the jettison event video recording: start of the burn

Fig. 3.5 Still frame from the jettison event video recording: burn in progress

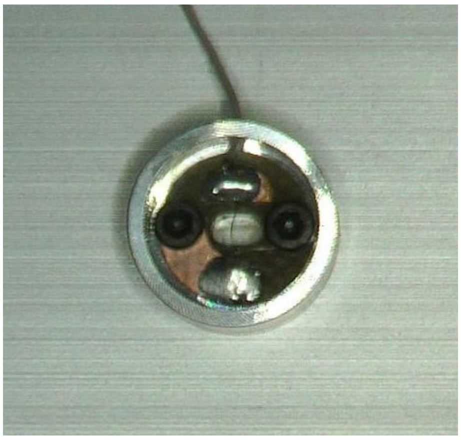


Fig. 3.6 Still frame from the jettison event video recording: end of the burn

The device was inspected against any damage before and after tests on each axis. During initial tests on axis in parallel with the mounting screws loose screws were observed after the test. To mitigate the problem a special adhesive (Loxeal $_{TM}$ 55-03 medio nut lock) was used on the screw threads. The test was repeated and no loose screws were observed after the fix.

The vibration and shock tests passed at all required acceleration levels and timings according to [1].

- Electrical tests

Electrical tests of the jettison device did not show any significant change in the device electrical resistance.

4. Conclusions

During development process a fully functional tether jettison device was designed, manufactured and tested. It is compliant to the current ESAIL mission configuration and both electrically and mechanically compliant to the design concept of the ESAIL remote unit subsystems.

A very similar design concept using electrically heatable resistance wire is used currently in the ESTCUBE-1 student satellite design for its telecommunication antenna and main payload deployment system. The satellite is currently in orbit and its antenna deployment system has performed correctly at first deployment attempt.

The jettison device is relatively easy to manufacture, light weight and can be easily integrated into the ESAIL remote unit design. Selection and optimization of some of its components can be still done depending on the actual remote unit configuration for any eventual space mission using the ESAIL design concept.

References

1. ESAIL D41Requirements specification of the Remote Unit