ESAIL D41.3
TEST PLAN – Remote unit

Work Package: **WP 41**

Version: **Version 1.0**

Prepared by:	Sven Wagner, Johan Sundqvist, and Greger Thornell, Ångström Space Technology Centre, Uppsala University
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Coordinating person:	Pekka Janhunen, pekka.janhunen@fmi.fi
WP Coordinator:	Greger Thornell, greger.thornell@angstrom.uu.se

(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

Introduction
This document details the testing of the so called Remote Unit, RU, which is a recurrent subsystem of the E-sail spacecraft under the contract FP7-SPACE-2010-1, project no. 262733, AD-1. It describes test conditions and parameters, the technical implementation of the tests, test order, responsibilities and facilities.

Applicable documents
AD-1: "Part B: Description of Work" of final EU E-sail application (final version)
AD-2: "ESAIL D4.1: Requirements specification of the remote unit" (final version)
AD-3: "ESAIL D4.2: Design description of the remote unit" (final version)
AD-4: "Ariane 5 – User´s manual"

Overall purpose of testing
Since subsystems of the RU, in turn, undergo testing separately, the main scope of the testing, and hence this document, is mechanical and thermal testing of the spacecraft bus, although a few operational tests are included. Of benefit for development of the ESAIL technology beyond this project, some testing does not just aim at verifying that the RU fulfils the requirements (Section 5.4, AD-2), but also at monitoring to what extent it does, or doesn't, do this. (The purposes of individual tests, including requirements addressed, are stated in the respective subsections.)

Short description of Remote Unit
The RU has two embodiments depending on which of the two propulsion systems: Cold Gas or FEEP, it is configured for. In both cases, the design is, basically, a flat heat shield on which shading wings (oblique to the shield, and on four sides of it), two auxiliary tether reels (located at two adjacent corners of the shield), and, via thermal spacers, a thermal box are attached, Figure 1. The thermal box, which is wrapped in MLI, accommodates parts sensitive to temperature extremes or fluctuations, such as the control system, power supply, and reel motor controllers. Whereas in the Cold Gas configuration, the propulsion system is inside the thermal box, it is put outside, between the box and the shield, and on the side of the box, in the FEEP case.

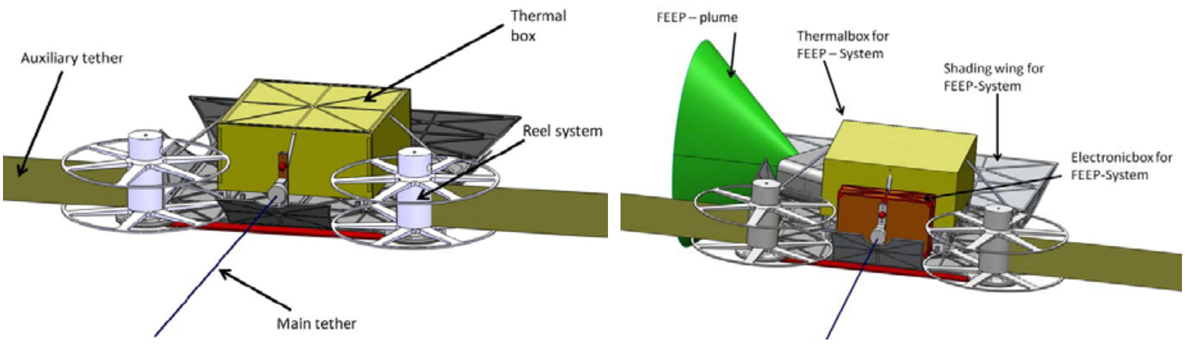


Figure 1: Overview of RU in Cold Gas configuration (left) and in FEEP configuration (right). The green cone in the right image is not a structural part.

In addition, the heat shield, which forms the chassis of the craft, carries solar cells, temperature as well as sun sensors, and an antenna on its sun-facing side, and a light beacon, a jettison mechanism and a heat dissipater on its other side. Design details are given in AD-3.

Overview of tests
Subject to a future decision depending on resources and relevancy, either or both of the two types of RUs will be tested. In the following, however, some details are illustrated specifically for the CG type. In case the FEEP-type RU is tested instead or in addition, these particular details are easily transferred.

The tests included in this study are listed in Table 1 together with their identifiers and applicable requirements.

Table 1: Overview of tests with reference to applicable requirements of AD-2.

ID	test	note	requirements
TI	technical inspection	mass, size, etc	ES1-RU-101, -102 (partly) -103
VCT	vacuum compatibility testing	mechanical effects, not outgassing	ES1-RU-605 (partly)
TT	thermal testing		ES1-RU-201 to 202, -214, -215, -603, -604 & -606 (partly)
SMT	static mechanical testing	launch load from fixture to main craft, and deployment load from tethers	ES1-RU-203 & -107
VT	vibrations testing	launch load	ES1-RU-203 & -204 (translating to ES1-301)
PT	pull test	Auxtether load	ES1-RU-211

The order of the tests is according to increasing risk of destruction and follows that of Table 1.

General pass criteria for the RU are: no visible damages on any of the parts and no critical degradation of functionality. A test fails if any of the general pass criteria or specified criteria, mentioned in the description, is not fulfilled.

As evident from the individual test descriptions, tests will be carried out at different facilities and under changing supervision. The logistics and time plan follow Table 2, which will be completed when the test facilities have been selected.

Table 2: Test planning. (Detailed schedule TBD.)

ID	start	end	facility	test responsible	dispatch responsible
TI			ÅSTC	ÅSTC	N/A
VCT			ÅSTC	ÅSTC	ÅSTC
TT					
SMT					
VT					
PT			ÅSTC	ÅSTC	N/A

Already in itself, the RU is equipped with sensors for its housekeeping. For test purposes, the RU will be equipped with additional thermal sensors and strain gauges. The positions of all sensors and gauges are illustrated in Appendix 1. The thermal sensors will be PT-100 or PT-1000 platinum resistance thermometers, while the strain sensors will be one- or two-element gauges with different temperature compensation materials. To compensate for temperature effects, each sensing element will use an identical dummy gauge. Some electronic circuitry will be needed in order to power the sensors, calibrate for tolerances, and amplify each output signal. This circuitry will be a stand-alone system, external to the RU, and will connect to the sensors through wires. Furthermore a design for a mechanical testing fixture is included in the appendix as well.

Technical inspection
A general inspection of the RU is necessary to match the shape and size specifications defined in AD-3 with the actual properties. This inspection will assess the mass of the system, the overall dimensions, mechanical interface tolerances, functionality of the subsystems and overall appearance.

The outcome will be compared with the specifications.

Vacuum compatibility test
The purpose of this test is to verify the functionality of the remote unit under vacuum conditions and at 20°C. The test includes two elements:

- *in-situ* operational testing of the reels, and
- verification of functionality of electrical components after having been subjected to vacuum.

Parts belonging to the propulsion subsystem are excluded from the test.

Equipment needed for this test is a chamber which can provide medium vacuum conditions (50 mbar or better), and has an overall dimension of at least 300x280x80 mm. An additional accessory for this test would be a video surveillance system. The possibility to use wireless communication would be welcome.

Test input parameters will be the vacuum conditions with a tolerance of +/-10%.

The motion parts will be programmed to start on/off cycling when the stated vacuum level has been reached. The cycling will run for 10 minutes and is divided into segments consisting of a 15-second continuous run followed by a 15-second pause.

If conducted together with the thermal test (see below), the RU will be mounted with a string system with specified fixture points on the thermal box. Otherwise it can be placed on small spacers of poor thermal conductivity.

The motion of the reels will be monitored continuously.

Thermal test
The purpose of this test is the verification of the RU under thermal conditions emulating the extremes expected from a mission. The test serves to verify that reel components work under these conditions, that the mechanical stability of the RU is enough, and that the specified operational temperature ranges are maintained at critical locations.

Equipment needed for the thermal test is a low-vacuum chamber with sunlight imitation capability. The RU will be operated and monitored in real time, and data from all temperature gauges will be saved. Inherently, the RU is equipped with 7 temperature sensors, and for pure test purposes, it will be equipped with additional temperature gauges according to Appendix 1.

If possible, thermal imaging with an IR camera will be made.

The vacuum compatibility test and the thermal test may be executed in the same test facility.

The test will be conducted at heat exposure conditions corresponding to 0° at 0.9 a.u., which represents the hottest mission condition (approx. 1700 W/m^2), and to 60° at 4.0 a.u. (approx. 42 W/m^2), which represents the coldest mission condition. In these cases, where the unit is exposed to the sun from its backside, i.e. the solar cell side, the steady state temperature is of greatest interest, although attempts will be made to record the entire thermal lapse.

In addition, the RU will simulate a complete turnover in which it stays exposed from its front side for 5 minutes at the simulated distance of 0.9 a.u. before it recovers back to 0° again.

Table 3: Thermal test specifications

Angle [°]	Distance [AU]	Time	Exposure [W]	Exposed side
0	0.9	until steady state	1700	back (solar cell side)
60	4.0	until steady state	42	ditto
Turnover	0.9	5 min	42	front

The test output parameters will be data from all temperature sensors. The received results are compared with design simulation results, as well as with requirements stated in AD-3.

Optionally, data from strain gauges will be recorded to give information on reversible thermal deformation.

The RU will be mounted in a string system both to minimize heat conduction to and from the environment and to avoid shading.

To include the effect of self-heating, the reels and control and power system will be operated continuously during the hot case. Correspondingly, the system will hibernate when the cold case is mimicked.

If possible, this test will be made together with the vacuum compatibility test described above.

Like with the vacuum test, thruster systems will not be tested here.

Mechanical test
This test is conducted to verify the ability of the system to withstand loads and forces occurring during the launch preparations and the launch itself. A successful pass means that the system is in a condition where it can be operated without any restrictions. During the test, the deformation will be monitored through strain gauges in certain areas. After testing, certain parts, the heat shield, thermal spacers, etc., will be checked for plastic deformation by measurement of dimensions.

The mechanical test can be divided into three subsections, which are named static, vibration and shock.

Data necessary to conduct this test is obtained from AD-4. The longitudinal direction in AD-4 refers to the launch vehicle's rotational axis. The RU is attached to a fixture (see Appendix 2) which is used during all mechanical tests. This fixture is connected to the thermal box and both reels.

In none of the mechanical tests, will actual thruster hardware be included. Instead dummies with equivalent mechanical properties will be used.

Static: The RU is exposed to static loads from acceleration, Figure 2, during ground preparations and during launch.

The equipment needed for this test has to be able to follow a load-vs-time graph such as the one shown in Figure 1. A centrifuge could possibly be used for such a test, but it is also possible to use a shaker at a low frequency to simulate static loading. The RU is loaded along one of its three principal directions at the time.

The input parameters for the longitudinal static acceleration are shown in Figure 2. The highest lateral static acceleration does not exceed 0.25 g. However, the first test will be a linear acceleration up to 4.25g to verify the overall resistance of the RU.

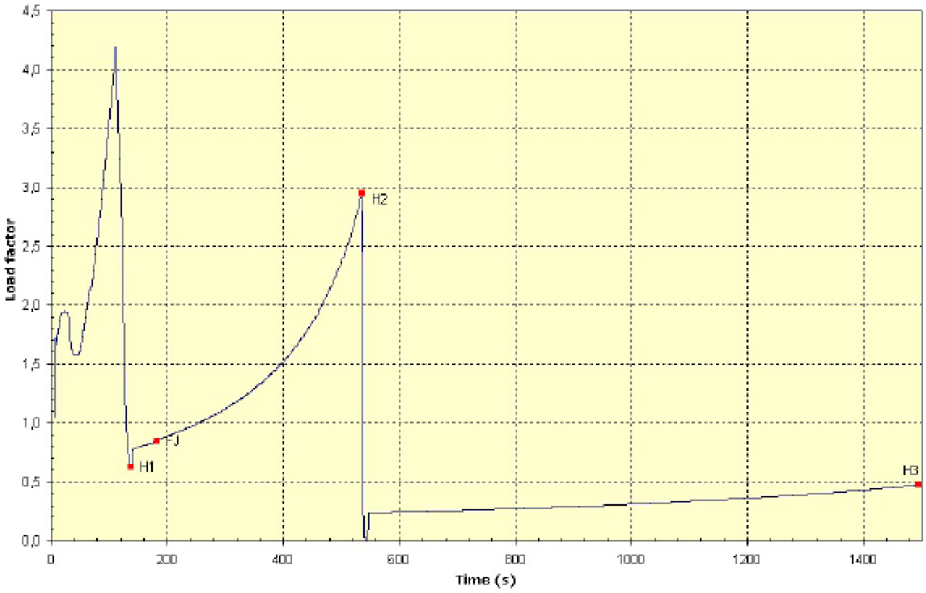


Figure 2: Typical longitudinal static acceleration.

The output parameters, continuous readout from the strain gauges (see Appendix 1), will be saved and provide the necessary information about test outcome. In case of an incomplete test, it becomes obvious at which load the system fails.

Vibration: The RU is mainly exposed to sinusoidal vibrations during launch. These will be simulated during this test in order to evaluate the impact and it effects towards mechanical integrity. The system is also exposed to vibrations during the preparation state, although they will not exceed the vibrations during the actual launch.

The equipment necessary for this test, is a vibration table which generates the specified frequency range. Like with the above tests, the RU will be equipped with strain gauges according to Appendix 1.

The input parameters are shown in Table 4 and illustrated in Figure 3.

Table 4: Vibration specification.

Direction	Frequency band (Hz)	Sine amplitude (g)
Longitudinal	2 - 50	1.0
	50 - 100	0.8
Lateral	2 - 25	0.8
	25 - 100	0.6

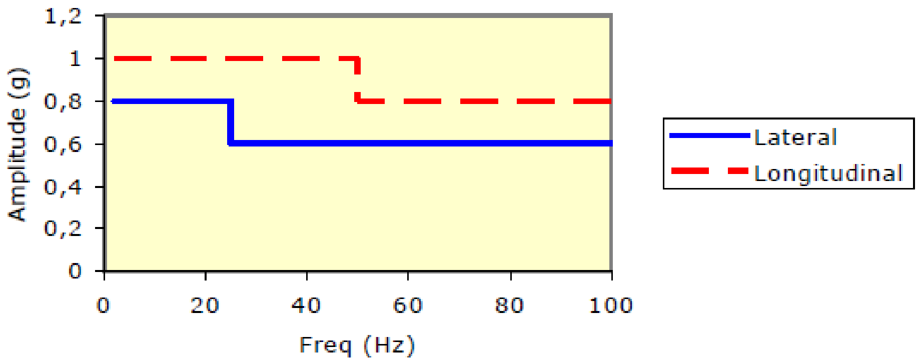


Figure 3: Amplitude vs frequency for vibrational testing.

In case of an incomplete test, it becomes obvious at which vibration level the system fails, which makes it possible to suggest different damping interfaces to reduce the effect on the RU.

Shock: The RU will be exposed to noticeable shocks during the events of launch vehicle upper stage separation from the main cryogenic stage, spacecraft separation and firing jettisoning. Without proper knowledge of the interface between the ESAIL main craft and the launcher vehicle, it is difficult to make justice to this test. In fact, without damping or reduction of the shock ordeals, the RU is likely to fail this test, wherefore it is removed from the test plan in favour of the Pull test (see below).

Pull test: The RUs are connected through the auxiliary tether which transfers loads between reels. The RU has to withstand a minimum auxiliary tether pulling load of 60 g, and a maximum pulling load of 3000 g, above which the tether will rip apart (Section 5.4.2, AD-2).

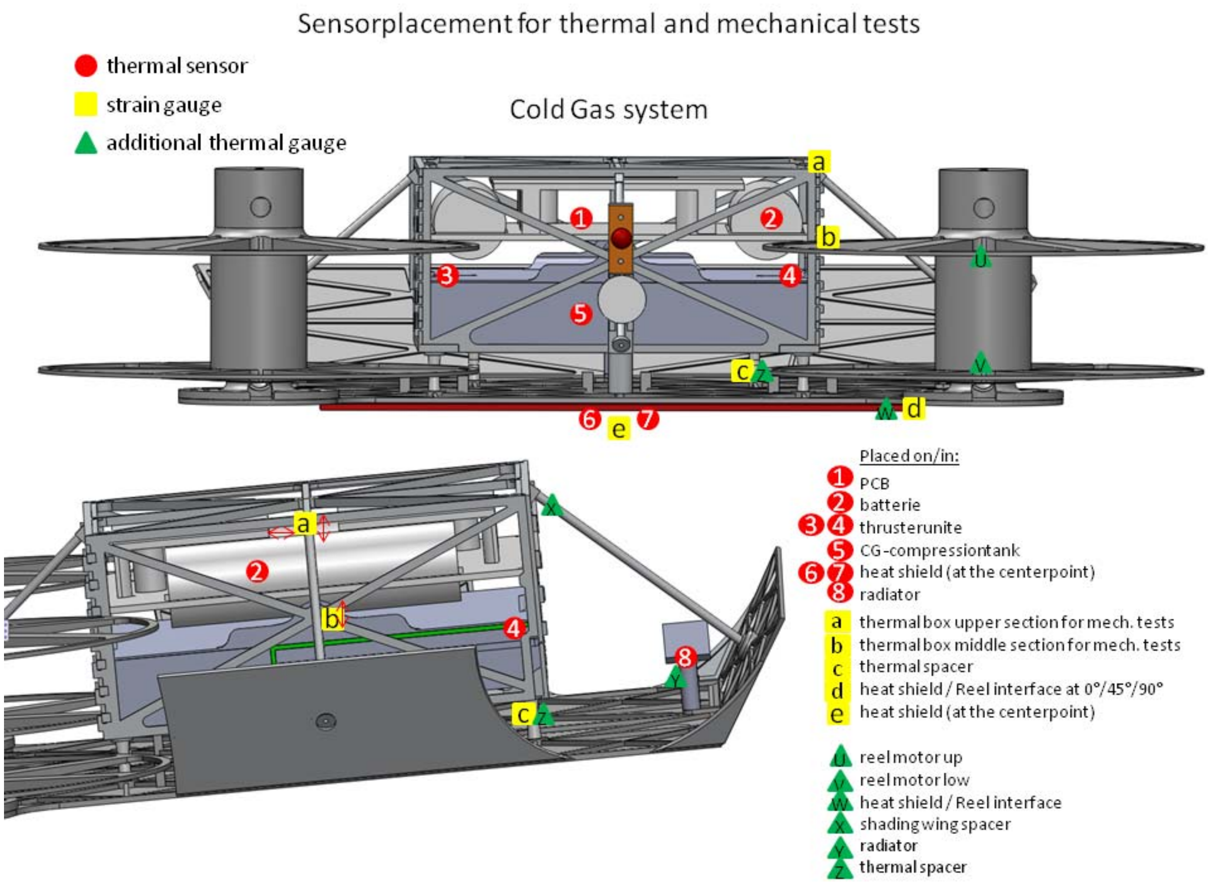
In this test, the pulling load the RU can withstand before it is either irreversibly deformed or before it cannot operate its reels will be examined.

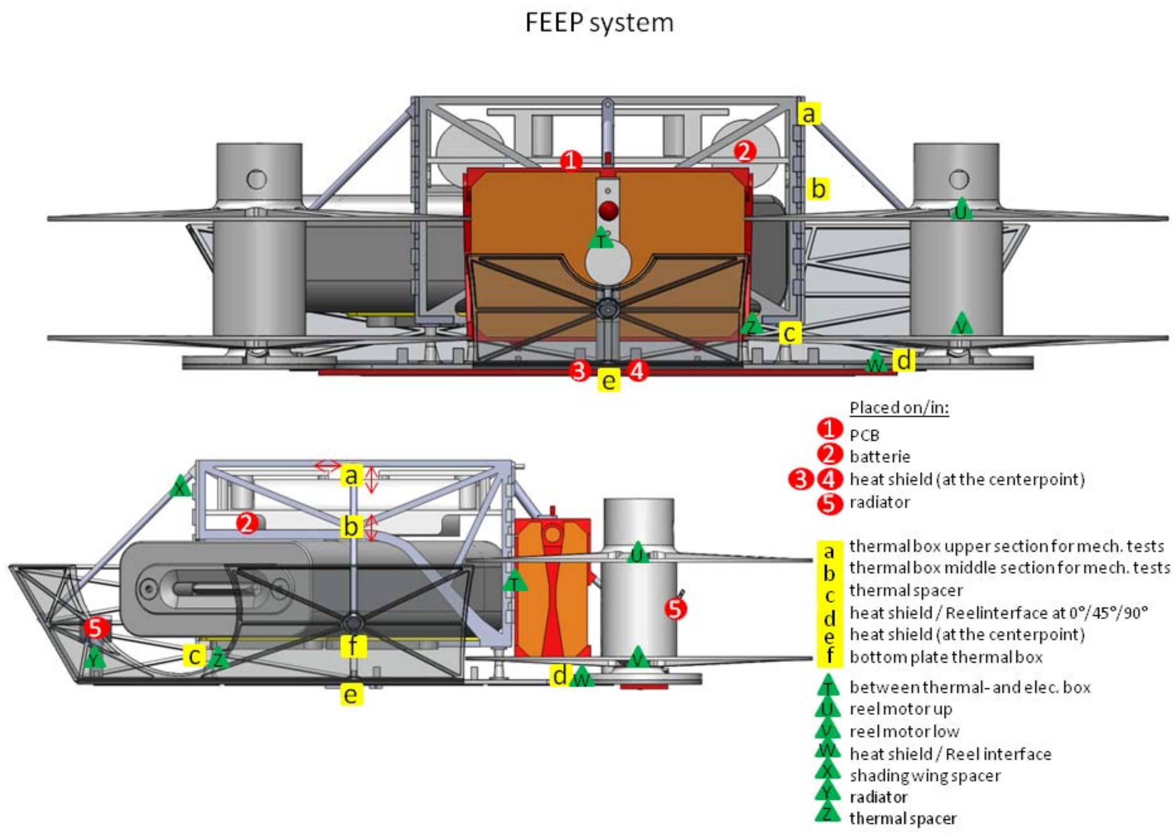
The equipment intended for this test, is a tailored set-up with dead weights, strings and pulleys, in which the RU is fixated by its thermal box allowing free deformation of reels and heat shield.

The input parameter for the loading starts with 60 g, which it is continuously kept for 1 minute to measure all deformations. After this, the load will be increased in steps of 50 g, each followed by a dwell time of 1 min until the load reaches 3000 g.

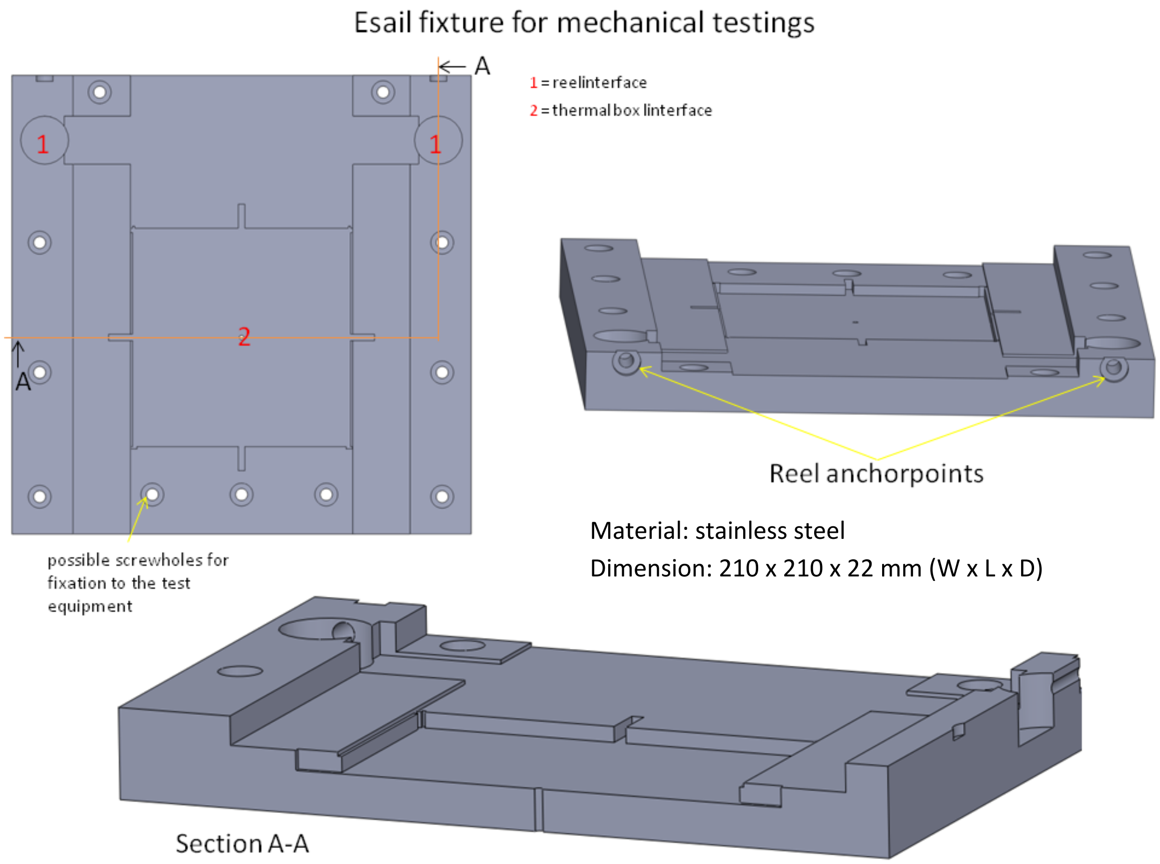
The output parameters will be a visual inspection of the RU in addition to readout from the strain gauges.

Appendix 1


Sensorplacement for thermal and mechanical tests
thermal sensor
strain gauge
additional thermal gauge
Cold Gas system
Placed on/in:
1 PCB
2 batterie
3 4 thrusterunite
5 CG-compressiontank
6 7 heat shield (at the centerpoint)
8 radiator
a thermal box upper section for mech. tests
b thermal box middle section for mech. tests
c thermal spacer
d heat shield / Reel interface at 0°/45°/90°
e heat shield (at the centerpoint)
U reel motor up
V reel motor low
W heat shield / Reel interface
X shading wing spacer
Y radiator
Z thermal spacer


FEEP system
Placed on/in:
1 PCB
2 batterie
3 4 heat shield (at the centerpoint)
5 radiator
a thermal box upper section for mech. tests
b thermal box middle section for mech. tests
c thermal spacer
d heat shield / Reelinterface at 0°/45°/90°
e heat shield (at the centerpoint)
f bottom plate thermal box
T between thermal- and elec. box
U reel motor up
V reel motor low
W heat shield / Reel interface
X shading wing spacer
Y radiator
Z thermal spacer

Appendix 2


Esail fixture for mechanical testings
A
1 = reelinterface
2 = thermalbox linterface
1
1
2
A
possible screwholes for fixation to the test equipment
Reel anchorpoints
Material: stainless steel
Dimension: 210 x 210 x 22 mm (W x L x D)
Section A-A