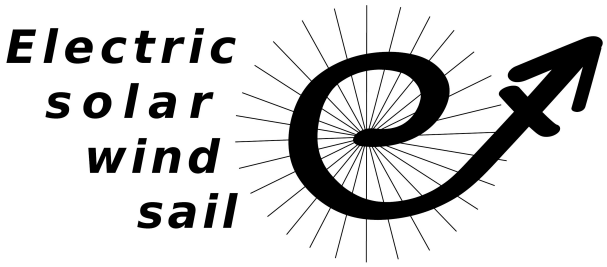

ESAIL D41
Requirements specification of the Remote Unit

Work Package: **WP 41**

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Prepared by: Ångström Space Technology Centre

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1 INTRODUCTION

This document details the general requirements for the so called Remote Unit (RU), which is a recurrent subsystem of the E-sail spacecraft. It provides a short description of this spacecraft and a plausible starting mission, it states the functions required from the RU, and translates and relates this to a requirements specification, which takes into account also the project objectives falling outside the scope of a mission in its usual sense.

Accordingly, mission should here be given a broader interpretation, and account not only for an actual space mission, but also for the project endeavor itself. Hence, the mission is here designed to fulfill also the requirements given by the project objectives. These are requirements based on trade-offs between different areas of interests and available means of accomplishing them.

With the RU still being a system, the requirements section does not reach a level making them listable in the usual envelope demands with respect to Structure (STR), Thermal energy management (THM), Power (POW), Communication (COM), Data handling, Interfaces and Environment, and answers the following generic questions:

- Structure: dimensions, mechanical qualification?
- Thermal energy management?
- Power: What is the maximum conceivable required power?
- Communication: What signals and data rates does the subsystem employ?
- Data handling: What kind of electronics is needed and what operations does the module perform?
- Environment: What environmental loads (thermal, radiation, ...) are the module subjected to?

This needs to await the requirements specification on a lower level, i.e. interpretation and breakdown of the requirements stated in this document. However, as a means to increase accessibility without compromising labeling and structure, and foregoing the next project tasks, the requirements on RU level and E-sail spacecraft level are categorized into: *Mass, size & shape* (or *Mass, size & shape, and connectivity* in the RU case), *Functionality*, *Launcher compatibility*, *Lifetime, Dependability & Autonomy*, and *Environment*.

Primarily, this document defines the system level requirements for the *Remote Unit* (RU) subsystem of the E-sail spacecraft to the extent the study under contract *FP7-SPACE-2010-1, project no. 262733* allows and requests. As far as possible, the requirements are generated by, and traceable to, requirements stemming from mission and spacecraft levels, which are also included herein. *Subsubsystem*[1] requirements, are touched upon when it is clear that the E-sail or RU must contain the subsystem in question as a well-

[1] As will be more evident from the Overview section, the RU, as much a craft or system it may be, will be referred to as a subsystem, whereas system is reserved for the complete ESAIL hardware. For this reason, *subsubsystem* is used to denote the next lower level, i.e. well-defined subsystems of the RU, e.g., its propulsion system.

defined entity in order for mission objectives to be manageable. (The thrust subsystem of the RU is an example.)

2 APPLICABLE DOCUMENTS

The documents referred to in the following are:
AD-1: "Part B: Description of Work" of final EU E-sail application (final version)
AD-2: minutes of meeting, Helsinki, Finland, December 8-9, 2010
AD-3: minutes of meeting, Tartu, Estonia, February 10-11, 2011
AD-4: minutes of meeting, Bremen, Germany, April 6-7, 2011
AD-5: ECSS-E-ST-20-06C_31July2008

3 OVERVIEW

3.1 E-sail Concept

The E-sail spacecraft is a gigantic, long-mission vehicle which, once deployed, could be propelled, and maybe also powered, entirely by the sun and the solar wind. It consists of a *main craft* from which a number of evenly spaced and equally long *tethers,* or *Main Tethers,* extend in one plane. Each tether ends with a piece of advanced hardware called a *Remote Unit (RU).* Each RU is connected to its two closest neighbors by other tethers referred to as *auxiliary tethers*, or *Auxtethers*, for short. Altogether, the embodiment resembles a wagon wheel. Besides carrying the payload and tethering the RU:s, the main craft controls the velocity and attitude of the E-sail spacecraft through its electron gun which charges the main tethers making them more or less repulsive to the solar wind.

3.2 Mission

With the extended definition of mission, the mission objective is to bring the concept to a maturity enough to proceed with an actual test mission without intermediate steps. Although not explicitly requiring that full-fledged parts are manufactured and fully tested, it requires that, given a relevant (real or fictive) flight mission (in the following referred to as a *model mission*), all technological issues are treated and that all foreseeable problems are addressed and, to a reasonable extent, solved.

The model mission shall:

- cover a range of 0.9-4 AU (from sun),
- have a duration of 5 years,
- assume no eclipses after deployment, and
- contain the phases of deployment[1], locomotion[2], and cruising[3],

where the three phases are referred to as *Mission Mode* (MM) I, II and III, respectively.

[1] *deployment* is the "unfolding" of the sail by reeling out the tethers of the craft
[2] *locomotion* entails active propulsion, i.e., charging the main tethers and being carried by the solar wind
[3] *cruising* denotes the phase where propulsion is switched off and the spacecraft left to drift

There are numerous scientifically justified missions covered by this broad description. Asteroid flybys and rendezvouses, off-Lagrange point solar wind monitoring, and non-Keplerian circular orbit helioseismology are some examples.

In a wider sense, where the mission objectives contain also the project objectives, the following *engineering objectives* shall be achieved:

- demonstration of kilometer-scale main tether production,
- demonstration of reeling of said tether,
- manufacturing and testing of prototype reel for said tether,
- building and testing of prototype RU,
- building and testing of prototype gas and FEEP thruster systems, and
- development of E-sail design and mission concept,

the completion of which, dimensioned for implementation on a so called *Baseline E-sail* with a thrust of 1 N and a mass of 100 kg, able to deliver, e.g., a payload of 1 ton to any part of the solar system in XX years, allows for the instigation of a test mission.

3.3 Function of Remote Unit

The RU shall be a rather functional and close to self-sustaining spacecraft essentially depending on the main craft of the E-sail only for its own orbit around it as governed either jointly by the main tether and the auxtethers to its two closest neighbor RU:s, or, on loosing the main tether, only by the auxtethers. (Should one of the auxtethers break, all requirements on the RU are void.)

The functions required from the (single) RU are:

- shielding payload[1] from detrimental radiation (all MM:s)
- offering the temperature required by payload (all MM:s)
- mechanically supporting payload (all MM:s)
- providing a (passive) means of mount to main craft until separation/deployment
- providing an end mass to its main tether to facilitate its deployment (MM I)
- providing an end mass to its auxtether to facilitate their deployment (MM I)
- providing an end mass to its main tether to stabilize it (MM II & III)
- acting as an optical beacon to reveal the location of the end of the main tether to the main craft (all MM:s)
- containing and controlling a jettison mechanism for its end of the main tether (all MM:s)
- accommodating auxtethers connecting it with the two closest RU:s (all MM:s)
- controlling the deployment of said auxtethers (MM I)
- assisting in deployment and, at least, unidirectional spin rate control of E-sail by onboard propulsion units, based on FEEP or CG (MM I)
- harvesting and storing power for its own use (all MM:s)
- monitoring, and communicating with main craft, its temperature (all MM:s)
- monitoring, and communicating with main craft, its attitude to sun (all MM:s)

[1] *payload* is used here to denote parts of the vehicle crucial for its operative functions

- providing communication with main craft (all MM:s)
- providing the command and data handling required from the above (all MM:s)

From the RU:s collectively, the required functions are:

- providing overall stability to the E-sail by their connectivity and distributed mass (all MM:s)
- facilitating bidirectional spin rate control (MM I)
- monitoring the overall attitude of the E-sail to sun (all MM:s)

4 DEFINITIONS

In order to relate and trace requirements, it is convenient to define requirements levels, Figure 1. In many respects, and after an origin in the mission objectives, these correspond to a technological refinement of the mission vehicle. Although the E-sail project doesn't fully conform to this breakdown, and missing links and flawed traceability are bound to occur, this requirements specification adapts to this structure as far as it can both for its own accessibility, and to serve as a basis for further requirements specification. This will result in the statement of requirements not applicable to the RU requirements specification, i.e. the main topic of this document.

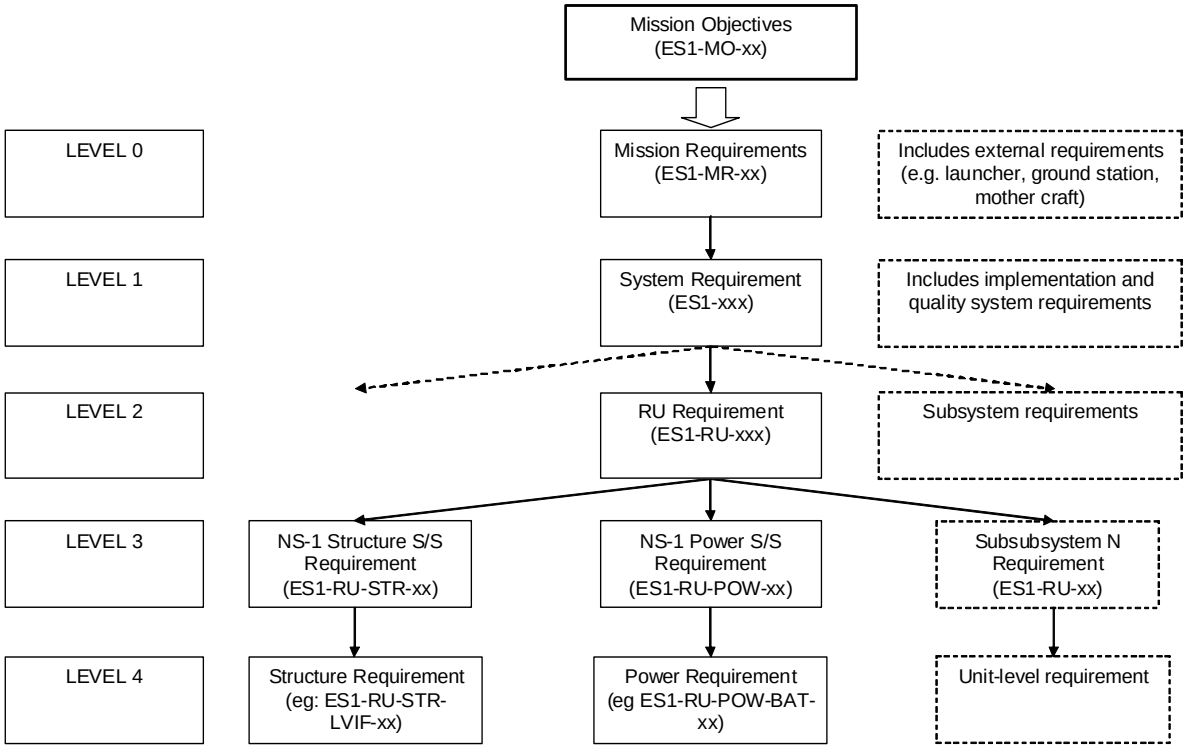

Figure 1. Requirement breakdown structure.

Starting on the highest level of technological abstraction and going down:

The *Mission Objectives* (MO) define the purpose of the mission, here still with its extended interpretation. The format is ES1-MO-xx, where ES1 denotes the first E-sail mission, and xx is a serial number.

Level 0 requirements are the *Mission Requirements* (MR). These requirements are generated by the Mission Objectives and other "hard requirements" related to external interfaces such as the launcher, the mother craft, the ground station network etc. The format is ES1-MR-xx.

Level 1 requirements are the requirements on ES1 *system level*, i.e. *spacecraft level*. The format is ES1-xxx. These requirements originate typically from three sources. The first source is the Level 0 requirements. The second source is the implementation requirements, which are defined as the spacecraft design evolves. The third source is quality-related requirements. Level 1 requirements should ideally be written in such a way that they are verifiable. If this is not possible, the verification of a level 1 requirement can also be performed by the verification of all lower level requirements which have the level 1 requirement as parent.

Level 2 requirements are the requirements on ES1 subsystem level. Subsystems of the E-sail spacecraft include main craft, main tethers, auxtethers and, of prime concern here, remote units. The numbering format is ES1-YY-xxx, where YY is the defined abbreviation for the subsystem in question, e.g. RU for remote unit.

Level 3 requirements are the requirements on ES1 subsubsystem level. Ideally, these requirements shall be traceable to the Level 2 requirements, and written in such a way that they are verifiable. If this is not possible, the verification of a Level 3 requirement can also be performed by the verification of all lower level requirements which have the level 3 requirement as parent. The format is ES1-YY-ZZZ-xx, where ZZZ denotes the type of requirement, e.g. POW for power-related requirements.

Level 4 requirements are the requirements on "unit" level. On ES1, examples of units are beacon, chassis, and jettison mechanism. The requirements on a unit shall be traceable to the Level 3 (subsubsystem) requirements. Level 4 requirements must be written in such a way that they are verifiable. The format is ES1-YY-ZZZ-WWW-xx, where WWW denotes the unit, e.g. BAT for battery if this is a component/unit in the power subsubsystem.

5 REQUIREMENTS DEFINITION

5.1 Mission objectives

The mission objectives are defined in AD-1 and AD-3, and can be phrased as follows:

ES1-MO1-01
To prove, beyond reasonable doubt, that the E-sail concept allows for realization.

ES1-MO1-02
To prove that this realization complies with requirements given by a baseline E-sail (see above) fulfilling a test mission described as having a range of 0.9-4 AU, a duration of 5 years, exhibiting no eclipses after deployment, containing the mission modes of deployment, locomotion and cruising, and having a thrust of 1 N class at 1 AU.

ES1-MO2-01
To demonstrate kilometre-scale Main Tether production

ES1-MO2-02
To demonstrate reeling of Main Tether.

ES1-MO2-03
To manufacture and testing of prototype reel for Main Tether.

ES1-MO2-04
To manufacture and test prototype Remote Unit

ES1-MO2-05
To build and test prototype cold gas thruster system

ES1-MO2-06
To build and test prototype FEEPs thruster system

ES1-MO2-07
To develop E-sail design and mission concept.

5.2 ES-1 MISSION REQUIREMENTS

These are the Mission Requirements (Level 0) based on the above Mission Objectives, all of which, except for ES1-MO2-07, were readily accounted for.

Requirement Id	Parent document	Parent requirement Id	Version
ES1-MR-01	AD-1	ES1-MO1-01	1
The technological development and corresponding embodiment of the E-sail shall either be based on known and proven technology (hardware, software, ...), or where exceptions are necessary, entail new technology successfully tested (in whole or by parts, live or by simulation) and documented to the extent likely to gain approval by a peer engineer.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-MR-02	AD-1	ES1-MO1-02	1
A baseline E-sail resulting from a mere scaling of the work made here, shall allow for the fulfilment of a mission according to ES1-MO1-02.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-MR-03	AD-1	ES1-MO1-03	1
A main tether with a minimum length of 1 km shall be manufactured.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-MR-04	AD-1	ES1-MO1-04	1
Reeling of a main tether fulfilling ES1-MR-03 shall be demonstrated.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-MR-05	AD-1	ES1-MO1-05	1
A prototype cold gas thruster system shall be built and tested.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-MR-06	AD-1	ES1-MO1-06	1
A prototype FEEP thruster system shall be built and tested.			

5.3 E-SAIL SPACECRAFT REQUIREMENTS

Below are the E-sail spacecraft requirements (Level 1, i.e. system level) grouped by main aspects, each of which is given a separate numbering series (represented by the first digit).

5.3.1 Mass, size & shape

Requirement Id	Parent document	Parent requirement Id	Version
ES1-101	AD-1	ES1-MR-02	1
The mass of the (separated/deployed) baseline E-sail shall not exceed 200 kg.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-102	AD-1	ES1-MR-02	1
The diameter of the deployed E-sail shall be 20 km.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-103	AD-4	ES1-MR-02	1
The diameter of the stowed E-sail shall be less than 3 m.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-104	AD-1	ES1-MR-02	1
The shape of the deployed E-sail shall, essentially, exhibit rotational symmetry.			

5.3.2 Functionality

Requirement Id	Parent document	Parent requirement Id	Version
ES1-201	AD-1	ES1-MR-02	1
The E-sail spacecraft shall be “unfolded”, i.e. its main tethers reeled out, by centrifugal forces.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-202	AD-1	ES1-MR-02	1
The spin plane orientation, and, consequently, the thrust direction, shall be governed by controlled differential charging of the main tethers, and the interaction of this charging with the solar wind.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-203			1
After deployment, the E-sail spacecraft shall offer a pointing accuracy of at least 3° when payload is active.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-204	AD-1	ES1-MR-02	1
After deployment, the spacecraft shall be powered either by onboard power supply or by sun.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-205	AD-1	ES1-MR-02	1
The configuration of the spacecraft shall be monitored by the main craft throughout the mission as long as the sail is operational. *This translates directly to Remote Unit requirement ES1-RU-207, and is void if an auxtether breaks. (It is assumed that a number of RU:s may malfunction in this respect without the requirement here still being fulfilled.)*			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-206	AD-1	ES1-MO1-02	1
After full deployment, the E-sail shall be able to self-amputate one or several main tethers to maintain stability. *The reason for this is primarily multiple impacts on a main tether threatening to break it and cause entanglement or similar problems with other parts of the spacecraft.*			

5.3.3 Launcher compatibility

Requirement Id	Parent document	Parent requirement Id	Version
ES1-301			1
The E-sail spacecraft shall be designed to be possible to accommodate on any of the Vega, Soyuz and Ariane 5 launch vehicles.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-302			1
Any launch altitude above 200 km shall be acceptable. A launch with an angle of up to 30° between the spacecraft main axis (normal to E-sail plane) and sun must be acceptable.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-303			1
The E-sail spacecraft shall be completely (energy) charged at time of separation.			

5.3.4 Lifetime

Requirement Id	Parent document	Parent requirement Id	Version
ES1-401	AD-1	ES1-MR-02	1
Except for auxtether reeling mechanisms and main craft-based spin generation			

devices, the spacecraft shall be designed to be fully operational for 5 years.

5.3.5 Dependability & Autonomy

Requirement Id	Parent document	Parent requirement Id	Version
ES1-501		ES1-MR-02	1
With the only exceptions of auxtether and main craft charging device failure, the E-sail spacecraft and all its subsystems shall be single-point-failure tolerant.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-502		ES1-MR-02	1
In case of main tether damage, the E-sail spacecraft shall be able to control damage by self-amputation.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-503		ES1-MR-02	1
In case of detection of an onboard anomaly, any autonomous part of the E-sail spacecraft shall automatically enter a Safe Mode. The Safe Mode shall: - ensure power supply to relevant onboard (sub-) systems - maintain operational temperature for respective subsystem - provide necessary communication capacity			

5.3.6 Environment

Requirement Id	Parent document	Parent requirement Id	Version
ES1-601	AD-1	ES1-MR-02	1
Except for those relevant only for deployment, the spacecraft shall be designed to fulfil all requirements after having been subjected to all environmental conditions anticipated from ground activities to completion of mission.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-602		ES1-MR-02	1
The spacecraft shall be tolerant to a total radiation dose of 100 krad assuming a 1-mm thick aluminium shielding, or its equivalent.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-603	AD-3	ES1-MR-02	1
The spacecraft shall be fully operational when exposed to maximum heat radiation (sun at 0.9 AU, Earth albedo and Earth IR).			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-604	AD-3	ES1-MR-02	1

Except for deployment-specific functions, the spacecraft shall be fully operational when exposed to minimum heat radiation (sun at 4 AU and 60° incidence to spacecraft plane, no albedo and no other IR).

Requirement Id	Parent document	Parent requirement Id	Version
ES1-605		ES1-MR-02	1
During the mission life time, the spacecraft shall withstand a vacuum level higher than 10^{-7} mbar without degradation.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-606		ES1-MR-02	1
The spacecraft shall be tolerant to a UV radiation dose corresponding to a worst case scenario of 5 years at 0.9 AU.			

5.4 REMOTE UNIT REQUIREMENTS

Below are the requirements for the Remote Unit subsystem of the E-sail spacecraft (Level 2) grouped by main aspects, each of which is given a separate numbering series (represented by the first digit) after the overall-employed part of the label: "ES1-RU-". Requirements for other subsystems of the E-sail (main tethers, auxtethers and main craft) are not accounted for here.

5.4.1 Mass, size & shape, and connectivity

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-101		ES1-101	1
The dry mass of the separated Remote Unit shall not exceed 1.0 kg.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-102	AD-3	ES1-101, ES1-103	1
The shape and size of an individual Remote Unit shall comply with the configuration of all remote units on the main craft before deployment. *(This is to be decided, but could tentatively imply that the effective width of the unit shall be in the order of main craft circumference divided by the number of remote units.)*			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-103	AD-3	ES1-201	1
The Remote Unit shall be tethered inside of its centre of mass (CM) as viewed from the main craft.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-104	AD-3	ES1-204	1
The Remote Unit must remain operational when the time-averaged angle between its pointing vector and the sun direction is 0-60°.			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-105	AD-4	ES1-202	1
In an embodiment based on FEEP thrusters, the RU shall be at the same electrical potential as its main tether, otherwise this is to be decided. *(This together with ES1-RU-106 imply that the RU is at floating potential in case main tether is broken.)*			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-106	AD-4	ES1-202	1
The RU and its attachment to its tethers must be designed with proper HV spacecraft engineering practices (AD-5).			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-107	AD-4	ES1-201	1
The RU:s connection to the main tether shall handle the same peak load as the main tether without yielding. *In theory, the anticipated peak load is 6 g, and the strength per stressed main tether member 16 g (gram forces).*			

5.4.2 Functionality

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-201		ES1-601	1
The RU shall ensure the operational temperature range required by all its subsystems when these are operational. *Note: This is to be decided, but according to preliminary information, a range of 0 to +50°C is operational for all subsystems during operation. However, parts likely to be exposed to temperatures outside of this, tolerate approx. -25 to +85°C during operation.*			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-202		ES1-401	1
The RU shall ensure the tolerable temperature range required by all its subsystems when these are non-operational. *Note: This is to be decided, but according to preliminary information, a range of -30 to +60°C is tolerable for all subsystems. However, parts likely to be exposed to temperatures outside of this, tolerate approx. -40 to +85°C,*			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-203		ES1-301	1
The RU shall offer mechanical support to all its subsystems at all times. *This requirement is ultimately determined by the launch conditions.*			

Requirement Id	Parent document	Parent requirement Id	Version

ES1-RU-204		ES1-301	1
The RU shall provide a (passive) means of mount to main craft until separation/deployment (of RU). *This requirement is ultimately determined by the launch conditions.*			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-205	AD-1	ES1-201	1
The RU shall work as an end mass to its main tether and auxtethers to facilitate their deployment. *A reasonable minimum mass for this purpose is 50 g.*			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-206	AD-1	ES1-203	1
Once the E-sail is deployed, the RU shall work as an end mass to stabilize the system.			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-207	AD-1	ES1-104 (ES1-102)	1
Within angular ranges of ±3° azimuthal, and ±15° in the bulging direction of the sail with respect from a flat sail, the RU shall be able to reveal its position to the main craft by an optical beacon, either at a predetermined schedule or on request. *The fulfilment of this requirement depends on the resolution and sensitivity of the receiving part onboard the main craft. Reasonable performance of this will be assumed.*			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-208	AD-1	ES1-206	1
At any time, and on confirmed request from main craft, the RU shall be able to free itself from its main tether by jettisoning it. *As this relates to minimizing the risk of the tether interfering with the rest of the spacecraft, the procedure must be carefully tailored from simulation data.*			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-209		ES1-201	1
Until deployment, the RU shall accommodate one or parts of the two auxtethers connecting it with its two closest neighbours.			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-210	AD-4	ES1-201	1
During deployment, the RU shall control the reeling out of the auxtethers and adjust the pace to that of the reeling out of the main tether. The amount of auxtether reeled out shall be monitored with 5-mm accuracy.			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-211	AD-4	ES1-201	1

At all times, the connection of the auxtether to the RU shall be able to withstand a load of 3000 g (gram load) without yielding. *(The average anticipated gram force is 60 g.)*

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-212	AD-1	ES1-201, ES1-203	1
The RU shall contain either cold gas thrusters or FEEP thrusters, to assist in deployment and to adjust E-sail spin rate. The required *delta v* for these shall be 40 m/s. *Unidirectional thrusting suffices, but bidirectional thrusting may be beneficial.*			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-213	AD-1	ES1-204	1
Throughout the mission, the RU must supply itself with power. *The amount is yet to be determined, but preliminary data indicate maximum continuous power consumption of 4.1, 2.1 and 0.1 W for MM I, MM II and MM III, respectively, if any need for heating power is neglected.*			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-214	AD-1	ES1-601	1
The RU shall monitor its temperature and communicate this with main craft either at a predetermined schedule or on request. *With "temperature" is understood the temperature or the temperatures necessary to ensure that the RU's subsystems operational and tolerable conditions are not violated.*			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-215	AD-3	ES1-204, ES1-401	1
The RU shall monitor its angle to the sun and communicate this with main craft either at a predetermined schedule or on request. *This is the angle between the RU, whose direction is defined in ES1-RU-104 to sun, and the reporting to main craft is to determine how much the RU oscillates.*			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-216	AD-1	ES1-401	1
The RU shall be able to communicate via radio with main craft. *Quantitatively, a capacity of 1 kbit/s (bidirectional), and a latency of 10 s is required. The latency is a maximum value only to be reached if a "last-in-line RU" requests to communicate with the main craft.*			

Requirement Id	Parent document	Parent requirement Id	Version
ES1-RU-217	AD-1	ES1-401	1
At all times, the RU shall maintain the command and data handling required for its internal functions as well as communication with main craft.			

5.4.3 Launcher compatibility

As the Remote Unit is a subsystem of the E-sail spacecraft, it shall fulfil the requirements put on the full spacecraft in applicable respects. However, "Launcher" could also be translated to the Main Craft acting as a launcher for the Remote Unit. In this case the applicable requirements were declared as ES1-RU-203 and ES1-RU-204 under Functionality.

5.4.4 Lifetime

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-401	AD-1	ES1-401	1
Except for auxtether reeling mechanisms, the RU shall be designed to be fully operational for 5 years.			

5.4.5 Dependability & Autonomy

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-501		ES1-503	1
In case of detection of an onboard anomaly, the RU shall automatically enter a Safe Mode. The Safe Mode shall: - ensure power supply to relevant subsystems - maintain operational temperature - provide necessary communication capacity			

5.4.6 Environmental requirements

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-601	AD-1	ES1-601	1
Except for those relevant only for deployment, the RU shall be designed to fulfil all requirements after having been subjected to all environmental conditions anticipated from its deployment to completion of mission.			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-602	AD-1	ES1-602	1
The RU shall be tolerant to a total radiation dose of 100 krad assuming a 1-mm thick aluminium shielding, or its equivalent.			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-603	AD-3	ES1-603	1
The RU shall be fully operational when exposed to maximum heat radiation (sun at 0.9 AU, normal incidence, Earth albedo and Earth IR).			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**

ES1-RU-604	AD-3	ES1-604	1
Except for deployment-specific functions, the RU shall be fully operational when exposed to minimum heat radiation (sun at 4 AU and 60° incidence to spacecraft plane, no albedo and no other IR).			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-605		ES1-605	1
During the mission life time, the RU shall withstand a vacuum level higher than 10^{-7} mbar without degradation.			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-606			1
The Remote Unit must survive a turnover, i.e. a full reversal of its pointing vector, for up to 5 min without overheating or overcooling, and during this time maintain safe-mode functionality.			

Requirement Id	**Parent document**	**Parent requirement Id**	**Version**
ES1-RU-607		ES1-602	1
The RU shall be tolerant to a total UV radiation dose corresponding to a worst case scenario of 5 years at 0.9 AU.			

6 CONCLUSION

This document has listed the requirements on the Remote Unit of the E-sail Spacecraft as extracted, derived and interpreted from higher-level requirements and objectives. It has also proposed a structure for further breakdown of the requirements into the subsystems of the Remote Unit.

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