**EUROPEAN SPACE AGENCY**

# MARS ROBOTIC EXPLORATION PREPARATION -2 PROGRAMME

## TECHNOLOGY PLAN

## Programme of Work and relevant Procurement Plan

**SUMMARY**

This document presents the work plan update for the MREP-2 Programme, defining the activities to be implemented in 2014.

This document is provided for information only and may be subjected to future updates.

December 2013

Page 2 – This page is left intentionally blank

# 1 Background and scope

The MREP-2 programme (Mars Robotic Exploration Preparation-2, ESA/PB-HME(2012)56, rev.1) was subscribed at the C/MIN 2012, with the objective to reinforce Europe's position in Mars robotic exploration and prepare for a European contribution to a future international Mars Sample Return (MSR) mission.

This document provides the programme of work defining the activities to be initiated in 2014.

When building this work plan, the Executive took into account the preliminary findings and recommendations of the PB-HME Working Group - as summarized in the report ESA/PB-HME(2013)48 – on the candidate missions following ExoMars missions 2016/2018 and the European strategy for future participation to MSR. The emphasis on Mars Sample Return technology preparation is reinforced. In particular, all proposed activities have a direct link to the envisaged European contribution to Mars Sample Return international mission as identified in Working Group report, while equally serving in many cases the technology preparation of the identified intermediate missions.

With regard to the long term enabling technologies - namely on Nuclear Power Sources and Propulsion - the activities as approved in previous work plans are either running or being initiated. No new activity was added in this work plan update.

# 2 Work Plan Elaboration and Implementation

## 2.1 - Definition of the activities

As for previous MREP work plans, the programme of work presented here was defined using the ESA End-to-End process as described in ESA/IPC(2005)39, involving the TECNET (TEChnology NETwork) Service Domain 9 (SD9), who is specifically in charge of Robotic Exploration and constituted of technical and mission experts from all ESA Directorates. The process ensures coordination with activities planned in other Directorates, in particular in HSO, and makes the best use of the industrial and internal studies achieved so far for Mars future missions. The work plan makes use essentially of MREP-2 (ETP) and TRP. Some activities are also recommended for implementation in GSTP .

For the practical implementation of ESA TDAs, all the newly proposed activities seeking approval are to be initiated in 2014. Some contracts are intended to be contractually phased and in these cases the budget intended for Phase 1 is shown in the "Remarks" column of the tables in Annex 1. It is planned to revisit the MREP-2 Technology Plan on a regular basis and update the plan with the results ongoing activities (e.g. system studies, technology developments) and discussions with Member States and international partners (e.g. bilateral discussions with Roscosmos, IMEWG Working Groups on MSR)

The baseline approach is to have a single contract for each activity, unless otherwise stated in the work plan. In case of specific interest for the Programme - e.g. risk reduction, investigation of different technical solutions, or for enabling competition on critical hardware in the future phases - the Executive may envisage placing parallel contracts provided that good quality offers are received and subject to budget compatibility. In such a case, the parallel contract will be reflected in the regular update of the work plan, which occurs as a minimum on a yearly basis, for keeping the PB-HME and IPC fully informed of the work plan implementation.

## 2.2 - ESA Technology Development Activities: role of TRP, ETP and GSTP

Robotic Exploration technology activities mainly rely on ETP, TRP and GSTP technology budgets. The TRP budget is devoted to initial technology developments, leading to an experimental feasibility verification of critical functions or to a validation at breadboard level in laboratory environment (TRL 4). In case of components this might be extended to e.g. radiation hardening, since otherwise a proof of feasibility is not possible.

The ETP (Exploration Technology Programme) is constituted of technology activities that are directly funded by the MREP-1 and/or MREP-2 programmes. It is used to fund robotic exploration-related activities at any TRL level. However, it focuses on TRL >3, building on earlier developments funded through TRP.

For ETP, the activities will be implemented so as to meet a geographical distribution reflecting the Participating States subscriptions to MREP-2.

For both TRP/ETP funding, some changes in procurement policies are possible in the frame of the measures necessary to structurally recover georeturn deficits.

The GSTP (General Support Technology Programme) budget is used mainly for activities at a high TRL level (TRL 4 or higher) to complement the availability of ETP funding. Note however that while the GSTP activities shown in this work plan have been defined and internally agreed through the SD9 TECNET process, they are only provided here for information and not for approval. Approval for all GSTP activities will be submitted to IPC in dedicated GSTP work plans.

## 2.3- Annexes and detailed information

Annex 1 provides the summary tables for the new activities to be implemented in 2014, and the corresponding detailed description sheets. Only MREP-2 funded activities are submitted to PB-HME approval.

Annex 2 provides the update of MREP technology roadmaps, reflecting the latest developments and enabling a visual understanding of the logic underlying the proposed activities.

Annex 3, 4 and 5 provide additional background information.

| Annex | Title | Content |
|---|---|---|
| Annex 1 | Definition of 2014 activities<br>(for approval) | Summary tables and description for new activities to be implemented in 2014, under ETP (MREP-2) and TRP funding.<br>Note: Only MREP-2 funded activities are submitted for PB-HME approval. |
| Annex 2 | Update of MREP technology roadmaps<br>(for information) | The following technology roadmaps have been updated: Phootprint, Inspire, Mars Precision Lander, Mars Sample Return and Long term enabling technologies (Nuclear Power Systems and Propulsion) |
| Annex 3 | Activities recommended for implementation in GSTP<br>(for information) | The proposed activities could be implemented in 2014 |
| Annex 4 | Summary description of future Mars missions<br>(for information) | Summary of current definition of future Mars missions:<br>- PHOOTPRINT (Phobos Sample Return)<br>- INSPIRE (Network science mission)<br>- Mars Precision Lander (MPL)<br>- Mars Sample Return (MSR) |
| Annex 5 | Summary of Technology Development Activities<br>(for information) | Summary tables and description of activities from the previous MREP work plans. The tables include: running activities; approved activities under preparation; and activities to be possibly implemented in 2015-2016 are presented. |

Table 1- List and content of the Annexes

## KEY TO TABLES

Each activity is given a programmatic reference, which will remain unchanged until completion. Additional planning elements associated with each of the activities are:

| | |
|---|---|
| **Programme:** | Programme budget foreseen for the activity |
| **Reference:** | Unique ESA generated reference for TDA |
| **Activity Title:** | Title of the proposed TDA |
| **Budget:** | The total Contract Authorisation (CA) values are given in KEURO, at yearly economic conditions. The year for which the budget is intended is specified. |
| **Procurement Policy (PP):** | Procurement Types:<br>C = Open Competitive Tender; (Ref. Article 13.1 ESA Procurement Regulations)<br>C(1)* = Activity restricted to non-prime contractors (incl. SMEs).<br>C(2)* = A relevant participation (in terms of quality and quantity) of non-primes (incl. SMEs) is required.<br>C(3)* = Activity restricted to SMEs & R&D Entities<br>C(4)* = Activity subject to SME subcontracting clause<br>C(R) = Competition is restricted to a few companies, indicated in the "Remarks" column; (Ref. Article 13.2 ESA Procurement Regulations).<br>DN/C = Direct Negotiation/Continuation; the contract will be awarded in continuation to an existing contract; (Ref. Article 14.1.D ESA Procurement Regulations)<br>DN/S = Direct Negotiation/Specialisation; the contract will be awarded by direct negotiation in implementation of a defined industrial policy or resulting from a sole supplier situation; (Ref. Articles 14.1.A,C ESA Procurement Regulations)<br>* See ESA/IPC(2005)87, rev4., Industry has been informed, through the EMITS "News", of the content of that document. |
| **SW clause applicability:** | Special approval is required for activities labelled: either *“Operational Software”* or *“Open Source Code”*, for which the Clauses/sub-clauses 42.8 and 42.9 (“Operational Software”) and 42.10 and 42.11 (“Open Source Code”) of the General Clauses and Conditions for ESA Contracts (ESA/REG/002), respectively, are applicable. |
| **Objectives:** | The aims of the proposed TDA. |
| **Description:** | Overview of the work to be performed. |
| **Deliverables:** | Provides a short description of the tangible outcome e.g. breadboard, demonstrator, S/W, test data. **A final report is standard for every activity.** |
| **Current TRL:** | Describes the current Technology Readiness Level of the product that is going to be developed in this activity. |
| **Target TRL:** | The TRL expected for the product at the **end of the activity**. For equipment, TRP usually concludes with TRL 3, ETP at TRL 5/6. However in the case of components target TRL in TRP could be higher. It is also understood that TRLs do not apply to S/W and tools. For these cases description of SW quality, i.e.: architecture, beta version, prototype, or full |

| | |
|---|---|
| | operational, achieved at the end of the activity. |
| **Application Need/Date:** | Describes the required TRL and date for the technology development of which the respective activity is part of on the base of the maturity required by the application. The general rule is that a requirement specifies the need date for a product. For equipment/payloads this is in general TRL **5/6, -** the level generally required for **Phase B of a project.** The exceptions are components, where TRL 8 (flight readiness) should be achieved. For S/W and tools separate readiness levels are defined below |
| **Technology Readiness Level** | TRL1 **-** Basic principles observed and reported<br>TRL2 **-** Technology concept and/or application formulated<br>TRL3 **-** Analytical and experimental critical function and/or characteristic proof-of-concept<br>TRL4 **-** Component and/or breadboard validation in laboratory environment<br>TRL5 **-** Component and/or breadboard validation in relevant environment<br>TRL6 **-** System/subsystem model or prototype demonstration in a relevant environment (ground or space)<br>TRL7 **-** System prototype demonstration in a space environment<br>TRL8 **-** Actual system completed and "flight qualified" through test and demonstration (ground or space)<br>TRL9 **-** Actual system "flight proven" through successful mission operations |
| **Technology Readiness Levels for S/W and tools** | Algorithm: Single algorithms are implemented and tested to allow their characterisation and feasibility demonstration.<br>Prototype: A subset of the overall functionality is implemented to allow e.g. the demonstration of performance.<br>Beta Version: Implementation of all the software (software tool) functionality is complete. Verification & Validation process is partially completed (or completed for only a subset of the functionality).<br>S/W Release: Verification and Validation process is complete for the intended scope. The software (software tool) can be used in an operational context. |
| **Application Mission:** | Possible mission application/follow-on. |
| **Contract Duration:** | Duration of the activity in months. |
| **Reference to ESTER:** | Identifies the related requirement in the ESTER database |
| **Consistency with Harmonisation Roadmap and conclusion:** | Identifies the related Harmonisation Roadmap Requirement |

Intentionally left blank

# Annex 1:

1. Summary table of 2014 ETP and TRP activities
2. Budget summary
3. Detailed descriptions of 2014 ETP and TRP activities

# Summary of all new activities seeking approval for 2014

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget 2013 | Budget 2014 | Budget 2015 | Budget 2016 | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Phootprint** | | | | | | | | | | | |
| ETP | IPC | E913-012MM | Sample Acquisition Means for the Phootprint Lander: Experiments and first Realisation (SAMPLER) | 0 | 1500 | 0 | 0 | C | | NA | Intended phased contract (Phase1, 700kEuros) |
| ETP | AC | E905-017EC | Guidance, Navigation, and Control (GNC) for PHOOTPRINT descent and landing | 0 | 400 | 0 | 0 | C(R) | PO | N/A | |
| ETP | IPC | E920-005MS | Phootprint Landing Gear System to TRL5 (PLanGS) | 0 | 1500 | 0 | 0 | C(2) | | N/A | Intended phased contract (Phase 1, 400kEuros) |
| ETP | N/A | E913-013MM | Robotically-Enhanced Surface Touchdown (REST) | 0 | 430 | 0 | 0 | C(1) | | N/A | |
| TRP | AC | T921-004MT | Development of a rigid conformal ablator for extreme heat flux applications | 0 | 400 | 0 | 0 | DN/S | FR | N/A | |
| **Mars Precision Lander** | | | | | | | | | | | |
| ETP | IPC | E918-008MP | Preliminary design and performance verification of critical elements for guided entry thrusters | 0 | 800 | 0 | 0 | C | | N/A | |
| ETP | IPC | E905-021EC | Stand Alone 3 Axis European Accelerometer Unit | 0 | 500 | 0 | 0 | C(1) | | N/A | |
| TRP | N/A | T916-004MM | Compressive Sensing Technologies for compact LIDAR systems | 0 | 475 | 0 | 0 | C(3) | | N/A | |
| TRP | N/A | T906-008ET | Entry, Descent and Landing Communications technology assessment | 0 | 350 | 0 | 0 | (C) | | N/A | |
| **SFR Robotics and Mechanisms** | | | | | | | | | | | |
| ETP | IPC | E915-004FP | Mechanisms Technologies that operate at very low temperatures (Extended test campaign) - CCN | 0 | 350 | 0 | 0 | DN/C | IT,AT | N/A | This activity will be implemented as a CCN to ESTEC contract # 4000105947/12/NL/HB, budget 475 k€ |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **MSR** | | | | | | | | | | | |
| ETP | N/A | E904-005EE | Modelling of the Mars Environment for Future Missions | 0 | 400 | 0 | 0 | C(2) | | N/A | |
| ETP | IPC | E914-004QI | Biosealing and Monitoring Technologies for a Sample Containment System - Sealing tests and EM design | 0 | 1000 | 0 | 0 | DN/C | IT | N/A | |
| TRP | IPC | T912-005GS | X-Band cryogenic feed prototyping | 0 | 600 | 0 | 0 | C(1) | | N/A | |
| TRP | N/A | T921-005MT | Deployable & Inflatable Heatshield & Hypersonic Decelerator Concepts - Phase 1 | 0 | 400 | 0 | 0 | (C) | | N/A | |
| **Total of all 2014 ETP activities seeking approval** | | | | **0** | **6880** | **0** | **0** | | | | |
| **Total of all 2014 TRP activities seeking approval** | | | | **0** | **2225** | **0** | **0** | | | | |
| **Total of all 2014 ETP and TRP activities seeking approval** | | | | **0** | **9105** | **0** | **0** | | | | |

Intentionally left blank

| Application/Mission | Progr. | 2013 | 2014 | 2015 | 2016 | Total |
|---|---|---|---|---|---|---|
| Phootprint | | | | | | |
| | ETP (15) | 1300 | 4830 | 5100 | 800 | 12030 |
| | TRP (3) | 450 | 400 | 400 | | 1250 |
| | GSTP (1) | | | 400 | | 400 |
| Total | | **1750** | **5230** | **5900** | **800** | **13680** |
| MPL | | | | | | |
| | ETP (17) | 500 | 1300 | 5500 | 7800 | 15100 |
| | TRP (6) | 800 | 1475 | | | 2275 |
| | GSTP (3) | | 1500 | | | 1500 |
| Total | | **1300** | **4275** | **5500** | **7800** | **18875** |
| SFR Robotics and Mechanisms | | | | | | |
| | ETP (7) | 500 | 1350 | 2400 | | 4250 |
| | TRP (7) | 1100 | | | | 1100 |
| | GSTP (1) | | | 2000 | | 2000 |
| Total | | **1600** | **1350** | **4400** | | **7350** |
| INSPIRE | | | | | | |
| | ETP (11) | 570 | | 2000 | 4800 | 7370 |
| | TRP (6) | 300 | | | | 430 |
| Total | | **870** | | **2000** | **4800** | **7800** |
| MSR | | | | | | |
| | ETP (17) | 2100 | 2100 | 5650 | 2500 | 12350 |
| | TRP (11) | 2170 | 1000 | 800 | | 3970 |
| | GSTP (2) | | 500 | | | 500 |
| Total | | **4270** | **3600** | **6450** | **2500** | **16820** |
| Long Term | | | | | | |
| | ETP (11) | 4000 | | 5300 | 8300 | 17600 |
| | TRP (2) | | | | | 0 |
| Total | | **4000** | | **5300** | **8300** | **17600** |
| **Total ETP MREP-1 2013** | | **2570** | | | | **2570** |
| **Total ETP MREP-2** | | **6400** | **9580** | **25950** | **24200** | **66130** |
| **Grand Total TRP (35)** | | **4820** | **2875** | **1200** | | **8895** |
| **Grand Total GSTP (7)** | | | **2000** | **2400** | | **4400** |
| **Grand Total ESA** | | **13790** | **14455** | **29550** | **24200** | **81995** |

**Budget summary table per commitment year**

Note: MREP-2 total budget for the 2014 activities to be approved in this workplan under MREP-2 is 6880 k€ (see summary table above). All budgets beyond 2014 are indicative and may be updated.

# Detailed descriptions of 2014 ETP and TRP activities

## Phootprint

| Sample Acquisition Means for the Phootprint Lander: Experiments and first Realisation (SAMPLER) | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E913-012MM |
| **Title:** | Sample Acquisition Means for the Phootprint Lander: Experiments and first Realisation (SAMPLER) | | |
| **Total Budget:** | 1500 | | |

**Objectives**

The activity addresses the robotic sampling operation of the PHOOTPRINT mission. The activity shall 1) experimentally assess the detailed requirements of the sampling operation 2) specify, 3) design, 4) realise and 5) test (in relevant environment) a breadboard of
the operation.

**Description**

Background:

Sampling operations in low-gravity (as on Phobos) for extended time (as in the case of PHOOTPRINT) are poorly understood. The dynamic motion induced by the sampling operation (to be expected in a non-homogeneous material) couples with the dynamic properties of the lander, its legs and even thrust or anchoring mechanism. For the total system to remain stable and for the sampling tool to effectively sample the surface, the total dynamic motion must be damped significantly. Possible provisions for damping dynamics can be realised on the sampling-tool, on the arm and on the lander. However these provide different performance and imply different costs. Experiments on the whole sampling operation are needed to ascertain the need/extent/implementation of damping provisions in the sampling chain (arm and sampling tool).

Programme of work: The programme of work is divided in two phases that deliver products and results with incremental TRL. The first phase intends to increase the understanding of the dynamic behavior of the sampling chain by delivering a simulator, validated through tests.
In the second phase the focus shifts into the development of high fidelity breadboard of the complete sampling chain and its demonstration trough test.

- Phase 1
i. Requirements specification
ii. Design of a number of sampling-tools as well as sampling strategies. Realisation of breadboards of the chosen tools.
iii. Design and development of a parametric test campaign (using an air bearing table ) for testing the chosen sampling tools/strategies with a range of representative soil analogues.
iv. Development of dynamic model and related simulator
v. Execution of the test campaign and correlation of the test data with the model produced at iv.

- Phase 2
i. Trade-off and design the complete sampling chain (supported by the validated simulator).
ii. Develop a real-scale breadboard of the sampling chain, a mockup of platform with representative dynamics and a test environment to exercise them. The test environment shall allow testing of the breadboard against different soil types.
iii. Perform tests
iv. Evaluate results from the tests

**Deliverables**

- Project documentation
- Mathematical model/simulator
- Breadboards
- Software
- Test rig
- Data archive containing both raw and processed data from all tests

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 1 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |

| | | | |
|---|---|---|---|
| **Application Mission:** | Phootprint | **Contract Duration:** | 24 |
| **S/W Clause:** | N/A | **Reference to ESTER** | T-9012 |

**Consistency with Harmonisation Roadmap and conclusion:**

The activity was not addressed by the 2012 harmonisation exercise on A&R, as the PHOOTPRINT mission had not yet been manifested

| Guidance, Navigation, and Control (GNC) for PHOOTPRINT descent and landing |
|---|

| | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-017EC |
| **Title:** | Guidance, Navigation, and Control (GNC) for PHOOTPRINT descent and landing | | |
| **Total Budget:** | 400 | | |

**Objectives**

The objective of the activity is to design and develop the GNC for PHOOTPRINT up to TRL 4. This shall include the mission vehicle management (MVM) and the FDIR for the PHOOTPRINT mission with Model In the Loop (MIL) full testing, and preliminary real time checks on a Processor in the Loop (PIL) environment.

**Description**

The aim of the activity is to design and develop the critical GNC algorithms needed for the PHOOTPRINT mission during proximity operations, descent, landing and departure. Moreover, in this activity it shall be defined the mission vehicle management (MVM) for this PHOOTPRINT mission taking into account the GNC system, the operating modes and the Failure Detection, Isolation and Recovery (FDIR) system.
The MVM is responsible for selecting the GNC modes providing scheduling service and FDIR functionalities. The system shall be robust to safely achieve the required performances in the presence of possibly large uncertainties.

The following tasks shall be performed:
- Consolidation of functional, operational, performance and environment requirements for the PHOOTPRINT mission taking into account the mission objectives and constraints.
- Definition of the GNC architecture, including sensor suite trade-off.
- Detailed analysis and definition of the GNC algorithms, including MVM, FDIR.
- Implementation of a Model In the Loop simulator with the complete GNC system architecture, FDIR and MVM.
- Validation of the simulator and performance tests for the PHOOTPRINT landing.
- Update of PANGU for the specific case of the PHOOTPRINT mission.
- Implementation of the modification of the MIL to perform autocoding for the PIL
- Implementation of a Processor In the Loop in a RASTA-like environment: test bench consisting on the assembly of the modified MIL and a flight representative motherboard.
- GNC verification and validation with the PIL.

**Deliverables**

- Technical notes
- Model in the loop simulator, including the GNC, MVM, and FDIR
- Processor in the loop test bench software

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2015 |
| **Application Mission:** | PHOOTPRINT | | **Contract Duration:** | 15 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |

**Consistency with Harmonisation Roadmap and conclusion:**

**Phootprint Landing Gear System to TRL5 (PLanGS)**

| | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E920-005MS |
| **Title:** | Phootprint Landing Gear System to TRL5 (PLanGS) | | |
| **Total Budget:** | 1500 | | |

**Objectives**

The objective is to develop an optimised landing gear system capable of providing safe landing on the surface of Phobos (micro-gravity conditions) and ensuring the required attitude and stability to allow surface operations (i.e. sample acquisition and robotic arm
motion).

**Description**

In the context of the Phootprint mission, the landing phase of its lander of 1000 to 1500kg (with CoG at 1m above the base of the S/C) will end with a free fall without using the braking thrusters, from 15m (TBC) above the surface and with a landing velocities range of <0.6 m/s vertical and < 0.15m/s horizontal. Therefore the landing gear design, including the foot-pad and possibly anchoring system (TBC) and breadboard, needs to be fully representative of the flight system with respect to its dynamic behaviour in the landing configuration for the final touchdown and surface operations. This activity shall also aim at the minimization of the mass of the landing gear system considering the use of CFRP components for the main structural elements (i.e. main and secondary struts) or other lightweight technological solutions. The need of damping of the shock transferred to the spacecraft at touchdown has to be considered in frame of the activity and simple solutions (possibly passive systems such as crushable materials, foams) shall be implemented and validated by test. Moreover, the possibility of implementing load limiting capabilities (i.e. collapsible load limiters) at the interfaces of the landing gear with the spacecraft need to be considered. In the frame of this activity, the functionality

| | | | | | |
|---|---|---|---|---|---|
| of the landing gear system shall also include provisions for deployment, latching and touchdown sensors.<br><br>The activity will consist on two (2) contractual phases:<br>Phase 1 (400 kEuros, 9 months) with the following main tasks to be implemented<br>- Review of the state of the art of configurations, design solutions and materials;<br>- Analysis of mission/system requirements and definition of the requirements for the landing gear subsystem;<br>- Perform characterisation tests on possible crushable materials and landing pads (the latter for friction coefficient characterisation)<br>- Establish the design concept of the complete landing gear system including all active (e.g. actuators) and passive (e.g. damping systems) solutions and including provisions for sampling handling and operations in micro-gravity conditions;<br>- Establish a dynamic model for landing simulations, using previous characterisation tests results for correlation, and identify by analysis the worst cases among the landing scenarios;<br>- Define the requirements for the manufacturing and validation of a landing gear demonstrator;<br>- Define the demonstrator verification approach considering all the environmental conditions and the relevant operational approaches.<br><br>Phase 2 (1100 kEuros, 15 months) with the following main tasks to be implemented<br>- Design the landing gear demonstrator on the basis of the requirements and verification approach established during phase 1;<br>- Breadboard manufacturing and verification plan. Establish the test procedures;<br>- Design, manufacturing and assembly of the landing test setup;<br>- Manufacturing of the breadboard components and assembly;<br>- Execution of the landing tests on the demonstrator | | | | | |
| **Deliverables** | | | | | |
| Demonstrator(s), Dynamic model, and Technical Notes including test Reports | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2016 |
| **Application Mission:** | Phootprint | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Robotically-Enhanced Surface Touchdown (REST)** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E913-013MM |
| **Title:** | Robotically-Enhanced Surface Touchdown (REST) | | |
| **Total Budget:** | 430 | | |
| **Objectives** | | | |
| Develop a prototype of an actively compliant landing gear for low-G environment using robotics derived technology | | | |
| **Description** | | | |
| Background:<br>Landing in low-g environments provides for some difficult issues for conventional landing gears but also for opportunity to implement smarter and more flexible landing gears. Essentially the issues are related to the possibility of rebounding due to the residual elasticity of the landing gear (which is impossible to eliminate completely), and the difficulty of leveling the platform once lading is achieved. The opportunities come from the fact that impact/settling forces and velocities during landing are minimal and hence compatible with the capabilities of electromagnetic actuators. Therefore it is possible to conceive an active landing gear that uses linear (or rotational) DC brushless motors to implement 1) deployment of the landing legs, 2) impedence-controlled absorption of the impact/settling forces and compensation of residual elasticity, 3) re-levelling of the lander platform, 4) rejection of vibration induced by sampling devices. To note, the use of impedence-control schemes for brushless DC motors is common in robotics in order to allow robotic joints to simulate virtual mechanical properties (i.e mass, damping and elasticity). The use of motor-driven absorption of forces at landing is not new: the PHILAE lander in the ROSETTA mission uses a capstan actuator<br><br>Programme of work:<br>1) requirement definition<br>2) design of prototype<br>3) manufacturing and assembly 4) test on air bearing table<br>5) closure | | | |
| **Deliverables** | | | |
| - standard project documentation<br>- technical notes,<br>- prototype hardware | | | |

| | | | | | |
|---|---|---|---|---|---|
| - videos | | | | | |
| **Current TRL:** | 1 | **Target TRL:** | 3/4 | **Application Need/Date:** | 2015 |
| **Application Mission:** | PHOOTPRINT, | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8937 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| The activity was not addressed by the 2012 harmonisation exercise on A&R. To be noted the PHOOTPRINT mission at that time was not manifested yet. | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Development of a rigid conformal ablator for extreme heat flux applications** | | | | | |
| **Programme:** | TRP | | **Reference:** | T921-004MT | |
| **Title:** | Development of a rigid conformal ablator for extreme heat flux applications | | | | |
| **Total Budget:** | 400 | | | | |
| **Objectives** | | | | | |
| Based on the existing ASTERM material, a European rigid conformal ablative heatshield material shall be developed and characterised for application on the Earth re-entry capsule of sample return missions (e.g. Mars, comets, asteroids). A material demonstrator with a representative size and geometry shall be manufactured. | | | | | |
| **Description** | | | | | |
| The ASTERM ablative heatshield material has recently been developed (under Astrium R&D and TRP-DEAM) and is currently in pre-qualification (under MREP-DEAM2). This development is specifically tailored for application on the Earth return capsule of sample return missions. The material is a low-density carbon-phenolic ablator and is produced by impregnating a low density rigid graphite felt with a phenolic resin.<br><br>Recent developments by NASA have demonstrated that by replacing the rigid graphite felt in the manufacturing process by a flexible felt can lead to a significant improvement of the material performance: Internal thermo-mechanical stresses are reduced making the material more robust to loads and deflections; thermal performance is improved leading to lower required thickness and therefore lower mass; manufacturable unit sizes are increased which might more easily allow to produce the ERC heatshield as one single piece avoiding interface issues. | | | | | |
| **Deliverables** | | | | | |
| Study reports<br>Material samples and demonstrator | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 5 | **Application Need/Date:** | 2016 |
| **Application Mission:** | Sample return missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8947, T-8142 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Consistent with D/TEC technology roadmap | | | | | |

## Mar Precision Lander

| Preliminary design and performance verification of critical elements for guided entry thrusters | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E918-008MP | |
| **Title:** | Preliminary design and performance verification of critical elements for guided entry thrusters | | | | |
| **Total Budget:** | 800 | | | | |
| **Objectives** | | | | | |
| Preliminary design and performance verification of critical elements for thrustes guided entry on Mars | | | | | |
| **Description** | | | | | |
| For a precision landing (on Mars) it is strictly required to guide and control the capsule in the first part of the entry. Indeed the most importance source of dispersion is the hypersonic flight.<br>The NASA Phoenix capsule was designed aiming at a controlled and guided entry but a more detailed analysis of the interaction of the jets of the Reaction Control System (RCS) and the flow at hypersonic and supersonic conditions suggest a significant interference capable to reduce the efficiency of the thrusters or even produce control reversal. The hypersonic guidance was finally removed from the Phoenix EDL architecture in 2005.<br><br>The activity shall focus on 3 sequential aspects:<br>- the preliminary design of a RCS capable to control and guide a reference entry probe of the ESA?s Mars Precision Lander mission. To this end the contribution of the RCS to forces and moments in low density flow have to be estimated taking into account the heat fluxes on the capsule surfaces due to the impingement of the hot gases. DSMC-CFD calculations (and ad-hoc preliminary tests if necessary) shall be foreseen. The jet flow interaction shall be assessed in view of system (propulsion, accommodation, performance, flight mechanics?) implications/aspects.<br>- derive the requirements for a test campaign (in an aerodynamics rarefied facility) to verify the performance of the designed system. Particular importance shall be given to appropriate duplication of flight conditions and accurate measurement techniques.<br>- Prepare (and eventually modify/upgrade) the selected facility and measurement techniques where to performed the test campaign<br><br>note: This activity prepares the actual test campaign of Mars guided entry thrusters system to TRL 5 in a following activity. | | | | | |
| **Deliverables** | | | | | |
| Reports and databases. Computational (and experimental) data. Test campaing requirements. Preparation (modification/upgrade) of the selected facility | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2019 |
| **Application Mission:** | MPL | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8101, T-8940, T-8093 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| ATD Harmonisation 2012 | | | | | |

| Stand Alone 3 Axis European Accelometer Unit | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-021EC |
| **Title:** | Stand Alone 3 Axis European Accelometer Unit | | |
| **Total Budget:** | 500 | | |
| **Objectives** | | | |
| To develop and test an Engineering Model (EM) of a miniaturised 3 Axis European Accelerometer unit based on a European accelerometer detector already being developed and suitable for use on Rovers and EDL missions. The target for the unit would be for PHOOTPRINT, Mars Precision Lander and other future Mars lander missions. | | | |
| **Description** | | | |
| European accelerometer components are currently in development (Colibrys (CH) and ESS (GR)); this activity will result in the availability of a miniaturised stand alone 3 axis unit based on these components. The general characteristics of the unit are expected to be:<br>< 350g<br>< 60*60* 60mm<br>< 2.5 W<br>28 Volt primary power supply<br>with both +/-1g and +/-20g measurement ranges per axis.<br><br>The activity will include the preliminary design, breadboarding, detailed design and EM manufacture and test. The tests will include performance and environmental testing (thermal and mechanical). | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Deliverables** | | | | | |
| Unit EM, data package | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |
| **Application Mission:** | All Mars missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Compressive Sensing Technologies for compact LIDAR systems** | | | | | |
| **Programme:** | TRP | | **Reference:** | T916-004MM | |
| **Title:** | Compressive Sensing Technologies for compact LIDAR systems | | | | |
| **Total Budget:** | 475 | | | | |
| **Objectives** | | | | | |
| The objective of this activity is to assess and develop to TRL4, novel technologies for future compact imaging LIDARs based on compressive sensing techniques. | | | | | |
| **Description** | | | | | |
| Imaging LIDAR sensors are currently foreseen to be used in various space applications like during the descent and landing of planetary spacecraft or supporting the rendezvous operation between two spacecraft (with or without cooperative targets).<br><br>Nowadays the major drawback of using traditional Imaging LIDAR sensors is still their high mass (>12Kg for the overall unit) and high power consumption (>80Watts). In addition these sensors, typically single element detectors using large mirror scanners, have limited performances for some of the space applications. For example for the planetary lander application the desired high number of image elements that the system has to scan, on a fixed field of view, to image the target full frame has a strong time constraint due to the dynamics of the landing. Several novel detector array technologies have emerged in Europe in the last years that can lead to the development of more compact Imaging LIDARs systems. However the current state of the art of these detector arrays in Europe is still far away (limited number of detector elements and fill factor) from the development of a fully flash type Imaging LIDAR system (no scanning).<br><br>Recently a novel imaging technique, designated as compressive sensing, has been identified as a possible technique also for ranging applications. Since only a single element detector is required for the measurements (ranging and imaging) based on compressive sensing the current lack of high pixel resolution arrays in Europe could be overcome. In addition the system can be used, in the same application, or as a single element ranging system (like an altimeter) or as 3D imager, depending only on the illumination/imaging modulation technology used and on the implemented operational mode. Imaging LIDARs based on compressive sensing offer more compact systems, as they do not need mechanical scanners, and in addition the signal to noise ratio available for each measurement is much higher than when directly compared with flash type systems, thereby offering longer range/lower power operation than other techniques.<br><br>Within this activity technologies for a Imaging LIDAR system based on compressive sensing shall be investigated, assessed, breadboarded and tested. A technology development plan for the performance optimization of the selected technologies shall be elaborated and executed. The technologies shall be integrated into a Imaging LIDAR technology demonstration breadboard and tested in laboratory conditions. As a result of this activity the feasibility of Imaging LIDAR systems based on compressive sensing shall be verified and assessed for different space applications. | | | | | |
| **Deliverables** | | | | | |
| Novel Imaging LIDAR technologies, Imaging LIDAR breadboard, data package | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2017 |
| **Application Mission:** | MPL, MSR | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-7860 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Entry, Descent and Landing Communications technology assessment** | | | |
| **Programme:** | TRP | **Reference:** | T906-008ET |

| | |
|---|---|
| **Title:** | Entry, Descent and Landing Communications technology assessment |
| **Total Budget:** | 350 |

**Objectives**

- To investigate and prepare for communication direct to Earth (DTE) allowing limited information (minimum redundant) about Lander health, position and its tracking during Entry Descent and Landing and - if necessary after landing - during robotic operations.
- To carry out investigations for optimum output possible with given radio signals transmitted during EDL, exploiting large antennas
on-ground if needed larger than 35 m.
- To identify critical technologies for on-board and on ground hardware.

**Description**

After the Beagle failure it has been recommended that ESA missions implement a means of providing information of the events occurred during the critical entry, descent and landing (EDL) phase so it is possible to perform an investigation in case of failure. It is therefore required that future missions implement a communications system capable of transmitting information during the EDL phase. Moreover, since the existence or the visibility of an orbiter cannot be guaranteed, it is mandatory to investigate a solution compatible with the transmission of information directly to Earth during this phase.
Increasing on-ground available aperture and combining different antennas in an interferometer (Very Long Baseline Interferometry) has proved to be extremely useful for detection and determination of the trajectory of Huygens when landing on Titan. The activity will be applicable to the entry, descent and landing phase on any planet or moon. Initially the Contractor shall analyse the corresponding mission scenarios and system requirements; considering among others the following systems aspects e.g. plasma environment, black-out effect, signal dynamics, etc.
A Multiple Frequency Shift Keying (MFSK) X-band system has been implemented by NASA but its detection is a very demanding task for a receiver. Current investigations indicate that with a 35m G/S and the state of the art on board technology, the required C/No to receive specific MFSK tones is not fulfilled in all circumstances at the ground station receiver..
The Contractor shall investigate the following concepts: ?Define precise communication scenarios RF requirements for on-board hardware, noting EDL power limits.
-Study different types of on-board antennas compatible with different EDL module configurations and analyse antenna patterns to provide a required Earth coverage at all times
-Evaluate time accuracies needed and oscillator performances
-Investigate other approaches for the transmission of data (e.g. coherent/non-coherent tones, modulation schemes, etc.)

The Contractor shall investigate for such scenarios the possible ground system solutions:
-Addition of apertures and VLBI/interferometer capabilities, cooperating with radio astronomy community
-Demonstrate how to arrive at accuracies like 100m rms, assisted by experiments,
-Exploit latest capabilities of the radio-astronomy community and the ground segment community, including E-VLBI
-Cooperate with European VLBI Network as external service.
-High bit-rate interconnect to central correlator will need to be adapted for SC tracking.
-Exploitation of software code developed for Huygens trajectory determination as applicable.

The contractor shall investigate the signal reception by a G/S receiver:
-Consolidate the receiver requirements;
-Study ways to improve the receiver architectures capable to detect the EDL signal under extreme conditions defined in the course of the activity with ESA 35m antennas.

**Deliverables**

-Propose different communication architectures and select the most promising one for an EDL receiver architectural concept identifying the critical technologies with subsequent breadboarding (proof-of-concept) required for high-risk developments;

TN's, reports, Final Report

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2018 |
| **Application Mission:** | INSPIRE, PHOOTPRINT, MPL | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8738 | |

**Consistency with Harmonisation Roadmap and conclusion:**

Harmonization Dossier "TT&C Transponders and Payload Data Transmitters" 2012.

## SFR Robotics and Mechanisms

<table>
<tr><th colspan="6">Mechanisms Technologies that operate at very low temperatures (Extended test campaign) - CCN</th></tr>
<tr><td>Programme:</td><td colspan="2">ETP</td><td>Reference:</td><td colspan="2">E915-004FP</td></tr>
<tr><td>Title:</td><td colspan="5">Mechanisms Technologies that operate at very low temperatures (Extended test campaign) - CCN</td></tr>
<tr><td>Total Budget:</td><td colspan="5">350</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td colspan="6">The objective is to undertake a more comprehensive testing campaign within the ongoing MREP "Cold mechanisms" activity (E915-002MS) in order to achieve a higher TRL and reliability.</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">In the activity, MREP Mechanisms Technologies that operate at very low temperature, the rover locomotion subsystem was identified as one of the main critical mechanism onboard a Mars surface element (Rovers/Lander) that would impose the most challenging requirements in terms of low temperature (benefits from early start-up operations at -80C) and total lifetime (Sample Fetching Rover (SFR) application 21km ground track). Among other parts of the locomotion subsystem, this imposes that the drive mechanism is expected to achieve more than 100 million cycles on the motor, more than 6 million cycles on the planetary gearbox and around 63,000 cycles on the harmonic drive (all intended at output shaft).<br><br>These two requirements are far from been achievable with the current mechanisms technologies used for Mars exploration; on one hand, the liquid lubricants (i.e. Braycote) due to the low extreme temperature, and on the other hand, the solid lubricants (i.e. sputtered MoS2) due to the long lifetime.<br><br>In the course of the activity, during the trade-offs and preliminary testing (i.e. Pin-On-Disc and fretting tests) of the most promising non-space and space mechanisms technologies, several solutions have shown interesting results:<br>- 4 solid lubricants based on MoSx/WC and MoS2+Sb2O3 have preliminary demonstrated an increase in the lifetime by a factor of a 100 versus sputtered MoS2.<br>- 2 liquid lubricants with specific additives have shown similar friction coefficients to Braycote601EF at -80C however they remain more promising since their viscosity at -80C is significantly lower.<br><br>On top of this, it has been estimated that different Harmonic Drive configuration designs could be promising e.g. the type specifically designed for dry lubrication (by maximising synergies with the harmLES project (EU)) with the option of reducing the preload on the teeth (TBC). Also new materials, such as ceramics for the planetary gears or a breakthrough concept based on contactless magnetic transmission were found promising.<br><br>Considering all these promising findings and the limited resources of the initial activity in regards to the testing campaign (i. e. only first ranked solutions, only two components selected from the full drive chain, HD and PG, will be tested) it is believed that there is a need for extending the test campaign. This way will substantiate the final outcome by increasing the reliability of the results and/or by increasing the range potential solutions, including hybrid (according to a consolidated "best practise" approach) and/or even extend to other components of the kinematic chain of a drive meachnisms by covering also, the bearings, hall sensors and motors.<br><br>Collateral effect of an adequate implementation of this extended test campaign will be the minimisation of the cost and design efforts.<br><br>Coordination and synergies with other European projects (i.e. harmLES) and ESA activities (Dry lubricated Gearbox) will also be maximised.</td></tr>
<tr><td colspan="6">Deliverables</td></tr>
<tr><td colspan="6">Technical notes, breadboards, qualified technologies that allow mechanisms used in Lander and Rovers to operate at very low temperatures,</td></tr>
<tr><td>Current TRL:</td><td>3</td><td>Target TRL:</td><td>5</td><td>Application Need/Date:</td><td>2015</td></tr>
<tr><td>Application Mission:</td><td colspan="2">Sample Fetching Rover, Phootprint and Inspire</td><td>Contract Duration:</td><td colspan="2">12</td></tr>
<tr><td>S/W Clause:</td><td colspan="2">N/A</td><td>Reference to ESTER</td><td colspan="2"></td></tr>
<tr><td colspan="6">Consistency with Harmonisation Roadmap and conclusion:</td></tr>
<tr><td colspan="6"></td></tr>
</table>

## MSR

| Modelling of the Mars Environment for Future Missions | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E904-005EE | |
| **Title:** | Modelling of the Mars Environment for Future Missions | | | | |
| **Total Budget:** | 400 | | | | |
| **Objectives** | | | | | |
| To develop user-oriented, integrated tools to analyse aspects of the Mars environment required for mission design, including atmosphere, dust, regolith, and radiation. | | | | | |
| **Description** | | | | | |
| Various studies have analysed aspects of the Martian environment, including climate data derived from global circulation models, radiation data derived from monte-carlo studies of cosmic ray propagation in the atmosphere and regolith, and various dust investigations. This activity will review the available models, and develop tools around them that allow easier use in engineering. This avoids that the engineer will have to work with complex tools whose subtleties require considerable effort to work with. Requirements will be established for both the underlying physical modelling, and the engineering tools. | | | | | |
| **Deliverables** | | | | | |
| Engineering tools and associated documentation. | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 37 | **Application Need/Date:** | 2017 |
| **Application Mission:** | All Mars missions | | **Contract Duration:** | 36 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| Biosealing and Monitoring Technologies for a Sample Containment System - Sealing tests and EM design | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E914-004QI |
| **Title:** | Biosealing and Monitoring Technologies for a Sample Containment System - Sealing tests and EM design | | |
| **Total Budget:** | 1000 | | |
| **Objectives** | | | |
| Based on the previous results of the MREP-1 activity "Biosealing and Monitoring Technologies for a Sample Containment System", the objective of this TDA is to perform additional, already identified, tests on critical components of the sealing system, adapt the design of the container accordingly, perform necessary breadboarding and produce a design of an EM of the biosealing and monitoring system. | | | |
| **Description** | | | |
| This mission enabling technology development for MSR is a continuation of a 2.5 year 1500 kEuro contract completed in June 2013 to develop a flight biosealing and monitoring system for a MSR mission.<br><br>Phase 1:<br>Based on the previous study and test results, the following additional tests on critical components of the sealing system are necessary:<br>-Aging of polymeric seals<br>-Further development of metal energized seals, incl. change from internal to external compression, seal mating surface<br>-Optimisation of the Nanofoil application for the breaking-the-chain lid<br>-Continuation of the particle penetration tests (sealing system performance validation) in line with PRA and updated metal seal application<br>-Optimisation of monitoring system<br>-Update of PRA<br>-Opening process<br>Some of these tests will introduce a design modification of the container (e.g., stiffening to better support the metal seal) and the sealing system and therefore will also result in new breadboards.<br>-Design of Engineering Model<br><br>Manufacturing and tests need to be under strict PA/QA control for Phase 1 to meet the schedule and ensure that the conclusions are relevant. | | | |
| **Deliverables** | | | |

| | | | | | |
|---|---|---|---|---|---|
| Updated breadboards for the sealing and for the containment system, design of EM updated PRA, DDVP for QM and FM. | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 4 | **Application Need/Date:** | 2017 |
| **Application Mission:** | MSR | | **Contract Duration:** | 20 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **X-Band cryogenic feed prototyping** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T912-005GS | |
| **Title:** | X-Band cryogenic feed prototyping | | | | |
| **Total Budget:** | 600 | | | | |
| **Objectives** | | | | | |
| To design an innovative X-Band cryogenic feed to be installed in the future in the Deep Space antennas . G/T in X-Band will be maximised by an integrated design of the feed (receive and transmit in X band) and the cryo- cooled LNA sub- systems | | | | | |
| **Description** | | | | | |
| The reception performances of the Deep Space Ground Stations is limited by the noise generated in the front end. Any reduction of this noise will allow to increase the data transmitted or to reduce the required mass and power on the spacecraft transmitter.<br>X band is presently used for the telemetry of all deep space missions and will still be the preferred frequency band for future Mars exploration missions. The existing feed and LNA systems have been designed separately. Therefore, the feed system is operated at room temperature while the LNA is operated at 12 K. The overall system noise temperature is therefore suboptimal due to the insertion loss of the waveguide connection and passive elements at room temperature. In order to increase the mission data return, it would be extremely beneficial improving the present G/T by more than 1 dB. This will be achieved by reducing the loss of the feed system and trying to cryo-cool as much as possible the passive components of the receiver front end (diplexer, polarizer, waveguides, tracking coupler...). The interconnection of the feed and LNA subsystems will be optimised and the cryo-cooler subsystem will be designed to guarantee a maximum availability and redundancy. The same feed is going to be used for the uplink at 20 kW. A proper study will be conducted to minimise the effect of the high power uplink on the cryogenic subsystem. | | | | | |
| **Deliverables** | | | | | |
| A prototype of X-Band cryo-feed subsystem. | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2016 |
| **Application Mission:** | All future missions in X band | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| No Harmonisation dossier | | | | | |

| **Deployable & Inflatable Heatshield & Hypersonic Decelerator Concepts - Phase 1** | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T921-005MT |
| **Title:** | Deployable & Inflatable Heatshield & Hypersonic Decelerator Concepts - Phase 1 | | |
| **Total Budget:** | 400 | | |
| **Objectives** | | | |
| To review the European capabilities in terms of deployable and inflatable heatshield and hypersonic decelerator technologies and to assess the potential which such technologies might bring to enable new mission concepts for Mars exploration. Eventually to initiate development of the main technological elements of the concept identified as most suited for Europe. | | | |
| **Description** | | | |
| Europe has previously invested in early development of inflatable decelerator technology which resulted in a partially successful flight demonstration (IRDT). This technology has strong potential for enabling new Mars mission concepts and is therefore proposed for further investigation.<br><br>Very significant effort was spent by NASA in recent years on related technologies (hypersonic inflatable decelerators, mechanically deployable structures, multi-functional carbon fabrics for deployable heatshields, etc.). It is not viable for Europe to embark on similar developments in all of these fields, therefore it is recommend to initiate first a technology assessment to downselect the most | | | |

promising concepts for future missions.

The objectives of this activity shall be achieved through the following steps:

- Identify and study different inflatable and deployable heatshield & hypersonic aerodynamic decelerator concepts for atmospheric entry probes, and to assess their potential benefits for potential future Mars exploration missions. In particular, it shall be identified which missions such technologies could enable which are today considered not feasible.
- Review the related technological elements available in Europe, and assess their maturity for a relevant mission application. The required key technologies shall be identified, existing solutions be assessed and any required delta-development be identified. The expected technological limits shall be identified.
- Perform a trade-off on the various concepts considering the expected benefit/interest for future missions and the required development effort and risks.
- At system level the following aspects will have to be considered: Packing, configuration, aerodynamic stability, potential separation strategies.
- The technologies to be specifically assessed shall include high temperature fabrics, deployment and inflation mechanisms and integration of the TPS material.

The heatshields used so far for entry probes of planetary exploration missions are based on a thermal protection system on a rigid structure. The heatshield typically also acts as hypersonic decelerator. While its dimension is typically limited by geometrical constraints, like e.g. the fairing of the launcher, enlarging the hypersonic decelerator would allow to significantly reduce the ballistic coefficient and thereby the loads experienced by the heatshield during the atmospheric entry.

Deployable and inflatable heatshield concepts have therefore moved in the focus of interest in recent years. Such technology might enable future planetary exploration missions which are not feasible today, e.g. increased landed P/L masses or currently unreachable (higher altitude) landing sites on Mars.

**Deliverables**

Study reports (technological review, mission & application assessment, trade-off)

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 1-2 | **Target TRL:** | 3-4 | **Application Need/Date:** | 2018 |
| **Application Mission:** | Future planetary exploration missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8079, T-7906, T-7879, T-8142 | |

**Consistency with Harmonisation Roadmap and conclusion:**

Consistent with D/TEC technology roadmap

# Annex 2 (for information only): Update of MREP technology roadmaps

1. Phootprint
2. Mars Precision Lander and Small, Science Rover
3. Inspire
4. Mars Sample Return
5. Long term technologies

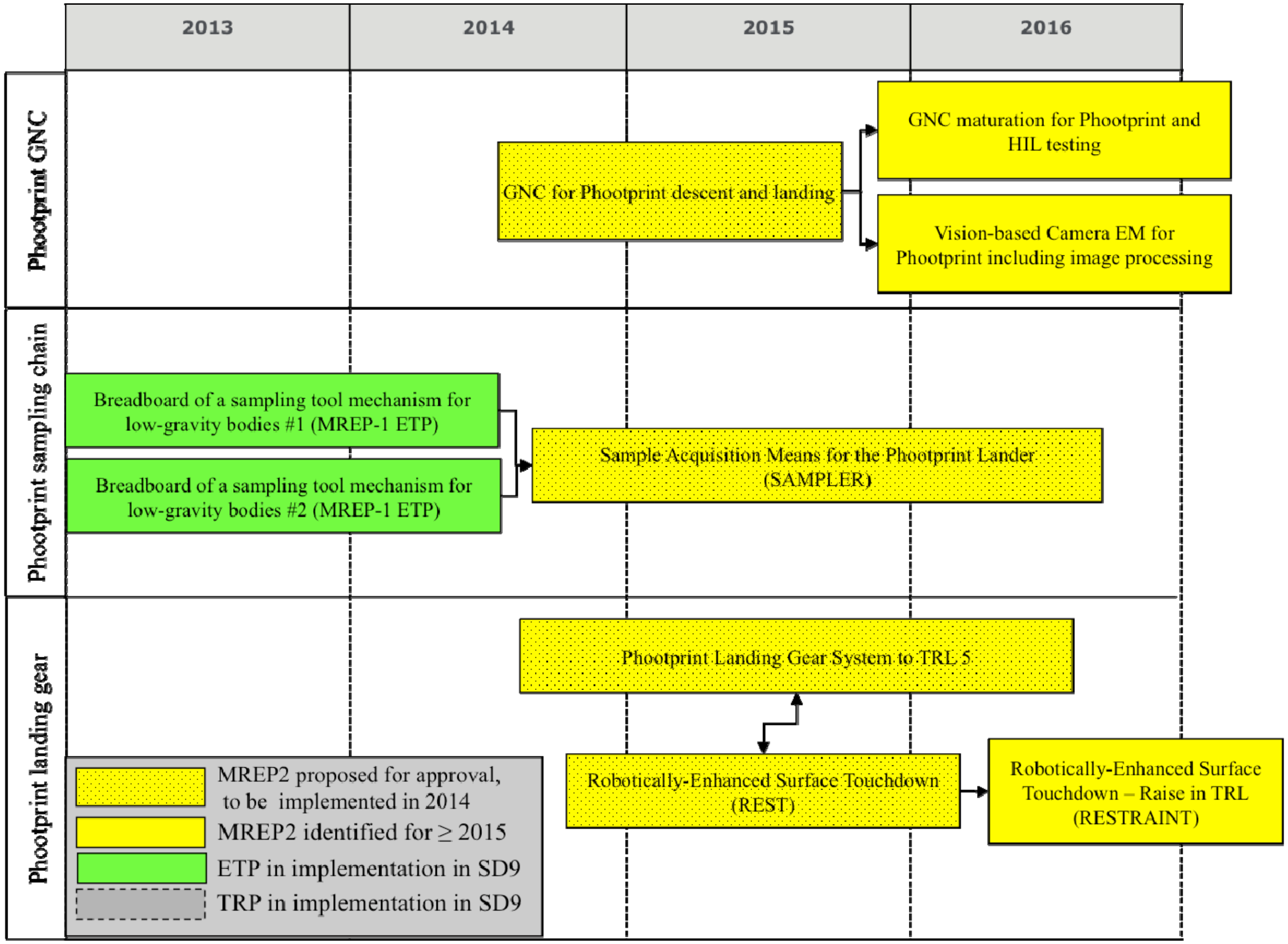


*Figure 1: PHOOTPRINT technologies roadmap 1./3*

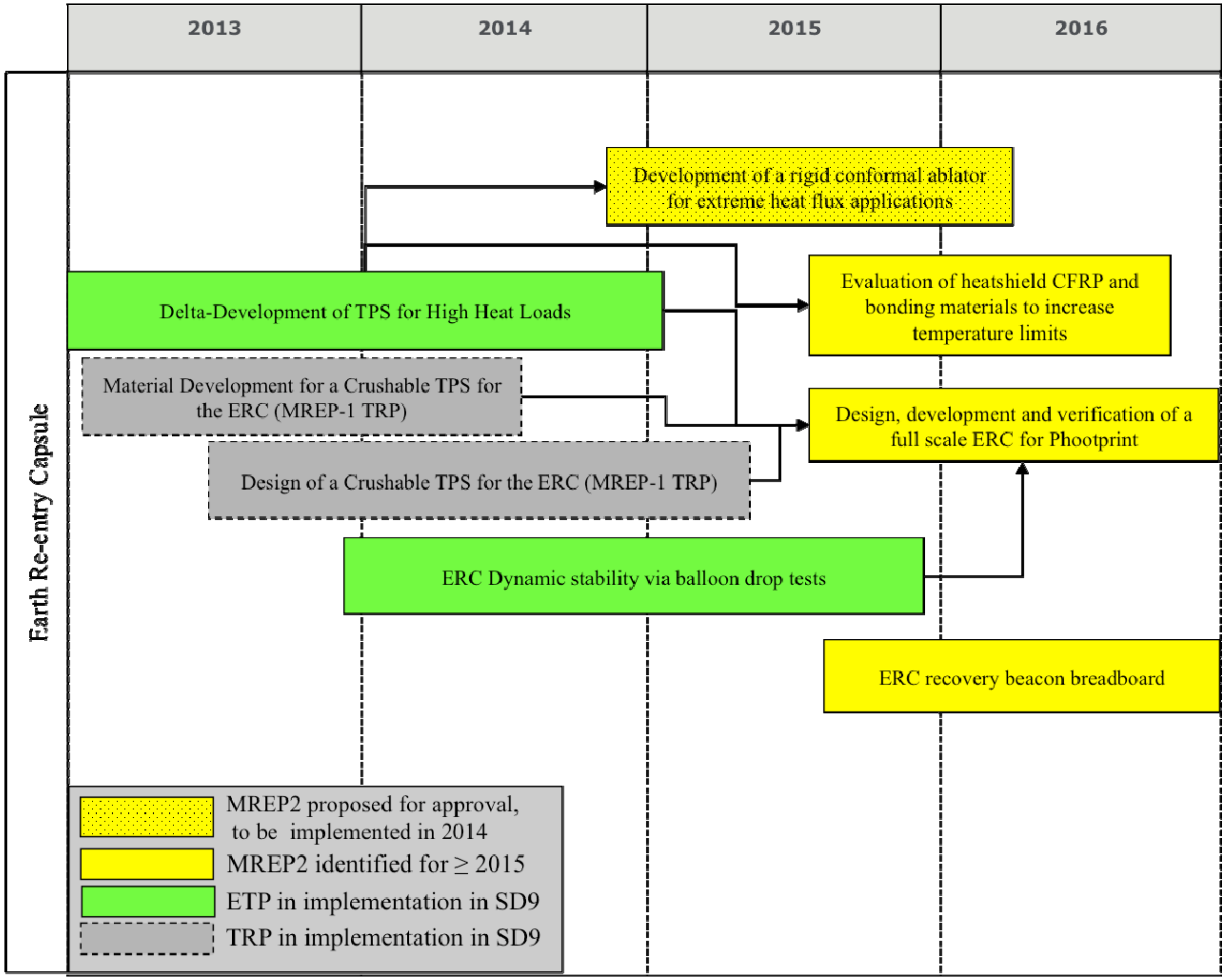


*Figure 2: PHOOTPRINT technologies roadmap 2./3*

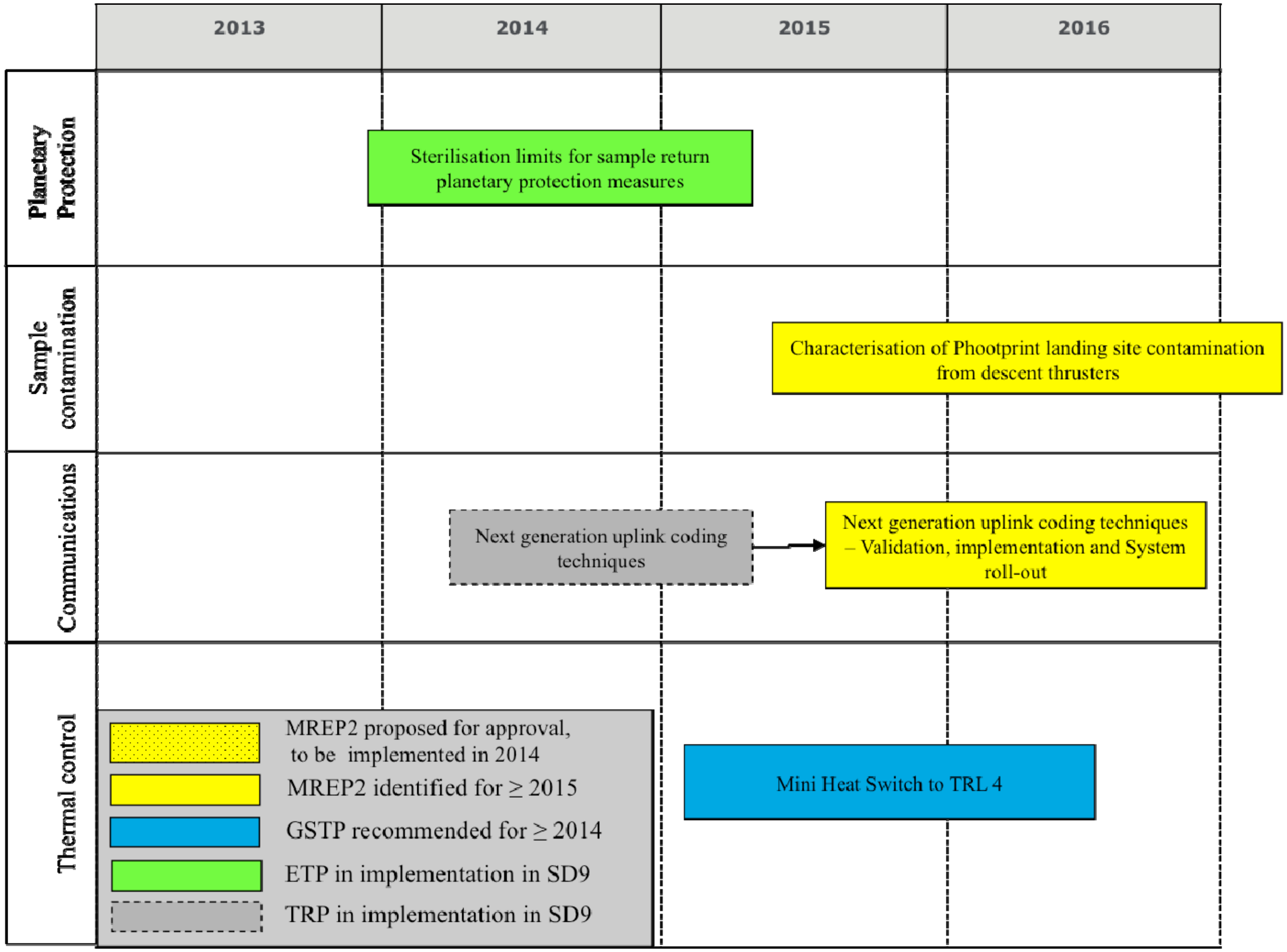


*Figure 3: PHOOTPRINT technologies roadmap 3./3*

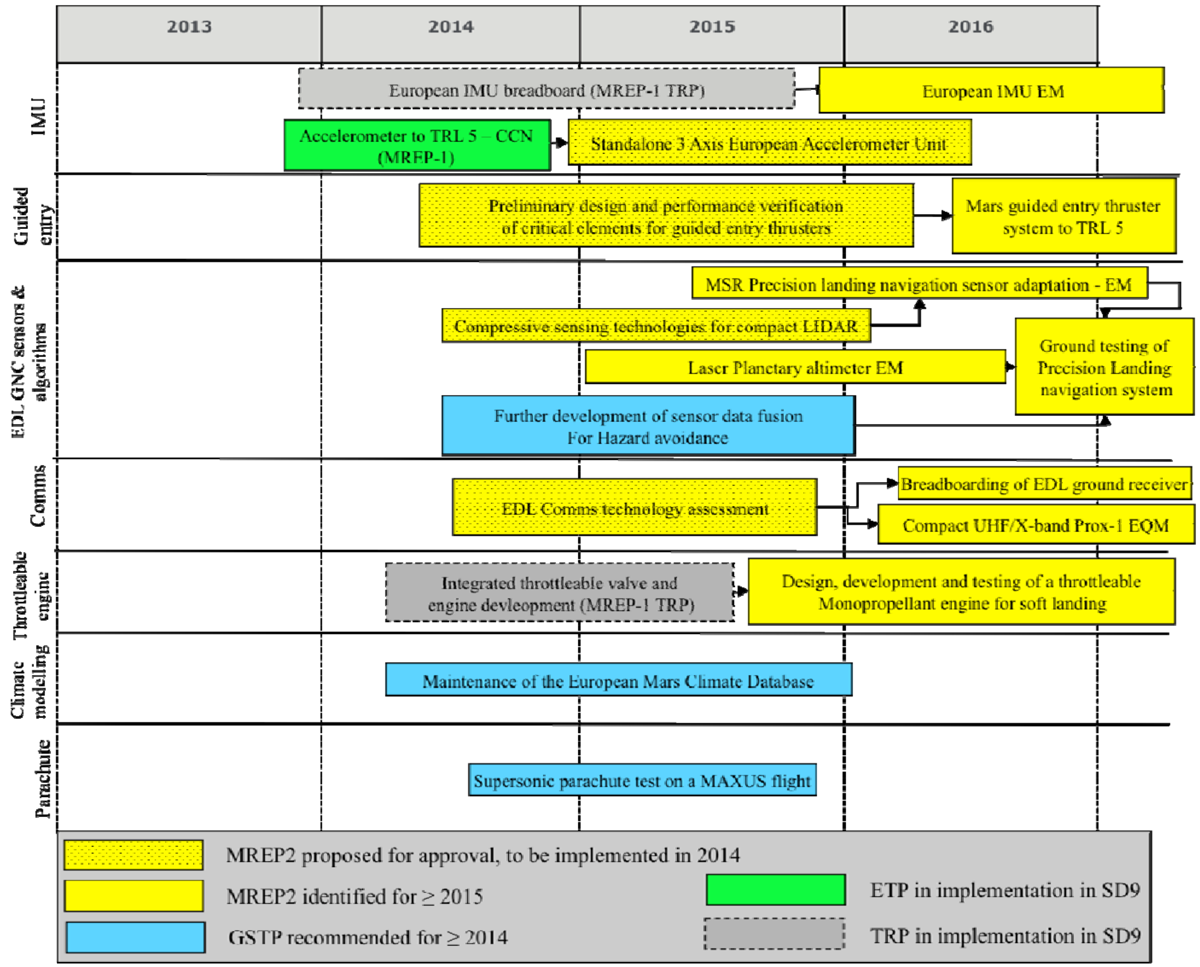


*Figure 4: Mars Precision Lander technologies roadmap*

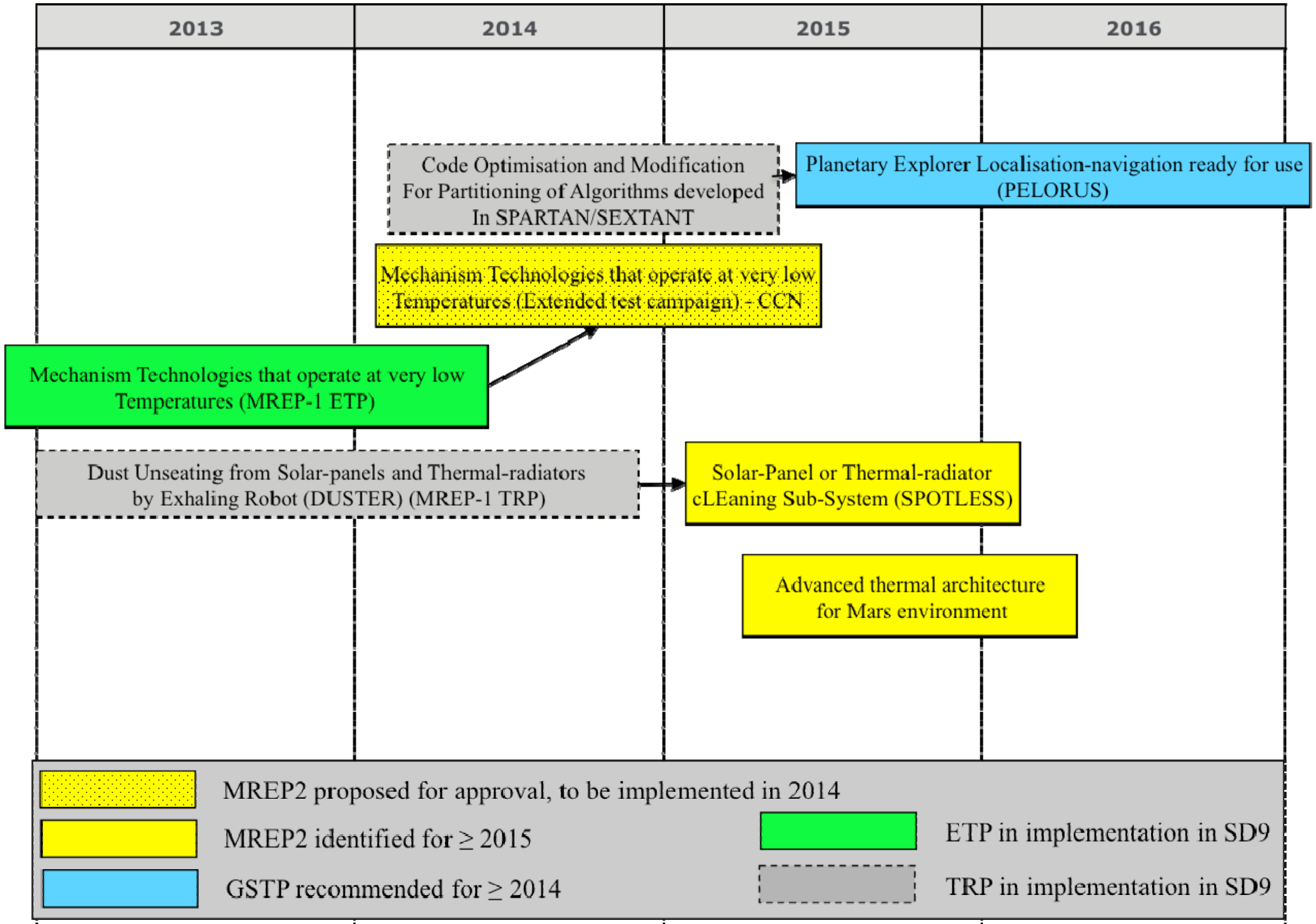


*Figure 5: SFR Robotics and Mechanisms technologies roadmap*

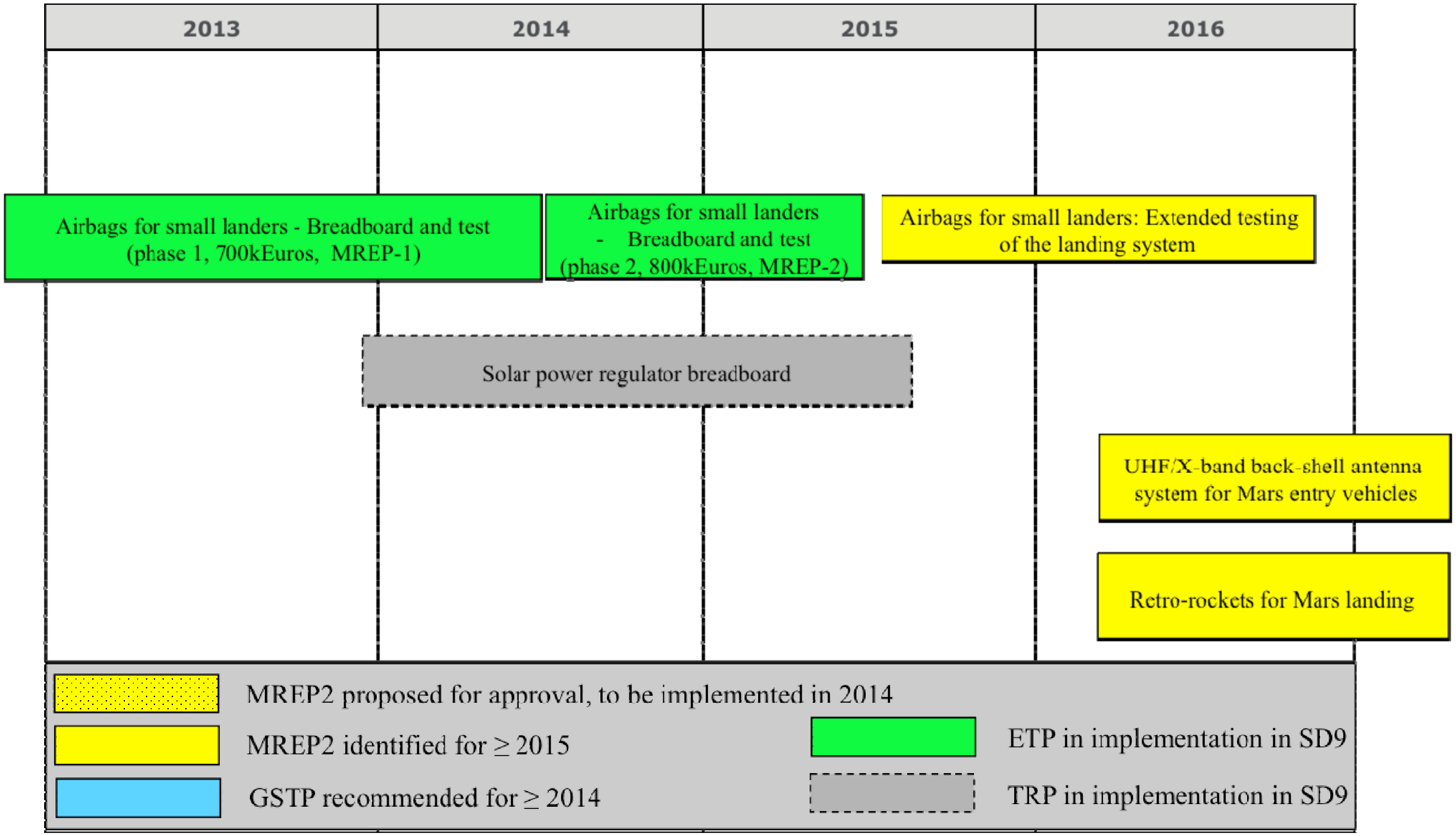


*Figure 6: INSPIRE technologies roadmap*

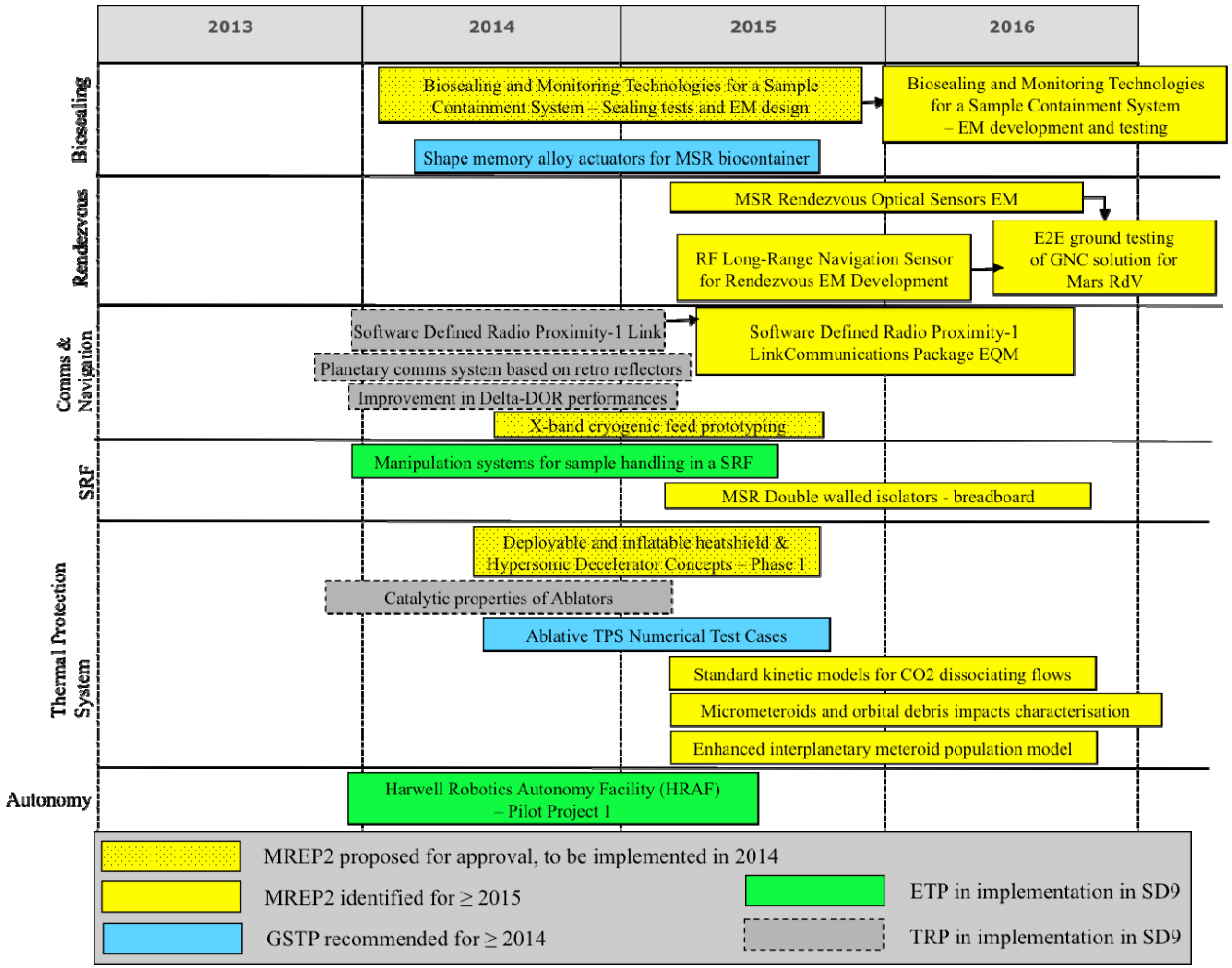


*Figure 7: Mars Sample Return technologies roadmap*

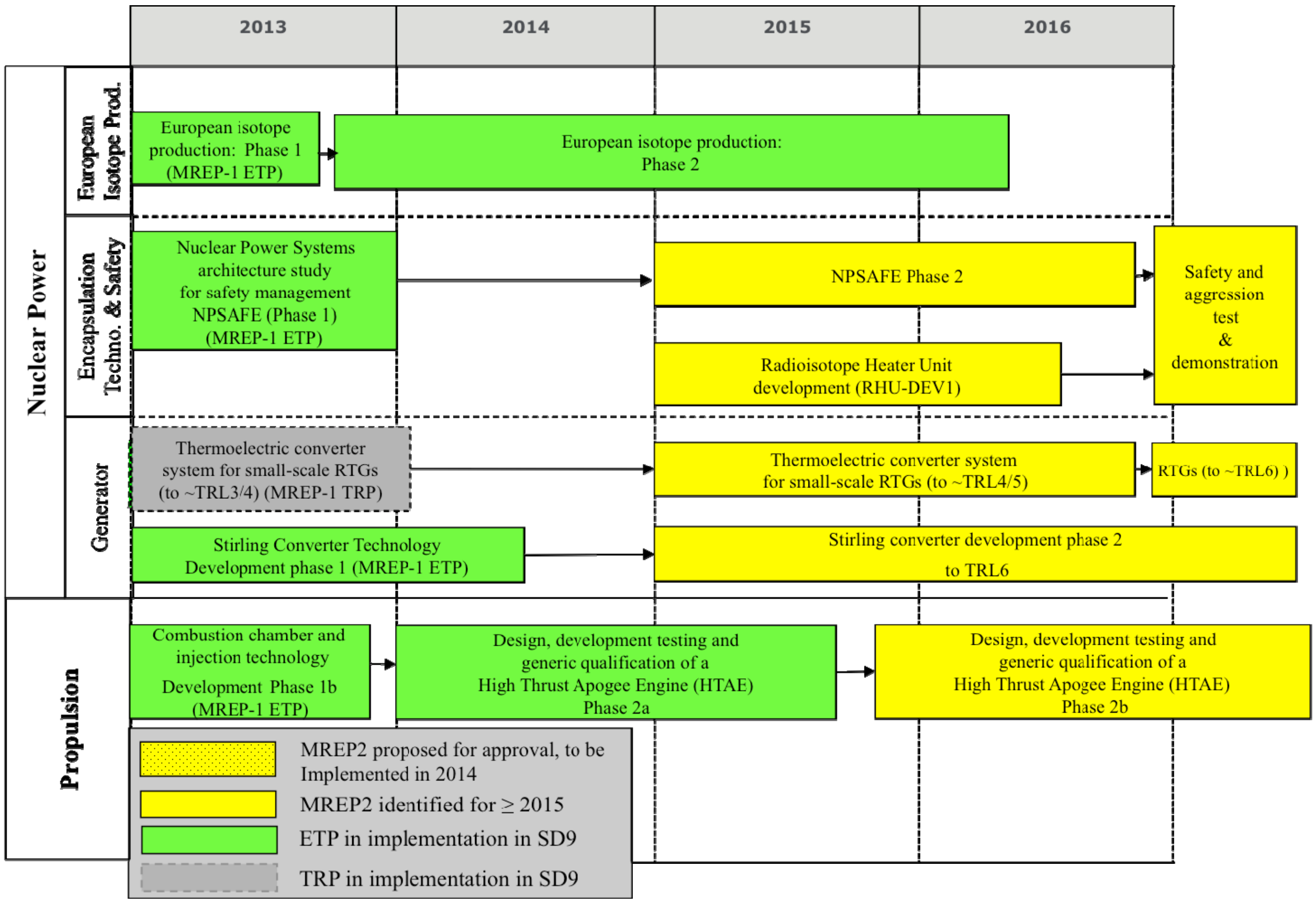


*Figure 8: Long term technologies roadmap*

Intentionally blank

# Annex 3: Summary tables and descriptions of TDAs recommended for GSTP (for information only)

## Summary table of TDAs recommended for GSTP (for information only)

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget 2013 | Budget 2014 | Budget 2015 | Budget 2016 | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GSTP | N/A | G921-008MT | Mini Heat Switch to TRL 4 | 0 | 0 | 400 | 0 | | | N/A | |
| GSTP | N/A | G904-002EE | Maintenance of the European Mars Climate Database | 0 | 300 | 0 | 0 | | | N/A | |
| GSTP | N/A | G905-022EC | Further development of Sensor Data Fusion for Hazard Avoidance | 0 | 700 | 0 | 0 | | | N/A | |
| GSTP | N/A | G918-007MP | Supersonic parachute test on a MAXUS flight | 0 | 500 | 0 | 0 | | | N/A | |
| GSTP | N/A | G913-016MM | Planetary Explorer LOcalisation-navigation Ready for USe (PELORUS) | 0 | 0 | 2000 | 0 | | | N/A | |
| GSTP | N/A | G215-001FP | Shape Memory Alloy actuators for MSR biocontainer sealing - feasibility demonstration | 0 | 200 | 0 | 0 | | | N/A | |
| GSTP | N/A | G921-007MT | Ablative TPS Numerical Test Cases - Mathematical Code Assessment & Improvement | 0 | 300 | 0 | 0 | | | N/A | |
| **Total GSTP** | | | | **0** | **2000** | **2400** | **0** | | | | |

# Detailed descriptions of TDAs recommended for GSTP

| Mini Heat Switch to TRL 4 | | | | | |
|---|---|---|---|---|---|
| **Programme:** | GSTP | | **Reference:** | G921-008MT | |
| **Title:** | Mini Heat Switch to TRL 4 | | | | |
| **Total Budget:** | 400 | | | | |
| **Objectives** | | | | | |
| The objective is to develop and qualify a miniaturized heat switch capable of conducting 0.5 to 10W of waste heat to a radiator. The heat switch shall be a passive device, which at a specified temperature, makes a thermal link with a cold sink and reject the excess heat. | | | | | |
| **Description** | | | | | |
| Robotic exploration missions that are subject to long diurnal cycles, require the used heat switches to thermally decouple from the cold external environment in order to save energy. A heat switch based on the Loop Heat Pipe technology was developed in the frame of a TRP. The technology is currently baselined for the Exomars Rover. The heat switch LHP was designed to transport 10 to 50W of waste heat. However,when managing small power dissipation coming from RHUs or payloads, a dedicated LHP Heat switch may be oversized and too complex for the application. A miniaturized heat switch TRP activity was initiated with a goal to have a mass lower than 60g and would be installed in series between the radiator and the dissipative unit. The heat transport of the device is targeted to be between 0.5W to 10W. The proposed activity, plans to further enhance the design of the mini heat switch based on results from previous developments activities. A qualification model shall be manufactured in order to perform environmental testing as well as extend life testing. In addition, the testing of the mini heat switch shall include an end to end validation using a representative payload and radiator mounted in a appropriate configuration. | | | | | |
| **Deliverables** | | | | | |
| Qualification Model and a full set of design and test documentation | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 6 | **Application Need/Date:** | 2016 |
| **Application Mission:** | Robotic Exploration Missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8839 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Consistent with D/TEC technology roadmap | | | | | |

| Maintenance of the European Mars Climate Database | | | | | |
|---|---|---|---|---|---|
| **Programme:** | GSTP | | **Reference:** | G904-002EE | |
| **Title:** | Maintenance of the European Mars Climate Database | | | | |
| **Total Budget:** | 300 | | | | |
| **Objectives** | | | | | |
| To maintain and keep up-to-date Martian climate models which have been developed under TRP | | | | | |
| **Description** | | | | | |
| Under TRP comprehensive models of the martian atmopsheric environement have been developed and used to develop a generic data base of atmospheric data, used in EDL. This database is supplemented with additional models at progessively smaller scales to cover all aspects of mission design, including near ground environment (z<20 m). The boundary conditions for these models need to be continually upgraded as data from current Mars missions become available. New data is also used for upgrade and validation of physical parameterizations used in these models. It is anticipated that some of the effort will be devoted to the improved modelling of dust lifting and transport mechanisms, hence giving access to realistic dust spatial variability. The activity will be in two phases, with phase two activities being more tightly defined in the light of progress in phase developments, and new problems and requirements arising in scenario analyses. | | | | | |
| **Deliverables** | | | | | |
| Upgraded Martian general circulation model and documentation. Upgraded Martian mesoscale/microscale model and documentation.<br>New version of Mars Climate Database (refined dust scenarios) and validation documentation. Technical notes on scenario studies. | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 7 | **Application Need/Date:** | 2017 |
| **Application Mission:** | All Mars missions | | **Contract Duration:** | 36 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |

| Further development of Sensor Data Fusion for Hazard Avoidance | | | | | |
|---|---|---|---|---|---|
| **Programme:** | GSTP | | **Reference:** | G905-022EC | |
| **Title:** | Further development of Sensor Data Fusion for Hazard Avoidance | | | | |
| **Total Budget:** | 700 | | | | |
| **Objectives** | | | | | |
| The goal of this activity is to further develop the fusion of sensor data for hazard avoidance and piloting initiated under two parallel studies (Astrium SAS and Spin.Works / T905-008EC).<br>The activity bring the sensor data fusion techniques for hazard avoidance and piloting from a TRL 3 to TRL 5 through the implementation of the algorithms on a dedicated processor, along with an associated relative navigation scheme; the algorithm will then be test on a real-time PIL, which will include high-fidelity models of passive and active sensors. | | | | | |
| **Description** | | | | | |
| Future solar system landing missions will be targeting region of high scientific interest but with significant risk (e.g. craters, boulders, shadowed areas, slopes.) The availability of both cameras and active optical sensors (scanning Lidars, flash Lidar/3-D cameras) with their different characteristics in term of measurement type, rate and field-of-view led to the investigation of hazard detection algorithms that would fuse the data from these two sensor types (and additionally from inertial and altimetric sensors when available) to provide accurate hazard maps to the flight control software. Several sets of sensors pairs, fusion algorithm (fusing sensor data at low- or high level) and scenarios (Mars and asteroid) are being defined, implemented, simulated on SIL platform and benchmarked within the frame of activity T905-008EC run by two parallel teams, one lead by Astrium SAS (TRP activity) and the other by SpinWorks (ETP and TRP).<br><br>The logical next step is to further test the winning combination(s) performance in a PIL simulation test-bed with a dedicated processor for the HDA and relative navigation software. The main tasks of this follow-up activity shall be :<br><br>- to review the results of the two previous activities, including their conclusion on the relevance of the HDA algorithm to relative navigation and to select for both Mars and asteroid missions at most 2 sets of sensors/algorithms (specifically, the reliability of the method(s) in estimating local slope values and identifying dangerous areas with steep slopes shall be the primary selection criterion.)<br><br>- to assess whether it is required, for performance reasons, to implement the HDA and/or relative terrain navigation algorithm(s) on a dedicated processor, and in that case, to implement HDA and relative navigation algorithm on the dedicated processor (e.g. FPGA, DSP, LEON-FT);<br><br>- making use of ESTEC laboratory dSpace-based test bench, to integrate this processor into a PIL simulation, where the flight control software will be implemented on a LEON2 processor, and high-fidelity models of both optical sensors shall be used. In order to run real-time simulation, it might be necessary to restrict the tests to open-loop simulations only in order to feed high-realism virtual images to the sensor model;<br><br>- based on the simulation results, to assess the sensor/algorithm simulations in term of accuracy of hazard detection, accuracy of relative navigation and overall CPU performance. | | | | | |
| **Deliverables** | | | | | |
| - Sensor data fusion algorithms and associated real-time software<br>- Sensor data fusion processor<br>- Technical documents, including test documentation | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |
| **Application Mission:** | Mars/asteroid landing missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| Supersonic parachute test on a MAXUS flight | | | |
|---|---|---|---|
| **Programme:** | GSTP | **Reference:** | G918-007MP |
| **Title:** | Supersonic parachute test on a MAXUS flight | | |
| **Total Budget:** | 500 | | |
| **Objectives** | | | |

| | | | | | |
|---|---|---|---|---|---|
| The objective of this activity is to demonstrate the capability to test new supersonic parachute designs in representative conditions for<br>space missions and reduce the reliance on existing non-European parachute systems by using European sounding rockets. | | | | | |
| **Description** | | | | | |
| As already proved feasible by the flight of the CIRA Sounding Hypersonic Atmospheric Re-entering Kapsule (SHARK) on the MAXUS-8 sounding rocket, the present activity shall make use of the spare payload volume, otherwise used for ballast, to perform a low cost flight test of a supersonic parachute on the MAXUS mission in 2015. Also, an initial internal feasibility study showed that there is possible to test a suitable sized parachute (1m diameter) in the available mass and volume constraints given by MAXUS, therefore there is a very good opportunity to develop state-of-the-art technologies for testing supersonic parachutes in Europe. The proposed activity includes:<br>- the detailed design of the capsule, parachute and deployment system including instrumentation and avionics<br>- the procurement (COTS)/development/manufacture of all items above<br>- installation the payload on MAXUS - (launch)<br>- post flight analysis<br>The following minimum instrumentation is foreseen to obtain flight data for design:<br>? Timer to measure events from MAXUS separation (initiation) to touchdown<br>? Video of the deployment and steady state descent,<br>? Accelerations and Angular rates of the capsule,<br>? Axial force during deployment, and<br>? Pressure sensor(s)<br>Further, since the capsule will be analysed by CFD to assess the wake, heating and the stability for the reference mission, there is also an opportunity to test future mission capsule shape dynamics in relevant conditions | | | | | |
| **Deliverables** | | | | | |
| Reports of detail designs, flight data and post flight analysis. Also flight hardware (all items procured/developed/manufactured under<br>the present activity). | | | | | |
| **Current TRL:** | 5 | **Target TRL:** | 7 | **Application Need/Date:** | 2018 |
| **Application Mission:** | MREP | | **Contract Duration:** | 36 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8101, T-8873, T-8940, T-7906 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| ATD Harmonisation 2012 | | | | | |

| | | | |
|---|---|---|---|
| **Planetary Explorer LOcalisation-navigation Ready for USe (PELORUS)** | | | |
| **Programme:** | GSTP | **Reference:** | G913-016MM |
| **Title:** | Planetary Explorer LOcalisation-navigation Ready for USe (PELORUS) | | |
| **Total Budget:** | 2000 | | |
| **Objectives** | | | |
| This activity shall achieve Technology Readiness Level (TRL) 5 for the hardware logic cores of computer vision algorithms (for use by Martian rovers in visual navigation and localisation) that have been developed in the previous SPARTAN/SEXTANT and COMPASS activities. | | | |
| **Description** | | | |
| Background:<br><br>The "SPAring Robotics Technologies for Autonomous Navigation (SPARTAN)" activity has implemented in logic cores a series of computer vision algorithms necessary to implement navigation systems for planetary probes. Starting from their mainly sequential description, the algorithms have been turned into vectorial and highly-pipelined cores so that they can con work in the latest FPGA devices.<br>The "Spartan EXTension Activity - Not Tendered (SEXTANT)", in the final stage of development at the time of writing, has been extending the number of algorithms used (to allow robustness) and also it has been implementing a landmark-based global localisation scheme.<br>The activity "Code Optimisation and Modification for Partitioning of Algorithms developed in SPARTAN/SEXTANT (COMPASS)", in initiation at the time of writing, will partition the cores and port it from the present single-FPGA implementation (only possible with non qualified US FPGAs) into networks of smaller FPGA devices thus allowing the possibility of using European-<br>sourced FPGAs.<br><br>The timing of conclusion of the sequence of the three activities coincides with the first availability of high-density all-European FPGA (end of 2014). At the end of the three activities the logic cores will be mature for a transition into a hardware/software | | | |

| |
|---|
| architecture representative of a real space mission.<br>The PELORUS activity will take advantage of this fortunate conjunction to develop a hardware implementation of the cores based on the new FPGA.<br><br>Programme of work:<br>1. Definition of requirements<br>2. Co-design of the hardware and software<br>3. Manufacturing Coding and Assembly of the co-design<br>4. Testing in relevant environment<br>5. Closure of activity |
| **Deliverables** |
| 1. Normal project documentation<br>2. logic cores and supporting software<br>3. hardware implementation<br>4. test environment |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |
| **Application Mission:** | MSR | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8937 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Shape Memory Alloy actuators for MSR biocontainer sealing - feasibility demonstration** | | | |
| **Programme:** | GSTP | **Reference:** | G215-001FP |
| **Title:** | Shape Memory Alloy actuators for MSR biocontainer sealing - feasibility demonstration | | |
| **Total Budget:** | 200 | | |
| **Objectives** | | | |
| Demonstrate the feasibility of using shape memory alloys (SMA) as an actuator to close/seal the MSR biocontainer structure as an alternative to current state-of-the-art sealing technologies. | | | |
| **Description** | | | |
| A) Analyis of required performance of SMA candidates with respect to function as a mechanism for seal closure of a BioContainment for MSR mission:<br>- Required force to lock the seal<br>- Reliability of function<br>- Tolerance against environment and qualification limit<br>- Temperature, pressure, EMC, radiation<br>- Launch environment<br>- DHMR compatibility<br><br>B) Literature survey of candidate SMAs and application examples.<br>C) Definition of test set up<br>- How to proof function<br>- Develop analytical procedure to proof tightness<br>- Pressure test vs. material research (analyse slice by e.g. SEM, x ray tomography etc.<br>D) Design of test set-up<br>- Design of SMA clamp<br>- Analyse resource requirements power, weight etc.<br>- Design of seal structure to be clamped (diameter32 cm)<br>- Design of seals | | | |
| **Deliverables** | | | |
| Documentation and breadboard | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2019 |
| **Application Mission:** | MSR | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |

| Ablative TPS Numerical Test Cases - Mathematical Code Assessment & Improvement | | | |
|---|---|---|---|
| **Programme:** | GSTP | **Reference:** | G921-007MT |
| **Title:** | Ablative TPS Numerical Test Cases - Mathematical Code Assessment & Improvement | | |
| **Total Budget:** | 300 | | |

**Objectives**

To assess the reliability of the mathematical codes used to size the thickness of ablative TPS on entry heatshields; to refine and possibly reduce the related uncertainties; and to identify relevant areas to improve the codes.

**Description**

In the frame of the European Ablation Working Group, several simplified numerical ablation test cases have been defined and were used by different partners to assess the performance of available codes for ablative TPS sizing. Those test cases were based on literature data which, however, turned out to be incomplete and in several aspects not consistent. Missing data had to be complemented by assumptions, which strongly limited the suitability of the derived test cases to assess the performance of the mathematical codes used for ablative TPS sizing.

In recent years a new European lightweight ablative material has been developed (TRP-DEAM, MREP-DEAM2) specifically tailored for the Earth return capsule of sample return missions. Also for this new material, now called ASTERM, material and test data cannot be made openly available due to industrial confidentiality aspects. However, a similar material exists, called AQ61, which in its physical composition and performance is very similar to ASTERM, but due to its more complicated manufacturing process is not considered as candidate for relevant flight applications. Within a previous TRP (Thermal Response Characterisation of Reference TPS Material) a dedicated set of plasma tests has been performed which are intended to be used now to establish numerical test cases based on real test data.

While also a basic set of material characteristics of AQ61 is available, material characterisation will have to be completed as part of this activity. In order to rebuild the numerical test case, an integrated solution for charring ablators (including thermo-chemistry), is needed. This can be achieved by the coupling (exchange by files or on the fly evaluation of properties) of a response code for charring ablators with a code for equilibrium chemistry calculations. In order to rebuild the plasma test, the thermal response code must be capable of modelling the test specimen (an axis-symmetric model), and the chemistry code must have the capabilities to model the charring materials used in real ablators (like AQ61, MONA, ASTERM, ...).

The following work is to be conducted in this activity:
? Establish a booklet with a set of numerical ablation test cases based on available plasma test results of the AQ61 material
? Where necessary the available data shall be complemented by relevant additional material characterisation
? Coupling of a response code for charring ablators with a code for equilibrium chemistry calculations
? Model and run the above test cases with at least three of the ablative TPS sizing codes available in Europe
? Compare the results with the available plasma test data, assess the code/model performance and identify the weaknesses of the used codes
? Derive relevant uncertainties based on the test cases and extrapolate these uncertainties to relevant entry analysis
? Identify relevant code improvements and code delta-development

The booklet shall be established in progressive steps, starting from a simple test case which is iteratively increasing in complexity. E.g. the ablation-chemistry coupling would be an element of an advanced iteration.

**Deliverables**

- Booklet with the definition of a set of numerical test cases.
-Technical Notes on material characterisation, test case results and code assessment

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2016 |
| **Application Mission:** | Sample return missions; | | **Contract Duration:** | 20 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8282, T-8277 | |

**Consistency with Harmonisation Roadmap and conclusion:**

Activity identified in D/TEC technology roadmap

# Annex 4:
# Summary description of post-ExoMars candidate missions
# and
# Mars Sample Return

## A4.1 The Phootprint mission

PHOOTPRINT will return a sample from the Mars moon Phobos. It is launched by Ariane 5 (or similar launcher) into direct escape to Mars in 2024. The spacecraft composite is made of three main elements:

- A <u>lander</u> carrying the ERV/ERC, performing the transfer to Mars, the Mars orbit insertion and operations around and on Phobos including landing and sampling
- An <u>Earth Return Vehicle</u> (ERV) performing Mars escape, transfer back to Earth and ERC release few hours before re-entry
- An <u>Earth Re-entry Capsule</u> (ERC) with hard landing on Earth

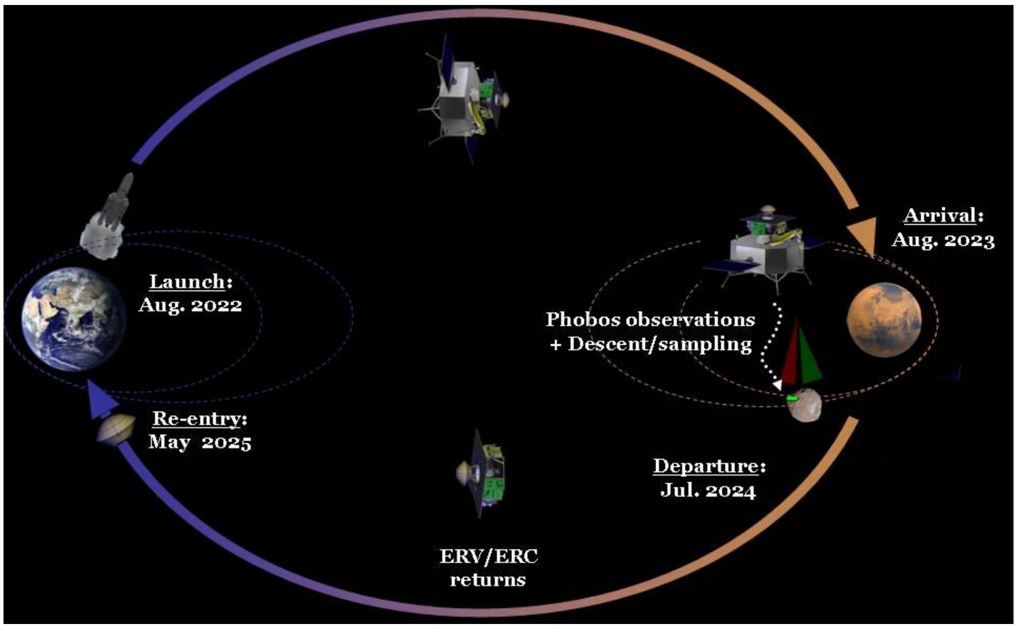


*Figure 9: PHOOTPRINT mission scenario (note that foreseen launch date is now 2024)*

The composite will transfer to Mars during 11 months. A number of burns will bring the spacecraft to a 6500 km circular Mars orbit near Phobos, where it will stay for about a year. Throughout this year, Phobos will be characterised and potential landing sites will be identified using its onboard instrumentation. First observations will take place from a remote distance of a few hundreds of km, then closer at to 50 to 100 km. After this characterisation and the selection of a scientifically interesting and technically suitable and safe landing site, the composite will descent towards Phobos and perform a soft landing on its surface.

Eventually, the spacecraft will stay on Phobos for a number of day/night cycles to allow iterations with the ground team to select a sampling spot. The 2-meter robotic arm will deploy a sampling tool to collect 100 gram samples on the chosen spot. If the soil is not appropriate for sampling the robotic arm can be repositioned to another location. As the surface gravity is extremely low (2 to 8 $mm/s^2$), thrusters will be continuously fired to push the lander on the surface and ensure stability when sampling occurs.

After confirmation of a successful sampling procedure, the sample will be transferred to the re-entry capsule and sealed. The ERV/ERC-composite will take-off from Phobos and transferred into a Mars escape orbit to perform from there the Mars escape manoeuvre and transfer back to Earth. After 8 months return trip the ERC will be released a few hours before Earth arrival and re-enter the atmosphere at 12 km/s.

| | **Value** | **Unit** |
|---|---|---|
| Launch mass | ~ 3900 | kg |
| Total Delta V | ~ 4500 | $m \cdot s^{-1}$ |
| Mass around Phobos (Lander/ERV/ERC) | ~ 1500 | kg |
| Mass returned to Earth (ERC) | ~ 30 | kg |
| Re-entry velocity | ~12 | $km \cdot s^{-1}$ |
| Earth landing site | Woomera test Range | |
| Mission duration | < 3 | year |

*Table 1: Key mission parameters*

## A4.2 The Mars Precision Lander (MPL) with Small, Science Rover (SFR) mission

The mission objective is to perform a soft precision landing on Mars with precision of 10 km (3 sigma) and to deliver a ~100kg rover to the Martian surface. The mission is launched by a Soyuz Fregat from Kourou either into a GTO orbit, or into a direct escape followed by an Earth fly-by. The spacecraft composite is made of three main elements:

- A <u>carrier</u> to support the lander during the cruise phase and deliver it to Mars. After release of the lander about 15 minutes before Mars entry, the carrier will break up and burn up in the Martian atmosphere.
- A <u>lander</u> performing the precision entry, descent and landing including hazard avoidance
- A 100 kg class highly-mobile rover for extended-range scientific exploration, which would also demonstrate the fast roving capability required for the MSR (Sample Fetch Rover),

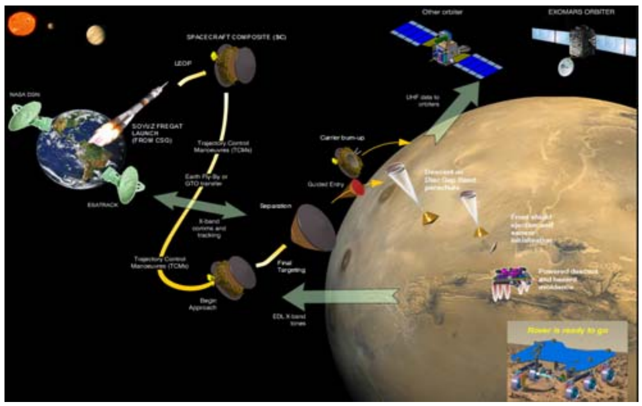


*Figure 10: Mars Precision Lander mission scenario*

Once safely landed, the rover will start its surface mission for over 180 sols, exploring a landing site normally not accessible without the precision landing capability. The technology to land more precisely on Mars directly offers a substantial increase in the number of available landing sites on the surface that could be targeted by future missions. As an example, without precision landing only 1 out of 12 last candidate landing sites from the MSR and MSL would be accessible. It should be noted that a data relay orbiter is required to support the rover operations.

| | **Earth Fly-By (EFB) + dropship** | **GTO + conventional lander** |
|---|---|---|
| **Launcher capability** | 1625 kg | 3180 kg |
| **Possible launch dates** | November 2025 (or later) | October 2024 or November 2026 |
| **Mars arrival** | September 2025 or August 2027 | |
| **Delta-v for transfer** | No DSM,<br>70 m/s navigation delta/v | 1.6 -1.9 m/s |
| **Total launch mass including adapter** | 1391 kg | 3240 kg |
| **Landing sites** | Latitude : -15° to +30°, Longitude : Any<br>Altitude: <0 km MOLA | |

*Table 2: Key mission parameters*

## A4.3 The INSPIRE mission

The INSPIRE mission aims at delivering a network of probes on the surface of Mars to perform simultaneous seismic and meteorological measurements.

**Launch and Interplanetary Transfer**

The mission concept is based on a Soyuz-Fregat launch from Kourou. Direct escape as well as launching into GTO can be considered for this mission. The GTO launch scenario is however preferred to increase the mass available per probe, which is needed to make the mission as robust as possible (i.e. to allow for implementation of a direct to Earth data link, to increase entry descent and landing margins and to allow for flexible payload deployment by means of a robotic arm). The GTO transfers within the 2022-2026 time frame have the additional benefit that the arrival conditions will be more favourable (i.e. lower arrival velocity and landing further away from the global dust storm season).

**Lander release**

Tens of days before arrival at Mars, the tracking campaign of the spacecraft will become more intense as preparations take place for the release of the landers. The first probe will be released about 12 days before arrival at Mars followed by further tracking and retargeting manoeuvres to release the second lander a few days later. The last lander can be released minutes before Mars entry. After all probes are released, the carrier will enter the Martian atmosphere and break-up and burn-up.

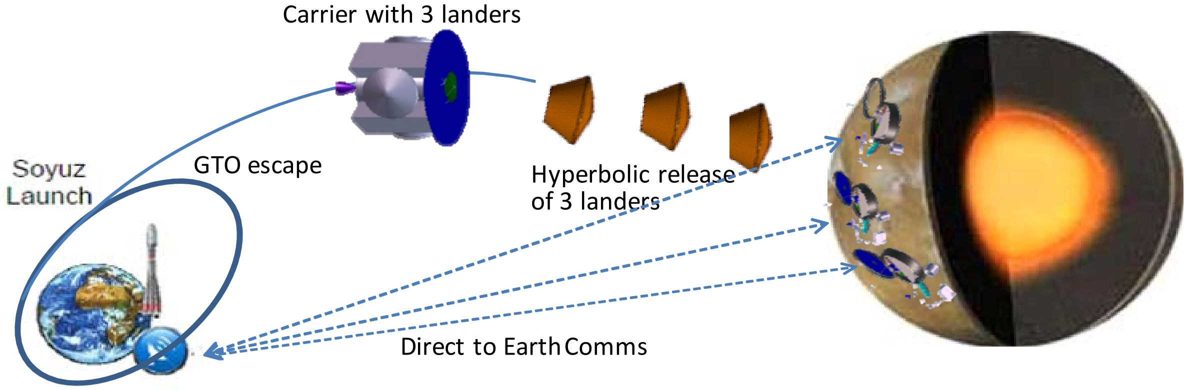


*Figure 11: Proposed INSPIRE Mission Architecture*

| | Via GTO 2022 | Via GTO 2024 | Via GTO 2026 |
|---|---|---|---|
| Launch | Sep-22 | Oct-24 | Nov-26 |
| Arrival | Aug-23 | Aug-25 | Jul-27 |
| Launch performance excl launch margin | 3180 | 3180 | 3180 |
| GTO Escape Delta-V [m/s] | 1691 | 1539 | 1409 |
| GTO Escape Mass [kg] | 1785 | 1870 | 1952 |
| Arrival Solar longitude [Ls] | 111 | 126 | 139 |
| Carrier propellant mass [kg] | 1399 | 1311 | 1231 |
| Maximum mass available per probe [kg] | 384 kg | 413 kg | 440 kg |

*Table 3: Main characteristics of possible transfers to Mars.*

**Entry, Descent and Landing (EDL)**

The probes enter the Martian atmosphere performing a ballistic entry protected by its heatshields. At the appropriate conditions, the supersonic disc-gap-band parachute is opened, further decelerating the probes. This is followed by a brief retro propulsion phase, a short freefall and finally a semi-soft landing using unvented (bouncy) airbags. Throughout this phase, critical event data is downlinked to Earth. A similar EDL strategy has been proven successfully by Mars Pathfinder (MPF) and Mars Exploration Rover (MER) missions.

**Surface operations**

After the lander has come to rest, the airbags are jettisoned to allow the clamshell to open and the solar panel will be deployed. The lander proceeds with check-outs and communications direct-to-earth are established. High-resolution, colour panoramic pictures of the landing sites are then taken for relay to earth providing an early opportunity to visualise the immediate surroundings of the lander for operational, scientific and especially public outreach purposes. The following days will see the deployment of the different payloads: the meteorological boom is unfolded and the mole and seismometer will be placed onto the surface by the robotic arm. The mole will start its hammering process to dig itself into the surface whilst making scientific measurements. Once fully deployed, the landers will become long term (goal of > 1 Martian year) seismic and atmospheric monitoring stations taking simultaneous measurements without the need for complex operational planning and cost.


*Figure 12:* Entry, Descent and Landing chain

## A4.4 The Mars Sample Return mission

The summary presented here focuses on the MSR-Orbiter (MSR-O) mission that has been studied by ESA with two industrial teams. The entire MSR reference mission campaign, as resulting from i-Mars report and ESA/NASA joint effort in 2009-2011, is shown and described in the following figure. This reference mission campaign is subject to evolution, since the International Mars Exploration Working Group (IMEWG) has recently decided to re-initiate the work on MSR architecture, by extending the participation new partners such as Roscosmos.

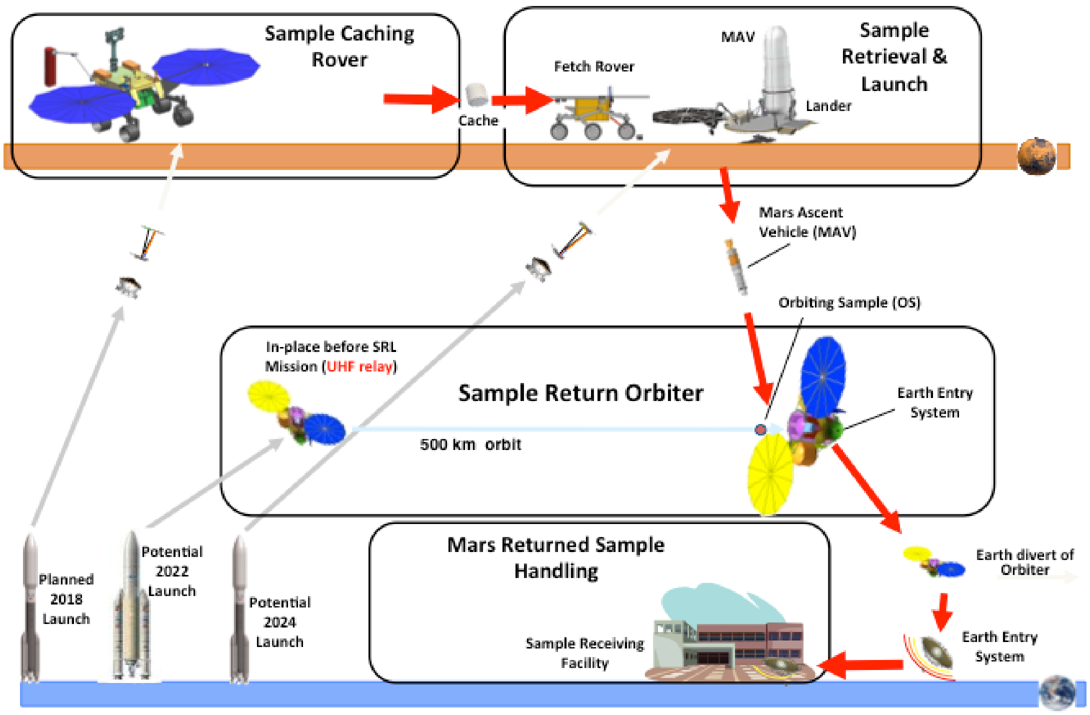


*Figure 13: The four elements of the MSR campaign: The caching rover selects the samples and places them in a cache. The sample retrieval and launch mission retrieves later the pre-stored cache with a sample fetch rover, places it in the orbiting sample container, which is launched in low Mars orbit by the Mars Ascent Vehicle. The MSR-O searches, rendezvous and captures the OS, seals it and returns it to the Earth. Finally the Earth Re-entry Capsule enters the Earth atmosphere and lands on the surface. Note: All launch dates are now delayed to late 2020s/early 2030s.*

The baseline launcher for MSR-O is an Ariane 5, assuming late 2020's or early 2030's as launch dates. Two major injection strategies have been analysed: (1) direct injection to Mars and (2) injection into a high elliptical orbit (HEO) followed by an Earth escape performed by the propulsion module. This second strategy allows for increased mass delivered to Mars at the cost of a large propulsion module and some increased operational risk. Other alternatives, like Earth swing-by or long transfers have been also analysed. In general these lead to higher mass at Mars at the cost of a longer transfer duration. The baseline is focused on short transfers (typically 10 months) to minimise the overall mission lifetime and to provide a solid margin for covering the arrival of the MSR-R element, intended to be launched 2 years after MSR-O.

At Mars the spacecraft performs the Mars Orbit Insertion (MOI), followed by an apocentre lowering manoeuver and jettison of the propulsion module. Aerobraking is used to save around 1.000 m/s delta-v for further lowering of the orbit apocentre down to parking orbit altitude of around 500 km. In the parking orbit MSR-O waits for the MSR-R descent module arrival to cover its entry, descent and landing on Mars. MSR-O serves also as communication relay for all operating MSR surface elements (lander and MAV, fetching rover) for a duration of 6 months. During this period the sample fetching rover is deployed, transfers to the pre-stored sample cache, returns it back to the lander, where the cache is put into the Orbiting Sample (OS) container, ready to launch with the Mars Ascent Vehicle (MAV). MSR-O follows the MAV launch and in particular the OS release, performs an orbit estimation of the OS, to size end execute the rendezvous manoeuvres up to the final capture of the OS. The rendezvous and capture phase nominally lasts less than 10 days.

The OS is placed inside the bio-container (BC) after capture and sealed according to planetary protection requirements. Once bio-sealed, the BC is transferred into the Earth Re-entry Capsule (ERC). The OS handling system is no longer needed and is jettisoned to reduce the Orbiter mass.

MSR-O escapes from Mars to an Earth transfer leg of around 10 months. At Earth arrival the ERC is released for re-entry at ~12 km/s, followed by a hard landing (no parachute is used for reliability reasons) in Utah or Australia. The Mars samples are retrieved and transferred to the Sample Receiving Facility (SRF) for further storage and analysis.

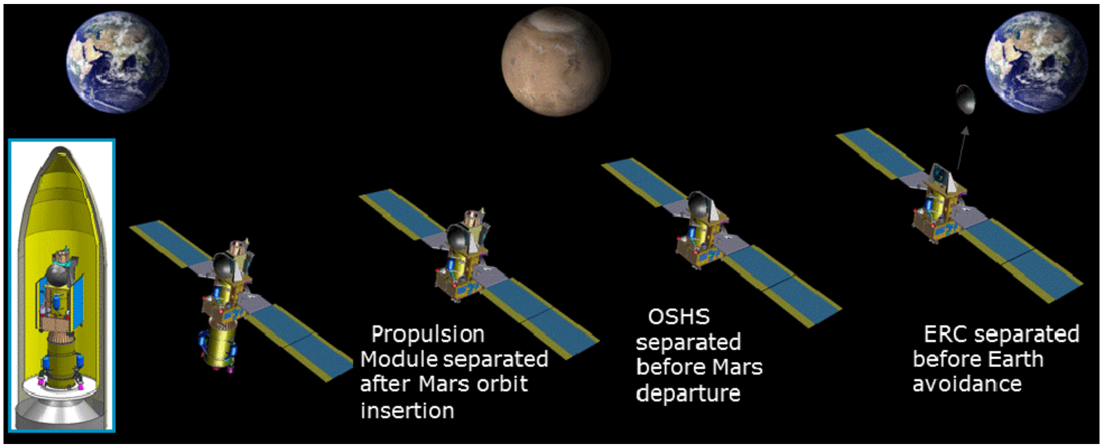


*Figure 14: The MSR-O staging strategy is optimised for mass performance*

MSR-O design is dominated by the high overall demanded delta-v, driven by the following major manoeuvres for typical typical direct escape scenario:

- Deep space manoeuver (DSM) of ~500 m/s
- Mars orbit insertion (MOI) of ~700 m/s followed by an aerobraking phase
- Mars escape orbit acquisition of ~1200 m/s and a Mars escape of ~1000 m/s

Numerous additional smaller manoeuvres are necessary. In the case of HEO injection additional ~800 m/s are needed for Earth escape.

# Annex 5 (for information only):

1. List of completed MREP-1 Programme activities
2. List of Removed/replaced activities from previous MREP-1 programme workplans
3. Summary tables and detailed descriptions of all running, approved or proposed activities from the MREP-1 and MREP-2 Programmes

# Completed MREP-1 Programme activities

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget | | | | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2013 | 2014 | 2015 | 2016 | | | | |
| ETP | Y2009 | E913-001MM | SPAring Robotics Technologies for Autonomous Navigation (SPARTAN) | 0 | 0 | 0 | 0 | C | BE | N/A | |
| ETP | Y2009 | E913-002MM | Study of a Sample Fetching Rover for MSR | 0 | 0 | 0 | 0 | C | UK | N/A | |
| ETP | Y2009 | E913-002MM-B | Study of a Sample Fetching Rover for MSR | 0 | 0 | 0 | 0 | C | IT | N/A | |
| ETP | Y2011 | E913-007MM | Shock Mitigation Operating Only at Touch-down by use of minimalist/dispensable Hardware (SMOOTH) | 0 | 0 | 0 | 0 | C | IT | N/A | |
| TRP | Y2008 | T305-031EC | Robust Autonomous Aerobraking Strategies | 0 | 0 | 0 | 0 | C | FR | N/A | |
| TRP | Y2008 | T305-031EC-B | Robust Autonomous Aerobraking Strategies | 0 | 0 | 0 | 0 | C | FR | N/A | |
| SI | Y2009 | S901-001ED | Extremely low power timer board EM for landers | 0 | 0 | 0 | 0 | C(1) | DK | N/A | |
| TRP | Y2009 | T319-035MC | Airbags for small landers - Design | 0 | 0 | 0 | 0 | C(1) | UK | N/A | |
| TRP | Y2008 | T306-044ET | Lander Compact Dual UHF/X-band Frequency Communication Package Study | 0 | 0 | 0 | 0 | C(2) | UK | N/A | |
| TRP | Y2008 | T314-033MM | Evaluation of Encapsulated Bioburden on Flight Hardware | 0 | 0 | 0 | 0 | C(2) | DE | N/A | |
| ETP | Y2009 | E903-001EP | European isotope production: Phase 1, samples and testing. (Including safety provisions) | 0 | 0 | 0 | 0 | C(1) | UK | N/A | |
| TRP | Y2008 | T303-039EP | European Nuclear Isotope Evaluation, Selection and Feasibility Study | 0 | 0 | 0 | 0 | C(1) | UK | N/A | |
| TRP | Y2008 | T303-039EP-B | European Nuclear Isotope Evaluation, Selection and Feasibility Study | 0 | 0 | 0 | 0 | C(1) | FR | N/A | |
| TRP | Y2009 | T303-040EP | Nuclear fuel capsule and aeroshell design study | 0 | 0 | 0 | 0 | C(2) | UK | N/A | |
| TRP | Y2008 | T203-006EP | Stirling Engine Radioisotopic Power System Requirement Study | 0 | 0 | 0 | 0 | C | UK | N/A | |
| TRP | Y2008 | T304-038EE | Maintenance of Martian Atmospheric circulation models (large scale, mesoscale, upper atmosphere) and continued validation of Martian Climate database | 0 | 0 | 0 | 0 | DN/C | FR | N/A | |
| ACP | Y2007 | CA10 | On-Line Reconfiguration Control System and Avionics Technologies (ORCSAT) | 0 | 0 | 0 | 0 | C | UK | N/A | |
| ACP | Y2007 | CE60 | Validation of Aerothermodynamics Experimental and Computational Tools for the Support of Future Mars | 0 | 0 | 0 | 0 | C | BE | N/A | |

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget | | | | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2013 | 2014 | 2015 | 2016 | | | | |
| | | | Missions | | | | | | | | |
| ACP | Y2007 | CG10 | GNC Maturation and Validation for Rendezvous in Elliptical Orbit (GNCOMAT) | 0 | 0 | 0 | 0 | DN | PO | N/A | |
| ACP | | CG20 | Automated Orbit Determination Techniques for Rendezvous (AODER) | 0 | 0 | 0 | 0 | C(R) | PO | N/A | |
| ACP | | CG40 | Worst Case & Safety Analysis Tools for Autonomous Rendezvous System | 0 | 0 | 0 | 0 | C | ES | N/A | |
| ACP | Y2007 | CG60 | Virtual Spacecraft Image Generator Tool | 0 | 0 | 0 | 0 | DN | UK | N/A | |
| ACP | Y2007 | CK10 | Bioburden and biodiversity evaluation in spacecraft facilities and lifetime test of rapid spore assay | 0 | 0 | 0 | 0 | C | DE | N/A | |
| ACP | Y2007 | CK20 | Extension of Dry Heat Sterilisation Process to High Temperature | 0 | 0 | 0 | 0 | C | DE | N/A | |
| ACP | Y2007 | CK30 | Development of a Complementary Low Temperature Sterilisation Method | 0 | 0 | 0 | 0 | C | UK | N/A | |
| ACP | Y2007 | CK50 | Definition of Functional Requirements for a MSR Biological Containment Facility | 0 | 0 | 0 | 0 | C | CH | N/A | |
| ACP | Y2007 | CR10 | Mars Surface Sample Transfer / Manipulation | 0 | 0 | 0 | 0 | C | UK | N/A | |
| | | | | **0** | **0** | **0** | **0** | | | | |

# Removed/replaced activities from previous MREP workplans

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget | | | | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2013 | 2014 | 2015 | 2016 | | | | |
| **MSR** | | | | | | | | | | | |
| ETP | Y2010 | E906-001ET | Compact dual UHF/X-band Proximity-1 Communication EM | 0 | 0 | 0 | 0 | | | N/A | Budget of 700k in 2010. Replaced by new E906-009ET Compact Dual UHF/X-band Proximity-1 Communications Package EQM, 2500k for 2016. |
| ETP | Y2011 | E906-003ET | Compact dual UHF/X-band Proximity-1 Communication EM – Phase 2 | 0 | 0 | 0 | 0 | | | N/A | Budget of 800k in 2011. Replaced by new E906-009ET Compact Dual UHF/X-band Proximity-1 Communications Package |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | EQM, 2500k for 2016. |
| ETP | N/A | E914-006MM | Micro remote manipulation systems for MSR Sample Receiving Facility | 400 | 0 | 0 | 0 | | | N/A | Replaced by new E913-010MM Manipulation systems for sample handling in a Sample Receiving Facility, 1000k for 2013. |
| **Long term** | | | | | | | | | | | |
| ETP | Y2009 | E903-007EP | Thermoelectric converter system for small-scale RTGs (to ~TRL4/5) | 0 | 0 | 0 | 0 | | | N/A | Budget of 700k in 2009. Replaced by E903-007FP Small-scale RTG development to TRL 5, 1000k for 2015. |
| ETP | N/A | E903-004EP | Encapsulation further development to TRL 5. | 1200 | 0 | 0 | 0 | | | N/A | Replaced by E903-004FP Nuclear Power Systems architecture study for safety management and fuel encapsulation NPSAFE (phase 2), 1000k for 2015. |

# All running, approved and proposed activities from MREP-1 and MREP-2

## Phootprint

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget | | | | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2013 | 2014 | 2015 | 2016 | | | | |
| ETP (MREP1) | Y2011 | E915-003MS | Breadboard of a sampling tool mechanism for low-gravity bodies | 0 | 0 | 0 | 0 | C | IT | N/A | Approved 2012 for 750kEuros. First phase of 450 kEuros, running activity with Selex-Galileo (IT). StrIn (95kEuro) to Finland. |
| ETP (MREP1) | Y2011 | E915-003MS-B | Breadboard of a sampling tool mechanism for low-gravity bodies | 0 | 0 | 0 | 0 | C | ES | N/A | Approved 2012 for 750kEuros. First phase of 450 kEuros, running activity with AVS (ES). |
| ETP (MREP2) | IPC | E913-012MM | Sample Acquisition Means for the Phootprint Lander: Experiments and first Realisation (SAMPLER) | 0 | 1500 | 0 | 0 | C | | N/A | Intended phased contract (Phase 1, 700kEuros) |
| ETP (MREP2) | N/A | E905-017EC | Guidance, Navigation, and Control (GNC) for PHOOTPRINT descent and landing | 0 | 400 | 0 | 0 | C(R) | PO | N/A | |
| ETP (MREP2) | N/A | E905-018EC | Guidance, navigation and control (GNC) maturation for PHOOTPRINT and hardware in the loop (HIL) testing | 0 | 0 | 600 | 0 | | | N/A | |
| ETP (MREP2) | N/A | E905-020EC | Vision-based navigation camera EM for PHOOTPRINT including image processing | 0 | 0 | 1000 | 0 | | | N/A | |
| ETP (MREP2) | IPC | E920-005MS | Phootprint Landing Gear System to TRL5 (PLanGS) | 0 | 1500 | 0 | 0 | C(2) | | N/A | Intended phased contract (Phase 1, 400kEuros) |
| ETP (MREP2) | N/A | E913-013MM | Robotically-Enhanced Surface Touchdown (REST) | 0 | 430 | 0 | 0 | C(1) | | N/A | |
| ETP (MREP2) | N/A | E913-014MM | Robotically-Enhanced Surface Touchdown - RAise In TRL (RESTRAINT) | 0 | 0 | 0 | 800 | | | N/A | |
| TRP | Y2013 | T906-001ET | Next generation uplink coding techniques | 450 | 0 | 0 | 0 | C | | N/A | |
| ETP (MREP2) | N/A | E906-006ET | Next generation uplink coding techniques - Validation, Implementation and System Roll-Out | 0 | 0 | 800 | 0 | | | N/A | |
| ETP (MREP2) | Y2013 | E914-001QI | Sterilisation limits for sample return planetary protection measures | 300 | 1000 | 0 | 0 | C(1) | | N/A | |
| ETP (MREP2) | N/A | E918-005MP | Characterisation of Phootprint landing site contamination from descent thrusters | 0 | 0 | 500 | 0 | | | N/A | |
| TRP | N/A | T924-004MT | Evaluation of heatshield CFRP and bonding materials to | 0 | 0 | 400 | 0 | | | N/A | |

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget 2013 | 2014 | 2015 | 2016 | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | increased temperature limits | | | | | | | | |
| TRP | N/A | T921-004MT | Development of a rigid conformal ablator for extreme heat flux applications | 0 | 400 | 0 | 0 | DN/S | FR | N/A | |
| ETP (MREP2) | Y2013 | E918-003MP | ERC dynamic stability via balloon drop tests | 1000 | 0 | 0 | 0 | C | | N/A | |
| ETP (MREP2) | N/A | E906-011FP | ERC RF recovery beacon breadboard | 0 | 0 | 400 | 0 | | | N/A | |
| ETP (MREP2) | N/A | E920-004MS | Design, development and verification of a full scale Earth Return Capsule for Phootprint | 0 | 0 | 1800 | 0 | | | N/A | |
| GSTP | N/A | G921-008MT | Mini Heat Switch to TRL 4 | 0 | 0 | 400 | 0 | | | N/A | |
| **Total Phootprint** | | | | **1750** | **5230** | **5900** | **800** | | | | |

## Mars Precision Lander

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget 2013 | 2014 | 2015 | 2016 | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TRP | Y2011 | T904-001EE | Extension and validation of Mars atmospheric and dust environment models | 0 | 0 | 0 | 0 | DN/C | FR | N/A | Approved 2011 for 150kEuros. Running activity with LMD (FR). |
| GSTP | N/A | G904-002EE | Maintenance of the European Mars Climate Database | 0 | 300 | 0 | 0 | | | N/A | Proposed to GSTP |
| ETP (MREP1) | Y2009 | E905-006EC | End to end Optimisation and GNC design for High Precision Landing on Mars | 0 | 0 | 0 | 0 | C | FR | N/A | Approved 2009 for 500keuros. Running activity with Astrium (FR) |
| TRP | Y2011 | T905-014EC | European IMU breadboard | 800 | 0 | 0 | 0 | C | | N/A | Approved 2011 for 800kEuros. Contract intended with Astrium (FR). |
| ETP (MREP2) | N/A | E905-015EC | European IMU EM | 0 | 0 | 2000 | 0 | | | N/A | |
| ETP (MREP1) | Y2011 | E905-016EC | Accelerometer component to TRL5 | 0 | 0 | 0 | 0 | C | CH | N/A | Approved 2011 for 700kEuros. Running activity with Colibrys (CH). |
| ETP (MREP1) | Y2012 | E905-017FT | Accelerometer to TRL5 - CCN | 300 | 0 | 0 | 0 | DN/C | CH | N/A | Contract intended with Colibrys (CH) |
| ETP (MREP2) | IPC | E905-021EC | Stand Alone 3 Axis European Accelerometer Unit | 0 | 500 | 0 | 0 | C(1) | | N/A | |

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget 2013 | 2014 | 2015 | 2016 | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ETP (MREP1) | Y2009 | E905-007EC | Camera-aided Mars Landing and Rendezvous navigation system | 0 | 0 | 0 | 0 | C | FR | N/A | Approved 2009 for 350kEuros. Running activity with Astrium SAS (FR) |
| ETP (MREP1) | Y2009 | E905-007EC-B | Camera-aided Mars Landing and Rendezvous navigation system | 0 | 0 | 0 | 0 | C | IT | N/A | Approved 2009 for 350kEuros.Running activity with TAS (IT) |
| TRP | Y2010 | T905-008EC | Sensor Data Fusion for Hazard Mapping and Piloting | 0 | 0 | 0 | 0 | C | FR | N/A | Approved 2010 for 200kEuros. Running activity with Astrium (FR). |
| ETP (MREP1) | Y2010 | E905-008EC | Sensor Data Fusion for Hazard Mapping and Piloting | 200 | 0 | 0 | 0 | C | PT | N/A | Approved 2010 for 200kEuros. Running activity with Spinworks (PT). |
| GSTP | N/A | G905-022EC | Further development of Sensor Data Fusion for Hazard Avoidance | 0 | 700 | 0 | 0 | | | N/A | Proposed to GSTP |
| ETP (MREP2) | N/A | E916-003MM | MSR Precision landing navigation sensor adaptation - Engineering Model | 0 | 0 | 1000 | 0 | | | N/A | |
| ETP (MREP2) | N/A | E905-019EC | Laser Planetary Altimeter Engineering Model | 0 | 0 | 1500 | 0 | | | N/A | |
| TRP | N/A | T916-004MM | Compressive Sensing Technologies for compact LIDAR systems | 0 | 475 | 0 | 0 | | | N/A | |
| ETP (MREP2) | N/A | E905-009EC | Ground Testing of Precision Landing navigation system | 0 | 0 | 500 | 0 | | | N/A | |
| ETP (MREP2) | Y2011 | E915-001MS | Lowering system Breadboard for Mars landers | 0 | 0 | 500 | 0 | C | | N/A | Approved 2011 for 500kEuros. Postponed to 2015. |
| GSTP | N/A | G918-007MP | Supersonic parachute test on a MAXUS flight | 0 | 500 | 0 | 0 | | | N/A | Proposed to GSTP |
| TRP | N/A | T906-008ET | Entry, Descent and Landing Communications technology assessment | 0 | 350 | 0 | 0 | | | N/A | |
| ETP (MREP2) | N/A | E906-009ET | Compact Dual UHF/X-band Proximity-1 Communications Package EQM | 0 | 0 | 0 | 2500 | | | N/A | |
| ETP (MREP2) | N/A | E906-010GS | Breadboarding of EDL Ground Receiver | 0 | 0 | 0 | 300 | | | N/A | |
| ETP (MREP2) | IPC | E918-008MP | Preliminary design and performance verification of critical elements for guided entry thrusters | 0 | 800 | 0 | 0 | C | | N/A | |
| ETP (MREP2) | N/A | E918-009MP | Mars guided entry thruster system to TRL5 | 0 | 0 | 0 | 1000 | | | N/A | |
| TRP | Y2011 | T919-001MP | Integrated throttleable valve and engine development for Mars landings | 0 | 650 | 0 | 0 | C | | N/A | |

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget 2013 | 2014 | 2015 | 2016 | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ETP (MREP2) | N/A | E919-003MP | Design, development and testing of a throttleable monopropellant engine for soft landing | 0 | 0 | 0 | 4000 | | | N/A | |
| **Total MPL** | | | | **1300** | **4275** | **5500** | **7800** | | | | |

# SFR, Robotics and Mechanisms

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget 2013 | 2014 | 2015 | 2016 | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TRP | Y2007 | T309-002HS | Innovative Rover Operations Concepts- Autonomous Planning (IRONCAP) | 0 | 0 | 0 | 0 | C | DE | Operational Software | Approved 2007 for 400kEuros. Running activity with Vega (DE). |
| ETP (MREP1) | Y2011 | E913-005MM | Spartan EXTension Activity - Not Tendered (SEXTANT) | 0 | 0 | 0 | 0 | DN/C | ES | N/A | Approved 2011 for 180kEuros. Running activity with GMV (ES). |
| TRP | Y2013 | T913-011MM | Code Optimisation and Modification for Partitioning of Algorithms developed in SPARTAN/SEXTANT (COMPASS) | 200 | 0 | 0 | 0 | DN/S | ES | N/A | |
| GSTP | N/A | G913-016MM | Planetary Explorer LOcalisation-navigation Ready for USe (PELORUS) | 0 | 0 | 2000 | 0 | | | N/A | Proposed to GSTP |
| TRP | Y2010 | T913-003MM | DExtrous LIghtweight Arm for exploratioN (DELIAN) | 0 | 0 | 0 | 0 | C | CH | N/A | Approved 2010 for 800kEuros. Running activity with Selex-Galileo (IT). |
| TRP | Y2010 | T913-004MM | Surface-Wheel Interaction modelling for Faster Traverse (SWIFT) | 0 | 0 | 0 | 0 | C(1) | CH | N/A | Approved in 2010 for 400kEuros. Running activity with RUAG (CH). |
| ETP (MREP1) | Y2011 | E913-006MM | EXperimental Production of data/Evidence on Rover Tractive performance In Soils relevant for Exploration (EXPERTISE) | 0 | 0 | 0 | 0 | C | CH | N/A | Approved 2011 for 300kEuros. Running activity with RUAG (CH) |
| TRP | Y2011 | T913-008MM | Dust Unseating from Solar-panels and Thermal-radiators by Exhaling Robot (DUSTER) | 450 | 0 | 0 | 0 | C(1) | UK | N/A | Approved 2011 for 450kEuros. Running with MagnaParva (UK). |
| TRP | Y2011 | T913-008MM-B | Dust Unseating from Solar-panels and Thermal-radiators by Exhaling Robot (DUSTER) | 450 | 0 | 0 | 0 | C(1) | GR | N/A | Approved 2011 for 450kEuros. Running activity with HTR (GR). |
| ETP (MREP2) | N/A | E913-015MM | Solar-Panel Or Thermal-radiator cLEaning Sub System (SPOTLESS) | 0 | 0 | 1400 | 0 | | | N/A | |
| ETP (MREP1) | Y2010 | E915-002MS | Mechanisms technologies that operate at very low temperatures | 0 | 0 | 0 | 0 | C | IT | N/A | Approved 2010 for 475kEuros. Running activity with Tecnomare (IT). |

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget 2013 | 2014 | 2015 | 2016 | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ETP (MREP2) | IPC | E915-004FP | Mechanisms Technologies that operate at very low temperatures (Extended test campaign) - CCN | 0 | 350 | 0 | 0 | DN/C | IT, AT | N/A | This activity will be implemented as a CCN to ESTEC contract # 4000105947/12/NL/HB, budget 475 k€ |
| ETP (MREP2) | N/A | E921-006MT | Advanced Thermal Architecture for Mars Environment | 0 | 0 | 1000 | 0 | | | N/A | |
| TRP | Y2011 | T924-002QT | High specific stiffness metallic materials | 0 | 0 | 0 | 0 | C(3) | AT | N/A | Approved 2011 for 500kEuros. Co-funded by STRIN (165k). Running activity with AAC (AT) |
| ETP (MREP2) | Y2013 | E901-003ED | Miniaturized Integrated Avionics for planetary landers | 500 | 1000 | 0 | 0 | C(2) | | N/A | |
| **Total SFR Robotics and Mechanisms** | | | | **1600** | **1350** | **4400** | **0** | | | | |

# INSPIRE

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget 2013 | 2014 | 2015 | 2016 | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TRP | Y2010 | T921-001QE | Adaptation of Aerogel Materials for thermal insulation | 0 | 0 | 0 | 0 | C(1) | PT | N/A | Approved 2010 for 300k. Running activity with AST (PT). |
| ETP (MREP1) | Y2009 | E901-001ED | Extremely low power timer board EM for landers | 0 | 0 | 0 | 0 | C(1) | AT | N/A | Approved 2009 for 300kEuros. Running activity with RUAG (AT). 235kEuros funded by STRIN. |
| ACP | Y2012 | A923-001FI | Extremely low power timer board EM for landers - CCN | 280 | 0 | 0 | 0 | DN/C | AT | N/A | Approved 2012 for 280kEuros. Running activity with RUAG (AT). |
| ETP (MREP1) | Y2009 | E901-002ED | Tailored On-Board Computer EM for planetary landers | 0 | 0 | 0 | 0 | C | SE | Operational Software | Approved 2009 for 700kEuros. Running activity with RUAG (SE). |
| TRP | Y2009 | T918-001MP | Subsonic Parachute Trade-Off and Testing | 0 | 0 | 0 | 0 | C(2) | UK | N/A | Approved 2009 for 500kEuros. Running activity with Vorticity (UK). |
| ETP (MREP1 +MREP2) | Y2012 | E918-001MP | Subsonic parachute trade-off and testing - CCN | 350 | 0 | 0 | 0 | DN/C | UK | N/A | Approved 2012 for 350kEuros. Phase 1 (130k) funded by MREP-1, Phase 2 to be funded by MREP-2. Running activity with Vorticity (UK). |
| ETP | Y2009 | E905-002EC | EDLS GNC Optimisation and Technology Specification | 0 | 0 | 0 | 0 | C(1) | FR | N/A | Approved 2009 for 250 kEuros. Running |

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget 2013 | Budget 2014 | Budget 2015 | Budget 2016 | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (MREP1) | | | for small Mars landers | | | | | | | | with Astrium SAS (FR). |
| TRP | Y2009 | T905-003EC | Assessment and breadboarding of a planetary Altimeter | 0 | 0 | 0 | 0 | C(1) | PT | N/A | Budget of 1471kEuros. Initial approval of 900 kEuro in 2011 + 571k CCN in 2012. Running activity with EFACEC (PT) |
| ETP (MREP2) | N/A | E905-005EC | Ground Testing of the EDLS Navigation Chain for small Mars landers | 0 | 0 | 500 | 0 | | | N/A | |
| ETP (MREP2) | N/A | E919-001MP | Retro Rockets for Mars landing | 0 | 0 | 0 | 4000 | | | N/A | |
| ETP (MREP1 +MREP2) | Y2010 | E920-001MS | Airbags for small landers - Breadboard and Test | 0 | 0 | 0 | 0 | C | IT | N/A | Approved 2010 for 1500kEuros. Only Phase 1 (700k) contracted so far with Aerosekur (IT). |
| ETP (MREP2) | N/A | E920-003MS | Airbags for Small Landers: Extended testing of the landing system with a large variety of impact parameters | 0 | 0 | 1500 | 0 | | | N/A | |
| TRP | Y2013 | T903-012EP | Solar Power Regulator Breadboard for Mars Surface Missions | 300 | 0 | 0 | 0 | C | | N/A | |
| TRP | Y2011 | T903-014EP | Characterisation of space and terrestrial cells for future Mars lander/rover missions | 0 | 0 | 0 | 0 | C(1) | DE | N/A | Approved 2011 for 200kEuros. Running activity with Azur Space (DE). |
| ETP (MREP1) | Y2009 | E903-013EP | Development of a low temperature Lithium ion battery and survivability tests | 0 | 0 | 0 | 0 | C(1) | UK | N/A | Approved 2009 for 450kEuros. Running activity with ABSL (UK). |
| TRP | Y2010 | T911-001GR | Simulation tool for breakup/burnup analysis of Mars orbiters | 0 | 0 | 0 | 0 | C | DE | Operational Software | Approved 2010 for 300kEuros. Running activity with HTG (DE). |
| ETP (MREP1) | N/A | E906-003FI | SPEX (Spectro-Polarimeter for Planetary Exploration) Characterization Program | 220 | 0 | 0 | 0 | DN/S | NL | N/A | Contracted as Special Measure to NL. Running activity with SRON (NL). |
| ETP (MREP2) | N/A | E907-007EE | UHF/X-band back-shell antenna system for Mars entry vehicles | 0 | 0 | 0 | 800 | | | N/A | |
| **Total INSPIRE** | | | | **1150** | **0** | **2000** | **4800** | | | | |

# MSR

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget 2013 | Budget 2014 | Budget 2015 | Budget 2016 | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget 2013 | Budget 2014 | Budget 2015 | Budget 2016 | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ETP (MREP1) | Y2009 | E914-001MM | MSR biocontainment system sealing and monitoring technologies - development and validation | 0 | 0 | 0 | 0 | C(2) | IT | N/A | Approved 2009 for 1500kEuros. Completed activity with SelexGalileo (IT). |
| ETP (MREP2) | IPC | E914-004QI | Biosealing and Monitoring Technologies for a Sample Containment System - Sealing tests and EM design | 0 | 1000 | 0 | 0 | DN/C | IT | N/A | |
| ETP (MREP2) | N/A | E914-005QI | Biosealing and Monitoring Technologies for a Sample Containment System - EM development and testing | 0 | 0 | 2000 | 0 | | | N/A | |
| GSTP | N/A | G215-001FP | Shape Memory Alloy actuators for MSR biocontainer sealing - feasibility demonstration | 0 | 200 | 0 | 0 | | | N/A | Proposed to GSTP |
| TRP | Y2011 | T914-005MM | MSR Double walled isolators - feasibility concept study | 200 | 0 | 0 | 0 | C | UK | N/A | Approved 2011 for 200kEuros. Running activity with SEA (UK). |
| ETP (MREP2) | N/A | E914-005MM | MSR Double walled isolators - breadboard | 0 | 0 | 800 | 0 | | | N/A | |
| ETP (MREP2) | Y2013 | E913-010MM | Manipulation systems for sample handling in a Sample Receiving Facility | 300 | 700 | 0 | 0 | C(1) | | N/A | |
| ETP (MREP1) | Y2009 | E905-010EC | Integrated GNC solution for Autonomous Mars Rendezvous and Capture | 0 | 0 | 0 | 0 | C | ES | N/A | Approved 2010 for 750kEuros. Running activity with GMV (ES). |
| ACP | Y2007 | CG80 | RF Long Range Navigation Sensor Breadboard | 0 | 0 | 0 | 0 | C | ES | N/A | Approved 2007 for 300k. Running activity with TAS (ES). |
| ETP (MREP1) | Y2007 | E906-004ET | RF Long Range Navigation Sensor Breadboard | 300 | 0 | 0 | 0 | C | ES | N/A | Approved 2007 for 300kEuros. Running activity with EMXYS (ES) |
| ETP (MREP2) | N/A | E906-005ET | RF Long-Range Navigation Sensor EM Development | 0 | 0 | 1000 | 0 | | | N/A | |
| ETP (MREP2) | N/A | E905-012EC | End to end ground testing of GNC solution for Autonomous Mars Rendezvous and Capture | 0 | 0 | 800 | 0 | | | N/A | |
| ACP | Y2007 | CG50 | Sample Canister Capture Mechanism Design and Breadboard | 0 | 0 | 0 | 0 | C | IT | N/A | Approved 2007 for 350kEuros. Running activity with Carlo Gavazzi Space (IT) |
| ETP (MREP1) | Y2011 | E915-005MS | Sample canister capture mechanism parabolic flight test | 0 | 0 | 0 | 0 | DN/C | IT | N/A | Approved 2011 for 150kEuros. Running activity with CGS (IT). |
| TRP | Y2013 | T912-001GS | Improvement of Delta DOR performances for 1 nrad accuracy for precise landing support | 250 | 0 | 0 | 0 | C | | N/A | |
| TRP | Y2013 | T916-003MM | Planetary communication system based on modulated retro-reflection | 300 | 0 | 0 | 0 | C | | N/A | |

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget | | | | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2013 | 2014 | 2015 | 2016 | | | | |
| TRP | N/A | T904-003EE | Enhanced interplanetary meteoroid population model | 0 | 0 | 300 | 0 | | | N/A | |
| ETP (MREP2) | N/A | E904-004FP | Micro Meteorids and Orbital Debris (MMOD) impacts characterisation and protection for the MSR Earth Re-entry Capsule (ERC) | 0 | 0 | 700 | 0 | | | N/A | |
| ETP (MREP2) | Y2011 | E905-001EC | Aerobraking Flight Representative Demonstrator | 0 | 0 | 350 | 0 | C | | N/A | Postponed to 2015 |
| TRP | Y2010 | T319-036MC | Design of a crushable TPS for the ERC | 370 | 0 | 0 | 0 | C | FR | N/A | Approved 2010 for 370kEuros. Running activity with MECANO (FR). |
| TRP | Y2010 | T920-002QT | Material development for a crushable TPS for the ERC | 250 | 0 | 0 | 0 | C | UK | N/A | Approved 2010 for 350kEuros. Running activity with Magna Parva (UK). |
| ETP (MREP1) | Y2010 | E921-002PA | Delta-development of TPS for high heat loads | 0 | 0 | 0 | 0 | C | FR | N/A | Approved 2010 for 1000kEuros. Implemented at 700k with Astrium ST (FR) |
| ETP (MREP1) | Y2011 | E921-003PA | Adaptation of TPS materials of High-density for High Heat load (AT3H) re-entry applications | 300 | 0 | 0 | 0 | C | FR | N/A | Approved 2011 for 300kEuros. Running activity with Safran (FR). |
| GSTP | N/A | G921-007MT | Ablative TPS Numerical Test Cases - Mathematical Code Assessment & Improvement | 0 | 300 | 0 | 0 | | | N/A | Proposed to GSTP |
| TRP | N/A | T921-005MT | Deployable & Inflatable Heatshield & Hypersonic Decelerator Concepts - Phase 1 | 0 | 400 | 0 | 0 | C | | N/A | |
| TRP | N/A | T918-006MP | Standard kinetic models for CO2 dissociating flows | 0 | 0 | 500 | 0 | | | N/A | |
| TRP | Y2013 | T918-004MP | Catalytic properties of Ablators | 500 | 0 | 0 | 0 | C | | N/A | |
| TRP | Y2013 | T906-002ET | Software Defined Radio Proximity-1 Link Communications Package design Study | 300 | 0 | 0 | 0 | C | | N/A | |
| ETP (MREP2) | N/A | E906-007ET | Software Defined Radio Proximity-1 Link Communications Package design EQM | 0 | 0 | 0 | 2500 | | | N/A | |
| TRP | IPC | T912-005GS | X-Band cryogenic feed prototyping | 0 | 600 | 0 | 0 | C(1) | | N/A | |
| ETP (MREP2) | N/A | E904-005EE | Modelling of the Mars Environment for Future Missions | 0 | 400 | 0 | 0 | C(2) | | N/A | |
| ETP (MREP2) | Y2013 | E908-001FP | Harwell Robotics Autonomy Facility (HRAF) - Pilot project 1 | 1200 | 0 | 0 | 0 | DN/C | UK | N/A | |
| **Total MSR** | | | | **4270** | **3600** | **6450** | **2500** | | | | |

# Long term enabling technologies

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget | | | | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2013 | 2014 | 2015 | 2016 | | | | |
| ETP (MREP2) | Y2013 | E903-015EP | European Isotope Production Phase 2 | 2000 | 0 | 0 | 0 | DN/C | UK | N/A | Contract intended with NNL (UK) |
| ETP (MREP1) | Y2010 | E903-003EP | Nuclear Power Systems architecture study for safety management and fuel encapsulation prototype development. | 0 | 0 | 0 | 0 | C(2) | FR | N/A | Approved 2010 for 1000kEuros. Running activity with AREVA (F). |
| ETP (MREP2) | N/A | E903-004FP | Nuclear Power Systems architecture study for safety management and fuel encapsulation NPSAFE (phase 2) | 0 | 0 | 1000 | 0 | | | N/A | |
| ETP (MREP2) | N/A | E903-020FP | Radioisotope Heater Unit development (RHU-DEV1) | 0 | 0 | 1000 | 0 | | | N/A | |
| ETP (MREP2) | N/A | E903-005EP | Safety and aggression tests & demonstrations | 0 | 0 | 0 | 2000 | | | N/A | |
| TRP | Y2009 | T903-006EP | Thermoelectric converter system for small-scale RTGs (to ~TRL3/4) | 0 | 0 | 0 | 0 | C | UK | N/A | Approved 2009 for 550kEuros. Running activity with Univ. Leicester (UK). Parallel contract to T903-006EP-B. |
| TRP | Y2009 | T903-006EP-B | Thermoelectric converter system for small-scale RTGs (to ~TRL3/4) | 0 | 0 | 0 | 0 | C | FR | N/A | Approved 2009 for 550kEuros. CCN of 110kEuros in 2012. Running activity with Areva (F). |
| ETP (MREP2) | N/A | E903-007FP | Small-scale RTG development to TRL 5 | 0 | 0 | 1000 | 0 | | | N/A | |
| ETP (MREP2) | N/A | E903-008EP | Thermoelectric converter system for small-scale RTGs (to ~TRL6) | 0 | 0 | 0 | 3000 | | | N/A | |
| ETP (MREP1) | Y2009 | E903-009EP | Stirling Converter Technology Development phase 1 | 0 | 0 | 0 | 0 | C | UK | N/A | Approved 2009 for 2000kEuros. Running activity with SEA (UK). |
| ETP (MREP2) | N/A | E903-010EP | Stirling converter development phase 2 to TRL6 | 0 | 0 | 0 | 3300 | | | N/A | |
| ETP (MREP1) | Y2009 | E919-011EP | Combustion chamber and injection technology development | 0 | 0 | 0 | 0 | C | UK | N/A | Approved 2009 for 2000kEuros. Running activity with MOOG-ISP(UK). Under Strategic Initiative to Ireland and UK (ETP 640kEuros). |
| ETP (MREP2) | Y2013 | E919-012MP | Design, development testing and generic qualification of a High Thrust Apogee Engine (HTAE) | 2000 | 0 | 2300 | 0 | DN/C | | N/A | Phase 2a (2000kEuros) proposed for 2013, Phase 2b (2300kEuros) intended |

| Prog. | IPC Appr. | ESA Ref. | Activity Title | Budget | | | | PP | C'try | SW Clause applicab. | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2013 | 2014 | 2015 | 2016 | | | | |
| | | | | | | | | | | | for 2015 |
| **Total Long Term** | | | | **4000** | **0** | **5300** | **8300** | | | | |

# Phootprint

| Breadboard of a sampling tool mechanism for low-gravity bodies | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E915-003MS |
| **Title:** | Breadboard of a sampling tool mechanism for low-gravity bodies | | |
| **Total Budget:** | 750 | | |

**Objectives**

Design Modeling, Breadboarding and validation of a sampling tool in order to reduce the risk related to the very unknown nature of asteroids' surfaces which are targets of future science and exploration mission candidates (Phobos/Deimos sample return, asteroid sample return)

**Description**

In future exploration missions (e.g. of a Mars moon or a near-Earth asteroid) it is planned to collect tens of grams of regolith (dust but also cm-sized stones) and return them to Earth for further ground-based analysis. Several sampling tools (samplers) have been proposed, such as a rotating corer (as baselined in the previous Marco Polo assessment study) or counter-rotating brushes (as proposed in the new MarcoPolo-R science mission proposal for Cosmic-Vision M3).
For the exploration mission candidate Phobos/Deimos sample return, a sampler identical to the one that will be used in MarcoPolo-R can be assumed as the requirements are almost identical in terms of mass and type of soil to be collected.
There is no single sampling technology for low-gravity bodies that has undergone a rigorous engineering assessment, aiming at proving the ability of the sampler to collect material in any envisaged situation. This is the purpose of the subject activity.

Phase 1 of this activity shall consist of:
1) refinement of the requirement specifications produced in ESA CDF studies,
2) trade-off of possible sampling concepts and preliminary design of the two best candidate sampling systems
3) dynamic modelling of soil-sampler interaction (considering micro-g level and composite soil expected for Asteroid/ Phobos/Deimos) to perform sensitivity analyses to different soil physical characteristics
4) detailed design of the best performing sampler and definition of test campaign/equipment
5) breadboarding of the best performing sampler and production of test equipment
6) ground testing

The nature of the soil on asteroids is poorly known so a laboratory (ground) testing campaign which covers a large range of soil simulants with various soil properties (in terms of compressive strength, density, grain size, shape, cohesiveness) shall be undertaken in adequate environmental conditions.

Phase 2 of this activity shall consist of:
1) Parabolic flight testing
2) Additional modifications to the breadboard if required

The proposed technology development shall allow assessing:
- the amount of collected sample as a function of soil properties,
- the type of sample that can be realistically collected,
- the resulting forces and torques induced on the spacecraft,
- the most suitable interface with the transfer system,
- the extent of cross-contamination in case of multiple sampling.

Note.
1. It is not foreseen to perform the detailed design or breadboarding of the transfer and containment system, but the constraints/interfaces associated to it will strongly be taken into account when producing the design of the sampling tool itself.

**Deliverables**

Breadboard, Design justification file, tests results

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 4/5 | **Application Need/Date:** | TRL 5 by 2014 |
| **Application Mission:** | Phootprint | | **Contract Duration:** | 21 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |

**Consistency with Harmonisation Roadmap and conclusion:**

| Breadboard of a sampling tool mechanism for low-gravity bodies | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E915-003MS-B |
| **Title:** | Breadboard of a sampling tool mechanism for low-gravity bodies | | |

| | |
|---|---|
| **Total Budget:** | 750 |
| **Objectives** | |
| Design Modeling, Breadboarding and validation of a sampling tool in order to reduce the risk related to the very unknown nature of asteroids' surfaces which are targets of future science and exploration mission candidates (Phobos/Deimos sample return, asteroid sample return) | |
| **Description** | |
| In future exploration missions (e.g. of a Mars moon or a near-Earth asteroid) it is planned to collect tens of grams of regolith (dust but also cm-sized stones) and return them to Earth for further ground-based analysis. Several sampling tools (samplers) have been proposed, such as a rotating corer (as baselined in the previous Marco Polo assessment study) or counter-rotating brushes (as proposed in the new MarcoPolo-R science mission proposal for Cosmic-Vision M3).<br>For the exploration mission candidate Phobos/Deimos sample return, a sampler identical to the one that will be used in MarcoPolo-R can be assumed as the requirements are almost identical in terms of mass and type of soil to be collected.<br>There is no single sampling technology for low-gravity bodies that has undergone a rigorous engineering assessment, aiming at proving the ability of the sampler to collect material in any envisaged situation. This is the purpose of the subject activity.<br><br>Phase 1 of this activity shall consist of:<br>1) refinement of the requirement specifications produced in ESA CDF studies,<br>2) trade-off of possible sampling concepts and preliminary design of the two best candidate sampling systems<br>3) dynamic modelling of soil-sampler interaction (considering micro-g level and composite soil expected for Asteroid/ Phobos/Deimos) to perform sensitivity analyses to different soil physical characteristics<br>4) detailed design of the best performing sampler and definition of test campaign/equipment<br>5) breadboarding of the best performing sampler and production of test equipment<br>6) ground testing<br><br>The nature of the soil on asteroids is poorly known so a laboratory (ground) testing campaign which covers a large range of soil simulants with various soil properties (in terms of compressive strength, density, grain size, shape, cohesiveness) shall be undertaken in adequate environmental conditions.<br><br>Phase 2 of this activity shall consist of:<br>1) Parabolic flight testing<br>2) Additional modifications to the breadboard if required<br><br>The proposed technology development shall allow assessing:<br>- the amount of collected sample as a function of soil properties,<br>- the type of sample that can be realistically collected,<br>- the resulting forces and torques induced on the spacecraft,<br>- the most suitable interface with the transfer system,<br>- the extent of cross-contamination in case of multiple sampling.<br><br>Note.<br>1. It is not foreseen to perform the detailed design or breadboarding of the transfer and containment system, but the constraints/interfaces associated to it will strongly be taken into account when producing the design of the sampling tool itself. | |
| **Deliverables** | |
| Breadboard, Design justification file, tests results | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 4/5 | **Application Need/Date:** | TRL 5 by 2014 |
| **Application Mission:** | Moon of mars sample return | | **Contract Duration:** | 21 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Sample Acquisition Means for the Phootprint Lander: Experiments and first Realisation (SAMPLER)** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E913-012MM |
| **Title:** | Sample Acquisition Means for the Phootprint Lander: Experiments and first Realisation (SAMPLER) | | |
| **Total Budget:** | 1500 | | |
| **Objectives** | | | |
| The activity addresses the robotic sampling operation of the PHOOTPRINT mission. The activity shall 1) experimentally assess the detailed requirements of the sampling operation 2) specify, 3) design, 4) develop and 5) test (in relevant environment) a breadboard of<br>the operation. | | | |

| **Description** |
|---|
| Background:<br><br>Sampling operations in low-gravity (as on Phobos) for extended time (as in the case of PHOOTPRINT) are poorly understood. The dynamic motion induced by the sampling operation (to be expected in a non-homogeneous material) couples with the dynamic properties of the lander, its legs and even thrust or anchoring mechanism. For the total system to remain stable and for the sampling tool to effectively sample the surface, the total dynamic motion must be damped significantly. Possible provisions for damping dynamics can be realised on the sampling-tool, on the arm and on the lander. However these provide different performance and imply different costs. Experiments on the whole sampling operation are needed to ascertain the need/extent/implementation of damping provisions in the sampling chain (arm and sampling tool).<br><br>Programme of work: The programme of work is divided in two phases that deliver products and results with incremental TRL. The first phase intends to increase the understanding of the dynamic behavior of the sampling chain by delivering a simulator, validated through tests.<br>In the second phase the focus shifts into the development of high fidelity breadboard of the complete sampling chain and its demonstration trough test.<br><br>- Phase 1<br>i. Requirements specification<br>ii. Design of a number of sampling-tools as well as sampling strategies. Realisation of breadboards of the chosen tools.<br>iii. Design and development of a parametric test campaign (using an air bearing table ) for testing the chosen sampling tools/strategies with a range of representative soil analogues.<br>iv. Development of dynamic model and related simulator<br>v. Execution of the test campaign and correlation of the test data with the model produced at iv.<br><br>- Phase 2<br>i. Trade-off and design the complete sampling chain (supported by the validated simulator).<br>ii. Develop a real-scale breadboard of the sampling chain, a mockup of platform with representative dynamics and a test environment to exercise them. The test environment shall allow testing of the breadboard against different soil types.<br>iii. Perform tests<br>iv. Evaluate results from the tests |
| **Deliverables** |
| - Project documentation<br>- Mathematical model/simulator<br>- Breadboards<br>- Software<br>- Test rig<br>- Data archive containing both raw and processed data from all tests |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 1 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |
| **Application Mission:** | Phootprint | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-9012 | |

| **Consistency with Harmonisation Roadmap and conclusion:** |
|---|
| The activity was not addressed by the 2012 harmonisation exercise on A&R, as the PHOOTPRINT mission had not yet been manifested |

| **Guidance, Navigation, and Control (GNC) for PHOOTPRINT descent and landing** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-017EC |
| **Title:** | Guidance, Navigation, and Control (GNC) for PHOOTPRINT descent and landing | | |
| **Total Budget:** | 400 | | |

| **Objectives** |
|---|
| The objective of the activity is to design and develop the GNC for PHOOTPRINT up to TRL 4. This shall include the mission vehicle management (MVM) and the FDIR for the PHOOTPRINT mission with Model In the Loop (MIL) full testing, and preliminary real time checks on a Processor in the Loop (PIL) environment. |
| **Description** |
| The aim of the activity is to design and develop the critical GNC algorithms needed for the PHOOTPRINT mission during proximity operations, descent, landing and departure. Moreover, in this activity it shall be defined the mission vehicle management (MVM) for this PHOOTPRINT mission taking into account the GNC system, the operating modes and the Failure Detection, Isolation and Recovery (FDIR) system.<br>The MVM is responsible for selecting the GNC modes providing scheduling service and FDIR functionalities. The system shall be |

robust to safely achieve the required performances in the presence of possibly large uncertainties.

The following tasks shall be performed:
- Consolidation of functional, operational, performance and environment requirements for the PHOOTPRINT mission taking into account the mission objectives and constraints.
- Definition of the GNC architecture, including sensor suite trade-off.
- Detailed analysis and definition of the GNC algorithms, including MVM, FDIR.
- Implementation of a Model In the Loop simulator with the complete GNC system architecture, FDIR and MVM.
- Validation of the simulator and performance tests for the PHOOTPRINT landing.
- Update of PANGU for the specific case of the PHOOTPRINT mission.
- Implementation of the modification of the MIL to perform autocoding for the PIL
- Implementation of a Processor In the Loop in a RASTA-like environment: test bench consisting on the assembly of the modified MIL and a flight representative motherboard.
- GNC verification and validation with the PIL.

**Deliverables**

- Technical notes
- Model in the loop simulator, including the GNC, MVM, and FDIR
- Processor in the loop test bench software

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2015 |
| **Application Mission:** | PHOOTPRINT | | **Contract Duration:** | 15 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |

**Consistency with Harmonisation Roadmap and conclusion:**

**Guidance, navigation and control (GNC) maturation for PHOOTPRINT and hardware in the loop (HIL) testing**

| | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-018EC |
| **Title:** | Guidance, navigation and control (GNC) maturation for PHOOTPRINT and hardware in the loop (HIL) testing | | |
| **Total Budget:** | 600 | | |

**Objectives**

The objective of this activity is to maturate the GNC for PHOOTPRINT (coming from a previous activity) and test it in a close loop control in hardware in the loop (HIL) environment. In particular, this test-bed shall use of a robotic test bench to fully test the PHOOTPRINT proximity operations, including descent, landing in closed loop control.

**Description**

For the real-time validation and verification of a GNC system it is required to test the GNC design in a closed loop real-time simulation with sensor hardware in the loop and a representative test bed environment with robot arms and translation devices. This tests will allow to understand the interaction of sensors in the complete GNC subsystem, measure the processing times to gather data from sensors and understand the overall GNC response to failures including sensors in the loop.

This activity shall, first of all, consolidate and mature the GNC design for PHOOTPRINT Entry, Descent, Landing and Departure (coming from a preceding activity) including the Mission Vehicle management (MVM) and the Failure Detection, Isolation and Recovery (FDIR). Moreover this activity shall test the GNC for PHOOTPRINT in a real-time environment aiming to fully validate and verify the Entry, Descent and Landing mission arcs in European facilities. This end-to-end GNC test benching shall include all navigation sensors (including hardware), the guidance algorithms, and the control loops.

The test bench shall consist of the assembly of a processor in the loop (PIL) and the flight representative set of sensors to form a closed loop controlled system. The ability to simulate failure injection and contingency operations shall be covered in the scope of this test environment. The PIL to be assembled in the HIL shall be taken from previous development activities (MREP2 "GNC for PHOOTPRINT descent and landing").

In the frame of this activity the following tasks shall be performed:
- Consolidation and maturation of the GNC design including the MVM and the FDIR for PHOOTPRINT Entry, Descent, Landing and Departure.
- In-depth analysis and selection of the most suitable European facility and detailed evaluation of its suitability for the planned mission, including the feasibility of both real-size and scaled-down simulations.
- If needed, the selected facility shall be upgraded and validated.
- Definition and development of a real-time test bench (HIL) to be used for GNC verification and validation.
- On the base of previous development activities, the test bench shall allow for testing the GNC, the Mission Vehicle Manager (MVM), and the FDIR in the end-to-end test-bed.

| | | | | | |
|---|---|---|---|---|---|
| - Functional and performance validation of the GNC, MVM, and FDIR in the real-time facility. | | | | | |
| **Deliverables** | | | | | |
| GNC maturation<br>GNC, MVM, and FDIR End-to-End testing.<br>Full technical documentation shall be delivered, covering software specifications, architecture, design and justification, testing, verification, and validation | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 6 | **Application Need/Date:** | 2017 |
| **Application Mission:** | PHOOTPRINT | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Vision-based navigation camera EM for PHOOTPRINT including image processing** | | | | | |
| **Programme:** | ETP | | **Reference:** | E905-020EC | |
| **Title:** | Vision-based navigation camera EM for PHOOTPRINT including image processing | | | | |
| **Total Budget:** | 1000 | | | | |
| **Objectives** | | | | | |
| The objective of this activity is to develop an engineering model (EM) of a vision-based camera for PHOOTPRINT. This activity shall also include the image processing algorithms. | | | | | |
| **Description** | | | | | |
| The features of Phobos differ from those in a planetary environment (gravity, regolit composition, orbital environment). The aim of the activity is to adapt existing navigation cameras (NPAL, VisNAV, etc) to meet the needs of the PHOOTPRINT mission in its arc of descent and landing. PHOOTPRINT needs an accurate navigation to correctly guide the spacecraft in its descent and touch-and-go trajectory towards Phobos. Current cameras are being developed for vision-based navigation in planetary entry, descent and landing applications, that can be adapted for the specific case of PHOOTPRINT. The camera shall then be able to perform autonomous vision-based navigation using feature landmark recognition. Image-processing algorithms shall be developed and implemented into a NPAL-like camera to perform vision-based navigation around and towards Phobos. Furthermore the activity shall assess the environment characteristics to which the camera will be subjected for the PHOOTPRINT mission (temperature variations, radiation, vibration environment, contamination) and captured in a technical note in the form of requirements to create an EM of the camera.<br><br>The activity shall be divided in three parts.<br>The first part shall perform:<br>- the incorporation of the requirements created during the design of the GNC for PHOOTPRINT.<br>- the incorporations of the experience and development performed for the NPAL camera<br>- the detailed design, including miniaturisation, of the EM<br><br>The second part shall consist of building an engineering model of the camera.<br><br>The third part of the activity shall concentrate on testing the camera to verify its performance in a representative environment. | | | | | |
| **Deliverables** | | | | | |
| - Full technical documentation (CDR datapackage) shall be delivered, covering software specifications, architecture, design and justification, testing, verification, and validation.<br>- Camera EM | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 4 | **Application Need/Date:** | 2017 |
| **Application Mission:** | PHOOTPRINT | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8071 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| |
|---|
| **Phootprint Landing Gear System to TRL5 (PLanGS)** |

| | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E920-005MS |
| **Title:** | Phootprint Landing Gear System to TRL5 (PLanGS) | | |
| **Total Budget:** | 1500 | | |

**Objectives**

The objective is to develop an optimised landing gear system capable of providing safe landing on the surface of Phobos (micro-gravity conditions) and ensuring the required attitude and stability to allow surface operations (i.e. sample acquisition and robotic arm motion).

**Description**

In the context of the Phootprint mission, the landing phase of its lander of 1000 to 1500kg (with CoG at 1m above the base of the S/C) will end with a free fall without using the braking thrusters, from 15m (TBC) above the surface and with a landing velocities range of <0.6 m/s vertical and < 0.15m/s horizontal. Therefore the landing gear design, including the foot-pad and possibly anchoring system (TBC) and breadboard, needs to be fully representative of the flight system with respect to its dynamic behaviour in the landing configuration for the final touchdown and surface operations. This activity shall also aim at the minimization of the mass of the landing gear system considering the use of CFRP components for the main structural elements (i.e. main and secondary struts) or other lightweight technological solutions. The need of damping of the shock transferred to the spacecraft at touchdown has to be considered in frame of the activity and simple solutions (possibly passive systems such as crushable materials, foams) shall be implemented and validated by test. Moreover, the possibility of implementing load limiting capabilities (i.e. collapsible load limiters) at the interfaces of the landing gear with the spacecraft need to be considered. In the frame of this activity, the functionality of the landing gear system shall also include provisions for deployment, latching and touchdown sensors.

The activity will consist on two (2) contractual phases:
Phase 1 (400 kEuros, 9 months) with the following main tasks to be implemented
- Review of the state of the art of configurations, design solutions and materials;
- Analysis of mission/system requirements and definition of the requirements for the landing gear subsystem;
- Perform characterisation tests on possible crushable materials and landing pads (the latter for friction coefficient characterisation)
- Establish the design concept of the complete landing gear system including all active (e.g. actuators) and passive (e.g. damping systems) solutions and including provisions for sampling handling and operations in micro-gravity conditions;
- Establish a dynamic model for landing simulations, using previous characterisation tests results for correlation, and identify by analysis the worst cases among the landing scenarios;
- Define the requirements for the manufacturing and validation of a landing gear demonstrator;
- Define the demonstrator verification approach considering all the environmental conditions and the relevant operational approaches.

Phase 2 (1100 kEuros, 15 months) with the following main tasks to be implemented
- Design the landing gear demonstrator on the basis of the requirements and verification approach established during phase 1;
- Breadboard manufacturing and verification plan. Establish the test procedures;
- Design, manufacturing and assembly of the landing test setup;
- Manufacturing of the breadboard components and assembly;
- Execution of the landing tests on the demonstrator

**Deliverables**

Demonstrator(s), Dynamic model, and Technical Notes including test Reports

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2016 |
| **Application Mission:** | Phootprint | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |

**Consistency with Harmonisation Roadmap and conclusion:**

**Robotically-Enhanced Surface Touchdown (REST)**

| | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E913-013MM |
| **Title:** | Robotically-Enhanced Surface Touchdown (REST) | | |
| **Total Budget:** | 430 | | |

**Objectives**

Develop a prototype of an actively compliant landing gear for low-G environment using robotics derived technology

**Description**

Background:
Landing in low-g environments provides for some difficult issues for conventional landing gears but also for opportunity to implement smarter and more flexible landing gears. Essentially the issues are related to the possibility of rebounding due to the

| |
|---|
| residual elasticity of the landing gear (which is impossible to eliminate completely), and the difficulty of leveling the platform once lading is achieved. The opportunities come from the fact that impact/settling forces and velocities during landing are minimal and hence compatible with the capabilities of electromagnetic actuators. Therefore it is possible to conceive an active landing gear that uses linear (or rotational) DC brushless motors to implement 1) deployment of the landing legs, 2) impedence-controlled absorption of the impact/settling forces and compensation of residual elasticity, 3) re-levelling of the lander platform, 4) rejection of vibration induced by sampling devices. To note, the use of impedence-control schemes for brushless DC motors is common in robotics in order to allow robotic joints to simulate virtual mechanical properties (i.e mass, damping and elasticity). The use of motor-driven absorption of forces at landing is not new: the PHILAE lander in the ROSETTA mission uses a capstan actuator<br><br>Programme of work:<br>1) requirement definition<br>2) design of prototype<br>3) manufacturing and assembly 4) test on air bearing table<br>5) closure |
| **Deliverables** |
| - standard project documentation<br>- technical notes,<br>- prototype hardware<br>- videos |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 1 | **Target TRL:** | 3/4 | **Application Need/Date:** | 2015 |
| **Application Mission:** | PHOOTPRINT, | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8937 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| The activity was not addressed by the 2012 harmonisation exercise on A&R. To be noted the PHOOTPRINT mission at that time was not manifested yet. | | | | | |

| **Robotically-Enhanced Surface Touchdown - RAise In TRL (RESTRAINT)** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E913-014MM |
| **Title:** | Robotically-Enhanced Surface Touchdown - RAise In TRL (RESTRAINT) | | |
| **Total Budget:** | 800 | | |
| **Objectives** | | | |
| Increase the readiness level (up to TRL5) of an actively compliant landing gear for low-G environment | | | |
| **Description** | | | |
| Background<br>The Robotically-Enhanced Surface Touchdown (REST) activity, aims at the implementation of an active landing gear that by means of a smart actuator system can perform 1) deployment of the landing legs, 2) impedence-controlled absorption of the impact/settling forces and compensation of residual elasticity, 3) re-levelling of the lander platform, 4) rejection of vibration induced by sampling devices. The REST activity will produce a prototype of such landing gear, just implementing (and testing experimentally) critical functions and other characteristics for an initial proof-of-concept (TRL3)<br><br>The RESTRAINT activity shall continue the development of the active landing gear so that at the end of it a landing gear breadboard will be validated in a relevant environment (TRL 5).<br><br>Programme of work:<br>1) requirement definition<br>2) design of prototype<br>3) manufacturing and assembly<br>4) test in relevant environment<br>5) closure | | | |
| **Deliverables** | | | |
| - standard project documentation<br>- technical notes,<br>- prototype hardware<br>- videos | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2015 |
| **Application Mission:** | PHOOTPRINT | | **Contract Duration:** | 18 | |

| | | | |
|---|---|---|---|
| **S/W Clause:** | N/A | **Reference to ESTER** | T-8937 |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | |
| The activity was not addressed by the 2012 harmonisation exercise on A&R. To be noted the PHOOTPRINT mission at that time was not manifested yet. | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Next generation uplink coding techniques** | | | | | |
| **Programme:** | TRP | | **Reference:** | T906-001ET | |
| **Title:** | Next generation uplink coding techniques | | | | |
| **Total Budget:** | 450 | | | | |
| **Objectives** | | | | | |
| For exploration missions, powerful coding techniques need to be studied in order to enable high rate communication uplinks directly from Earth as well as to extend the supported maximum distance, despite the constraint of limited received power. In the frame of CCSDS NASA has already proposed some techniques to this purpose. Current constraints seen by exploration missions, such as the need to ensure commanding at distances up to 2.7 AU, make the introduction of new uplink coding techniques a must. | | | | | |
| **Description** | | | | | |
| A system study is required to assess the impact of different coding techniques for the TC uplink of exploration missions, in order to enable the use of high rate uplink directly from Earth as well as to extend the supported maximum distance, particularly for emergency situations.<br><br>As seen in current Mars Robotic Exploration missions under study or preparation, spacecraft commanding through the LGA (Low Gain Antenna) can be rather challenging, once distances of up to 2.7 AU are considered and reliance of the NASA 70m ground station antenna cannot be assumed any longer. The use of uplink coding, possibly in combination with low data rates (7.8 bps or lower), will provide the additional margin needed to ensure commanding for these challenging scenarios.<br>At the same time, new coding techniques are expected to mitigate to a great extent the problems due to the introduction of higher uplink data rates, dictated by payload calibration as well as operational needs, i.e. use of CFDP with high rate telemetry downlink, which poses serious constraints to the designers. This is even more critical once fail safe RFDU architectures are employed where switches in the receiver chain are replaced by 3-dB hybrids.<br><br>The study should first consider coding techniques already proposed in the frame of CCSDS, i.e. LDPC codes, and to investigate other alternative coding schemes, including non-binary codes. Besides other figure of merits, the undetected error performance will be prominent in the assessment and decoding algorithms suitable to maintain low undetected errors will be implemented. The study shall assess the impact of the new coding techniques towards higher layer protocols, i.e. TC or AOS, as well as towards the physical layer, i.e. the impact on the demodulator due to the lower SNR allowed by the coding gain. Finally, the study shall address the impact on the architecture of the overall O/B receiver, considering in particular the complexity, power consumption and flexibility required. Suitable decoding algorithms will be studied, proposing the relevant trade-offs between performance and O/B resource utilization. A bread-board shall complete the activity, in order to minimize the risk for future missions adopting the new coding techniques, as well as to promote such techniques in the proper standardization bodies, e.g. CCSDS and ECSS.<br><br>This activity is highly relevant to the associated ETP activity entitled "Compact Dual UHF/X-band Proximity-1 Communication EQM". | | | | | |
| **Deliverables** | | | | | |
| End to end system study on next generation uplink coding for Mars exploration missions and a hardware proof of concept (breadboard). | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2022-2024 |
| **Application Mission:** | MSR, INSPIRE, PHOOTPRINT | | **Contract Duration:** | 14 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | N/A | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Harmonization Dossier "TT&C Transponders and Payload Data Transmitters," 2012 | | | | | |

| | | | |
|---|---|---|---|
| **Next generation uplink coding techniques - Validation, Implementation and System Roll-Out** | | | |
| **Programme:** | ETP | **Reference:** | E906-006ET |
| **Title:** | Next generation uplink coding techniques - Validation, Implementation and System Roll-Out | | |
| **Total Budget:** | 800 | | |
| **Objectives** | | | |

| |
|---|
| For exploration missions, powerful coding techniques are needed in order to enable high rate communication uplinks directly from Earth as well as to extend the supported maximum distance. Current constraints seen by Mars missions, such as the need to ensure commanding at very high distances (up to 2.7 AU) and for emergency communications make the introduction of new uplink coding techniques and the corrensponding adaptation of the spacecraft receiver a mission driver. An End-to-End validation in a realistic operational environment shall be conducted as part of this activty. |
| **Description** |
| A previous TRP activity will have completed the associated system study in order to assess the impact of different coding techniques for the uplink of exploration missions in order to enable the use of high rate uplink directly from Earth as well as to extend the supported maximum distance. As seen in current Mars Robotic Exploration missions under study or preparation, spacecraft commanding through the LGA (Low Gain Antenna) can be rather challenging, particularly at the max Earth-Mars distance 2.7 AU are considered. The use of uplink coding, possibly in combination with low data rates (7.8 bps or lower) will provide the additional margin needed to ensure spacecraft commanding for these challenging scenarios which have a very low signal to noise ratio.<br><br>This ETP activity will take the results from the previous TRP activity and define the operational implementation and System Roll-out aspects in a consolidated way. The previous TRP study will have selected and validated the most appropriate TC uplink codes for operational usage. This ETP activity will then optimise the algorithms, trade-off architectural implementations to be used for both the ground segment and the space segment and build and validate the end to end system demonstrator based on representative ground station assets (e.g. Mission Control System) and flight representative TT&C receivers and TC uplink decoding units. The TC uplink decoding blocks could reside within either the TT&C unit/receiver itself or in the O/B data handling unit, depending upon the mission scenario. The selected detailed implementation shall address the impact on the architecture of the overall O/B receiver by considering in particular the complexity, power consumption, reliability and flexibility. The activity shall also define a roadmap and phased schedule for implementing the TC uplink codes in the ESOC ground stations and any associated delta developments required for the on-board TT&C/ data handling subsystems.<br><br>An End-to-end validation of TC upling encoding and decoding in a realistic environment shall be conducted by making use of representative ground segment and TT&C flight representative assets. |
| **Deliverables** |
| Technical Notes, End to end system validation of TC uplink coding for high data rate uplinks, Roadmap for operational implementation. |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2018 |
| **Application Mission:** | INSPIRE, PHOOTPRINT, MSR | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-7725 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Sterilisation limits for sample return planetary protection measures** | | | |
| **Programme:** | ETP | **Reference:** | E914-001QI |
| **Title:** | Sterilisation limits for sample return planetary protection measures | | |
| **Total Budget:** | 1300 | | |
| **Objectives** | | | |
| The objective of this activity is to produce test data in order to derive sterilisation limits (i.e. heat, radiation, pressure) for backward planetary protection measures essential to support MSR mission studies (e.g., MSR-O and ERC) and related technology developments (e.g., containment system) and to confirm the Phootprint planetary protection category in light of recent studies indicating substantial material transfer from Mars to Phobos. | | | |
| **Description** | | | |
| Backward planetary protection (i.e. protection of the Earth's biosphere from potentially harmful extraterrestrial material) is a key issue for any sample return missions and in particular MSR. In order to identify the limits of heat, radiation and pressure whereby sterilisation is expected to occur (which impacts, for example, the design of the MSR biosealing system, the earth return capsule etc), this activity is proposed with the following tasks:<br><br>Phase 1:<br>1. Identification and description of representative biological samples based on latest ESF report, identification and characterisation of representative sample preparation and conditioning, including matrix material, for the heat/radiation inactivation tests, identification of material (non-vesicular picritic basalt for most tests, martian meteorites for confirmation tests) and characterisation (chemistry and pore space using tomography) of projectile and targets for the hypervelocity impact tests, identification of the criteria for biological inactivation, identification of the test and measurement approach to evaluate the heat and radiation inactivation covering a dynamic range with each method up to and including a SAL-6, identification of the test and measurement approach (produce a test plan), including high speed cameras, flash X-rays, in-situ tracers and chemical analysis of the pressure and | | | |

| |
|---|
| heat affecting the projectile for the hypervelocity impact tests,<br>This task will conclude the Phase 1 of this activity, at which point COSPAR will be consulted in order to agree the way forward with respect to the testing to be done in the Phase 2.<br><br>Phase2<br>1. perform inactivation tests using separately heat and gamma radiation in ambient and vacuum environment,<br>2. perform hypervelocity impact tests in the velocity range of 0.5- 4.5 km/sec with particles in the micron to millimetre range and a target with a bulk density of 1 g/ccm and a size distribution in the 50-100 micron range, statistical approach for all tests to achieve a confidence interval in the 95-99% range, develop hydrodynamic simulations and material models to extrapolate the hypervelocity impact test results.<br><br>Experimental work requires a dedicated heat-kill set-up, a cobalt 60 radiation source with about 2 Gy/sec, a two-stage light gas gun facility and capabilities for handling and preparing biological samples (microbes, viruses and phages) and geological samples. |
| **Deliverables** |
| Description of preparation and characterisation of the samples, projectiles and target materials, description of criteria for biological inactivation, description of experimental set-up for heat/radiation inactivation tests and impact tests, TRRs, test reports for the different tests, hydrodynamic simulations and material models for impact tests, recommendations for inactivation levels. |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | N/A | **Target TRL:** | N/A | **Application Need/Date:** | Q3 2014 |
| **Application Mission:** | MSR, Phootprint | | **Contract Duration:** | 16 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Characterisation of Phootprint landing site contamination from descent thrusters** | | | |
| **Programme:** | ETP | **Reference:** | E918-005MP |
| **Title:** | Characterisation of Phootprint landing site contamination from descent thrusters | | |
| **Total Budget:** | 500 | | |
| **Objectives** | | | |
| The objective of this activity is to characterise the contamination of the Phootprint landing site by the lander thrusters used during the descent. | | | |
| **Description** | | | |
| The PHOOTPRINT mission will likely have a deceleration phase which ends significantly above Phobos followed be a hard landing. It is therefore assumed that there will be no strong plume surface interaction and therefore no significant site alteration from the thrusters plumes is expected (i.e. no soil blown from the plumes). However, some particles rejected from the thrusters before free-fall are expected to contaminate the landing site. This has science implications as chemical contamination of the sample is not wanted. The current science requirement with that respect is:<br>"The number of contaminating molecules deposited on the asteroid surface by the propulsion system shall be lower than 10+14 / cm2 (goal 10+13 / cm2)".<br><br>The current descent strategy foresees a forced motion phase followed by a free fall down to touch-down, from about 15m. Thrusters are shut off at the start of this free fall phase. In order to consolidate the system trade between altitude of free fall (the higher the more demanding for GNC and landing gear) and sample contamination by thrusters (the higher the free fall the better), characterisation in vacuum of surface contamination from thrusters (22N bi-propellant MON-MMH currently baselined) at several heights is needed, as well as correlation with models, in order to allow making reliable predictions of soil contamination from several thrusters configurations & free-fall heights.<br><br>The project will therefore include experimental tests at a suitable vacuum facility where the bi-propellant thrusters will be directed toward a surface at specified distances which are such that the ground to flight scenario is comparable in terms of forces and species interaction with the surface. the outcome will be the appropriate sticking factors (of all species of mass fraction greater than 5%), forces on the surface and contamination distribution on the surface<br><br>The test will be further supplemented with numerical tests using DSMC codes to recover the forces and contamination found during experiments. the sticking factors measured during experiments will be input to the DSMC code.<br><br>The outcome of this task will be:<br>a) further understanding of the contamination process and predictions of likely contaminations;<br>b) validation of DSMC codes for use when the exact mission as described. | | | |
| **Deliverables** | | | |
| Reports including test plan, test data, numerical reconstruction and assessment of the results. Experimental data in electronic format | | | |

| | | | | | |
|---|---|---|---|---|---|
| (Data Base) and numerical data also in electronic format to allow future comparisons and/or benchmark tests | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2016 |
| **Application Mission:** | PHOOTPRINT | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8091, T-8940, T-7906 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| ATD Harmonisation 2012 | | | | | |

| **Evaluation of heatshield CFRP and bonding materials to increased temperature limits** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T924-004MT | |
| **Title:** | Evaluation of heatshield CFRP and bonding materials to increased temperature limits | | | | |
| **Total Budget:** | 400 | | | | |
| **Objectives** | | | | | |
| The objective is to develop CFRP substrate materials (including honeycomb structures) as well as a bonding material for the attachment of an ablative TPS for an increased temperature limit of 250degC. | | | | | |
| **Description** | | | | | |
| One important constraint in the sizing process of an ablative TPS is the temperature limit of the supporting heatshield structure and of the bonding material used to attach the TPS. This temperature limit is typically in the range of 150-180degC. For the CFRP the limiting factor is typically the resin. New resin materials have commercially become available in recent years which indicate higher temperature limits. Such increased limits would allow to reduce the required TPS thickness and therefore to reduce the mass of the TPS.<br><br>The objective of the activity shall be achieved through the following steps:<br>* Perform a market research of advanced CFRP resin materials as well as bonding materials for the attachment of the TPS suited for increased temperatures<br>* Perform a trade-off (including relevant screening tests)<br>* Develop a selected CFRP material as well as a TPS bonding material to achieve an operational temperature of 250degC | | | | | |
| **Deliverables** | | | | | |
| Study report and material samples | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |
| **Application Mission:** | Sample return missions. | | **Contract Duration:** | 15 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8142 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Development of a rigid conformal ablator for extreme heat flux applications** | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T921-004MT |
| **Title:** | Development of a rigid conformal ablator for extreme heat flux applications | | |
| **Total Budget:** | 400 | | |
| **Objectives** | | | |
| Based on the existing ASTERM material, a European rigid conformal ablative heatshield material shall be developed and characterised for application on the Earth re-entry capsule of sample return missions (e.g. Mars, comets, asteroids). A material demonstrator with a representative size and geometry shall be manufactured. | | | |
| **Description** | | | |
| The ASTERM ablative heatshield material has recently been developed (under Astrium R&D and TRP-DEAM) and is currently in pre-qualification (under MREP-DEAM2). This development is specifically tailored for application on the Earth return capsule of sample return missions. The material is a low-density carbon-phenolic ablator and is produced by impregnating a low density rigid graphite felt with a phenolic resin.<br><br>Recent developments by NASA have demonstrated that by replacing the rigid graphite felt in the manufacturing process by a | | | |

| | | | | | |
|---|---|---|---|---|---|
| flexible felt can lead to a significant improvement of the material performance: Internal thermo-mechanical stresses are reduced making the material more robust to loads and deflections; thermal performance is improved leading to lower required thickness and therefore lower mass; manufacturable unit sizes are increased which might more easily allow to produce the ERC heatshield as one single piece avoiding interface issues. | | | | | |
| **Deliverables** | | | | | |
| Study reports<br>Material samples and demonstrator | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 5 | **Application Need/Date:** | 2016 |
| **Application Mission:** | Sample return missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8947, T-8142 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Consistent with D/TEC technology roadmap | | | | | |

| **ERC dynamic stability via balloon drop tests** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E918-003MP | |
| **Title:** | ERC dynamic stability via balloon drop tests | | | | |
| **Total Budget:** | 1000 | | | | |
| **Objectives** | | | | | |
| To provide a full end-to-end dynamic stability tests to validate an Earth re-entry capsules | | | | | |
| **Description** | | | | | |
| Sample return missions such as MSR, Phootprint, Marco Polo-R etc., foresee a capsule re-entering the earth atmosphere at high velocity (typically ranging from 11 to 14 km/s) without the usage of a supersonic parachute as an aerodynamic decelerator; as such, the dynamic stability of the ERC during the entry phases is essential in this situation.<br><br>An assessment is presently running to investigate and trade-off different re-entry capsule shapes (identifying pros and cons concerning accommodation capability, stability, CoG positioning, thermal exposition, and landing conditions) and preliminary characterize the dynamic stability stability in the transition phase from supersonic to subsonic velocity of a few selected configurations.<br><br>In this proposed activity, a full end-to-end dynamic stability assessment to validate the ERC shape shall be carried out by means of balloon drop tests at high altitude. A detailed aerodynamic characterization of a number of selected ERC configurations shall be obtained via these free flight tests. Within the activity, the contractor shall also design and implement the inertia metrology package needed for attitude and position data acquisition (and storage).<br><br>Wind tunnel test and CFD simulations can be foreseen if needed. | | | | | |
| **Deliverables** | | | | | |
| Reports, results of tests (and calculations), databases, instrumented models, synthesis, recommendations on methodologies | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 6 | **Application Need/Date:** | 2023 |
| **Application Mission:** | MSR, Phootprint and Marco Polo-R | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8101, T-7904 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| ATD Harmonisation 2012 | | | | | |

| **ERC RF recovery beacon breadboard** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E906-011FP |
| **Title:** | ERC RF recovery beacon breadboard | | |
| **Total Budget:** | 400 | | |
| **Objectives** | | | |
| The objective of this activity is to develop and test a breadboard of a small size RF beacon aimed at easing the ERC recovery operations after landing. | | | |

| **Description** | | | | | |
|---|---|---|---|---|---|
| The ERC is a critical element of the Phootprint mission as being the one bringing back the samples for laboratories investigations. In order to secure its recovery after landing, it is currently foreseen to implement an RF beacon from which the signal can be easily recovered by ground facilities to guide them to the landing site.<br><br>The main requirements of this beacon are:<br>- light mass, low power consumption, powered by a small battery hosted in the ERC (the battery is considered part of the beacon)<br>- must operate during at least 4 hours after landing<br>- must endure high g-loads at ERC impact, in the order of 2000g<br><br>This activity shall design and build a beacon breadboard meeting the above requirements. The breadboard will then go through a test and validation campaign. | | | | | |
| **Deliverables** | | | | | |
| RF beacon breadboard, tests numerical data, technical reports | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2017 |
| **Application Mission:** | Phootprint | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Design, development and verification of a full scale Earth Return Capsule for Phootprint** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E920-004MS | |
| **Title:** | Design, development and verification of a full scale Earth Return Capsule for Phootprint | | | | |
| **Total Budget:** | 1800 | | | | |
| **Objectives** | | | | | |
| The objective of this study is to undertake the design, development and verification of an Earth Return Capsule (ERC) which is capable of bringing back safely till high velocity touch down, returned samples from the Martian moon Phobos. | | | | | |
| **Description** | | | | | |
| During the re-entry phase of the mission, the ERC is subjected to extreme heat and mechanical loads. To ensure the integrity of the returned samples, stringent thermal and mechanical requirements are set. The ERC is usually protected by TPS (Thermal Protection System) to minimise the heat load due to high surface heat fluxes at the early Earth entry phase and by high energy absorbent core material to limit the mechanical load (2000g max at sample level ) upon the hard landing phase on Earth. To accomplish such requirements, the architecture of the ERC is as critical as what the performance of the protection materials can offer. The following activities are foreseen in this study :<br><br>- Review of Phootprint requirements for ERC<br>- Investigate the most optimal design solution based on the mission requirements. To achieve that, trade-off studies shall be performed using a combination of TPS material, crushable materials and other structural materials. The possibility of having a matrix of crushable materials of different density and mechanical behaviour, leading to gradual reduction of impact load at the bio-container, shall be examined. In addition, the outcomes from two ongoing ESA studies namely : T319-036MC "Design of a crushable TPS for the ERC" and T920-002QT "Material development for a crushable TPS for the ERC", shall be considered as potential inputs to the investigation.<br>- Design, analysis and verification by breadboard tests of one or multiple ERC concepts. The proposed design shall be able to offer maximum protection to accommodated payloads such as the returned sample bio-container, beacon, batteries, etc. Sample tests shall be performed to support the development.<br>- Manufacturing of full scale structural models of a selected ERC concept to be used in thermal and mechanical verification tests. | | | | | |
| **Deliverables** | | | | | |
| Documentation (Final Report, Summary Report, Technical Data Package including photograpic ducmentation)<br>Hardware (breadboard and full scale models) | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |
| **Application Mission:** | Phootprint | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |

| Mini Heat Switch to TRL 4 | | | | | |
|---|---|---|---|---|---|
| **Programme:** | GSTP | | **Reference:** | G921-008MT | |
| **Title:** | Mini Heat Switch to TRL 4 | | | | |
| **Total Budget:** | 400 | | | | |
| **Objectives** | | | | | |
| The objective is to develop and qualify a miniaturized heat switch capable of conducting 0.5 to 10W of waste heat to a radiator. The heat switch shall be a passive device, which at a specified temperature, makes a thermal link with a cold sink and reject the excess heat. | | | | | |
| **Description** | | | | | |
| Robotic exploration missions that are subject to long diurnal cycles, require the used heat switches to thermally decouple from the cold external environment in order to save energy. A heat switch based on the Loop Heat Pipe technology was developed in the frame of a TRP. The technology is currently baselined for the Exomars Rover. The heat switch LHP was designed to transport 10 to 50W of waste heat. However, when managing small power dissipation coming from RHUs or payloads, a dedicated LHP Heat switch may be oversized and too complex for the application. A miniaturized heat switch TRP activity was initiated with a goal to have a mass lower than 60g and would be installed in series between the radiator and the dissipative unit. The heat transport of the device is targeted to be between 0.5W to 10W. The proposed activity, plans to further enhance the design of the mini heat switch based on results from previous developments activities. A qualification model shall be manufactured in order to perform environmental testing as well as extend life testing. In addition, the testing of the mini heat switch shall include an end to end validation using a representative payload and radiator mounted in a appropriate configuration. | | | | | |
| **Deliverables** | | | | | |
| Qualification Model and a full set of design and test documentation | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 6 | **Application Need/Date:** | 2016 |
| **Application Mission:** | Robotic Exploration Missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8839 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Consistent with D/TEC technology roadmap | | | | | |

# Mars Precision Lander

| Extension and validation of Mars atmospheric and dust environment models | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T904-001EE | |
| **Title:** | Extension and validation of Mars atmospheric and dust environment models | | | | |
| **Total Budget:** | 150 | | | | |
| **Objectives** | | | | | |
| To maintain and improve the capacity to predict the Martian atmospheric environment | | | | | |
| **Description** | | | | | |
| Extended validation of densities at lower thermospheric altitudes for aerobraking<br>Extended validation of mesoscale modelling and nesting and GCM subgrid-scale parametrisation schemes for precision landing.<br>State of the art dust lifting and transport scheme for the mesoscale and large scale circulation models. | | | | | |
| **Deliverables** | | | | | |
| Validation reports | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 4 | **Application Need/Date:** | continuing |
| **Application Mission:** | all Mars missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| Maintenance of the European Mars Climate Database | | | | | |
|---|---|---|---|---|---|
| **Programme:** | GSTP | | **Reference:** | G904-002EE | |
| **Title:** | Maintenance of the European Mars Climate Database | | | | |
| **Total Budget:** | 300 | | | | |
| **Objectives** | | | | | |
| To maintain and keep up-to-date Martian climate models which have been developed under TRP | | | | | |
| **Description** | | | | | |
| Under TRP comprehensive models of the martian atmopsheric environement have been developed and used to develop a generic data base of atmospheric data, used in EDL. This database is supplemented with additional models at progessively smaller scales to cover all aspects of mission design, including near ground environment (z<20 m). The boundary conditions for these models need to be continually upgraded as data from current Mars missions become available. New data is also used for upgrade and validation of physical parameterizations used in these models. It is anticipated that some of the effort will be devoted to the improved modelling of dust lifting and transport mechanisms, hence giving access to realistic dust spatial variability. The activity will be in two phases, with phase two activities being more tightly defined in the light of progress in phase developments, and new problems and requirements arising in scenario analyses. | | | | | |
| **Deliverables** | | | | | |
| Upgraded Martian general circulation model and documentation. Upgraded Martian mesoscale/microscale model and documentation.<br>New version of Mars Climate Database (refined dust scenarios) and validation documentation. Technical notes on scenario studies. | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 7 | **Application Need/Date:** | 2017 |
| **Application Mission:** | All Mars missions | | **Contract Duration:** | 36 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| End to end Optimisation and GNC design for High Precision Landing on Mars | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-006EC |

| | | | | | |
|---|---|---|---|---|---|
| **Title:** | End to end Optimisation and GNC design for High Precision Landing on Mars | | | | |
| **Total Budget:** | 500 | | | | |
| **Objectives** | | | | | |
| The objective of this activity is to optimise and design complete (entry to touchdown) GNC solutions for High Precision Landing on Mars. | | | | | |
| **Description** | | | | | |
| On-going activities on Mars entry, descent and landing (EDL) aim to demonstrate the feasibility of achieving a 10 km landing accuracy with a possibility that improved navigation at Entry and a smart parachute deployment strategy might reduce this accuracy to 3 km. Significant additional efforts are however required, on each of the EDL phases, to further improve the GNC performance and decrease, below that level, the size of the final landing ellipse of MSR-like landers.<br><br>Based on the MSR mission characteristics, the study will perform the optimisation of the each of the EDL phases and their chaining. It will include an analysis of affordable strategies for improving the controlled entry until parachute deployment, the control of the descent phases (parachute and powered), as well as the definition of an innovative end-to-end navigation architecture. A detailed design of the selected GNC solutions for all the phases of a fully controlled Martian EDL sequence will then be performed. The study shall more particularly address the optimisation of the approach and insertion strategies, the use of advanced guidance techniques during the hypersonic entry, smart parachute deployment, efficient drift compensation systems during Descent, and optimised powered landing with some divert and hazard avoidance capabilities Benefits of on-line identification and reconfiguration solutions throughout the EDL sequence shall also be investigated, as well as control during the descent phase that will be dealt within a robust, multi-variable control setting. The limits of performance of the GNC design shall be established. Requirements for the terrain relative sensors shall be established and high fidelity simulation models will be developed. The robustness and performance assessment of the GNC solutions will be conducted on an end-to-end high fidelity simulation environment demonstrating the implementability of the selected algorithms and strategies on flight-like processors. | | | | | |
| **Deliverables** | | | | | |
| The Agency will be delivered with a set of GNC solutions for high-precision landing on Mars. The testing and benchmarking of these solutions at simulation will identify and prepare further TRL increasing and the development phases of the corresponding EDLS components. | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2012 |
| **Application Mission:** | Precision lander, MSR | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **European IMU breadboard** | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T905-014EC |
| **Title:** | European IMU breadboard | | |
| **Total Budget:** | 800 | | |
| **Objectives** | | | |
| Breadboard and demonstrate the performance of an IMU for Mars exploration | | | |
| **Description** | | | |
| There is a clear need of a European IMU for the Robotic exploration programme. This is considered a critical technology to enable the future exploration missions during cruise, Aerobraking, Entry, Descent and Landing and in-orbit Rendezvous. The available European gyro products are not optimised for the exploration requirements. Current low mass products have low performance while available high performance products have a hig mass. Furthermore, there is no European space qualified accelerometer (US space qualified off the shelf products are available) however a TRP-funded European accelerometer feasibility demonstrator has just been launched in 2010, and may form a basis for the European IMU development pending confirmation of its performance vs. MREP requirements.<br><br>This activity intends to invite industry to propose an optimised IMU concept, based on an existing design, with gyro and accelerometer functions compliant with the MREP programme exploration needs. PDR stage shall be reached at the end of this activity with bread boarding to demonstrate the critical functions and performances.<br><br>The activity would include:<br>- analysis of the driving requirements and major constraints based on IMU specifications provided from the MREP High-precision landing GNC optimisation TDA (E905-006EC) and MREP Precision Lander system study.<br>- main design modification trade-offs<br>- detailed interfaces with the accelerometer and gyro preparatory work based on reuse of existing gyros building blocks and necessary delta-developments | | | |

| | | | | | |
|---|---|---|---|---|---|
| - early prototyping and testing of critical functions to demonstrate feasibility of meeting the key MREP performance requirements<br>- development plan till EQM qualification and estimation of the recurring cost of the IMU | | | | | |
| **Deliverables** | | | | | |
| Technical Data pack<br>- Test reports of IMU breadboard<br>- Development plan of IMU to EQM<br><br>H/W: Breadboard of IMU | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3/4 | **Application Need/Date:** | TRL5 by 2015 |
| **Application Mission:** | Precision lander, MSR | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| AOCS sensors and actuators Gyros and IMUs. AIM E1 | | | | | |

| **European IMU EM** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E905-015EC | |
| **Title:** | European IMU EM | | | | |
| **Total Budget:** | 2000 | | | | |
| **Objectives** | | | | | |
| To develop and test to TRL5, an European IMU for the Exploration. | | | | | |
| **Description** | | | | | |
| The activity shall develop an EM of an European IMU following from a previous breadboarding activity for the gyro and a separate accelerometer development activity. The IMU design shall be based on the gyro prototype architecture and the accelerometer component development. An EM shall be manufactured and tested in a relevant environment simulating its use on a Mars precision landing mission. | | | | | |
| **Deliverables** | | | | | |
| H/W: An IMU EM meeting MREP programme performance specifications | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 5 | **Application Need/Date:** | 2016 |
| **Application Mission:** | All Mars missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| AOCS Sensors and Actuators harmonisation 2009 - Gyros and IMUs Aim E1 & E2 | | | | | |

| **Accelerometer component to TRL5** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-016EC |
| **Title:** | Accelerometer component to TRL5 | | |
| **Total Budget:** | 700 | | |
| **Objectives** | | | |
| 1) To develop and demonstrate by test, a European accelerometer component with integrated readout electronics and performances compatible with future ESA exploration missions | | | |
| **Description** | | | |
| This activity shall be based on the TRP accelerometer feasibility demonstrator protoyping (T705-032EC). That activity has already shown the feasibility of the detector element via manufacture and test and performed the feasibility assessment of the enhanced, radiation hard analogue ASIC required to drive and condition the detectors. No radiation testing has been performed.<br><br>This activity shall develop, manufacture and test to TRL5, an European accelerometer as a component suitable for integration into a gyro and compatible with being used as a stand alone acceleromter.<br><br>The accelerometer component shall consist of co-packaged 1g and 20g detectors with a fully radiation hardened analogue readout | | | |

| |
|---|
| and control ASIC allowing enhanced performances. This activity shall result in a prototype fully representative of the envisaged end product in terms of performance, packaging and radiation hardness.<br><br>The prototype accelerometer shall be subjected to full performance and radiation testing. The remaining work to reach a to fully qualified EEE component is expected to consist of implementation of any design corrections arising from testing, full batch procurement and detailed evaluation and qualification testing. This would be handled under separate contractual cover. |
| **Deliverables** |
| Final report<br>Prototype accelerometer components *10 |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 4 | **Target TRL:** | 5 | **Application Need/Date:** | TRL5 by 2013 |
| **Application Mission:** | All future exploration missions | | **Contract Duration:** | 21 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-7818 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| AOCS Sensors and Actuators Harmonisation 2009 - Accelerometers, AIM A2 and A3 | | | | | |

| **Accelerometer to TRL5 - CCN** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-017FT |
| **Title:** | Accelerometer to TRL5 - CCN | | |
| **Total Budget:** | 300 | | |
| **Objectives** | | | |
| Additional testing of accelerometer component to achieve TRL 5/6. | | | |
| **Description** | | | |
| This CCN is intended to cover additional testing (and possible ASIC and/ or packaging modifications if required) of an accelerometer component that is being developed in an MREP activity (E905-016EC).<br><br>The testing shall include:<br>1) Thermal environment for space and Mars entry<br>2) Mechanical environment of launch, transfer and planetary EDL.<br>3) Life testing (thermal cycling + high temperature accelerated life)<br>4) Constructional analyses<br><br>By the end of the activity, a pre-qualification level of the accelerometer component should be achieved. | | | |
| **Deliverables** | | | |
| Tested accelerometer components, documentation | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 5 | **Target TRL:** | 5/6 | **Application Need/Date:** | 2015 |
| **Application Mission:** | All exploration missions | | **Contract Duration:** | 9 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| **Stand Alone 3 Axis European Accelometer Unit** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-021EC |
| **Title:** | Stand Alone 3 Axis European Accelerometer Unit | | |
| **Total Budget:** | 500 | | |
| **Objectives** | | | |
| To develop and test an Engineering Model (EM) of a miniaturised 3 Axis European Accelerometer unit based on a European accelerometer detector already being developed and suitable for use on Rovers and EDL missions. The target for the unit would be for PHOOTPRINT, Mars Precision Lander and other future Mars lander missions. | | | |
| **Description** | | | |

| |
|---|
| European accelerometer components are currently in development (Colibrys (CH) and ESS (GR)); this activity will result in the availability of a miniaturised stand alone 3 axis unit based on these components. The general characteristics of the unit are expected to be:<br>< 350g<br>< 60*60* 60mm<br>< 2.5 W<br>28 Volt primary power supply<br>with both +/-1g and +/-20g measurement ranges per axis.<br><br>The activity will include the preliminary design, breadboarding, detailed design and EM manufacture and test. The tests will include performance and environmental testing (thermal and mechanical). |
| **Deliverables** |
| Unit EM, data package |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |
| **Application Mission:** | All Mars missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Camera-aided Mars Landing and Rendezvous navigation system** | | | |
| **Programme:** | ETP | **Reference:** | E905-007EC |
| **Title:** | Camera-aided Mars Landing and Rendezvous navigation system | | |
| **Total Budget:** | 350 | | |
| **Objectives** | | | |
| To assess the impact of the specific Martian and landing vehicle environment (dust, atmosphere, thrusters plume, etc.) on a camera-aided navigation system and to define the functional, performance and operational specifications of a camera navigation system for Mars landing or rendezvous, consolidating the GNC and image processing approach and algorithms and to evaluate in a high-fidelity simulation environment the closed-loop performance robustness of the candidate camera-aided GNC system.. | | | |
| **Description** | | | |
| Future candidate missions of the MREP programme require the delivery of valuable payload on the Martian surface or in the case of the Mars Sample Return (MSR) mission, the capture of a sample container in Mars orbit. Previous MSR system definition studies have identified that a vision-based navigation system is an attractive solution for fulfilling the mission performance requirements. Previous generic activities have demonstrated the suitability of camera-aided measurements to assist the GNC system. This needs to be specifically addressed in the context of a Mars mission and its environment.<br><br>Building on previous activities, specific camera requirements (e.g. optical, sensor, image processing, mass, power, autonomy) for the above scenarios shall be refined taking into account Mars specific operational conditions with respect to (for example but not only):<br>* The dynamics during Mars entry, descent and landing (e.g. use of camera system during the parachute descent, transition to powered descent)<br>* The specific atmospheric and dust environment as well as thrusters plume impingement (subsequent decrease of the SNR and distortion effects will be assessed)<br>* The particular surface conditions taking into account the latest findings from ongoing Mars missions (e.g. MEX, MRO)<br>* The requirements associated with a surface landmark database (built up by previous missions) for very high precision landing and its implications on the GNC during the camera-aided descent<br>* Illumination and viewing conditions<br>* Orbital conditions (e.g. canister Sun illumination for rendezvous)<br><br>Critical analysis of the accommodation of the system (e.g. presence of airbags, aeroshell, etc.) for the two reference applications will be done together with analysis of all external error sources having an impact on the system performances.<br><br>Subsequently, candidate image processing (IP) and navigation algorithms will be identified, analysed and traded-off. Investigations in the possibility to perform hazard detection (slope, rocks, craters, etc.) with a camera system during the descent, might also be addressed. For an agreed reference application (i.e. Mars landing or rendezvous and capture), a baseline navigation chain solution, including IMU and complementary navigation sensors such as laser altimeter for landing applications, will be selected in agreement with the Agency.<br><br>The adapted GNC components and algorithms will be validated in open loop for the agreed reference case. | | | |

| |
|---|
| Upon successful completion of this activity, closed-loop performance robustness of the candidate camera-aided GNC will be evaluated against requirements in a high fidelity simulation environment. |
| **Deliverables** |
| Full technical documentation, covering as a minimum, requirements specifications, architecture, IP and navigation algorithms, performance and physical-based simulation model, and simulation test campaign results<br>All software developed during the activity (source and binary code)<br>Library of validated autonomous GNC components tailored to a Mars reference mission scenario (e.g. landing or rendezvous) |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 4 | **Application Need/Date:** | 2011 |
| **Application Mission:** | Precision lander, MSR | | **Contract Duration:** | 10 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Camera-aided Mars Landing and Rendezvous navigation system** | | | |
| **Programme:** | ETP | **Reference:** | E905-007EC-B |
| **Title:** | Camera-aided Mars Landing and Rendezvous navigation system | | |
| **Total Budget:** | 350 | | |
| **Objectives** | | | |
| To assess the impact of the specific Martian and landing vehicle environment (dust, atmosphere, thrusters plume, etc.) on a camera-aided navigation system and to define the functional, performance and operational specifications of a camera navigation system for Mars landing or rendezvous, consolidating the GNC and image processing approach and algorithms and to evaluate in a high-fidelity simulation environment the closed-loop performance robustness of the candidate camera-aided GNC system.. | | | |
| **Description** | | | |
| Future candidate missions of the MREP programme require the delivery of valuable payload on the Martian surface or in the case of the Mars Sample Return (MSR) mission, the capture of a sample container in Mars orbit. Previous MSR system definition studies have identified that a vision-based navigation system is an attractive solution for fulfilling the mission performance requirements. Previous generic activities have demonstrated the suitability of camera-aided measurements to assist the GNC system. This needs to be specifically addressed in the context of a Mars mission and its environment.<br><br>Building on previous activities, specific camera requirements (e.g. optical, sensor, image processing, mass, power, autonomy) for the above scenarios shall be refined taking into account Mars specific operational conditions with respect to (for example but not only):<br>* The dynamics during Mars entry, descent and landing (e.g. use of camera system during the parachute descent, transition to powered descent)<br>* The specific atmospheric and dust environment as well as thrusters plume impingement (subsequent decrease of the SNR and distortion effects will be assessed)<br>* The particular surface conditions taking into account the latest findings from ongoing Mars missions (e.g. MEX, MRO)<br>* The requirements associated with a surface landmark database (built up by previous missions) for very high precision landing and its implications on the GNC during the camera-aided descent<br>* Illumination and viewing conditions<br>* Orbital conditions (e.g. canister Sun illumination for rendezvous)<br><br>Critical analysis of the accommodation of the system (e.g. presence of airbags, aeroshell, etc.) for the two reference applications will be done together with analysis of all external error sources having an impact on the system performances.<br><br>Subsequently, candidate image processing (IP) and navigation algorithms will be identified, analysed and traded-off. Investigations in the possibility to perform hazard detection (slope, rocks, craters, etc.) with a camera system during the descent, might also be addressed. For an agreed reference application (i.e. Mars landing or rendezvous and capture), a baseline navigation chain solution, including IMU and complementary navigation sensors such as laser altimeter for landing applications, will be selected in agreement with the Agency.<br><br>The adapted GNC components and algorithms will be validated in open loop for the agreed reference case.<br><br>Upon successful completion of this activity, closed-loop performance robustness of the candidate camera-aided GNC will be evaluated against requirements in a high fidelity simulation environment. | | | |
| **Deliverables** | | | |
| Full technical documentation, covering as a minimum, requirements specifications, architecture, IP and navigation algorithms, performance and physical-based simulation model, and simulation test campaign results<br>All software developed during the activity (source and binary code) | | | |

| | | | | | |
|---|---|---|---|---|---|
| Library of validated autonomous GNC components tailored to a Mars reference mission scenario (e.g. landing or rendezvous) | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 4 | **Application Need/Date:** | 2011 |
| **Application Mission:** | Precision lander, MSR | | **Contract Duration:** | 10 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Sensor Data Fusion for Hazard Mapping and Piloting** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T905-008EC | |
| **Title:** | Sensor Data Fusion for Hazard Mapping and Piloting | | | | |
| **Total Budget:** | 200 | | | | |
| **Objectives** | | | | | |
| An hazard detection and avoidance system contains a hazard mapping function that identifies the terrain characteristics and a piloting function that fuse the maps information and select the landing site. The main objective of the activity is to mature the data fusion techniques required when both active and passive optical sensors to perform the hazard mapping and piloting tasks inside the hazard detection and avoidance function that will fly on future Mars landing missions. | | | | | |
| **Description** | | | | | |
| Redundancy and the proper addressing of the illumination conditions for hazard detection and hazard avoidance in planetary landing applications using the current optical sensors technology often require the simultaneous use of both a passive sensor and of an active LIDAR. The various Agency-led activities on hazard avoidance considered either the fusion of camera-based (plus some altimetric data) images or LIDAR images with inertial measurements. It never considered the synergetic use of both LIDAR and camera or more generally of tiered fusion involving several heterogenous imaging sensors (optical, radar) where a sensor limitation can be compensated by the characteristics of another and while this can increase both robustness and the features set of the terrain sensing.<br><br>The activity will :<br>- trade-off the possible terrain sensors fusion solutions for hazard detection & avoidance for planetary D & L applications<br>- develop the hazard mapping data fusion and their integration into some existing simulation environment (including the piloting function)<br>- perform the benchmarking of the proposed solutions based on their complexity, performance and robustness.<br>- assess the applicability of the methods to terrain relative navigation. | | | | | |
| **Deliverables** | | | | | |
| The Agency will be provided with a technical dossier containing the performance test results, the hazard mapping functions implementted inside a complete hazard detection and avoidance function, the TNs describing all the development. | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2012 |
| **Application Mission:** | MSR | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | TBD | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Sensor Data Fusion for Hazard Mapping and Piloting** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-008EC |
| **Title:** | Sensor Data Fusion for Hazard Mapping and Piloting | | |
| **Total Budget:** | 200 | | |
| **Objectives** | | | |
| A hazard detection and avoidance system contains a hazard mapping function that identifies the terrain characteristics and a piloting function that fuse the maps information and select the landing site. The main objective of the activity is to mature the data fusion techniques required when both active and passive optical sensors to perform the hazard mapping and piloting tasks inside the hazard detection and avoidance function that will fly on future Mars landing missions. | | | |
| **Description** | | | |

| |
|---|
| Redundancy and the proper addressing of the illumination conditions for hazard detection and hazard avoidance in planetary landing applications using the current optical sensors technology often require the simultaneous use of both a passive sensor and of an active LIDAR. The various Agency-led activities on hazard avoidance considered either the fusion of camera-based (plus some altimetric data) images or LIDAR images with inertial measurements. It never considered the synergetic use of both LIDAR and camera or more generally of tiered fusion involving several heterogenous imaging sensors (optical, radar) where a sensor limitation can be compensated by the characteristics of another and while this can increase both robustness and the features set of the terrain sensing.<br><br>The activity will :<br>- trade-off the possible terrain sensors fusion solutions for hazard detection & avoidance for planetary D & L applications<br>- develop the hazard mapping data fusion and their integration into some existing simulation environment (including the piloting function)<br>- perform the benchmarking of the proposed solutions based on their complexity, performance and robustness.<br>- assess the applicability of the methods to terrrain relative navigation. |
| **Deliverables** |
| The Agency will be provided with a technical dossier containing the performance test results, the hazard mapping functions implementated inside a complete hazard detection and avoidance function, the TNs describing all the development. |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2012 |
| **Application Mission:** | MSR | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | TBD | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Further development of Sensor Data Fusion for Hazard Avoidance** | | | |
|---|---|---|---|
| **Programme:** | GSTP | **Reference:** | G905-022EC |
| **Title:** | Further development of Sensor Data Fusion for Hazard Avoidance | | |
| **Total Budget:** | 700 | | |
| **Objectives** | | | |
| The goal of this activity is to further develop the fusion of sensor data for hazard avoidance and piloting initiated under two parallel studies (Astrium SAS and Spin.Works / T905-008EC). The activity bring the sensor data fusion techniques for hazard avoidance and piloting from a TRL 3 to TRL 5 through the implementation of the algorithms on a dedicated processor, along with an associated relative navigation scheme; the algorithm will then be test on a real-time PIL, which will include high-fidelity models of passive and active sensors. | | | |
| **Description** | | | |
| Future solar system landing missions will be targeting region of high scientific interest but with significant risk (e.g. craters, boulders, shadowed areas, slopes.) The availability of both cameras and active optical sensors (scanning Lidars, flash Lidar/3-D cameras) with their different characteristics in term of measurement type, rate and field-of-view led to the investigation of hazard detection algorithms that would fuse the data from these two sensor types (and additionally from inertial and altimetric sensors when available) to provide accurate hazard maps to the flight control software. Several sets of sensors pairs, fusion algorithm (fusing sensor data at low- or high level) and scenarios (Mars and asteroid) are being defined, implemented, simulated on SIL platform and benchmarked within the frame of activity T905-008EC run by two parallel teams, one lead by Astrium SAS (TRP activity) and the other by SpinWorks (ETP and TRP).<br><br>The logical next step is to further test the winning combination(s) performance in a PIL simulation test-bed with a dedicated processor for the HDA and relative navigation software. The main tasks of this follow-up activity shall be :<br><br>- to review the results of the two previous activities, including their conclusion on the relevance of the HDA algorithm to relative navigation and to select for both Mars and asteroid missions at most 2 sets of sensors/algorithms (specifically, the reliability of the method(s) in estimating local slope values and identifying dangerous areas with steep slopes shall be the primary selection criterion.)<br><br>- to assess whether it is required, for performance reasons, to implement the HDA and/or relative terrain navigation algorithm(s) on a dedicated processor, and in that case, to implement HDA and relative navigation algorithm on the dedicated processor (e.g. FPGA, DSP, LEON-FT);<br><br>- making use of ESTEC laboratory dSpace-based test bench, to integrate this processor into a PIL simulation, where the flight control software will be implemented on a LEON2 processor, and high-fidelity models of both optical sensors shall be used. In order to run real-time simulation, it might be necessary to restrict the tests to open-loop simulations only in order to feed high-realism virtual images to the sensor model; | | | |

| | | | | | |
|---|---|---|---|---|---|
| - based on the simulation results, to assess the sensor/algorithm simulations in term of accuracy of hazard detection, accuracy of relative navigation and overall CPU performance. | | | | | |
| **Deliverables** | | | | | |
| - Sensor data fusion algorithms and associated real-time software<br>- Sensor data fusion processor<br>- Technical documents, including test documentation | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |
| **Application Mission:** | Mars/asteroid landing missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **MSR Precision landing navigation sensor adaptation - Engineering Model** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E916-003MM | |
| **Title:** | MSR Precision landing navigation sensor adaptation - Engineering Model | | | | |
| **Total Budget:** | 1000 | | | | |
| **Objectives** | | | | | |
| Based on the results and requirements of the End-to-End optimisation and GNC design study, this activity will further develop the EDLS sensors for MSR High Precision Landing, building on the pre-developments performed under the Aurora program. An elegant prototype shall be manufactured to demonstrate the successful incorporation of HW and SW modifications and to be used in the MSR precision landing field testing which is a next step. | | | | | |
| **Description** | | | | | |
| Optical-based navigation systems are required on several key stages of future exploration missions. Such systems allow autonomous navigation manoeuvres to be performed during the precise landing of a descent module in order to allow high precision landing and avoid hazards. This task can be performed by vision-based camera systems and LIDARs. Both systems have been explored and breadboards have been developed for demonstration purpose under other ESA activities, in particular the NPAL/VisNav breadboard for a vision-based navigation demonstration, and an imaging LIDAR breadboard.<br><br>Other studies are planned to further define and refine the EDLS GNC for high-precision landing on Mars and the optimum methods of<br>data fusion between different sensors to assist the Hazard mapping and subsequent avoidance piloting that ensure such landings can be performed safely and with a high reliability.<br><br>These studies are expected to have impacts on the sensing hardware by refining the requirements on accuracy, resolution, update rate, range, power, mass and hardware to software (GNC s/w to Sensor hardware/s/w) interfaces. This updated information will be fed into the development of the sensor design, and the hardware and software of the sensors will be upgraded to meet them.<br><br>The activity shall be executed in two phases:<br>In Phase 1 the specifications for an elegant prototype shall be consolidated and the detailed desing of the sensor shall be established.<br>During Phase 2 an elegant prototype of the navigation sensor will be manufactured and validated by test, ready for its integration into the MSR Precision Landing Field testing which occurs in a next step. | | | | | |
| **Deliverables** | | | | | |
| MSR Precision landing EDL Sensor elegant prototype | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 5 | **Application Need/Date:** | 2016 |
| **Application Mission:** | MSR | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-7860 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Consistent | | | | | |

| **Laser Planetary Altimeter Engineering Model** |
|---|

| | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E905-019EC | |
| **Title:** | Laser Planetary Altimeter Engineering Model | | | | |
| **Total Budget:** | 1500 | | | | |
| **Objectives** | | | | | |
| The goal of this activity is to develop an Engineering Model of a compact laser altimeter to be used during the final stage of landing sequences of Mars and asteroid missions, and at low altitude (typically less than 7 Km) . The engineering model shall be developed from the breadboards produced by the Assessment and Breadboarding of a Planetary Altimeter TRP (T905-003EC). | | | | | |
| **Description** | | | | | |
| The need for small, low-power and yet accurate altimeter for surface proximity operation of planetary lander can be identified for missions such as Mars lander (landing mechanism activation a few meters from the surface) and asteroid lander (landing, hovering and hazard detection). Following up on the Assessment and Breadboarding of a Planetary Altimeter TRP (T905-003EC), which will produce by 2014 a field-tested breadboard of a radar and a laser altimeter (for each, mass is less than 1Kg, power less than 5W), this activity shall develop the laser ABPA breadboard into an Engineering Model to be tested in a relevant environment.<br><br>Main tasks shall include:<br>- incorporation of the conclusions of the ABPA study, including the breadboard itself<br>- update of mission requirements taking into account those of Mars and asteroid mission in development or proposed at the start of this activity, with a focus on accurate range measurement at low altitude (typically below 7 Km). - design of the Engineering Model<br>- development, procurement of parts and integration<br>- testing, verification and validation, including the use of space environment simulator, and outdoor test campaigns, including dynamic testing to be performed with a suitable flying platform (e.g. drone, helicopter) reproducing the kinematics conditions of Mars/asteroid descent trajectories. At least in the case of Mars (a) terrestrial analogue terrain(s) shall be selected for its (their) optical properties. | | | | | |
| **Deliverables** | | | | | |
| Engineering Model | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 6 | **Application Need/Date:** | 2018 |
| **Application Mission:** | Mars/Asteroid landing missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Compressive Sensing Technologies for compact LIDAR systems** | | | |
| **Programme:** | TRP | **Reference:** | T916-004MM |
| **Title:** | Compressive Sensing Technologies for compact LIDAR systems | | |
| **Total Budget:** | 475 | | |
| **Objectives** | | | |
| The objective of this activity is to assess and develop to TRL4, novel technologies for future compact imaging LIDARs based on compressive sensing techniques. | | | |
| **Description** | | | |
| Imaging LIDAR sensors are currently foreseen to be used in various space applications like during the descent and landing of planetary spacecraft or supporting the rendezvous operation between two spacecraft (with or without cooperative targets).<br><br>Nowadays the major drawback of using traditional Imaging LIDAR sensors is still their high mass (>12Kg for the overall unit) and high power consumption (>80Watts). In addition these sensors, typically single element detectors using large mirror scanners, have limited performances for some of the space applications. For example for the planetary lander application the desired high number of image elements that the system has to scan, on a fixed field of view, to image the target full frame has a strong time constraint due to the dynamics of the landing. Several novel detector array technologies have emerged in Europe in the last years that can lead to the development of more compact Imaging LIDARs systems. However the current state of the art of these detector arrays in Europe is still far away (limited number of detector elements and fill factor) from the development of a fully flash type Imaging LIDAR system (no scanning).<br><br>Recently a novel imaging technique, designated as compressive sensing, has been identified as a possible technique also for ranging applications. Since only a single element detector is required for the measurements (ranging and imaging) based on compressive sensing the current lack of high pixel resolution arrays in Europe could be overcome. In addition the system can be used, in the same application, or as a single element ranging system (like an altimeter) or as 3D imager, depending only on the illumination/imaging modulation technology used and on the implemented operational mode. Imaging LIDARs based on compressive sensing offer more compact systems, as they do not need mechanical scanners, and in addition the signal to noise ratio | | | |

| |
|---|
| available for each measurement is much higher than when directly compared with flash type systems, thereby offering longer range/lower power operation than other techniques.<br><br>Within this activity technologies for a Imaging LIDAR system based on compressive sensing shall be investigated, assessed, breadboarded and tested. A technology development plan for the performance optimization of the selected technologies shall be elaborated and executed. The technologies shall be integrated into a Imaging LIDAR technology demonstration breadboard and tested in laboratory conditions. As a result of this activity the feasibility of Imaging LIDAR systems based on compressive sensing shall be verified and assessed for different space applications. |
| **Deliverables** |
| Novel Imaging LIDAR technologies, Imaging LIDAR breadboard, data package |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2017 |
| **Application Mission:** | MPL, MSR | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-7860 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Ground Testing of Precision Landing navigation system** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-009EC |
| **Title:** | Ground Testing of Precision Landing navigation system | | |
| **Total Budget:** | 500 | | |
| **Objectives** | | | |
| The main objectives of the activity are to perform the field testing, in flight-like conditions, of the GNC and image processing algorithms developed for the Hazard avoidance and Terrain-relative navigation functions enabling high precision landing at Mars | | | |
| **Description** | | | |
| Based on the GNC solutions retained for high precision at Mars and the upgraded sensors prototype developed in preceding activities, a series of field experiments using the extended PLGTF platform and the corresponding Electrical Ground Support Equipment (EGSE) will be performed. The tests will demonstrate via closed-loop experiments the performance and robustness of the terrain relative navigation and hazard avoidance functions previously developed on a flight-representative breadboard (e.g. EAGLE Avionics Test Bench). The experiment results will be provided in a format allowing post-processing and an evaluation of the navigation performance achieved under realistic flight-like conditions and for various terrain characteristics. | | | |
| **Deliverables** | | | |
| The Agency will be delivered with validated navigation and hazard avoidance functions from field tests results allowing verification of the performance and robustness of the MSR high precision landing navigation sensors | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 4 | **Target TRL:** | 5 | **Application Need/Date:** | TRL5 by 2017 |
| **Application Mission:** | IM | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | TBD | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| AOCS Sensor and Actuator Harmonisation Roadmap Issue 3, 3D Cameras, Aim D, System Study | | | | | |

| **Lowering system Breadboard for Mars landers** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E915-001MS |
| **Title:** | Lowering system Breadboard for Mars landers | | |
| **Total Budget:** | 500 | | |
| **Objectives** | | | |
| To design and breadboard a lowering system for the EDL final phase of the Network science mission | | | |
| **Description** | | | |
| The Network Science Probes likely will require a lowering system that lowers the lander from the back cover before using its solid retro-rocket system for braking. A trade-off will be performed between different lowering systems such as the US bridle and descent rate limiter or an integrated system as proposed for the Netlander mission. Based on the requirements derived in the systems study | | | |

| | | | | | |
|---|---|---|---|---|---|
| and the small lander EDLS GNC study, a breadboard will be built of the lowering system and its performance tested. | | | | | |
| **Deliverables** | | | | | |
| Documentation<br>Lowering system breadboard and test results | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 4 | **Application Need/Date:** | TRL by 2013 |
| **Application Mission:** | Inspire, MPL | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | None | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| **Supersonic parachute test on a MAXUS flight** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | GSTP | | **Reference:** | G918-007MP | |
| **Title:** | Supersonic parachute test on a MAXUS flight | | | | |
| **Total Budget:** | 500 | | | | |
| **Objectives** | | | | | |
| The objective of this activity is to demonstrate the capability to test new supersonic parachute designs in representative conditions for space missions and reduce the reliance on existing non-European parachute systems by using European sounding rockets. | | | | | |
| **Description** | | | | | |
| As already proved feasible by the flight of the CIRA Sounding Hypersonic Atmospheric Re-entering Kapsule (SHARK) on the MAXUS-8 sounding rocket, the present activity shall make use of the spare payload volume, otherwise used for ballast, to perform a low cost flight test of a supersonic parachute on the MAXUS mission in 2015. Also, an initial internal feasibility study showed that there is possible to test a suitable sized parachute (1m diameter) in the available mass and volume constraints given by MAXUS, therefore there is a very good opportunity to develop state-of-the-art technologies for testing supersonic parachutes in Europe. The proposed activity includes:<br>- the detailed design of the capsule, parachute and deployment system including instrumentation and avionics<br>- the procurement (COTS)/development/manufacture of all items above<br>- installation the payload on MAXUS - (launch)<br>- post flight analysis<br>The following minimum instrumentation is foreseen to obtain flight data for design:<br>- Timer to measure events from MAXUS separation (initiation) to touchdown<br>- Video of the deployment and steady state descent,<br>- Accelerations and Angular rates of the capsule,<br>- Axial force during deployment, and<br>- Pressure sensor(s)<br>Further, since the capsule will be analysed by CFD to assess the wake, heating and the stability for the reference mission, there is also an opportunity to test future mission capsule shape dynamics in relevant conditions | | | | | |
| **Deliverables** | | | | | |
| Reports of detail designs, flight data and post flight analysis. Also flight hardware (all items procured/developed/manufactured under<br>the present activity). | | | | | |
| **Current TRL:** | 5 | **Target TRL:** | 7 | **Application Need/Date:** | 2018 |
| **Application Mission:** | MREP | | **Contract Duration:** | 36 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8101, T-8873, T-8940, T-7906 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| ATD Harmonisation 2012 | | | | | |

| **Entry, Descent and Landing Communications technology assessment** | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T906-008ET |
| **Title:** | Entry, Descent and Landing Communications technology assessment | | |
| **Total Budget:** | 350 | | |

| Objectives |
|---|
| - To investigate and prepare for communication direct to Earth (DTE) allowing limited information (minimum redundant) about Lander health, position and its tracking during Entry Descent and Landing and - if necessary after landing - during robotic operations.<br>- To carry out investigations for optimum output possible with given radio signals transmitted during EDL, exploiting large antennas<br>on-ground if needed larger than 35 m.<br>- To identify critical technologies for on-board and on ground hardware. |
| **Description** |
| After the Beagle failure it has been recommended that ESA missions implement a means of providing information of the events occurred during the critical entry, descent and landing (EDL) phase so it is possible to perform an investigation in case of failure. It is therefore required that future missions implement a communications system capable of transmitting information during the EDL phase. Moreover, since the existence or the visibility of an orbiter cannot be guaranteed, it is mandatory to investigate a solution compatible with the transmission of information directly to Earth during this phase.<br>Increasing on-ground available aperture and combining different antennas in an interferometer (Very Long Baseline Interferometry) has proved to be extremely useful for detection and determination of the trajectory of Huygens when landing on Titan. The activity will be applicable to the entry, descent and landing phase on any planet or moon. Initially the Contractor shall analyse the corresponding mission scenarios and system requirements; considering among others the following systems aspects e.g. plasma environment, black-out effect, signal dynamics, etc.<br>A Multiple Frequency Shift Keying (MFSK) X-band system has been implemented by NASA but its detection is a very demanding task for a receiver. Current investigations indicate that with a 35m G/S and the state of the art on board technology, the required C/No to receive specific MFSK tones is not fulfilled in all circumstances at the ground station receiver..<br>The Contractor shall investigate the following concepts: -Define precise communication scenarios RF requirements for on-board hardware, noting EDL power limits.<br>-Study different types of on-board antennas compatible with different EDL module configurations and analyse antenna patterns to provide a required Earth coverage at all times<br>-Evaluate time accuracies needed and oscillator performances<br>-Investigate other approaches for the transmission of data (e.g. coherent/non-coherent tones, modulation schemes, etc.)<br><br>The Contractor shall investigate for such scenarios the possible ground system solutions:<br>-Addition of apertures and VLBI/interferometer capabilities, cooperating with radio astronomy community<br>-Demonstrate how to arrive at accuracies like 100m rms, assisted by experiments,<br>-Exploit latest capabilities of the radio-astronomy community and the ground segment community, including E-VLBI<br>-Cooperate with European VLBI Network as external service.<br>-High bit-rate interconnect to central correlator will need to be adapted for SC tracking.<br>-Exploitation of software code developed for Huygens trajectory determination as applicable.<br><br>The contractor shall investigate the signal reception by a G/S receiver:<br>-Consolidate the receiver requirements;<br>-Study ways to improve the receiver architectures capable to detect the EDL signal under extreme conditions defined in the course of the activity with ESA 35m antennas. |
| **Deliverables** |
| -Propose different communication architectures and select the most promising one for an EDL receiver architectural concept identifying the critical technologies with subsequent breadboarding (proof-of-concept) required for high-risk developments;<br><br>TN's, reports, Final Report |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2018 |
| **Application Mission:** | INSPIRE, PHOOTPRINT, MPL | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8738 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Harmonization Dossier "TT&C Transponders and Payload Data Transmitters" 2012. | | | | | |

| Compact Dual UHF/X-band Proximity-1 Communications Package EQM | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E906-009ET |
| **Title:** | Compact Dual UHF/X-band Proximity-1 Communications Package EQM | | |
| **Total Budget:** | 2500 | | |
| **Objectives** | | | |
| The aim of this activity is to develop and test an Engineering and Qualification Model of a compact dual frequency (UHF/X-band) communication package for Mars lander/rover missions | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Description** | | | | | |
| The activity is a follow on of the completed TRP activity: Dual UHF/X-band communications package study<br>This activity targets the design, development and testing of an engineering and qualification model of a communications package for planetary probes/landers/rovers which is able to communicate both with an Orbiter (for data relay) and directly to the Earth from the surface of Mars. The design is flexible to cope with the different mission requirements, e.g. implementation of the UHF only capabilities, X-band functions o both while keeping compact unit dimensions and low mass.<br>Mars missions typically implement a UHF proximity-link with a data-relay Orbiter as their primary link for returning science data. The use of relay links is attractive for reasons of power efficiency and higher possible data-rates compared to direct-to-Earth links. Nevertheless, in order to support communications during Entry Descent and Landing (EDL), for contingency cases or missions in which an orbiter cannot be guaranteed, the inclusion of a direct link to/from Earth in the X-band is required.<br><br>The direct to Earth link will be implemented in the X-band Deep Space band frequency allocation.<br>The direct link with Earth offers some advantages; it is not subject to the usual delay in operations due to the visibility of the orbiter from the Earth, allowing the possibility to upload operational commands in real time. This equipment could also be used besides the nominal surface operations, during the cruise phase, in emergency situations and for contingency operations, as well as during the entry, descent an landing (EDL) phase either by transmitting health status beacon tones or modulated telemetry.<br><br>Instead of fitting two separate transponders into the constrained lander/rover, a single unit serving both UHF and X-band links would bring important savings in mass and volume without sacrificing functionality or mission safety. | | | | | |
| **Deliverables** | | | | | |
| Technical Notes, EQM, EIDPs | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 6 | **Application Need/Date:** | 2026 |
| **Application Mission:** | INSPIRE, MSR | | **Contract Duration:** | 29 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8738 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Harmonization Dossier "TT&C Transponders and Payload Data Transmitters," 2012 | | | | | |

| | | | |
|---|---|---|---|
| **Breadboarding of EDL Ground Receiver** | | | |
| **Programme:** | ETP | **Reference:** | E906-010GS |
| **Title:** | Breadboarding of EDL Ground Receiver | | |
| **Total Budget:** | 300 | | |
| **Objectives** | | | |
| - Based on the results of a previous activity on EDL Comms that defined the systems for Direct-to-Earth (DTE) communication to the landers during Entry, Descent and Landing (EDL) phases, this activity will produce the architectural design of the EDL receiver, identify the critical technologies for the ground receiver and Breadboard and validate the EDL ground receiver, incorporating the developments made of the critical technologies. | | | |
| **Description** | | | |
| After the Beagle failure it has been recommended that ESA missions implement a means of providing information of the events occurring during critical EDL phase, to allow an investigation in case of failure.<br><br>A preceding activity on EDL communications technology assessment under TRP will have assessed and defined the architecture of a communications system capable of transmitting information during the EDL phase. Moreover, since communications by an orbiter cannot be guaranteed, the solution shall allow transmission of information directly to Earth during EDL phases.<br>A Multiple Frequency Shift Keying (MFSK) X-band system has been implemented by NASA but its detection is a very demanding task for a receiver. Current investigations indicate that with a 35m antenna and the state of the art on board technology, the required C/No to receive specific MFSK tones is not fulfilled in all circumstances at the ground station receiver.<br>The architecture of a receiver able to deal with the signal received during EDL phase, will be drafted in the previous activity, in order to allow the communication system assessment.<br>The receiver architecture will be finalised and a breadboard produced and validated under this activity.<br><br>Based on the results of the previous EDL Comms activity the Contractor shall:<br>- Consolidate the requirements of the ground receiver capable to detect the EDL signal under the extreme conditions previously identified, with ESA ESTRACK 35m antennas;<br>- Produce the architectural design of the EDL receiver,<br>- Identify the critical technologies.<br>- breadboard (proof-of-concept) required for the high-risk developments;<br>- Design and develop the breadboard of the complete EDL Ground receiver (BB EDL Rx)<br>- Full Test and validation of the breadboard receiver development using realistic signal characteristics. | | | |
| **Deliverables** | | | |

| | | | | | |
|---|---|---|---|---|---|
| -Propose different communication architectures and select the most promising one for an EDL receiver architectural concept identifying the critical technologies with subsequent breadboarding (proof-of-concept) required for high-risk developments;<br><br>TN's, reports, Final Report | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2018 |
| **Application Mission:** | INSPIRE, PHOOTPRINT, MPL | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8738 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Harmonization Dossier "TT&C Transponders and Payload Data Transmitters" 2012. | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Preliminary design and performance verification of critical elements for guided entry thrusters** | | | | | |
| **Programme:** | ETP | | **Reference:** | E918-008MP | |
| **Title:** | Preliminary design and performance verification of critical elements for guided entry thrusters | | | | |
| **Total Budget:** | 800 | | | | |
| **Objectives** | | | | | |
| Preliminary design and performance verification of critical elements for thrusters guided entry on Mars | | | | | |
| **Description** | | | | | |
| For a precision landing (on Mars) it is strictly required to guide and control the capsule in the first part of the entry. Indeed the most importance source of dispersion is the hypersonic flight.<br>The NASA Phoenix capsule was designed aiming at a controlled and guided entry but a more detailed analysis of the interaction of the jets of the Reaction Control System (RCS) and the flow at hypersonic and supersonic conditions suggest a significant interference capable to reduce the efficiency of the thrusters or even produce control reversal. The hypersonic guidance was finally removed from the Phoenix EDL architecture in 2005.<br><br>The activity shall focus on 3 sequential aspects:<br>- the preliminary design of a RCS capable to control and guide a reference entry probe of the ESA's Mars Precision Lander mission. To this end the contribution of the RCS to forces and moments in low density flow have to be estimated taking into account the heat fluxes on the capsule surfaces due to the impingement of the hot gases. DSMC-CFD calculations (and ad-hoc preliminary tests if necessary) shall be foreseen. The jet flow interaction shall be assessed in view of system (propulsion, accommodation, performance, flight mechanics) implications/aspects.<br>- derive the requirements for a test campaign (in an aerodynamics rarefied facility) to verify the performance of the designed system. Particular importance shall be given to appropriate duplication of flight conditions and accurate measurement techniques.<br>- Prepare (and eventually modify/upgrade) the selected facility and measurement techniques where to performed the test campaign<br><br>note: This activity prepares the actual test campaign of Mars guided entry thrusters system to TRL 5 in a following activity. | | | | | |
| **Deliverables** | | | | | |
| Reports and databases. Computational (and experimental) data. Test campaign requirements. Preparation (modification/upgrade) of the selected facility | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2019 |
| **Application Mission:** | MPL | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8101, T-8940, T-8093 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| ATD Harmonisation 2012 | | | | | |

| | | | |
|---|---|---|---|
| **Mars guided entry thruster system to TRL5** | | | |
| **Programme:** | ETP | **Reference:** | E918-009MP |
| **Title:** | Mars guided entry thruster system to TRL5 | | |
| **Total Budget:** | 1000 | | |
| **Objectives** | | | |
| Raise the Technology Readiness Level of a Mars guided entry thruster Control System (RCS) to 5. Measurement of aerodynamic | | | |

| | | | | | |
|---|---|---|---|---|---|
| forces and moments, heat fluxes and chemical contaminations produced by the RCS during the first stage of planetary atmosphere entry | | | | | |
| **Description** | | | | | |
| Following the preliminary design activity, the derived test campaign requirements and the facility preparation performed during the MREP-2 TDA "Preliminary design and performance verification of critical elements for guided entry thruster study", this activity shall focus on the breadboard validation in relevant environment of a Mars guided entry thruster system.<br><br>The activity shall focus on 2 aspects:<br>- accurate measurement of the contribution of the Reaction Control System (RCS) to forces and moments in low density flow<br>- precise estimate of heat fluxes and contamination on the capsule surfaces due to the impingement of the hot gases of the RCS. Particular importance shall be given to appropriate duplication of flight conditions and accurate measurement techniques. | | | | | |
| **Deliverables** | | | | | |
| Reports and databases. Experimental data in electronic format (numerical data if available) | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2023 |
| **Application Mission:** | MPL (controlled entries) | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8101, T-8940, T-8093 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| ATD Harmonisation 2012 | | | | | |

| | | | |
|---|---|---|---|
| **Integrated throttleable valve and engine development for Mars landings** | | | |
| **Programme:** | TRP | **Reference:** | T919-001MP |
| **Title:** | Integrated throttleable valve and engine development for Mars landings | | |
| **Total Budget:** | 650 | | |
| **Objectives** | | | |
| Further development of an all European 2.5-3.5 kN throttleable valve for use as part of an all European Martian Entry Descent and Landing System (EDLS) To include close coupled testing in a flight like configuration with a mono propellant rocket motor. | | | |
| **Description** | | | |
| The MSR mission (and any proposed landing on the Martian surface with a large payload) requires a soft landing. The precision of this landing is also of increasing importance as site selection becomes a driver for science. Automatic hazard avoidance also becomes desirable. Both these requirements are best met with a propulsion system with a capacity for thrust modulation. Any exploration robotic missions requiring a soft landing such as MSR and its precursors will require dedicated engines that represent a clear case for European independence.<br><br>In general, throttleable mono-propellant solutions are required due to landing site contamination considerations. Further, the relative simplicity of the mono-propellant solutions leads to a more mass efficient propulsion subsystem.<br><br>A running activity on throttlable valve development shows promise that this capability can be acquired within Europe. This testing under the TRP program is to be limited to flow path development of the valve and obtaining metrics for flow quality and repeatability on a development model. Only simulants are to be used and the valve will not be coupled with an engine (though the contractor has been asked to consider thermal and structural constraints in the development)<br><br>The activity proposed herein is to take the previous work at valve level and examine the issues of coupling the valve to a flight engine. The activity scope is to include:<br><br>- Further development of the development model (DM) valve to include a flight like interface. - Design development and manufacture of throttle valve elegant breadboard DM<br>- Design and manufacture of valve driver electronics elegant breadboard DM - Demonstration of combined valve and controller in conjunction with battleship/existing chamber and catalyst bed.<br>- Valve development and verification based on existing mono-propellant hardware<br>- Verification of engine thermo-mechanical behaviour and catalyst performance in throttled conditions<br>- Preliminary requirements definition on a throttleable engine of 2.5-3.0kN rated thrust with a deep throttling capability<br>- Preliminary design definition and justification of a mission specific chamber and catalyst bed<br><br>A European product development in this area can be based on initial know-how built in the past by European industry and needs to be front loaded to cover throttle valve development which is an essential component of the overall engine design. Engine chamber technology already exists at a stand alone TRL of 5, however, the combined TRL is at best 3. | | | |
| **Deliverables** | | | |
| DM engine, valve and drive electronics models | | | |

| | | | | | |
|---|---|---|---|---|---|
| Valve PDR data pack (based on a generic URD)<br>Engine PRR datapack | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 4 | **Application Need/Date:** | TRL 5 by 2016 |
| **Application Mission:** | Mars Precision Lander, MSR | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| C3: 1-3 KN Throttable Engine(s) The decent engine is likely to require mono-propellant for Mars applications (though bi-propellant remains an option for lunar landing) | | | | | |

| **Design, development and testing of a throttleable monopropellant engine for soft landing** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E919-003MP | |
| **Title:** | Design, development and testing of a throttleable monopropellant engine for soft landing | | | | |
| **Total Budget:** | 4000 | | | | |
| **Objectives** | | | | | |
| Phase 2 development to CDR of an all European 2.5-3.5 kN throttleable monopropellant engine for use as part of an all European Martian Entry Descent and Landing System (EDLS) | | | | | |
| **Description** | | | | | |
| Throttleable Monopropellant solutions for soft and precise Mars landings are required due to landing site contamination considerations. Further, the relative simplicity of the monopropellant solutions leads to a more mass efficient propulsion subsystem.<br><br>The MSR mission (and any proposed landing on the Martian surface with a large payload) requires a soft landing. The precision of this landing is also of increasing importance as site selection becomes a driver for science Automatic hazard avoidance also becomes desirable. Both these requirements are best met with a propulsion system with a capacity for thrust modulation. Any exploration robotic missions requiring a soft landing such as MSR and its precursors e.g. Mars Precision Lander will require dedicated engines that represent a clear case for European independence. The activity described herein is intended as a follow on from a TRP activity (T919-001MP). | | | | | |
| **Deliverables** | | | | | |
| TBD | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 6 | **Application Need/Date:** | 2018 |
| **Application Mission:** | IM/MSR | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-7715, T-8268 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| C3: 1-3 KN Throttable Engine(s) | | | | | |

# SFR Robotics and Mechanisms

| Innovative Rover Operations Concepts- Autonomous Planning (IRONCAP) | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T309-002HS | |
| **Title:** | Innovative Rover Operations Concepts- Autonomous Planning (IRONCAP) | | | | |
| **Total Budget:** | 400 | | | | |
| **Objectives** | | | | | |
| Preparing for future robotic missions in the long-term. Investigation and prototyping of autonomy concepts and operations concepts and technologies. | | | | | |
| **Description** | | | | | |
| ESA has supported the definition of standards for model definition within the simulator domain (e.g. SMP2, ECSS E-40-07). This study will investigate how these standards can be used within an Exploration Family of Missions mission control environment and how existing models can be re-engineered to use the standard interfaces. This study will incorporate some existing simulator models into an example control system and explore how the enhanced ground models can increase operations effectiveness under different circumstances such as limited return-link bandwidth, time delays and complexity. | | | | | |
| **Deliverables** | | | | | |
| Report on the investigation on spacecraft and rover operations concepts.<br>Proposals for new concepts for operations of autonomous rovers.<br>Software prototype system.<br>Operational validation document. | | | | | |
| **Current TRL:** | 1 | **Target TRL:** | 3/4 | **Application Need/Date:** | 2012 |
| **Application Mission:** | Exomars follow-on | | **Contract Duration:** | 12 | |
| **S/W Clause:** | Operational Software | | **Reference to ESTER** | T-8430, T-8431 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| Spartan EXTension Activity - Not Tendered (SEXTANT) | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E913-005MM |
| **Title:** | Spartan EXTension Activity - Not Tendered (SEXTANT) | | |
| **Total Budget:** | 180 | | |
| **Objectives** | | | |
| Extension of the SPARTAN deliverables to include:<br>1) Implementation of the algorithms that scored 2nd and 3rd in the algorrithmic trade-off, cross comparison in terms of performance with respect to different terrain typologies<br>2) assessment of feasibility and prototyping of use of a-priori available top-down maps in the SLAM algorithm | | | |
| **Description** | | | |
| The SPAring Robotics Technologies for Autonomous Navigation (SPARTAN) activity targets the development in hardware logic (on FPGA) of computer vision algorithms used by Martian rovers in visual navigation and localisation. The activity has completed the first part, which consisted in selecting algorithms that have performance fullfilling the application requirements and that also have potential for an efficient implementation. As the trade-off was based for some criteria on estimates (factual data can only be derived by implementing the algorithm), it is possible that the algorithms ranked 2nd and 3rd may have performance similar or better than the selected ones. Therefore the activity in subject shall address the implementation of these runner-up algorithms and perform a comparison between them and the originally selected ones.<br><br>In the SPARTAN architecture, a Simultaneous Localisation and Mapping (SLAM) algorithm is implemented. Such algorithm participates to the localisation function. SLAM operates on visual features seen through rover cameras. However SLAM algorithms can also work on maps where other unique features (e.g. boulders scattered on a plain) are evident. Considering the flexibility of the algorithm and the fact that high-resolution orbital maps of the Martian surface are likely to be available long before a rover will be there, there is potential to improve the absolute localisation accuracy of a rover by merging the SLAM processing of rover images with orbital maps.<br><br>Therefore the activity in subject shall also investigate the possibility to integrate orbital maps into the SLAM part of SPARTAN. | | | |
| **Deliverables** | | | |
| Additional hardware logic implemented in the standard SPARTAN deliverables<br>Additional documentation covering these development activities. | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 3-4 | **Application Need/Date:** | TRL5 by 2015 |
| **Application Mission:** | SFR, MSR | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Code Optimisation and Modification for Partitioning of Algorithms developed in SPARTAN/SEXTANT (COMPASS)** | | | |
| **Programme:** | TRP | **Reference:** | T913-011MM |
| **Title:** | Code Optimisation and Modification for Partitioning of Algorithms developed in SPARTAN/SEXTANT (COMPASS) | | |
| **Total Budget:** | 200 | | |
| **Objectives** | | | |
| Enhance TRL of SPARTAN/SEXTANT computer vision cores, for navigation, towards flight | | | |
| **Description** | | | |
| Background: The SPARTAN and SEXTANT activities have implemented in VHDL logic a series of computer vision algorithms necessary to implement navigation systems for planetary probes. Starting from their mainly sequential description, the algorithms have been turned into vectorial and pipelined cores so that they can con work in the latest FPGA devices. However, these devices are not currently qualified for space use and even when they will be so, they will be subject to US export restrictions. The subject activity proposes to re-engineer the SPARTAN/SEXTANT cores so that they can be partitioned and ported from the present single-FPGA into networks of smaller FPGA devices thus allowing the possibility of using European-sourced FPGAs..<br>- Programme of work: 1. preliminary design of system and validation setup<br>2. detailed design<br>3. Manufacturing, assembly and unit testing<br>4. Testing<br>5. Closeout | | | |
| **Deliverables** | | | |
| - standard project documentation<br>- technical notes,<br>- FPGA cores<br>- demonstrators | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 4 | **Application Need/Date:** | 2015 |
| **Application Mission:** | MSR, PHOOTPRINT, future rovers | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8937 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| The activity was not addressed by the 2012 harmonisation exercise on A&R, although its precursor activities were presented. | | | | | |

| | | | |
|---|---|---|---|
| **Planetary Explorer LOcalisation-navigation Ready for USe (PELORUS)** | | | |
| **Programme:** | GSTP | **Reference:** | G913-016MM |
| **Title:** | Planetary Explorer LOcalisation-navigation Ready for USe (PELORUS) | | |
| **Total Budget:** | 2000 | | |
| **Objectives** | | | |
| This activity shall achieve Technology Readiness Level (TRL) 5 for the hardware logic cores of computer vision algorithms (for use by Martian rovers in visual navigation and localisation) that have been developed in the previous SPARTAN/SEXTANT and COMPASS activities. | | | |
| **Description** | | | |
| Background:<br><br>The "SPAring Robotics Technologies for Autonomous Navigation (SPARTAN)" activity has implemented in logic cores a series of computer vision algorithms necessary to implement navigation systems for planetary probes. Starting from their mainly sequential description, the algorithms have been turned into vectorial and highly-pipelined cores so that they can con work in the latest FPGA | | | |

| |
|---|
| devices.<br><br>The "Spartan EXTension Activity - Not Tendered (SEXTANT)", in the final stage of development at the time of writing, has been extending the number of algorithms used (to allow robustness) and also it has been implementing a landmark-based global localisation scheme.<br><br>The activity "Code Optimisation and Modification for Partitioning of Algorithms developed in SPARTAN/SEXTANT (COMPASS)", in initiation at the time of writing, will partition the cores and port it from the present single-FPGA implementation (only possible with non qualified US FPGAs) into networks of smaller FPGA devices thus allowing the possibility of using European-<br>sourced FPGAs.<br><br>The timing of conclusion of the sequence of the three activities coincides with the first availability of high-density all-European FPGA (end of 2014). At the end of the three activities the logic cores will be mature for a transition into a hardware/software architecture representative of a real space mission.<br>The PELORUS activity will take advantage of this fortunate conjunction to develop a hardware implementation of the cores based on the new FPGA.<br><br>Programme of work:<br>1. Definition of requirements<br>2. Co-design of the hardware and software<br>3. Manufacturing Coding and Assembly of the co-design<br>4. Testing in relevant environment<br>5. Closure of activity |
| **Deliverables** |
| 1. Normal project documentation<br>2. logic cores and supporting software<br>3. hardware implementation<br>4. test environment |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |
| **Application Mission:** | MSR | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8937 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **DExtrous LIghtweight Arm for exploratioN (DELIAN)** | | | |
| **Programme:** | TRP | **Reference:** | T913-003MM |
| **Title:** | DExtrous LIghtweight Arm for exploratioN (DELIAN) | | |
| **Total Budget:** | 800 | | |
| **Objectives** | | | |
| Development of a breadboard of robot arm (including annexed tool exchange device) capable of implementing 1) deployment and operation/application of scientific instruments/tools on surface soil/rock, 2) escavation/trenching/scooping of granular soil 3) support for coring 4) transfer of samples within and in/out of the arm base platform. | | | |
| **Description** | | | |
| The activity is a follow-on from a previous system study on a Sample Fetching Rover for MSR. The activity shall:<br>1) further detail the system requirements related to the robotic arm produced by the SFR system activity, include additional requirements that will be provided by the SOW, define verification requirements<br>2) re-visit the conceptual design on the basis of the updated requirements<br>3) design and validate by simulation the design<br>4) Manufacture, assemble and integrate the arm<br>5) test and demonstrate the breadboard<br>6) provide recommendations on technology development<br><br>The breadboard is needed: 1) to verify attainable performance and identify technological issues, 2) to provide a platform for integrated testing of sampling tools, sampling procedures, and the overall system. | | | |
| **Deliverables** | | | |
| Documentation: System Requirement Document, Detailed Design Document, User Manual, test report, video describing the development and documenting the tests | | | |

| | | | | | |
|---|---|---|---|---|---|
| Hardware: breadboard of robot arm<br>Software: executable code to enable use and testing | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2013 |
| **Application Mission:** | IM | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-2, T-7717 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Surface-Wheel Interaction modelling for Faster Traverse (SWIFT)** | | | | | |
| **Programme:** | TRP | | **Reference:** | T913-004MM | |
| **Title:** | Surface-Wheel Interaction modelling for Faster Traverse (SWIFT) | | | | |
| **Total Budget:** | 400 | | | | |
| **Objectives** | | | | | |
| Development and validation of a software modelling tool using state-of-the-art numerical modelling techniques of the relevant physical properties of Martian soil and its interaction with planetary rovers, in support of the design of energy efficient surface mobility and subsurface sample acquisition. | | | | | |
| **Description** | | | | | |
| A validated tool, based on measured physical/mineralogical properties of Martian soil, is required for design of suspension and wheels of MREP programme's future Sample Fetching Rover (SFR) to optimize energy consumption as well as reduce risk of immobilisation. Interaction of soil with sampling acquisition/handling equipment (important for the SFR) is also an area that can be modeled using the same numerical methods proposed here.<br><br>This activity will:<br>- Develop a beta version (working implementation) of a S/W modelling tool for use in predicting rover/lander vehicle-soil performances and to aid in the design of better wheels. A future extension for sample handling/processing tools can be envisaged;<br>- Use modern FEM methods to create models of Martian soil mechanics properties based on extracted in-situ data of the Martian soil from previous Mars orbital and surface missions complemented by terrestrial experimental data on representative simulants;<br>- Validate the simulation tool through tests under controlled conditions on existing testbeds, and through utilisation of the extensive test results from the ExoMars wheel and loco system tests to be undertaken from starting Oct 2010;<br>- Produce a parametric tool useable by non-experts at ESA and in aerospace industry based on outcomes of a large number of simulation runs.<br><br>A following activity would be desirable to further validate and strengthen the tool through additional testing using new data (from flight missions i.e., MEX, MRO, MSL) and new Martian soil hypotheses.<br><br>Phase 1: Review of state-of-the-art and identification of centres of expertise, existing numerical simulation tools and test equipment of the useable parts of soil mechanics and terramechanics for numerical modelling of terrain-vehicle interaction. This includes analysis of effects of gravity and Mars surface environment conditions such as atmospheric composition and temperature. Relevant literature, sources of experimental data and relevant facilities shall be identified and a validation plan shall be set up in order to correlate the simulation results with experimental data.<br><br>Phase 2: Development, Validation and Application of Numerical Simulation Tools. Work shall be organized as a S/W project with involvement of selected experts, shall include requirements elicitation for simulation tools and test equipment, procurement and implementation of simulation tools, their validation by means of existing testbeds. Based on the outcome of the literature survey and analysis, if required, dedicated equipment shall be used to assess possible effects of Martian atmospheric and temperature conditions on soil behaviour and these effects shall be included in the s/w model if they are shown to impact the soil behaviour significantly. Definition of conditions for terrestrial tests, e.g. relative density for the simulants and the means to realize these conditions in practice ,is part of the work.<br><br>Note: This activity could also benefit ESA's lunar lander/ rover mission. | | | | | |
| **Deliverables** | | | | | |
| 1. Validated Soil mechanics models of martian soil<br>2. Experimentally determined soil parameters of martian soil simulants<br>3. State-of-the art numerical techniques for modelling vehicle-terrain interaction<br>4. An easy-to-use, validated parametric model for system engineering of locomotion subsystem design purposes by non-expert users, at ESA<br>and in industry. | | | | | |
| **Current TRL:** | 1 | **Target TRL:** | 4 | **Application Need/Date:** | 2013 |

| | | | |
|---|---|---|---|
| **Application Mission:** | SFR, MSR | **Contract Duration:** | 24 |
| **S/W Clause:** | N/A | **Reference to ESTER** | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | |
| Consistent with harmonisation on Automation and Robotics exercise 2001. | | | |

| **EXperimental Production of data/Evidence on Rover Tractive performance In Soils relevant for Exploration (EXPERTISE)** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E913-006MM | |
| **Title:** | EXperimental Production of data/Evidence on Rover Tractive performance In Soils relevant for Exploration (EXPERTISE) | | | | |
| **Total Budget:** | 300 | | | | |
| **Objectives** | | | | | |
| Characterization of martian soil simulants and production of data on tractive performances of existing rover wheel models on these simulants. | | | | | |
| **Description** | | | | | |
| In preparation of the Sample Fetching Rover for MSR, experimental data of wheel-soil interaction are required, since no sufficiently validated mathematical models for the prediction of locomotion subsystem performances exist yet. Specifications of a set of martian soil simulants have been elaborated within the frame of the ExoMars Rover Phase B2X2 activities, however only a very limited set of wheel-soil interaction data has been produced before these industrial activities were suddenly stopped in March 2011 for programmatic reasons. Moreover no data on the characterization of the simulants has been provided. In the first instance these two types of data will allow complementary validation of the modelling based on Finite Element techniques foreseen in the TRP activity SWIFT (Surface-Wheel Interaction modelling for Faster Traverse).<br><br>Thorough expertise in soil mechanics as well as a suitable test equipment is required for performing these activities. | | | | | |
| **Deliverables** | | | | | |
| 1. Report on soil mechanics characterization of soil simulants based mainly on triaxial tests.<br>2. Wheel-soil interaction test report and data sets. | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | TRL5 by 2015 |
| **Application Mission:** | SFR | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Dust Unseating from Solar-panels and Thermal-radiators by Exhaling Robot (DUSTER)** | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T913-008MM |
| **Title:** | Dust Unseating from Solar-panels and Thermal-radiators by Exhaling Robot (DUSTER) | | |
| **Total Budget:** | 450 | | |
| **Objectives** | | | |
| Breadboarding and validation of a robotic system for cleaning solar arrays and thermal radiators, using the only proven-to-work-on-Mars dust removal principle. | | | |
| **Description** | | | |
| MER operations showed that wind, in the form of dust-devils, was a very efficient way to clean the rover solar panels. The proposed R&D activity aims at implementing the "air-cleaning" principle with simple robotic means that can blow dust off of critical surfaces. The manipulator, placed in a suitable location on the rover can puff air from its tip. The manipulator moves its tip on a pattern designed to progressively blow off the dust from the inner surfaces to the edges.<br><br>The main advantages of this solution are:<br>1) that it uses the only cleaning principle known to certainly work on Mars,<br>2) that it can be independent of the geometry and configuration of solar array and thermal radiators,<br>3) it does not impose extra hardware on these already densely populated surfaces, and,<br>4) it could potentially clean other surfaces (e.g optics of instruments). | | | |

The activity shall:
1. address the design, development of the three main elements of air-puffing system being 1) an ultra-lightweight stick manipulator including the bellow-duct technology to route the air in the joints, 2) a Martian-air compressor, 3) a puffing nozzle
2. define the optimal configuration for their placement on the deck of a planetary rover (SFR could be considered a study case) and the optimal operational use
3. Validate the system through testing of a breadboard in representative Martian environment

The stick manipulator shall (and can) be extremely light as being just made of air ducts and simple joints having no demanding positioning/orientation accuracy. The compressor is assumed to be best placed at the manipulator base. Potentially also all actuators can be placed at the base of the manipulator. In the case that another arm is present on the rover (e.g. DELIAN) the control electronics can be shared between the two systems.

Overall the activity shall aim at implementing the design of the DUSTER within very constrained mass envelope (few hundred grams) and with minimalist stowage and packing. A functional system demonstrator shall be produced. The activity finally shall also produce breadboard(s) to validate the DUSTER system and characterise its performance by tests in a simulated Martian environment.

**Deliverables**

1. DUSTER system functional demonstrator
2. DUSTER breadboard(s)
3. Test results.

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 1 | **Target TRL:** | 3 | **Application Need/Date:** | TRL5 by 2017 |
| **Application Mission:** | INSPIRE, SFR | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |

**Consistency with Harmonisation Roadmap and conclusion:**

**Dust Unseating from Solar-panels and Thermal-radiators by Exhaling Robot (DUSTER)**

| | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T913-008MM-B |
| **Title:** | Dust Unseating from Solar-panels and Thermal-radiators by Exhaling Robot (DUSTER) | | |
| **Total Budget:** | 450 | | |

**Objectives**

Breadboarding and validation of a robotic system for cleaning solar arrays and thermal radiators, using the only proven-to-work-on-Mars dust removal principle.

**Description**

MER operations showed that wind, in the form of dust-devils, was a very efficient way to clean the rover solar panels. The proposed R&D activity aims at implementing the "air-cleaning" principle with simple robotic means that can blow dust off of critical surfaces. The manipulator, placed in a suitable location on the rover can puff air from its tip. The manipulator moves its tip on a pattern designed to progressively blow off the dust from the inner surfaces to the edges.

The main advantages of this solution are:
1) that it uses the only cleaning principle known to certainly work on Mars,
2) that it can be independent of the geometry and configuration of solar array and thermal radiators,
3) it does not impose extra hardware on these already densely populated surfaces, and,
4) it could potentially clean other surfaces (e.g optics of instruments).

The activity shall:
1. address the design, development of the three main elements of air-puffing system being 1) an ultra-lightweight stick manipulator including the bellow-duct technology to route the air in the joints, 2) a Martian-air compressor, 3) a puffing nozzle
2. define the optimal configuration for their placement on the deck of a planetary rover (SFR could be considered a study case) and the optimal operational use
3. Validate the system through testing of a breadboard in representative Martian environment

The stick manipulator shall (and can) be extremely light as being just made of air ducts and simple joints having no demanding positioning/orientation accuracy. The compressor is assumed to be best placed at the manipulator base. Potentially also all actuators can be placed at the base of the manipulator. In the case that another arm is present on the rover (e.g. DELIAN) the control electronics can be shared between the two systems.

Overall the activity shall aim at implementing the design of the DUSTER within very constrained mass envelope (few hundred grams) and with minimalist stowage and packing. A functional system demonstrator shall be produced. The activity finally shall

| | | | | | |
|---|---|---|---|---|---|
| also produce breadboard(s) to validate the DUSTER system and characterise its performance by tests in a simulated Martian environment. | | | | | |
| **Deliverables** | | | | | |
| 1. DUSTER system functional demonstrator<br>2. DUSTER breadboard(s)<br>3. Test results. | | | | | |
| **Current TRL:** | 1 | **Target TRL:** | 3 | **Application Need/Date:** | TRL5 by 2017 |
| **Application Mission:** | INSPIRE, SFR | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Solar-Panel Or Thermal-radiator cLEaning Sub System (SPOTLESS)** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E913-015MM | |
| **Title:** | Solar-Panel Or Thermal-radiator cLEaning Sub System (SPOTLESS) | | | | |
| **Total Budget:** | 1400 | | | | |
| **Objectives** | | | | | |
| The activity shall further develop the most promising dust removal system that has been proven in previous early technology development activities and test in relevant environment to increase the end-to-end system TRL. | | | | | |
| **Description** | | | | | |
| The proposed activity will build upon the most successful dust removal principle demonstrated in previous TDAs (e.g. T913-008MM DUSTER or previous Aurora SAMM study concepts). The system design shall be revisited with the scope to increase the TRL and develop a full E(Q)M of the dust removal system, tailored to the candidate MREP2 mission needs.<br><br>The activity will look at SPOTLESS as a lander/rover subsystem (using INSPIRE or Small Rover as reference cases), where interfaces and lander/rover accommodation issues will be thoroughly investigated and incorporated in the design, as much as the lander/rover design maturity allows. The end-to-end control of the dust cleaning system will be designed as well as the detailed specification of dust-removal operational scenarios targeted to the INSPIRE/SFR missions will be outlined. Finally the system will be tested in a Martian environmental simulator both for validation and for overall characterization of performance metrics (w.r.t. resources, cleaning efficiency of operational scenarios, etc.)<br><br>Programme of work:<br>1. requirement specification<br>2. preliminary design of apparatus and validation setup<br>3. detailed design<br>4 Manufacturing, assembly and unit testing<br>5. Testing<br>6. Closeout | | | | | |
| **Deliverables** | | | | | |
| - project documentation<br>- technical notes,<br>- SPOTLESS hardware & software<br>- test data | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 6 | **Application Need/Date:** | 2015 |
| **Application Mission:** | INSPIRE, MSR | | **Contract Duration:** | 20 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-1, T-9012 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| The activity was not addressed by the 2012 harmonisation exercise on A&R, although its precursor activity was presented | | | | | |

| **Mechanisms technologies that operate at very low temperatures** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E915-002MS |

| | | | | | |
|---|---|---|---|---|---|
| **Title:** | Mechanisms technologies that operate at very low temperatures | | | | |
| **Total Budget:** | 475 | | | | |
| **Objectives** | | | | | |
| Development of mechanisms technologies (e.g. solid lubrication, surface treatments, bearings etc) that allow mechanisms to have safe operating temperatures below -40C, and as low as -100C (with flight allowable temperatures even lower than that) to allow the operation of rover locomotion systems, robotic arms, and other such deployable systems without significant pre-heating. | | | | | |
| **Description** | | | | | |
| The current pre-heating requirements of deployable mechanisms on Mars landers and rovers can require a considerable power budget if operation is needed from the early morning on a Martian sol, even at equatorial latitudes. The MERs were rated to safely operate at -55C while the Beagle 2 arm was rated to -40C.<br><br>On small rovers and landers, the constraints on battery and solar array size limits the power available for mechanism preheating as the available power has to be shared with locomotion and robot arm operations. Mechanisms (including actuators with motors and gearboxes, etc) that have safe operating temperatures below -40C, and as low as -100C (with flight allowable temperatures even lower than that) are in need of development to allow the operation of rover locomotion systems, robotic arms, and other such deployable systems without significant pre-heating.<br><br>This activity proposes the development of technologies (using inputs from an earlier system study that would identify required technology developments in this area) that would enable mechanisms to operate at very low temperature. | | | | | |
| **Deliverables** | | | | | |
| Qualified technologies that allow mechanisms used in landers/rovers to operate at very low temperatures. | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2013 |
| **Application Mission:** | SFR | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Mechanisms Technologies that operate at very low temperatures (Extended test campaign) - CCN** | | | |
| **Programme:** | ETP | **Reference:** | E915-004FP |
| **Title:** | Mechanisms Technologies that operate at very low temperatures (Extended test campaign) - CCN | | |
| **Total Budget:** | 350 | | |
| **Objectives** | | | |
| The objective is to undertake a more comprehensive testing campaign within the ongoing MREP "Cold mechanisms" activity (E915-002MS) in order to achieve a higher TRL and reliability. | | | |
| **Description** | | | |
| In the activity, MREP Mechanisms Technologies that operate at very low temperature, the rover locomotion subsystem was identified as one of the main critical mechanism onboard a Mars surface element (Rovers/Lander) that would impose the most challenging requirements in terms of low temperature (benefits from early start-up operations at -80C) and total lifetime (Sample Fetching Rover (SFR) application 21km ground track). Among other parts of the locomotion subsystem, this imposes that the drive mechanism is expected to achieve more than 100 million cycles on the motor, more than 6 million cycles on the planetary gearbox and around 63,000 cycles on the harmonic drive (all intended at output shaft).<br><br>These two requirements are far from been achievable with the current mechanisms technologies used for Mars exploration; on one hand, the liquid lubricants (i.e. Braycote) due to the low extreme temperature, and on the other hand, the solid lubricants (i.e. sputtered MoS2) due to the long lifetime.<br><br>In the course of the activity, during the trade-offs and preliminary testing (i.e. Pin-On-Disc and fretting tests) of the most promising non-space and space mechanisms technologies, several solutions have shown interesting results:<br>- 4 solid lubricants based on MoSx/WC and MoS2+Sb2O3 have preliminary demonstrated an increase in the lifetime by a factor of a 100 versus sputtered MoS2.<br>- 2 liquid lubricants with specific additives have shown similar friction coefficients to Braycote601EF at -80C however they remain more promising since their viscosity at -80C is significantly lower.<br><br>On top of this, it has been estimated that different Harmonic Drive configuration designs could be promising e.g. the type specifically designed for dry lubrication (by maximising synergies with the harmLES project (EU)) with the option of reducing the preload on the teeth (TBC). Also new materials, such as ceramics for the planetary gears or a breakthrough concept based on contactless magnetic transmission were found promising. | | | |

| |
|---|
| Considering all these promising findings and the limited resources of the initial activity in regards to the testing campaign (i. e. only first ranked solutions, only two components selected from the full drive chain, HD and PG, will be tested) it is believed that there is a need for extending the test campaign. This way will substantiate the final outcome by increasing the reliability of the results and/or by increasing the range potential solutions, including hybrid (according to a consolidated "best practice" approach) and/or even extend to other components of the kinematic chain of a drive mechanisms by covering also, the bearings, hall sensors and motors.<br><br>Collateral effect of an adequate implementation of this extended test campaign will be the minimisation of the cost and design efforts.<br><br>Coordination and synergies with other European projects (i.e. harmLES) and ESA activities (Dry lubricated Gearbox) will also be maximised. |
| **Deliverables** |
| Technical notes, breadboards, qualified technologies that allow mechanisms used in Lander and Rovers to operate at very low temperatures, |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2015 |
| **Application Mission:** | Sample Fetching Rover, Phootprint and Inspire | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Advanced Thermal Architecture for Mars Environment** | | | |
| **Programme:** | ETP | **Reference:** | E921-006MT |
| **Title:** | Advanced Thermal Architecture for Mars Environment | | |
| **Total Budget:** | 1000 | | |
| **Objectives** | | | |
| The objective is to develop an advanced thermal architecture for a warm compartment used for Mars surface operation. Several key thermal components, as stand-offs, insulation, convection baffles and harness feedthroughs, need to be enhanced in order to minimize the heat loss to the environment. | | | |
| **Description** | | | |
| Typically, a warm compartment of a Rover or Lander on the surface of Mars will lose its internal heat though the insulation. Nevertheless, mechanical stand-offs as well as harnesses will also contribute to between 1/3 to 1/2 of these heat losses. There are some development activities currently on-going concerning the Aerogel insulation. This proposed activity would be a follow-on to these Aerogel development activities, covering a full scale warm compartment. Even though several technologies for stand-offs harness feedthroughs are currently available, they are mostly not optimised for low thermal conductivity. Therefore, within this activity, a standardized and thermally optimised stand-off shall be developed and tested. In addition, low-conductive feed-throughs for harnesses and electrical or sensor wires shall be developed and tested, in order to reduce the parasitic heat losses. Finally, as the warm compartment may have several large volumes that could trigger natural convection, the uses of baffles can be of advantage to suppress natural convection. After the development and test (at sample/subsystem level) of these three technologies, a representative warm compartment shall be designed, manufactured and tested, implementing these technologies and the insulation technology currently being developed. | | | |
| **Deliverables** | | | |
| Full scale warm compartment breadboard<br>Trade-off, Design, Analysis & Test Documentation | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3-4 | **Target TRL:** | 6 | **Application Need/Date:** | 2015 |
| **Application Mission:** | INSPIRE | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8839 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| |
|---|
| **High specific stiffness metallic materials** |

| Programme: | TRP | Reference: | T924-002QT |
|---|---|---|---|
| Title: | High specific stiffness metallic materials | | |
| Total Budget: | 500 | | |

**Objectives**

To select and characterise metallic based materials having specific stiffness above currently used metals in view of reducing lander/ rover structural mass.

**Description**

The specific stiffness of all metals widely used in space application is about 24 GPa cm3/g. Hence, the benefit of using one metal instead of another is limited when dealing with stiffness driven applications.

In this study the metallic reinforcement state of the art will be reviewed for aluminium and titanium alloys; only means of increasing steadily specific stiffness for metallic materials. The in-situ formation of TiB reinforcement in titanium alloy, the Oxide Dispertion Strengthening (ODS) in Aluminium alloys and the concept of Metal Matrix Composites (MMCs) for both Aluminium and Titanium will be traded-off and the most promising materials will be selected for further development and characterisation. Characterisation will be performed according to Martian mission conditions.

With the hypothesis that the current design can be retained with highest specific stifffness alloy the weight saving could be up to 70% (probably quite optimisic) - With the hypothesis that current design has to be modified to accommodate processing limitations of the high specific stiffness material weight saving could be 50% (less optimistic). With the hypothesis that only some high stiffness ODS alloy is used, weitht saving would be 20% (pessimistic).

Upon adequate characterisation of materials and associated processes, design could be refined to allow additional weight saving.

As example, data in literature show: MMC based Ti alloys specific stifffness increased from 40 to 70%. For aluminium alloys, specific stiffness doubled. This leads to a 50% weight saving. With ODS aluminium, increase is 20% in specific stiffness.

These types of technologies are required to reach the mass target value of landers / rover. Such high performances alloys could be used also in less demanding application reducing further the mass.

NB: This TDA is not competing with the activities on magnesium alloys currently led by David Jarvis, where the structural aspects are not the primarily objectives

**Deliverables**

Technical notes, test-plan, test report, test-samples

| Current TRL: | 3 | Target TRL: | 5/6 | Application Need/Date: | 2014 |
|---|---|---|---|---|---|
| Application Mission: | SFR | | Contract Duration: | 18 | |
| S/W Clause: | N/A | | Reference to ESTER | T8393 | |

**Consistency with Harmonisation Roadmap and conclusion:**

## Miniaturized Integrated Avionics for planetary landers

| Programme: | ETP | Reference: | E901-003ED |
|---|---|---|---|
| Title: | Miniaturized Integrated Avionics for planetary landers | | |
| Total Budget: | 1500 | | |

**Objectives**

Design and Development of a miniaturized OBC-PCDU for planetary landers

**Description**

Planetary landers and rovers, require avionics that are low mass, low power and miniaturised as much as possible.
Based on the outcomes of the activity Tailored On-Board Computer EM for Planetary Landers, the proposed activity aims to design and develop an integrated and miniaturized all-in-one avionics solution that will provide the functionalities of data handling, command and control, data storage , landing phase control and power management, conversion and distribution for planetary landers.The inclusion of parts of the communication system shall also be addressed.

Several precursors or parallel relevant activities include:
- The Tailored On-Board Computer EM for planetary Landers ( ITT AO/1-6718/11/NL/EK) activity, which develops a single lane planetary landing data processing unit composed by a Processing module and a Power module; these items represent two of the elementary building blocks that will compose the future miniaturised avionics system.
- The Solar Power Regulator Breadboard for Mars Surface Missions (E903-012EP) activity, which will develop the most suitable

solar array power regulator for the planetary lander purposes.
- Aurora Avionics Architecture System Definition that was completed in 2005.

The proposed activity is split in two phases:
Phase 1 - Requirements Definition, Architectural Trade-off (which subsystems to be included), Architectural Design Phase and Interface Definition (500 kEuros)
Phase 2 - Detailed Design and Development of an elegant breadboard of the avionics (1000 kEuros)

Requirements for the integrated avionics for Planetary landers in particular for Digital and Power functions and interfaces (type and number) shall be defined. The requirement definition activity shall be concluded with a System Requirement Review and followed by an architectural design activity. Also the mechanical interfaces of such an integrated unit shall be analyzed in order to later have the possibility to procure such boards from different subcontracting companies (according to their best competence, for example OBDH, solar array power conversion, power management and distribution, etc).

A redundancy concept for the integrated avionics unit tailored for planetary landers shall be proposed and analyzed.

The avionics shall be based on a modular design that will allow adaptability and easy upgradeability of functions and performances. The Phase 1 will be concluded with a Architectural Design Review.

The Phase 2 will be started after a positive conclusion of Phase 1 and shall involve company(ies) with proven experience in D&D of OBC/CDMU/PCDU products. An elegant BB shall be designed, developed and tested accordingly to a set of agreed test plan and procedures.

**Deliverables**

Elegant Breadboard of a miniaturized avionics system, datapackage.

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2015 |
| **Application Mission:** | MSR, INSPIRE, future lander/rovers. | | **Contract Duration:** | 30 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-7795, T-7799, T-7753, T-8614 | |

**Consistency with Harmonisation Roadmap and conclusion:**

A miniaturized OBC-PCDU is consistent with the trends identified in the technical dossier on Data Systems and On-Board Computers (issue 3, 2012) and on Power Management and Distribution (2008).

# INSPIRE

| Adaptation of Aerogel Materials for thermal insulation | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T921-001QE | |
| **Title:** | Adaptation of Aerogel Materials for thermal insulation | | | | |
| **Total Budget:** | 300 | | | | |
| **Objectives** | | | | | |
| Develop and test of multifunctional aerogel for Mars exploration (landers and rovers) to reduce mass of the thermal insulators. | | | | | |
| **Description** | | | | | |
| Aerogel are produced by sol-gel processing and are the lighest solids known (with density down to 3times that of air). It has been shown in the past that they outperform MLI as a thermal insulation in a low pressure environment as existing on Mars. The objective of the study is to tune the properties of a suitable Aerogel such that also other desireable properties (flexibility, damping, ) can be achieved. By controlling the pore size and distribution such materials will outperform both MLI as well as classical foams in a low pressure environment. This can be achieved by adapting the materials processing window and by incorporating for instance hybrid compounds into an inorganic Aerogel network. After that key functional properties shall be evaluated and performance improvement shall be quantified. | | | | | |
| **Deliverables** | | | | | |
| Trade-off and selection of target properties, material processing, tuneable property assessment, test plans, test reports, test samples and technical notes | | | | | |
| **Current TRL:** | 2/3 | **Target TRL:** | 3/4 | **Application Need/Date:** | 2013 |
| **Application Mission:** | INSPIRE, SFR | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | None | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| Extremely low power timer board EM for landers | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E901-001ED | |
| **Title:** | Extremely low power timer board EM for landers | | | | |
| **Total Budget:** | 300 | | | | |
| **Objectives** | | | | | |
| The objective of this activity is to develop an engineering model of an extremely low power configurable timer board designed to wake-up the onboard computer of a lander before atmospheric entry. | | | | | |
| **Description** | | | | | |
| Driven by the robotic exploration programme, there is a requirement to provide a timer system to wake up a lander's electronics before atmospheric entry. During an approach cruise phase that may last up to 23 days, the autonomous lander has to rely solely on batteries which consequently implies a very constraining power budget. For this reason, most systems are powered-OFF until entry becomes imminent; the timer board is required to switch the systems ON after a pre-configured elapsed period and is therefore a mission critical component.The timer board shall be highly reliable and consume less than 10mW.<br><br>Three timer devices are to be implemented in hot redundancy and their output shall be fed into a simple but reliable majority voting device. The timers shall be independent to each other and provide separate communication links and connectors to the spacecraft onboard computers. Before the spacecraft-lander separation phase, the spacecraft shall communicate with each timer device with the goal of programming the accurate length of the timer period. The spacecraft shall also have the means to verify the stored period length for each timer. The majority voting device on the timer board triggers an external relay that will power ON the lander's main systems. It shall also take signals from external g-switches as inputs that will serve as backup. In regard to dimensions and mass constraints, a single board/module hosting the redundant components is foreseen to be the baseline design. The Timer board/module has to be developed in order to be an independent box.<br><br>The timer board shall convert the voltage it receives from the lander's battery to a more suitable and power-saving voltage. A trade-off shall also be made regarding the board's DC-DC converters redundancy scheme in order to investigate if cold redundancy could be used between the converters to further reduce current consumption. | | | | | |
| **Deliverables** | | | | | |
| An Engineering Model (EM) of the highly reliable and low-power timer board. | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 6 | **Application** | 2012 |

| | | | | | |
|---|---|---|---|---|---|
| | | | | **Need/Date:** | |
| **Application Mission:** | INSPIRE | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | None | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| **Extremely low power timer board EM for landers - CCN** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ACP | | **Reference:** | A923-001FI | |
| **Title:** | Extremely low power timer board EM for landers - CCN | | | | |
| **Total Budget:** | 280 | | | | |
| **Objectives** | | | | | |
| ASIC development and manufacturing of an extremely low power timer EM for MREP landers | | | | | |
| **Description** | | | | | |
| In an on-going activity with RUAG Austria an extremely low power timer EM for MREP landers, realised as a discrete solution, is under development (E901-001ED). This discrete concept is expected as a reliable and conservative solution. The aim of the proposed CCN is to develop in parallel an ASIC solution for the extremely low power timer.<br><br>If it would be possible to have the same function and reliability with an ASIC instead of a discrete solution this would give a large reduction of size and mass. For higher TRL levels an ASIC gives also the option to include the timer function on the onboard computer board instead of on an own board which would result in an additional reduction of mass and size.<br><br>This activity will consist of:<br>- Design Trade Offs and Preliminary Design with respect to (non-exhaustive): power consumption, reliability, radiation hardness, level of integration (e.g. internal or external switcher transistor), form of redundancy<br>- Detailed Design<br>- Test Plan<br>- ASIC Manufacturing<br>- Breadboard Manufacturing<br>- Test Set-Up, Test and Reporting<br>- Activy Synthesis | | | | | |
| **Deliverables** | | | | | |
| Breadboard, a few ASICs, Documentation | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2015 |
| **Application Mission:** | INSPIRE | | **Contract Duration:** | 15 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| **Tailored On-Board Computer EM for planetary landers** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E901-002ED |
| **Title:** | Tailored On-Board Computer EM for planetary landers | | |
| **Total Budget:** | 700 | | |
| **Objectives** | | | |
| The main objective of this activity is to develop an engineering model of a tailored, highly integrated, low mass and low power On Board Computer core to be used in planetary landers. | | | |
| **Description** | | | |
| The Robotic exploration programme requires the use of on board computers in planetary landers where mass, power and sizes are critical constraints.In particular the Network Science mission concept asks for a drastic mass miniaturization of the lander (approx. 150kg entry mass with P/L). Existing on board computers cannot satisfy these requirements and there is the need to rationalise the computer architecture with the prospect of a significant mass, power and dimensions reduction. | | | |

| |
|---|
| This activity will study and develop the concept of an architecture based on SCOC3 ASIC (SoC) and to be used as part of the On Board Computer of a lander in robotic exploration programs. One of main objectives of the activity shall be to optimise as much as possible the mass/volume/power of the Controller and the needed surrounding electronics (memories, power supplies regulators, etc.) whilst keeping an acceptable level of performances. The Controller shall include the TM/TC, the reconfiguration and the main computer functions and shall provide standardised hardware and software interfaces (SpW, 1553, CAN, but also future evolution like SpaceFibre) with the other Space Segment S/s. The On Board Computer shall implement a modular architecture that allows to include additional modules (like Mass Memory , HK modules, Motion Control module) controlled by the On board Controller. Also power distribution modules can be added to the OBC (e.g. to supply the GNC units). The modular architecture could be physically implemented into a single unit or as a decentralized one (i.e. more modules/units ). In both the cases standardized electrical interfaces (e.g. SpW) shall be used also as internal I/Fs. The use of miniaturized connectors, highly-integrated interfaces and wireless technologies (for debugging purposes at least on ground) shall be exploited.<br><br>Hardware and software power saving techniques (such as processor-frequency scaling and software driven off-idle-operative states individually selectable for the various implemented functions) shall be investigated in order to optimise the power consumption and leave the Controller in the lowest power state that satisfy the functional requirements during each phase of the mission. Depending on the mission scenarios the Controller shall be able to be configured as a reliable computing system or as high available system. In the first case the Controller must be operational for a long period of time and in case of failure a reconfiguration outage is acceptable. In the second case the availability of the Controller during critical phases like entry, descent and landing shall be guaranteed also in case of failure. Configurability according to the availability requirements shall be a driver for the design of the Controller and different redundancies schemes shall be properly addressed at hardware and software level.<br><br>The activity shall start with the definition of the requirements for a Tailored OBC for Small Landers. |
| **Deliverables** |
| 1) Requirements Specification and Design & Analysis docs<br>2) AIT procedures and reports<br>3) An Engineering Model (EM) of a miniaturised on Board Controller unit. |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |
| **Application Mission:** | INSPIRE | | **Contract Duration:** | 18 | |
| **S/W Clause:** | Operational Software | | **Reference to ESTER** | T-8382 ,T-7803, | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| A highly integrated core built up into few large ASICSs is mentioned in the Data Systems and OBCs harmonization dossier. | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Subsonic Parachute Trade-Off and Testing** | | | | | |
| **Programme:** | TRP | | **Reference:** | T918-001MP | |
| **Title:** | Subsonic Parachute Trade-Off and Testing | | | | |
| **Total Budget:** | 630 | | | | |
| **Objectives** | | | | | |
| To provide information for the selection of subsonic parachutes for Mars entry to deed in the overall trade-off for the EDL system. To develop methodologies for the understanding of inflation methods and development of aerodynamic databases including static and dynamic coefficients. | | | | | |
| **Description** | | | | | |
| The activity shall start with a selection of a limited number of parachute concepts, based on a trade-off between different candidate parachute shapes and features. For the selected candidates:<br>- Initial databases for static and dynamic aerodynamic coefficients shall be developped. - Inflation properties shall also be reviewed.<br>- CFD (Computational Fluid Dynamics) estimates of aerodynamic coefficients shall be performed.<br>- Wind tunnel or free flight tests shall be performed for the further development of databases. Scaling laws shall be developed. These databases shall also provide information for the validation of CFD.<br>- CFD validation for a limited number of conditions shall be undertaken.<br>- Preliminary development plans and costs shall be provided | | | | | |
| **Deliverables** | | | | | |
| Test models, databases, software and technical notes. | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2017 |
| **Application Mission:** | INSPIRE | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | None | |

| Consistency with Harmonisation Roadmap and conclusion: |
|---|
| N/A |

| Subsonic parachute trade-off and testing - CCN | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E918-001MP | |
| **Title:** | Subsonic parachute trade-off and testing - CCN | | | | |
| **Total Budget:** | 350 | | | | |
| **Objectives** | | | | | |
| Development of a particle imaging velocimery (PIV) system for enhanced subsonic wind tunnel testing and testing campaign with additional subsonic parachute designs for Mars missions. | | | | | |
| **Description** | | | | | |
| This CCN to the running TRP activity (T918-001MP) is intended to develop a system for Particle Imaging Velocimetry at the Canadian National Research Council (CNRC) subsonic wind tunnel, in order to enhance the quality of the test data that could be achieved for the development of subsonic parachutes for Mars EDL.<br>The activity is divided into two phases:<br>Phase one: Co-development (with CNRC) of the PIV for the subsonic wind tunnel.<br>Phase two: Production of a few parachute(s) with existing designs but using a material which changes color with strain to visualize the stress distribution, and test in CNRC (where the PIV will be available). Further tests (including design and manufacture) with different parachute type(s) than the one presently foreseen in the subsonic test campaign shall also be included. | | | | | |
| **Deliverables** | | | | | |
| Fully functional PIV system, scale-model parachutes, test data and documentation | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2015 |
| **Application Mission:** | Mars surface missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| EDLS GNC Optimisation and Technology Specification for small Mars landers | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-002EC |
| **Title:** | EDLS GNC Optimisation and Technology Specification for small Mars landers | | |
| **Total Budget:** | 250 | | |
| **Objectives** | | | |
| The successful landing of planetary probes on Mars is a capability yet to be demonstrated by Europe. Time- and cost-optimal delivery of multiple probes, within the 150kg class and widely spatially separated requires that dedicated optimisation tasks and trade-offs be conducted to rigorously define an optimised design of the EDLS. The main objective of the proposed activity is thus to define the complete EDL chain, benchmarking of the available technological solutions and specification of required technology developments in order to baseline a robust, optimised (in terms of cost, mass and reliability) EDLS design of the Mars Science Network mission | | | |
| **Description** | | | |
| Building up on recent industry and CDF studies (Mars NEXT, MarsGEN), the proposed activity will perform a detailed review and a quantitative benchmarking of existing and affordable EDLS strategies for a Mars Science Network mission. The selected architecture will be the result of an end-to-end optimisation of the entire multi-probe EDL sequence. At system level, special attention shall be given to: the logic of the triggering events since separation, the nature of the deceleration systems (1-stage vs. 2-stage parachute systems, presence of retro-rockets, nature of the airbags), the terrain relative navigation specifications (including an assessment on the need of lateral velocities control and of the benefits of using some descent imagery), the detailed specification of the selected altimetric sensor and to the overall robustness of the EDLS and of its components w.r.t. the environment conditions and the missions requirements. For the preferred solution, a technology development plan will be derived together with the specification of future technology development activities. At implementation level, efforts will be made towards mass and volume optimisation of the EDLS components (D&L components, GNC equipment and data handling). The selection of the proposed architecture, as well as the justification of the redundancy strategy, will rely on the use of a set of dedicated analysis tools allowing end-to-end parametric trades within an appropriate envelope of the landers and trajectories characteristics. | | | |
| **Deliverables** | | | |
| The Agency will be delivered with a detailed and comprehensive EDLS analyses including the lessons learned from previous | | | |

| | | | | | |
|---|---|---|---|---|---|
| missions and activities. A consolidated EDLS architecture and technology specification for 150kg-class Mars landers will be provided with its justification, as well as a detailed development and testing plan for European technology of the EDLS and of its components. | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2013 |
| **Application Mission:** | INSPIRE | | **Contract Duration:** | 9 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | None | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| **Assessment and breadboarding of a planetary Altimeter** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T905-003EC | |
| **Title:** | Assessment and breadboarding of a planetary Altimeter | | | | |
| **Total Budget:** | 1471 | | | | |
| **Objectives** | | | | | |
| The proposed 2-part activity will study the concept and develop at breadboard level a mass and power-optimized GNC altimeter for use during the spacecraft descent and landing phase of 150kg-class landers of the Mars Science Network mission. | | | | | |
| **Description** | | | | | |
| A direct and reliable measurement of the ground distance by an altimeter is a key asset for any planetary Descent and Landing system that allows the trigerring of key events of the Entry, Descent and Landing sequence. The first phase (6 months, 100K) shall compare and benchmark the two natural candidate technologies (radar and laser) that could produce such as an altimetric sensor. A detailed analysis of the equipment performance and robustness under engineering constraints (mass, power, cost), mission requirements (accuracy, range, continuous measurements vs. discrete triggerings) and environment constraints (dust and plume effects, terrain roughness) shall be performed. The study phase 1 shall also consider the integration of the altimetric measurements in the complete navigation chain and will derive a set of sensor requirements that will form the basis for follow-on developments in phase 2 once the most promising solution has been identified and selected.<br><br>Depending on phase 1 results, the altimetric sensor design will be furthered to breadboard level in phase 2 (10 months, 800K). The phase 2 study shall develop any sensor level critical technology, and the breadboard model shall be constructed based on requirements established in the earlier system study part. A time and cost-effective approach for a complete sensor development, its qualification and the integrated avionics testing shall be identified and specified. | | | | | |
| **Deliverables** | | | | | |
| Phase 1: feasability and comparative analyses, technology selection and specification, development plan<br>Phase 2: breadboard model ready for testing in realistic environment, available test equipment and documentation. | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2013 |
| **Application Mission:** | INSPIRE | | **Contract Duration:** | 16 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | None | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| **Ground Testing of the EDLS Navigation Chain for small Mars landers** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-005EC |
| **Title:** | Ground Testing of the EDLS Navigation Chain for small Mars landers | | |
| **Total Budget:** | 500 | | |
| **Objectives** | | | |
| One of the key steps in the verification of the Entry, Descent and Landing systems (EDLS) is the testing of its mission critical navigation chain. This testing can be conducted through simulation, laboratory experiments and field testing. The main objective of the proposed activity is to conduct a series of field tests in order to evaluate the performance and behaviour of the navigation part of the EDLS under flight-like conditions for a European Mars Science Network mission. | | | |
| **Description** | | | |
| Following the release of the thermal protection system, the navigation chain primary purpose is to fuse altimetric information with | | | |

| |
|---|
| inertial measurements and possibly descent imagery in order to trigger the various time-critical events like the deployment of the landing system and the retro-rockets ignition. An airborne platform like the ESA Planetary Landing GNC Test Facility (PLGTF) is an adequate environment to perform tests of an EDLS navigation chain and its components (inertial measurement unit, altimetric sensor, possibly a camera). A series of field experiments using the PLGTF and the associated Electrical Ground Support Equipment (EGSE) will be performed in order to demonstrate the good behaviour of the navigation chain w.r.t. mission-like descent dynamics and terrain characteristics. The tests will nominally be conducted in open-loop as they aim at the validation of the navigation function and no retargeting of the platform is required. The possibility of closed-loop tests using the extended PLGTF platform (ePLGTF) shall however be considered in the case the baseline EDLS include the necessity to control lateral velocities. |
| **Deliverables** |
| The Agency will be delivered with field tests allowing verification of the performance and robustness of the navigation chain for 150kg-class Mars landers. The experiment results will be provided in a format allowing post-flight processing and the tuning of the EDLS GNC sensors (especially the altimetric sensor) high fidelity models under realistic flight-like conditions and for various terrain characteristics. |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 4 | **Target TRL:** | 5 | **Application Need/Date:** | TRL5 by 2014 |
| **Application Mission:** | Network Science | | **Contract Duration:** | 10 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | None | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| **Retro Rockets for Mars landing** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E919-001MP |
| **Title:** | Retro Rockets for Mars landing | | |
| **Total Budget:** | 4000 | | |
| **Objectives** | | | |
| To develop a solid retro-rocket system for application during landing on a Network science lander mission. | | | |
| **Description** | | | |
| Solid propellant rocket motors that are usually mounted in a back shell for Descent and Landing applications where solely parachutes and airbags are not sufficient or are too heavy. The need for such motors has been identified during the CDF MarsGEN study (as well as during other CDF studies) in the past.<br><br>Overall (system) working principle:<br>Parachute terminal velocity is reduced to 0 by Solid Rocket Motors at a certain altitude above ground from which the Lander drops down to the surface. This way the landing airbags can be sized for a certain "fixed" velocity that is lower than the terminal velocity of a reasonable sized parachute).<br>Solid Rocket Motors burn for a short duration to generate the required thrust for slowing down the lander. There exist some scaling possibilities that make the application of a once developed motor possible to a wider range of missions.<br>Pre PDR level activities in Europe for such motors as well as semi throttle able motors (these motors have a minimum thrust and thrust can be increased by additional liquid propellant injection) have been conducted in the scope of a project, but were rejected.<br><br>The exact technology with the application of landing on Mars is not available in Europe.<br>HOWEVER: Since these are just retro rockets, very similar applications can be found in booster separation motors and stage separation motors of which many have been produced in Europe for the Ariane 5,4,3,2 and 1 launch vehicles as well as their predecessors. In addition a large military experience exists within Europe on the development and large scale manufacturing and use of solid propellant motors. Though the application in the Martian atmosphere is different, the working principle is the same. | | | |
| **Deliverables** | | | |
| Demonstration of solid retro-rockets tailored to requirements of a Network Science lander mission. | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |
| **Application Mission:** | Inspire | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | None | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| Airbags for small landers - Breadboard and Test | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E920-001MS | |
| **Title:** | Airbags for small landers - Breadboard and Test | | | | |
| **Total Budget:** | 1500 | | | | |
| **Objectives** | | | | | |
| Design, manufacture and test an airbag breadboard in relevant environment for a 150kg-class Mars lander. | | | | | |
| **Description** | | | | | |
| Following the phase 1 (airbags design and justification by analyses), Phase 2 focuses on breadboard manufacturing and tests.<br><br>The activity shall include:<br>1) Design and justify the airbag breadboard.<br>2) Define and justify the test plan, including elementary tests if necessary and full scale breadboard test in relevant environment (Mars pressure).<br>3) Manufacture the breadboard.<br>4) Prepare and conduct landing tests.<br>5) Evaluate the results and correlate the models | | | | | |
| **Deliverables** | | | | | |
| Documentation<br>Breadboard model tested in relevant environment to TRL5. | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 5 | **Application Need/Date:** | 2013 |
| **Application Mission:** | Network Science | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | EDL: Landing System for Touchdown of Small Surface Probes (i.e. airbags) | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| Airbags for Small Landers: Extended testing of the landing system with a large variety of impact parameters | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E920-003MS |
| **Title:** | Airbags for Small Landers: Extended testing of the landing system with a large variety of impact parameters | | |
| **Total Budget:** | 1500 | | |
| **Objectives** | | | |
| Verify the mechanical properties of the airbag materials under ageing and sterilization cycles effects involving joints tests.<br>Perform additional drop tests of the whole landing system with a large variety of impact paramenters and with many different types of abrasion layer constructions. | | | |
| **Description** | | | |
| Airbags for small landers have been developed at ESA in previous TRPs studies. The airbag design has been developed (T319-035MC) and a first set of appropriate standard material tests has been performed to provide data for the simulation mdoel validation of the airbag. In the follow-on activity (E920-001MS), running at the moment, the airbag will be manufactured and a first set of drop-<br>tests will be performed in certain horizontal and vertical velocity condition.<br><br>The purpose of this new study is to verify the mechanical properties under ageing and sterilization cycles effects involving as well joints and to perform more drop tests in different velocity conditions than the running contract.<br><br>In order to design the allowables for the materials, the following condition shall be taken into account for the airbag system (including joints):<br><br>- ageing loss: it is intended as the life cycle to which the materials are subjected is taken into account, including the DHMR (125 degC for 18 hours TBC) and the outgassing process (vacuum cycle TBD) under packaging pressure conditions (TBD).<br>- radiation loss: it is principally due to UV exposure during manufacturing. The exposure time is TBD hours considering the manufacturing flow chart. The ABS system is not exposed to space environment radiation.<br>- temperature loss: the operative mission temperature range for the ABS system is -100/+50 degC. The mechanical tests will be performed in temperature controlled ambient in order to evaluate the performances and losses in operative conditions.<br><br>Therefore the following tests shall be performed:<br><br>1. UV exposure<br>2. Outgassing: the materials are put through a vacuum cycle (TBD) under packaging pressure conditions | | | |

| | | | | | |
|---|---|---|---|---|---|
| 3. DHMR: the materials are put through the same temperature cycle of DHMR (3 heat treatment cycles) under packaging pressure<br>4. Operative temperature range: the materials are put through temperature cycles between +/-70 degC under packaging pressure conditions.<br><br>In order to reach TRL 6, the airbag system need to be tested with a large variety of impact parameters (i.e. velocities, rocks and slopes) and with as much flight representative equipments as possible. The system should include the airbag system itself, the inflation system as well as the jettisoning/retraction system.<br>The followign shall be performed:<br>- Drop tests of the system to be performed under different conditions and with many different types of abrasion layer constructions combined with different impact parameters<br>- Drop tests of the system, potentially in vacuum chamber in order to simulate Martian atmospheric pressures (1/100 of Earth's). | | | | | |
| **Deliverables** | | | | | |
| Hardware, Test plan, test results, material characterization, test video, Modelling and analysis of theoretical test cases, FEM | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 6 | **Application Need/Date:** | 2015 |
| **Application Mission:** | INSPIRE | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Solar Power Regulator Breadboard for Mars Surface Missions** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T903-012EP | |
| **Title:** | Solar Power Regulator Breadboard for Mars Surface Missions | | | | |
| **Total Budget:** | 300 | | | | |
| **Objectives** | | | | | |
| The main objective is the optimisation of power system topologies and control to achieve the maximum photovoltaic power transfer to the platform and the payload for Mars Surface Missions. | | | | | |
| **Description** | | | | | |
| Solar Arrays on the Mars Surface face harsh, non homogenous and highly unpredictable environments due to suspended dust in the atmosphere, dust deposition, occurrence of dust storms, high daily thermal excursion and sun incidence evolution during the daytime. Compared to conventional shunt switching regulators, regulators based on Pulse Width Modulation (PWM) converters and Maximum Power Point (MPP) Trackers (MPPTs) would enable a significant increase of photovoltaic power transferred by the conditioning electronics to the platform and the payload.<br><br>In the TEC-EP power laboratory, specific power topologies are currently being studied and tested which should allow efficiency and mass/size improvements over more conventional designs. The existing MPPT tracking algorithms are not well suited for Mars due to their inability to differentiate a local MPP to the absolute MPP, and other principles can be investigated and plugged into the conditioning electronics to be able to track maximum solar array power in any condition.<br><br>This activity consists of 4 main tasks:<br><br>- system analysis to identify the most promising power conditioning designs and MPPT solutions;<br>- trade offs and simulations for the identification of the most suited Solar Array Regulators and MPPT designs;<br>- detailed design of the innovative Solar Array Regulators and MPPT;<br>- breadboarding & testing of the selected design. | | | | | |
| **Deliverables** | | | | | |
| Breadboards, test results and study reports | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2015 |
| **Application Mission:** | Inspire | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | None | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| consistent with Harmonisation Power Management and Distribution second semester 2008 | | | | | |

| Characterisation of space and terrestrial cells for future Mars lander/rover missions | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T903-014EP | |
| **Title:** | Characterisation of space and terrestrial cells for future Mars lander/rover missions | | | | |
| **Total Budget:** | 200 | | | | |
| **Objectives** | | | | | |
| Characterisation of the latest available space and terrestrial solar cells under Mars surface environmental conditions to understand the expected performances as well as where potential improvements can be made in future developments to optimise them for use on Mars. | | | | | |
| **Description** | | | | | |
| Solar power continues to be the main source of power foreseen for future robotic Mars surface missions. Furthermore, for small lander/rover missions such as the Network Science lander or Sample Fetching Rover, where mass for solar panels is highly constrained, it is critical that the maximum amount of power can be obtained from the solar cells for a given area. Current space and terrestrial solar cells are not optimised for the illumination, dust and temperature environment seen by Mars landers and rover. Hence, the maximum cell efficiencies on Mars are below the effeciences quoted for space operation. Currently only the 28% triple-junction class cells have been characterised under Martian conditions, while newer 30% class cell designs have become available (scheduled to be qualifiied in 2012) and will likely be used in post-2018 lander/rover missions. Therefore, characterisation of these new cells needs to be undertaken to provide accurate assumptions of the power generation on Mars for solar power system sizing.<br><br>In addition, simulataneous characterisation of the best available terrestrial GaAs based cells will allow an assessment of their performance under Mars conditions and highlight areas where such cells could be partially-modified (in a future development limited to technology such as contract grid design, without changes to semiconductor layers) in order to optimise them for use on Mars. A previous TRP activity (contract 20509/06/NL/GLC, 'Solar Cell Development for Mars Exploration Missions') showed that 'metamorphic' cells designed for terrestrial applications may provide more power over a range of Mars surface conditions than cells which have been optimised for earth orbit.<br><br>This activity shall:<br>1) Characterise the latest available space and terrestrial GaAs based solar cells under Martian environmental conditions<br>2) Identify, based on the characterisation results, potential modifications that could be made to terrestrial cell structures in order to optimise them for operation in Mars conditions (in principle excluding modifications to the semiconductor layer structure)<br>3) update models of cell performance on Mars surface.<br>3) Produce a technology development plan for undertaking such modifications and qualifying such cells for space use. | | | | | |
| **Deliverables** | | | | | |
| Report on space and terrestrial cell performances<br>Recommendations for modifications to terrestrial cells and technology development plan | | | | | |
| **Current TRL:** | 2/3 | **Target TRL:** | 3/4 | **Application Need/Date:** | TRL 5 by 2015 |
| **Application Mission:** | All solar powered missions | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| Development of a low temperature Lithium ion battery and survivability tests | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E903-013EP |
| **Title:** | Development of a low temperature Lithium ion battery and survivability tests | | |
| **Total Budget:** | 450 | | |
| **Objectives** | | | |
| Development and life test of a Li ion battery at low temperature, after selection of cells by characterisation tests; and Assessment of the possibility of the Li ion battery recovery after storage at very low temperature (-50C or colder) | | | |
| **Description** | | | |
| In applications such as landers and rovers, the battery has to deliver high energy at low temperature. ABSL Space products (UK) evaluated in 2007 the best COTS Li ion cells operating at -20 degC for Exomars. A cell was selected and a battery was assembled and tested at Estec. Li ion cells are evolving quickly, due to terrestrial markets needs (electronics, automotive,...) and new cells with higher specific energy are now available and should be evaluated at low temperatures. Some manufacturers are also developing Li ion cells for low temperatures conditions; such cells could be of interest if they offer sufficient specific energy. After characterisation of available cells, the survivability of the cells in extreme temperatures will be assessed. In case of malfunction, or dust storm on Mars leading to loss of power and loss of thermal management, the Li ion battery could be exposed to very low temperatures. The recovery of a battery after exposure to temperatures below freezing point of the electrolyte, is not known.<br>The proposed activity will include two phases: | | | |

| | | | | | |
|---|---|---|---|---|---|
| Phase1 - Thorough evaluation of high specific energy COTS cells at low temperature, and of available prototype of cells optimised for low temperatures, - Selection of the best candidates, - Battery design and assembly,<br>- Life-test at low temperature.<br><br>Phase 2: - Very low temperature storage Test: storage at very low temperature at different state of charge, for different durations;<br>- Test of different recovery scenarios (i.e Charge conditions; rate, minimum temperature required). | | | | | |
| **Deliverables** | | | | | |
| Technical Notes, characterisation tests results, Battery breadboard, battery tests results, recovery plan | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2012 |
| **Application Mission:** | INSPIRE, SFR | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | None | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Yes. Follow-on from Battery roadmap issue 1 revision 3 September 24 2006. Activity D1 | | | | | |

| **Simulation tool for breakup/burnup analysis of Mars orbiters** | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T911-001GR |
| **Title:** | Simulation tool for breakup/burnup analysis of Mars orbiters | | |
| **Total Budget:** | 300 | | |
| **Objectives** | | | |
| Development and application of a generic simulator for the entry into Mars atmosphere from Mars-bound and hyperbolic initial orbits, modelling the aerothermal/aerodynamic heating, delamination and breakup effects in response to identify solutions for meeting planetary protection constraints as well as potential collision hazards during entry. | | | |
| **Description** | | | |
| As the validation of existing tools and models are based upon Earth break-ups, they need to be adapted to a Mars entry with particular attention to a lower density CO2 atmopshere and use of CFRP or high temperature alloys (e.g. titanium-based) structural materials.<br>In order to improve knowledge of a non-controlled entry with related destruction, the existing models need to be extended to validate their use for Mars entries:<br><br>a. improving the destructive entry analysis of non-tumbling and tumbling objects. This includes both rarefied and continuum flow in the related atmosphere with built in criteria for the transition region from rarefied to continuum flow and aerodynamic heating model for that regime.<br>b. CFD/DSMC solvers and possibly specific windtunnel tests shall be used to extend the database. For each selected free stream condition also the angle of flow incidence has to be varied between 0 and 180 ï¿½ with a step size of 15ï¿½. This will allow determining mean aerodynamic loads for one tumbling motion period. Based on this data base the tumbling entry and impact of these objects shall be analyzed. In order to assess the possible improvements the results shall be compared with results obtained by a well validated break-up tool with its present modelling system using some generic shapes.<br>c. To set up a database on the behaviour of specific materials for a Mars entry vehicle which consists of typical S/C material, including CFRPs and high temperature alloys (during entry in the Mars atmosphere, i.e. their ablation-rate and coupled thermal-material characteristics.<br>d. Investigate contribution of above models in implementing them into an existing break-up tool adapted to Mars atmosphere to better support modelling of fragmentation mechanisms including time dependency, in particular regarding the level of definition required to simulate relevant local destruction mechanisms which by local melting, perforation allow aero-thermal flux to penetrate in the spacecraft, induce loss of connections, large scale destructions, and finally fragmentation. Also, the tool shall be able to provide thermal heating information (time dependent temperature profiles) of the assemblies and components during entry and after break-up, so that the natural sterilization due to heating during entry can be evaluated and compared with the Planetary Protection bioburden requirements. If simple model used (few nodes), validation of a few generic cases (e.g., internal heating of a few electronic modules) is required. Assume tumbling and use average heat flux for input.<br>f. Validate tool by comparison with MRO entry analysis.<br>e. Apply the extended tool on some typical entry scenarios, including uncontrolled entry of the MSR Orbiter.<br><br>The goal is to have a reliable tool that can be used already for the mission and S/C design and reduce the impact of bioburden control (delta-qualification of parts) and mission operation by avoiding excessive margins currently applicable because of the non-optimized simulation tools. | | | |
| **Deliverables** | | | |
| Test results to verify new parameters used in the simulation.<br>Updated simulation tool.<br>Results of typical entry scenarios. | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 3/4 | **Application Need/Date:** | 2012 |
| **Application Mission:** | INSPIRE and all other Mars missions | | **Contract Duration:** | 9 | |
| **S/W Clause:** | Operational Software | | **Reference to ESTER** | T-1103 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| **SPEX (Spectro-Polarimeter for Planetary Exploration) Characterization Program** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E906-003FI | |
| **Title:** | SPEX (Spectro-Polarimeter for Planetary Exploration) Characterization Program | | | | |
| **Total Budget:** | 220 | | | | |
| **Objectives** | | | | | |
| The objectives are:<br>- Fully characterize the technology employed on SPEX;<br>- Develop the required support equipment/tools for determination of the polarimetric performance of the system;<br>- Characterize the thermal sensitivity of the system;<br>- Pre-qualification of SPEX system. | | | | | |
| **Description** | | | | | |
| SPEX, the Spectro-Polarimeter for Planetary Exploration, is a new technology development for remote sensing measurements of planetary atmospheres. The new concept makes use of the polarization properties of birefringent crystals, and allows for very compact instrument concepts without moving parts. A previous development program resulted in a breadboard (prototype) of the instrument through which a proof of principle was achieved.<br>As a potential technology for a Mars orbiting mission, the development activities are included for Mars robotic exploration program (MREP) beyond the ExoMars program, with the aim to increase the maturity of the system and its TRL to 5. | | | | | |
| **Deliverables** | | | | | |
| 14 technical notes and a final report. | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | |
| **Application Mission:** | Several | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **UHF/X-band back-shell antenna system for Mars entry vehicles** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E907-007EE |
| **Title:** | UHF/X-band back-shell antenna system for Mars entry vehicles | | |
| **Total Budget:** | 800 | | |
| **Objectives** | | | |
| To optimise and develop an antenna system based on proven technological concepts up to EM level for Entry, Descent and Landing operation for Robotic Exploration missions. | | | |
| **Description** | | | |
| Backshell antenna systems operating at UHF and X band are critical for Entry, Descent and Landing operation and need to be optimised to enhance the probability of success and gather all possible data about this critical mission phase. Current configurations are far from optimal as they use either a large number of radiating elements to ensure toroidal coverage resulting in a mass and complexity penalty or failing to provide the gain necessary to meet the link-budged over the required large field of view. The use of alternative solutions based on a thorough assessment of the interplay among radiating elements and lander geometry is expected to overcome these limitations. While the primary technology for radiating elements is available, the overall antenna system implementation needs to be optimised from the electrical, mechanical and mission operation point of view to ensure the necessary performances. The antenna system will be developed up to Engineering Model level. | | | |
| **Deliverables** | | | |
| Study report and Engineering Model | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2015 |
| **Application Mission:** | INSPIRE | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | Yes | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

# Mars Sample Return

| MSR biocontainment system sealing and monitoring technologies - development and validation | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E914-001MM | |
| **Title:** | MSR biocontainment system sealing and monitoring technologies - development and validation | | | | |
| **Total Budget:** | 1500 | | | | |
| **Objectives** | | | | | |
| The objectives of the activity are to:<br>i) to define the sealing technologies for the flight containment system required to ensure a safe return of Mars samples with respect to planetary protection category V, restricted Earth return, within the resources available.<br>ii) develop, test and verify the selected technologies;<br>iii) Update the design concept for the MSR Bio-Containment System; provide recommendations to the MSR system studies. | | | | | |
| **Description** | | | | | |
| The biocontainment system for a Mars Sample Return mission is one of the key technologies identified by the iMARS that require development. Robust sealing and containment verification is paramount during such a mission prior to a decision being made to allow a return capsule to be placed on a trajectory to enter the Earth. Earlier studies have shown that multiple levels of containment and sealing may be required to break the chain of contact between Mars and Earth.<br>A precursor activity (contract No.:20047/06/nl) demonstrated the basic feasibility of using explosive welding as methods of sealing of the Bio Container (BC). A TRL level 2 was achieved. Use of brazing methods was also explored.<br>The proposed activity includes:<br>i) Consideration and evaluation of the biocontainment requirements (including planetary protection) and of the mission requirements, including environmental aspects. Definition of a concept for the MSR Bio-Containment System, including appropriate scaling laws and their consequences in view of the early definitions available for MSR; identification of the required sealing technologies, definition of selected samples and tests;<br>ii) Development of sealing technologies and processes and their testing. The tests will:<br>- use representative test samples/models for the individual technologies and use flight-like materials;<br>- demonstrate the implications of the sealing processes on the spacecraft (e.g. heat and debris generation, shock loads, etc.);<br>iii) Update the design concept for the MSR Bio-Containment System and provide recommendations to the system design.<br><br>It is expected that a follow-on activity (not part of the present proposal) will then apply the validated technologies to a flight representative containment system breadboard for integrated testing | | | | | |
| **Deliverables** | | | | | |
| Documentation<br>Test Samples<br>Software models | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2015 |
| **Application Mission:** | MSR | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | N/A | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| not known | | | | | |

| Biosealing and Monitoring Technologies for a Sample Containment System - Sealing tests and EM design | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E914-004QI |
| **Title:** | Biosealing and Monitoring Technologies for a Sample Containment System - Sealing tests and EM design | | |
| **Total Budget:** | 1000 | | |
| **Objectives** | | | |
| Based on the previous results of the MREP-1 activity "Biosealing and Monitoring Technologies for a Sample Containment System", the objective of this TDA is to perform additional, already identified, tests on critical components of the sealing system, adapt the design of the container accordingly, perform necessary breadboarding and produce a design of an EM of the biosealing and monitoring system. | | | |
| **Description** | | | |
| This mission enabling technology development for MSR is a continuation of a 2.5 year 1500 kEuro contract completed in June 2013 to develop a flight biosealing and monitoring system for a MSR mission.<br><br>Phase 1: | | | |

| |
|---|
| Based on the previous study and test results, the following additional tests on critical components of the sealing system are necessary:<br>-Aging of polymeric seals<br>-Further development of metal energized seals, incl. change from internal to external compression, seal mating surface<br>-Optimisation of the Nanofoil application for the breaking-the-chain lid<br>-Continuation of the particle penetration tests (sealing system performance validation) in line with PRA and updated metal seal application<br>-Optimisation of monitoring system<br>-Update of PRA<br>-Opening process<br>Some of these tests will introduce a design modification of the container (e.g., stiffening to better support the metal seal) and the sealing system and therefore will also result in new breadboards.<br>-Design of Engineering Model<br><br>Manufacturing and tests need to be under strict PA/QA control for Phase 1 to meet the schedule and ensure that the conclusions are relevant. |
| **Deliverables** |
| Updated breadboards for the sealing and for the containment system, design of EM updated PRA, DDVP for QM and FM. |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 4 | **Application Need/Date:** | 2017 |
| **Application Mission:** | MSR | | **Contract Duration:** | 20 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Biosealing and Monitoring Technologies for a Sample Containment System - EM development and testing** | | | |
| **Programme:** | ETP | **Reference:** | E914-005QI |
| **Title:** | Biosealing and Monitoring Technologies for a Sample Containment System - EM development and testing | | |
| **Total Budget:** | 2000 | | |
| **Objectives** | | | |
| Based on the previous MREP-2 activity of biosealing and monitoring system development, manufacture an EM and perform end-to-end integrated tests. | | | |
| **Description** | | | |
| In this follow-on activity, the following work is envisaged:<br><br>-Manufacturing of EM, representative of all interfaces, material and processes, incl. internal (aluminium) and external (titanium) container, CBL with Nanofoil and C-seals, lid for internal and external container, monitoring system<br>-Integrated end-to-end test<br><br>Manufacturing and tests need to be under strict PA/QA control meet the schedule and ensure that the conclusions are relevant. | | | |
| **Deliverables** | | | |
| Engineering Model and test reports, data package. | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 4 | **Target TRL:** | 5 | **Application Need/Date:** | 2017 |
| **Application Mission:** | MSR | | **Contract Duration:** | 16 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Shape Memory Alloy actuators for MSR biocontainer sealing - feasibility demonstration** | | | |
| **Programme:** | GSTP | **Reference:** | G215-001FP |
| **Title:** | Shape Memory Alloy actuators for MSR biocontainer sealing - feasibility demonstration | | |

| | | | | | |
|---|---|---|---|---|---|
| **Total Budget:** | 200 | | | | |
| **Objectives** | | | | | |
| Demonstrate the feasibility of using shape memory alloys (SMA) as an actuator to close/seal the MSR biocontainer structure as an alternative to current state-of-the-art sealing technologies. | | | | | |
| **Description** | | | | | |
| A) Analyis of required performance of SMA candidates with respect to function as a mechanism for seal closure of a BioContainment for MSR mission:<br>- Required force to lock the seal<br>- Reliability of function<br>- Tolerance against environment and qualification limit<br>- Temperature, pressure, EMC, radiation<br>- Launch environment<br>- DHMR compatibility<br><br>B) Literature survey of candidate SMAs and application examples.<br>C) Definition of test set up<br>- How to proof function<br>- Develop analytical procedure to proof tightness<br>- Pressure test vs. material research (analyse slice by e.g. SEM, x ray tomography etc.<br>D) Design of test set-up<br>- Design of SMA clamp<br>- Analyse resource requirements power, weight etc.<br>- Design of seal structure to be clamped (diameter32 cm)<br>- Design of seals | | | | | |
| **Deliverables** | | | | | |
| Documentation and breadboard | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2019 |
| **Application Mission:** | MSR | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **MSR Double walled isolators - feasibility concept study** | | | |
| **Programme:** | TRP | **Reference:** | T914-005MM |
| **Title:** | MSR Double walled isolators - feasibility concept study | | |
| **Total Budget:** | 200 | | |
| **Objectives** | | | |
| Evaluate the feasibility of a concept Design for a "double walled isolator" as primary containment to receive and analyse MSR samples in an ultra clean environment. | | | |
| **Description** | | | |
| The challenge of the MSR containment facility is to comply with planetary protection requirements of a category V, restricted Earth return, mission and hence prevent any uncontrolled release of potentially hazardous martian material and at the same time protect the samples from terrestrial contamination that could jeopardize in particular the life detection and biohazard assessment protocol and in general compromise the sample quality.<br><br>To maintain a clean, contained environment for curation and analysis of returned Mars samples, the MSR biological containment facility parallel studies (ESA contracts Nr 21431, 22226) have identified a potential solution , e.g. a double walled isolator.<br><br>Such an isolator must provide a primary containment at least equivalent to Biological Safety Cabinet (BSC) class III. Interfaces need to be available to pass the samples into and out of the isolator. The isolator must be capable of housing a robotic manipulation system and interfacing with a range of analytical instrumentation. In addition, the control of terrestrial contamination and cross contamination between samples and the recovery of martian material following handling processes is of high importance. As such, compatibility with a decontamination process including sterilisation and ultra cleaning, needs to be accounted for in the design.<br><br>This study needs to determine whether such a concept is feasible, demonstrate by test or analysis critical functions, describe a risk analysis and mitigation solutions before entering in a subsequent phase in a detailed design and breadboarding activity.<br><br>Programmatic consideration: | | | |

| |
|---|
| - The double walled isolator is a key technology to be mastered before starting a design work for MSR containment facility. - It is not advisable to neglect this ground element since the development time for such a facility is longer than for most flight projects and the approval for use is given by external entities. The timeline follows recommendations provided by the international iMARS team, the latest US National Research Council Report and both (ESA and NASA) planetary protection advisory groups. |
| **Deliverables** |
| Feasibility study on a concept Design |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 1 | **Target TRL:** | 2/3 | **Application Need/Date:** | TRL5 by 2015 |
| **Application Mission:** | MSR | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **MSR Double walled isolators - breadboard** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E914-005MM |
| **Title:** | MSR Double walled isolators - breadboard | | |
| **Total Budget:** | 800 | | |
| **Objectives** | | | |
| Design, breadboard and validate double walled isolators to receive and analyse MSR samples in clean and ultra clean environment. | | | |
| **Description** | | | |
| The challenge of the MSR containment facility is to comply with planetary protection requirements of a category V, restricted Earth return, mission and hence prevent any backward contamination and generation of false positive and negative results in the life detection and biohazard tests.To maintain a clean, contained environment for curation and analysis of returned Mars samples, the MSR biological containment facility parallel studies (ESA contracts Nr 21431, 22226) have identified a potential solution , e.g. a double walled isolator (DWI).<br>A detailed feasibility study for a DWI concept, including a demonstration by test or analysis of critical functions has been proposed before entering a second phase of a detailed design and breadboarding activity.<br><br>This proposal addresses this second phase:<br>The DWI must provide a primary containment level at least equivalent to a Biological Safety Cabinet (BSC) class III. Interfaces need to be available to pass the samples into and out of the isolator. The isolator must be capable of housing a robotic manipulation system and interfacing with a range of analytical instrumentation. In addition, the control of terrestrial contamination and cross contamination between samples and the recovery of martian material following handling processes is of high importance. The compatibility with decontamination/cleaning processes needs to be taken into account and validated for the DWI. This process shall:<br>- Recover solid materials from surfaces<br>- Clean all equipment in contact with the MSR hardware and samples - Sterilise all equipment in contact with the MSR hardware and samples - Be administered by robotic means, to minimise human interaction with the sample<br>- Be able to be verified after operation (either by direct verification or process qualification) | | | |
| **Deliverables** | | | |
| Technical Data Package including Detailed design , and functional breadboard. | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 5 | **Application Need/Date:** | TRL5 by 2018 |
| **Application Mission:** | 2020+ | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Manipulation systems for sample handling in a Sample Receiving Facility** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E913-010MM |
| **Title:** | Manipulation systems for sample handling in a Sample Receiving Facility | | |
| **Total Budget:** | 1000 | | |
| **Objectives** | | | |

| | | | | | |
|---|---|---|---|---|---|
| Identify and demonstrate feasibility for a micro manipulation system interfaced to an isolation system for samples returned from Mars respecting the requirements for sample manipulation under containment, contamination control and maintaining sample quality. | | | | | |
| **Description** | | | | | |
| To handle returned Mars samples for biological hazard assessment, whilst maintaining the science contained within them, it will be necessary to make use of remote manipulation systems to remove contaminating humans as much as possible from the process.<br>These systems will need to be able to:<br>- Handle the samples and sub samples (order of grams down to micro grams)<br>- Operate in a freezer temperature (~250K), ambient or low pressure, dry nitrogen environment<br>- Produce a minimum of contamination into the sample environment from the materials and lubricants used in their construction.<br>- Be able to be sterilised decontaminated via a qualified process prior to installation in the containment area<br>- Be able to operate for a minimum of 6 months with a minimum of planned servicing<br>- Operate in a double walled isolator with minimal through wall intrusion<br><br>Activity in 2 phases:<br>i)200 kEuros for 12 months to consolidate the requirements, provide a preliminary design iteration & trade off, description of a development program<br>ii) 800 kEuros for 24 months for design and performing breadboard testing. | | | | | |
| **Deliverables** | | | | | |
| Requirements, preliminary design, development plan, detailed breadboard design, TRR, breadboard test report, recommendation for future activities. | | | | | |
| **Current TRL:** | 0 | **Target TRL:** | 4 | **Application Need/Date:** | 2015 |
| **Application Mission:** | MSR and other sample return missions | | **Contract Duration:** | 36 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Integrated GNC solution for Autonomous Mars Rendezvous and Capture** | | | |
| **Programme:** | ETP | **Reference:** | E905-010EC |
| **Title:** | Integrated GNC solution for Autonomous Mars Rendezvous and Capture | | |
| **Total Budget:** | 750 | | |
| **Objectives** | | | |
| To develop the complete design of the GNC system covering all the RVD phases of the MSR mission, capable to demonstrate the capture of a Martian canister. This will be done by reusing where applicable and further the available RVD development and experience in Europe. The complete GNC system will be designed, from the optimisation of the GNC strategies to the selection and specification of the rendezvous sensors suite, tailored to the current MSR scenari | | | |
| **Description** | | | |
| The activity shall start from past studies (incl. the 2 HARVD and Mars NEXT ones) and experiences and the GNC requirements for such systems. In particular, the synthesis and analysis of the multivariable GNC system. The design shall make use of sensors (cameras, RF sensors and LIDAR) and actuators developed in parallel activities with special emphasis on the design of the end-to-end rendezvous navigation chain for which dedicated feasibility analysis and preliminary requirements shall be provided.<br><br>Model uncertainties shall be identified, quantified and used in the design process. All the MSR rendezvous phases from finding the target in space to the capture shall be covered with the corresponding modes transition. A sofware simulation and validation platform with real-time and hardware-in-the-loop capabilities will be further developed starting from an existing one. FDIR needs and solutions shall be identified and developed to make the system failure tolerant beyond its inherent robustness by design.<br><br>Identified alternative techniques that can benefit to the success and optimisation of the MSR rendezvous strategy shall be considered to the level where comparative trade offs can be performed. This does include the study of elliptical scenarios in a dedicated WP (GNCO heritage), including an assessment of the maximal orbital parameters boundaries that can be handled by an autonomous GNC in the initial phases fo the MSR rendezvous.<br><br>Plans shall be elaborated for the development of the selected architecture for early prototyping prior to potential adoptation by a project at TRL6. | | | |
| **Deliverables** | | | |
| A fully functional GNC system for all the MSR RVD phases with all algorithms implemented on a real-time test-bench. Requirements for the MSR rendezvous sensors. A fully functional GNC performance simulator in both RT and non real time version. | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3/4 | **Target TRL:** | 5 | **Application Need/Date:** | 2012 |
| **Application Mission:** | IM | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **RF Long Range Navigation Sensor Breadboard** | | | |
|---|---|---|---|
| **Programme:** | ACP | **Reference:** | CG80 |
| **Title:** | RF Long Range Navigation Sensor Breadboard | | |
| **Total Budget:** | 300 | | |
| **Objectives** | | | |
| Design and Development of a breadboard of an RF Long Range Navigation Sensor for Long-Range Rendez-Vous stages in the Mars Sample Return. | | | |
| **Description** | | | |
| From Mars Sample Return mission analyses it has been shown that the best technology to support the Long-Range Rendez-Vous operations is the one based on RF. This activity will elaborate the necessary trade-offs to find the most suitable RF technology (transponder-like two-way ranging, Formation-Flying-like RF metrology, radar). The starting point will be the mission requirements (nominal plus a wide range of degraded mission scenarios) and a 1st-version of the technical specifications of the RF sensor. The contractor will also consolidate the technical specification based on the afore-mentioned trade-offs, and produce an architectural design. From this architectural design, a breadboard will be developed. This breadboard will be representative of the critical subsystems contained in the architectural design. The breadboard will be used by the contractor to demonstrate on the feasibility of the chosen technology and architecture for the Mars Sample Return Mission. | | | |
| **Deliverables** | | | |
| Technical Notes and breadboard to demonstrate on critical technologies. | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 1 | **Target TRL:** | 3 | **Application Need/Date:** | 2012 |
| **Application Mission:** | Mars Sample Return and missions alike with long-range Rendezvous requirements | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-7723, T-7745, T-8070 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| FF Radio Frequency Metrology. Technical Dossier and Roadmap. TEC-ETN/2007.64 | | | | | |

| **RF Long Range Navigation Sensor Breadboard** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E906-004ET |
| **Title:** | RF Long Range Navigation Sensor Breadboard | | |
| **Total Budget:** | 300 | | |
| **Objectives** | | | |
| Design and Development of a breadboard of an RF Long Range Navigation Sensor for Long-Range Rendez-Vous stages in the Mars Sample Return. | | | |
| **Description** | | | |
| From Mars Sample Return mission analyses it has been shown that the best technology to support the Long-Range Rendez-Vous operations is the one based on RF. This activity will elaborate the necessary trade-offs to find the most suitable RF technology (transponder-like two-way ranging, Formation-Flying-like RF metrology, radar). The starting point will be the mission requirements (nominal plus a wide range of degraded mission scenarios) and a 1st-version of the technical specifications of the RF sensor. The contractor will also consolidate the technical specification based on the afore-mentioned trade-offs, and produce an architectural design. From this architectural design, a breadboard will be developed. This breadboard will be representative of the critical subsystems contained in the architectural design. The breadboard will be used by the contractor to demonstrate on the feasibility of the chosen technology and architecture for the Mars Sample Return Mission. | | | |
| **Deliverables** | | | |
| Technical Notes and breadboard to demonstrate on critical technologies. | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 1 | **Target TRL:** | 3 | **Application** | 2012 |

| | | | | | |
|---|---|---|---|---|---|
| | | | | **Need/Date:** | |
| **Application Mission:** | Mars Sample Return and missions alike with long-range Rendezvous requirements | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-7723, T-7745, T-8070 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| FF Radio Frequency Metrology. Technical Dossier and Roadmap. TEC-ETN/2007.64 | | | | | |

| **RF Long-Range Navigation Sensor EM Development** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E906-005ET | |
| **Title:** | RF Long-Range Navigation Sensor EM Development | | | | |
| **Total Budget:** | 1000 | | | | |
| **Objectives** | | | | | |
| The development to Engineering Model level of a sensor able to provide long range sample canister location during MSR rendezvous. | | | | | |
| **Description** | | | | | |
| The MSR cannister of samples (target vehicle) will be launched from the Martian surface and injected in a stable orbit, with severe limitations on payload capacity and resources. Injection accuracy relative to the target vehicle waiting in orbit will be limited by the navigation means of the ascent stage, its surface location, timing and the target vehicle navigation. The target vehicle shall be then detected and tracked by an orbiter (chaser) that will subsequently performed the corresponding rendez-vous manoeuvres. In the detection of the target vehicle, a significant dispersion is expected, which will require therefore in-orbit navigation means from up to thousands of kilometers. Previous studies at mission analysis level and preparatory work for the Aurora Core Programme activity CG80 "RF Long-Range Navigation Sensor Breadboard and Engineering Model" (temporarily on hold) has shown that RF-based sensors in chaser and target vehicles are the optimal approach in order to achieve navigation across long ranges. Activity CG80 (to be shortly resumed with a re-arranged scope) targets the trade-offs, design and bread-boarding aspects. The next logical step is the development of the engineering model in the proposed activity as a follow-on of CG80. The CG80 activity (in its new scope) will achieve TRL3. The proposed activity will go from TRL3 to TRL5.<br><br>The objective of this activity is the development of the Engineering Model based of the RF Long-Range sensor based on the results of the previous Aurora CR80 activity, together with the corresponding lab testing and the necessary design consolidation. The engineering Model comprises two units. One to be installed in the chaser and the other to be installed in the target vehicle. Both units will be architecturally very different due to different nature of the platforms (chaser and target vehicle). This EM can be also used to study feasibility of the same concept for long-range rendez-vous in other planetary/Moon missions. Coordination with TEC-EC is foreseen. | | | | | |
| **Deliverables** | | | | | |
| Engineering model of the long-range RF sensor (two units: one to be on-board of orbiter and the other to be on-board of sample container vehicle). | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2018 |
| **Application Mission:** | MSR | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| FF Radio Frequency Metrology. Technical Dossier and Roadmap. TEC-ETN/2007.64 | | | | | |

| **End to end ground testing of GNC solution for Autonomous Mars Rendezvous and Capture** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E905-012EC |
| **Title:** | End to end ground testing of GNC solution for Autonomous Mars Rendezvous and Capture | | |
| **Total Budget:** | 800 | | |
| **Objectives** | | | |
| To perform an end-to-end integrated testing of the GNC system covering all the RVD and capture phases for a MSR and precursor type mission. The tests will be conducted in closed-loop in an existing dedicated ground facility, reproducing as much as possible flight-like conditions. | | | |
| **Description** | | | |
| Building on the dynamic test benches with hardware-in-the-loop capabilities developed in past studies (HARVD), the activity shall | | | |

| | | | | | |
|---|---|---|---|---|---|
| conduct ground validation campaigns of the previously developed GNC systems for Mars rendezvous. The goal will be to perform an integrated testing covering all the phases of the MSR rendezvous: search & detection, homing and terminal rendezvous in a representative dynamics environment and using mature GNC avionics. | | | | | |
| **Deliverables** | | | | | |
| Open and closed-loop tests results. Validated rendezvous system in a ground representative environment. | | | | | |
| **Current TRL:** | 5 | **Target TRL:** | 6 | **Application Need/Date:** | 2015 |
| **Application Mission:** | IM,MSR | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Sample Canister Capture Mechanism Design and Breadboard** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ACP | | **Reference:** | CG50 | |
| **Title:** | Sample Canister Capture Mechanism Design and Breadboard | | | | |
| **Total Budget:** | 350 | | | | |
| **Objectives** | | | | | |
| Develop alternatives concepts and BBM testing of a MSR capture mechanism (CM), not involving inflatable structures. | | | | | |
| **Description** | | | | | |
| The Mars Sample Return (MSR) mission will send a Lander to Mars, to acquire samples of Martian soil and return them to Earth. During the return phase, a Sample Container (SC) carried by a Mars Ascent Vehicle (MAV) shall be transferred to a Mars Orbiter and then to the Earth Return Capsule (ERC). The Phase A2 MSR system studies consider that the transfer of the SC from the MAV to the Orbiter could be performed either by Capture or by Docking, i.e. with:<br>- a Capture mechanism (CM), catching a free-flying, passive SC,<br>- a Docking mechanism (DM), mating the MAV on the Orbiter to take the SC.<br>In the capture scenario, the SC (quasi-spherical) will be released by the MAV into a free flying Mars orbit. The Orbiter will manoeuvre to approach the incoming SC with adequate position, velocity and attitude and the SC will be captured by the CM. The CM will transfer the captured SC through its outlet toward the trap, an enclosure in the Orbiter, in which it will be secured; from the trap, subsequent SC processing operations will be performed by other subsystems - essentially bio-sealing and transfer to the ERC.<br>In a previous ESA activity (Aurora Capture / Docking Mechanism - ACDM) a conceptual study of CM and DM candidates was carried out, and an Inflatable Capture mechanism (ICM), with a rigid frame, was selected and developed: a Breadboard Model was built and tested successfully on ground at ambient. In a follow-on ESA activity (Capture / Docking Mechanism Testing), a modified, fully inflatable ICM was developed at EM level for TV testing: following successful functional testing at ambient, the inflatable envelope was found leaking in several places after vibration testing; eventually, thermal vacuum testing could not be performed.<br><br>The aim of this activity is to investigate alternatives concepts for the CM, not involving inflatable structures. Relevant earlier concepts from ACDM will be revisited. A BBM with 0-g simulation GSE for SC will be tested in laboratory environment.<br><br>Follow-on activities will be proposed, to develop the CM up to TRL 5, including thermal vacuum (TV) and parabolic flight (PF) testing.<br><br>Note: the requirements of a CM with limited stowed volume imposed a deployable capture cone, which later favoured the selection of an inflatable CM. Alternatively, allowing a larger stowed envelope, a simpler CM with a solid, non-deployable capture cone has been developed for NASA-JPL by Honeybee Robotics and successfully tested in parabolic flight. A similar increase of the CM stowed envelope requirement would be beneficial for simplicity and mass. | | | | | |
| **Deliverables** | | | | | |
| BBM of CM, SC GSE ejection device with 0-g simulation, electronics, harness and required mechanical and electrical GSE for laboratory testing. | | | | | |
| **Current TRL:** | 2/3 | **Target TRL:** | 4 | **Application Need/Date:** | 2012 |
| **Application Mission:** | MSR | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| Sample canister capture mechanism parabolic flight test | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E915-005MS | |
| **Title:** | Sample canister capture mechanism parabolic flight test | | | | |
| **Total Budget:** | 150 | | | | |
| **Objectives** | | | | | |
| Parabolic Flight testing of a non-inflatable sample capture mechanism breadboard for automated Mars orbit rendezvous | | | | | |
| **Description** | | | | | |
| The current baseline for a MSR mission requires a rendezvous of the Mars orbiter with the Mars Ascent Vehicle (MAV) or free-flying Sample Container (SC) to capture and transfer the SC to the Earth Return Capsule (ERC). A previous activity under the Aurora Core Programme (CG50) will have developed a breadboard of a non-inflatable sample canister capture mechanism.<br><br>This activity is aimed at parabolic flight testing of the breadboard to demonstrate the terminal phase of autonomous sample capture during Mars orbit rendezvous. The contractor shall be responsible of relations with the French Centre d'essais en vol and with Novespace for the organization of a parabolic flight test campaign. | | | | | |
| **Deliverables** | | | | | |
| Test results from parabolic flight test campaign of the capture mechanism breadboard. | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 4 | **Application Need/Date:** | 2012 |
| **Application Mission:** | MSR | | **Contract Duration:** | 6 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| Improvement of Delta DOR performances for 1 nrad accuracy for precise landing support | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T912-001GS |
| **Title:** | Improvement of Delta DOR performances for 1 nrad accuracy for precise landing support | | |
| **Total Budget:** | 250 | | |
| **Objectives** | | | |
| The main objectives are<br>1) To evaluate the technological enhancements needed to improve the accuracy of the Delta-DOR system to the 1 nrad level, either by<br>enhancing the current Delta-DOR system or by using alternative satellite signal structure (e.g. spread-spectrum technique to increase<br>the similarity between the satellite downlink signal and the quasar calibrator) to perform the measurement.<br>2) To define the proper on-board and ground architectures<br>3) To simulate critical components of the system (on-board TT&C and on ground correlator) for spread spectrum signal. | | | |
| **Description** | | | |
| The precise knowledge of the S/C state at separation from the lander on MSR imposes strict navigation requirements especially on Delta-DOR. The target angular accuracy would be in the order of 1 nrad in the satellite localisation in the plane of sky. The feasibility of such level of accurcay has been partially investigated in the frame of a previous GSP activity (" Interdisciplinary study on enhancement of end-to-end accuracy for spacecraft tracking techniques"). Here it is proposed to address specifically the possibility to reach 1 nrad accuracy (in X- and Ka-band) with either technological improvements on the current systems or via development of alternative technologies in terms of S/C signal structure to be used for Delta-DOR measurements. The study shall therefore:<br>1) Evaluate the technological developments needed to enhance the current Delta-DOR system to the 1 nrad level<br>2) Evaluate possible alternatives on the S/C signal structure that could lead to the same (or better) level of accuracy. One of the solutions proposed in the previous GSP activity was to have the spacecraft transmitting a spread spectrum DOR signal over a bandwidth broadened to 152 MHz in the 34.2-34.7 GHz band (Ka-Band). This choice makes the spacecraft and the quasar signals very similar, thus maximizing the noise canceling effect of the interferometry measurement. Moreover, by adopting a spread spectrum DOR signal, the group delay ripple is reduced by a factor of 10, without the necessity of any particular calibration technique. In this case the DDOR correlator software has to be able to handle the de-spreading of the spread spectrum range signal. As part of the study the selection for the most appropriate spread spectrum modulation scheme will be traded off based on performance as well as available technology in the on-board domain. Simulations of the on-board and on-ground process shall be undertaken to demonstrate the feasibility of the concept and identify critical areas in the development<br>3) Trade off between solutions shall be provided with the final recommendation | | | |

| Deliverables | | | | | |
|---|---|---|---|---|---|
| * Technical documentation (design, trade-off)<br>* Simulators of on-board and on-ground enhanced Delta DOR systems. | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2018 |
| **Application Mission:** | MSR, Precision landing missions | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| Planetary communication system based on modulated retro-reflection | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T916-003MM | |
| **Title:** | Planetary communication system based on modulated retro-reflection | | | | |
| **Total Budget:** | 300 | | | | |
| **Objectives** | | | | | |
| The objective of this activity is to develop a laser communication system in which one partner terminal is extremely miniaturised in terms of size, mass and power consumption by using modulated retro-reflection of the light received. | | | | | |
| **Description** | | | | | |
| A low-power principle of laser communications between a Mars lander and an orbiter can be applied optically by modulating the reflectivity of a corner-cube or cat's-eye retro-reflector situated on the lander.<br><br>This type of optical communication system enables one terminal to be extremely small and lightweight with very low power consumption (required only for the modulation system). The outgoing laser beam can also be modulated (at a different frequency) enabling bidirectional communications. However, the maximum link distance is only in the order of a couple of hundred km, because the link budget drops with the fourth power of distance, which also limits the achievable data rate. Retro-reflectors require no pointing system, but for hemispherical coverage a retro-reflector array is necessary.<br><br>Several institutes are investigating the use of modulated retro-reflection systems for laser communication applications in asymmetrical link arrangements, where one partner terminal is located on a platform on which mass, volume and power consumption must be minimised, such as on planetary landers/rovers or sample-return missions.<br>The Contractor needs to have experience with modulated retro-reflector systems, but shall first investigate the latest results from literature. In addition he will identify the space missions/applications for which such a system could be beneficial. He shall then design an optimised system and develop a breadboard prototype and test it in a relevant environment. | | | | | |
| **Deliverables** | | | | | |
| Breadboard of a transceiver and a retro-reflection system for low-power communication | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2015 |
| **Application Mission:** | MSR, INSPIRE | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| Enhanced interplanetary meteoroid population model | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T904-003EE |
| **Title:** | Enhanced interplanetary meteoroid population model | | |
| **Total Budget:** | 300 | | |
| **Objectives** | | | |
| The main objective of the activity is the development of an enhanced meteoroid environment model that can be used for impact risk assessments for space missions in near-Earth and interplanetary space (applicable for heliospheric distanced of 0.05 to 10AU with main application being Near-Earth space from approx. 0.7 to 2AU).<br><br>The model shall compute number density, impact flux/ fluency, velocity (heliocentric and relative to spacecraft), impact angle | | | |

| | | | | | |
|---|---|---|---|---|---|
| distribution, and imparted linear momentum as a function of meteoroid mass. It shall cover the mass range 10-15 g to 100 gram. | | | | | |
| **Description** | | | | | |
| Every spacecraft in orbit is impacted by meteoroids. Because of their high velocity (10-70 km/s) even sub-millimetre sized particles can damage spacecraft partsand potentially disable spacecraft functions. Existing meteoroid flux models that can be apllied outside of Erath orbit are only at prototype state and have uncertainties of the flux at a given mass of a factor 5-10 even for the Mars distance. Such an uncertainty can lead to overdesign or an unacceptable large risk.<br>The interplanetary meteoroid environment consists of 3 main populations: The sporadic or background population, the stream population, and the interstellar population For most orbits and times the sporadic population is dominant. In recent years new data have become available, mainly radar and optical observations, have become available and the production process of meteoroids (mainly from comets) has been better understood. The new data and understanding should now allow to produce an enhanced interplanetary meteoroid population model. The new observational data shall be analysed, preprocessed and assessed for consistancy and suitability as input for a new model. This data reduction shall consider the experinec gained during the IMEX study (ESA contr. 4000106316) which addresses meteoroid streams. In a second step a computer based model shall be developed that predicts the meteorid fluxes for user specified interplanetary orbits, mission durations, target orientations and size and velocity ranges. The model shall include all known meteoroid populations. | | | | | |
| **Deliverables** | | | | | |
| Softwaae and related documentation of the developed enhanced interplanetary meteoroid model | | | | | |
| **Current TRL:** | SW | **Target TRL:** | SW | **Application Need/Date:** | 2015 |
| **Application Mission:** | Interplanetary missions from Mercury to Saturn | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Micro Meteorids and Orbital Debris (MMOD) impacts characterisation and protection for the MSR Earth Re-entry Capsule (ERC)** | | | | | |
| **Programme:** | ETP | | **Reference:** | E904-004FP | |
| **Title:** | Micro Meteorids and Orbital Debris (MMOD) impacts characterisation and protection for the MSR Earth Re-entry Capsule (ERC) | | | | |
| **Total Budget:** | 700 | | | | |
| **Objectives** | | | | | |
| The objectives of this activity are:<br>- to characterise MMODs impacts on the ERC Thermal Protection System (TPS) and define associated impact equations<br>- to verify the thermal behaviour of impacted TPS<br>- to develop a Micrometeorids detection system breadboard to be incorporated on the ERC TPS, | | | | | |
| **Description** | | | | | |
| The ERC is a critical element of the MSR mission since a failure during re-entry or landing would lead to a possible release of Martian particles into the Earth biosphere, which is unacceptable for Planetary Protection. Consequently a very high reliability must be demonstrated, including for the TPS which is a single point failure. Previous studies have shown that MMOD impacts are a critical event for the TPS performance. This activity focuses on MMOD impact mitigation and is divided in 2 phases:<br><br>Phase 1:<br>- perform high velocity impact tests with MMOD-like particles (mean micrometeorids velocity being about 15 Km/s) on TPS samples of 1 or 2 sorts (low density and high density). Some tests shall include an ERC cover simulator (this cover is foreseen to protect the ERC from the less energetic micrometeorids)<br>- derive impact equations to be used in future studies<br>- perform high enthalpy tests on impacted TPS samples to assess their performance, and from there refine the requirements on critical MMODs<br><br>Phase 2:<br>- starting from the phase 1 results, derive requirements for a micrometeorid (MM) detector system (MDS) that has been proposed in previous studies in order to detect the higher energy MM that perforate the TPS despite the ERC cover. This detector allows to reduce the mass of the ERC cover to an acceptable level, while fulfilling the Planetary Protection requirements with a very low probability of mission loss<br>- design and build an MDS breadboard<br>- verify the MDS breadboard performance using MM impact tests | | | | | |
| **Deliverables** | | | | | |
| TPS samples, MDS breadboard, tests numerical data, technical reports | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application** | 2018 |

| | | | | | |
|---|---|---|---|---|---|
| | | | | **Need/Date:** | |
| **Application Mission:** | MSR | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Aerobraking Flight Representative Demonstrator** | | | | | |
| **Programme:** | ETP | | **Reference:** | E905-001EC | |
| **Title:** | Aerobraking Flight Representative Demonstrator | | | | |
| **Total Budget:** | 350 | | | | |
| **Objectives** | | | | | |
| The main objectives of the activity is to implement a AOCS/GNC & avionics demonstrator to evaluate in a flight-representative environment Aerobraking Strategies in preparation of IM1, IM2 and subsequent missions. | | | | | |
| **Description** | | | | | |
| The activity consists in developing a flight-representative Aerobraking demonstrator, in order to support the real-time evaluation of Aerobraking Strategies as analyzed and designed in the activity "Robust Autonomous Aerobraking Strategies" (ref T305-031EC), assess their adequation with mission requirements, to support the preparation of their subsequent implementation on IM 1 and/or 2, and following missions.<br>In that purpose, following tasks will be carried on :<br>- detailed design of relevant AOCS/GNC algorithms (including Aerobraking algorithms) and their implementation on a flight-representative processor<br>- detailed HW design of the avionics subsystem, including flight-representative communications (protocols, delays, signal attenuation)<br>- detailed Aerobraking FDIR design to validate failure detection, isolation and reconfiguration in Aerobraking contingency cases.<br>- detailed design of Dynamics, Kinematics, Environment and Sensor Models for their implementation on a real-time kernel (like dSpace)<br>Note : the avionics detailed design will be based on ESA Reference Avionics System Architecture for exploration (RASTA).<br>AOCS/GNC testbench based on RASTA kernel and dSpace-like real-time environment<br>A set of flight-representative AOCS/GNC SW covering Aerobraking strategies as selected in the activity "Robust Autonomous Aerobraking Strategies" (ref T305-031EC)<br>Technical Documentation according to ECSS-E40 tailored for this application. | | | | | |
| **Deliverables** | | | | | |
| | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 4 | **Application Need/Date:** | TRL 5 by 2018 |
| **Application Mission:** | MSR | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | |
|---|---|---|---|
| **Design of a crushable TPS for the ERC** | | | |
| **Programme:** | TRP | **Reference:** | T319-036MC |
| **Title:** | Design of a crushable TPS for the ERC | | |
| **Total Budget:** | 370 | | |
| **Objectives** | | | |
| The objective of the proposed activity is to investigate ways of building a multifunctional structure, that acts as a heatshield for planetary re-entry (supporting Thermal Protection System, TPS), but also brings damping capability for hard landing. | | | |
| **Description** | | | |
| For the re-entry phase, the TPS is sized to limit the temperature on the inner side of the lander, i.e. a thermal insulation is needed between the external surface and the inside "cold" structure and payload. During the hard landing phase, mechanical decoupling is needed between the external surface that hits the ground at high velocity and the inner payload for which deceleration load shall be limited. This dual thermal/mechanical insulation need leads to the idea of using one single structure, possibly a composite made of | | | |

| | | | | | |
|---|---|---|---|---|---|
| several materials, e.g. CFRP foam, honeycomb or the titanium hollow spheres to be developed, to achieve both isolation functions. Such a multifunctional structure would allow simplifying the lander architecture, reducing the number of sub-assemblies and thus reducing the mass and complexity.<br>- Review of the MSR requirements for heatshield and earth impact after re-entry.<br>- Investigate solutions to combine the structural/thermal and impact damping functions of the heatshield. Identify the material characteristics needed and potential candidates, including foams, honeycomb and hollow spheres. Trade-off the solutions.<br>- Provide a material specification as input for the activity on low conductivity/high temperature crushable material using hollow spheres<br>- Design and analyses of a MSR integrated heatshield and earth impact damping structure, possibly using titanium hollow spheres if this material proves best suited and sufficiently mature.<br>- Manufacturing and impact tests of a breadboard (several might be needed for several destructive tests). | | | | | |
| **Deliverables** | | | | | |
| Documentation (Final Report, Summary Report, and Technical Data Package, incl. Photographic Documentation ).<br>Hardware (breadboard). | | | | | |
| **Current TRL:** | 1 | **Target TRL:** | 3 | **Application Need/Date:** | 2012 |
| **Application Mission:** | NEXT, MSR (>2016) | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | High Speed Earth Re-Entry of Sample Capsules: Advanced Heat Shield Concepts | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| N/A | | | | | |

| **Material development for a crushable TPS for the ERC** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T920-002QT | |
| **Title:** | Material development for a crushable TPS for the ERC | | | | |
| **Total Budget:** | 250 | | | | |
| **Objectives** | | | | | |
| To establish manufacturing technology and scale-up of crushable hollow-sphere made of Ti alloy for use in a crushable TPS for Earth landing during an MSR mission. To characterise the static and dynamic mechanical properties of the material, as well as the physical and chemical properties. To develop and characterise joining techniques of the Ti alloy hollow-sphere to conventional materials used in space applications. | | | | | |
| **Description** | | | | | |
| The crushable materials are today either honeycomb or polymeric (or carbon) foams. The honeycomb can sustain only compressive stresses and looses its effectiveness when stressed in the nominal direction, the foam are limited to low temperature or procured outside Europe.<br>In this activity, the pure Ti hollow-sphere technology (contract 18167) will be transferred to a high performance Ti alloy. The mechanical and physical characteristics of the material will be established at high and room temperature, the technologies for joining the Ti hollow-sphere to other materials will be developed and characterised.<br><br>This material is theoretically far better than any existing ones for such passive landing applications as it combines high specific stroke properties with high in-service temperature (about 600C) and a low thermal conductivity. | | | | | |
| **Deliverables** | | | | | |
| Technical notes - Test samples - Test reports - Breadboard - industrial development roadmap | | | | | |
| **Current TRL:** | 2/3 | **Target TRL:** | 3/4 | **Application Need/Date:** | 2012 |
| **Application Mission:** | MSR | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8148 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Delta-development of TPS for high heat loads** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E921-002PA |
| **Title:** | Delta-development of TPS for high heat loads | | |

| | | | | | |
|---|---|---|---|---|---|
| **Total Budget:** | 700 | | | | |
| **Objectives** | | | | | |
| The objective is to complete the development, and subsequently characterise and pre-qualify a European ablative heatshield TPS material for the Earth re-entry capsule, able to cope with the stringent environment (typical peak heat fluxes of 15-20MW/m2 and heat loads up to 200MJ/m2) while conforming to the mass budget. The development shall be based on the material developed in a previous TRP-activity. The pre-qualification shall include an extensive plasma test campaign. | | | | | |
| **Description** | | | | | |
| This activity shall also investigate aerodynamics issues such as static, dynamic stability, etc. and thus include wind tunnel tests with a representative demonstrator of the MSR re-entry capsule (on which the selected TPS material can be mounted) at different flight regimes taking into account ablation and pyrolysis effects which should be an outcome of the ablative material characterization phase described above.<br><br>The TRL shall be brought from 4 to 5 during this activity.<br><br>Technology Heritage<br>1) Low-density TPS - TRP activity: “Development of a European Ablative Material” (DEAM). The ongoing activity will prepare the ground (requirements consolidation, development of manufacturing routes, preliminary material development and characterisation). The activity proposed here will represent the logical follow-on to complete the material development and pre-qualification.<br>2) High-density TPS - SEPCORE concept (1990’s CNSR development), ARD and military applications (restricted access to the data) | | | | | |
| **Deliverables** | | | | | |
| Material samples, documentation | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 5 | **Application Need/Date:** | 2013 |
| **Application Mission:** | MSR | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8283, T-8538 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Adaptation of TPS materials of High-density for High Heat load (AT3H) re-entry applications** | | | | | |
| **Programme:** | ETP | | **Reference:** | E921-003PA | |
| **Title:** | Adaptation of TPS materials of High-density for High Heat load (AT3H) re-entry applications | | | | |
| **Total Budget:** | 300 | | | | |
| **Objectives** | | | | | |
| A lightweight high heat load material is being developed in a parallel activity (E921-002PA). Due to the very demanding reliability needs for the MSR mission, there is the need to assess all possible TPS options. The objective is to adapt existing highly reliable TPS materials for high heat loads to the need of high speed Earth re-entry for very demanding missions such as Mars Sample return | | | | | |
| **Description** | | | | | |
| High-density TPS materials (e.g. Carbon Phenolic) lead to a large mass penalty for sample return missions. However, they are often flown in military applications in very harsh thermal environment and thus have a large data record, decreasing overall risk, and some of them have flown in space projects (albeit with a milder environment, e.g. Carbon Phenolic on Ariane nozzles or Aleastrasil on ARD). A high-density material which fits best with sample return applications will be characterised. Its use in high speed Earth re-entry applications will be assessed. Adaptations of the existing material should be limited to the minimum to keep the flight data record as relevant as possible for risk analysis purposes. The reliability of the manufacturing processes will also be assessed. A major part of this activity will consist in testing this material in the relevant environment (heat fluxes of 15-20 MW/m2 and heat loads up to 200 MJ/m2) mostly at sample level and to perform a risk analysis of the TPS reliability which will be fed by the results of this test campaign. Testing will also cover the simulation of a re-entry after micrometeoroid impacts.<br><br>Technology heritage: high-density TPS - SEPCORE concept (90's, CNSR development), ARD and military applications. | | | | | |
| **Deliverables** | | | | | |
| Material samples, test results, documentation | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 4 | **Application Need/Date:** | TRL 5 by 2015 |
| **Application Mission:** | MSR, Moon of Mars sample return, MarcoPolo-R | | **Contract Duration:** | 15 | |
| **S/W Clause:** | N/A | | **Reference to** | | |

| | | | |
|---|---|---|---|
| | | **ESTER** | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | |
| | | | |

| **Ablative TPS Numerical Test Cases - Mathematical Code Assessment & Improvement** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | GSTP | | **Reference:** | G921-007MT | |
| **Title:** | Ablative TPS Numerical Test Cases - Mathematical Code Assessment & Improvement | | | | |
| **Total Budget:** | 300 | | | | |
| **Objectives** | | | | | |
| To assess the reliability of the mathematical codes used to size the thickness of ablative TPS on entry heatshields; to refine and possibly reduce the related uncertainties; and to identify relevant areas to improve the codes. | | | | | |
| **Description** | | | | | |
| In the frame of the European Ablation Working Group, several simplified numerical ablation test cases have been defined and were used by different partners to assess the performance of available codes for ablative TPS sizing. Those test cases were based on literature data which, however, turned out to be incomplete and in several aspects not consistent. Missing data had to be complemented by assumptions, which strongly limited the suitability of the derived test cases to assess the performance of the mathematical codes used for ablative TPS sizing.<br><br>In recent years a new European lightweight ablative material has been developed (TRP-DEAM, MREP-DEAM2) specifically tailored for the Earth return capsule of sample return missions. Also for this new material, now called ASTERM, material and test data cannot be made openly available due to industrial confidentiality aspects. However, a similar material exists, called AQ61, which in its physical composition and performance is very similar to ASTERM, but due to its more complicated manufacturing process is not considered as candidate for relevant flight applications. Within a previous TRP (Thermal Response Characterisation of Reference TPS Material) a dedicated set of plasma tests has been performed which are intended to be used now to establish numerical test cases based on real test data.<br><br>While also a basic set of material characteristics of AQ61 is available, material characterisation will have to be completed as part of this activity.<br><br>In order to rebuild the numerical test case, an integrated solution for charring ablators (including thermo-chemistry), is needed. This can be achieved by the coupling (exchange by files or on the fly evaluation of properties) of a response code for charring ablators with a code for equilibrium chemistry calculations. In order to rebuild the plasma test, the thermal response code must be capable of modelling the test specimen (an axis-symmetric model), and the chemistry code must have the capabilities to model the charring materials used in real ablators (like AQ61, MONA, ASTERM, ...).<br><br>The following work is to be conducted in this activity:<br>- Establish a booklet with a set of numerical ablation test cases based on available plasma test results of the AQ61 material<br>- Where necessary the available data shall be complemented by relevant additional material characterisation<br>- Coupling of a response code for charring ablators with a code for equilibrium chemistry calculations<br>- Model and run the above test cases with at least three of the ablative TPS sizing codes available in Europe<br>- Compare the results with the available plasma test data, assess the code/model performance and identify the weaknesses of the used codes<br>- Derive relevant uncertainties based on the test cases and extrapolate these uncertainties to relevant entry analysis<br>- Identify relevant code improvements and code delta-development<br><br>The booklet shall be established in progressive steps, starting from a simple test case which is iteratively increasing in complexity. E.g. the ablation-chemistry coupling would be an element of an advanced iteration. | | | | | |
| **Deliverables** | | | | | |
| - Booklet with the definition of a set of numerical test cases.<br>-Technical Notes on material characterisation, test case results and code assessment | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2016 |
| **Application Mission:** | Sample return missions; | | **Contract Duration:** | 20 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8282, T-8277 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Activity identified in D/TEC technology roadmap | | | | | |

| **Deployable & Inflatable Heatshield & Hypersonic Decelerator Concepts - Phase 1** |
|---|

| | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T921-005MT |
| **Title:** | Deployable & Inflatable Heatshield & Hypersonic Decelerator Concepts - Phase 1 | | |
| **Total Budget:** | 400 | | |

**Objectives**

To review the European capabilities in terms of deployable and inflatable heatshield and hypersonic decelerator technologies and to assess the potential which such technologies might bring to enable new mission concepts for Mars exploration. Eventually to initiate development of the main technological elements of the concept identified as most suited for Europe.

**Description**

Europe has previously invested in early development of inflatable decelerator technology which resulted in a partially successful flight demonstration (IRDT). This technology has strong potential for enabling new Mars mission concepts and is therefore proposed for further investigation.

Very significant effort was spent by NASA in recent years on related technologies (hypersonic inflatable decelerators, mechanically deployable structures, multi-functional carbon fabrics for deployable heatshields, etc.). It is not viable for Europe to embark on similar developments in all of these fields, therefore it is recommend to initiate first a technology assessment to downselect the most promising concepts for future missions.

The objectives of this activity shall be achieved through the following steps:

- Identify and study different inflatable and deployable heatshield & hypersonic aerodynamic decelerator concepts for atmospheric entry probes, and to assess their potential benefits for potential future Mars exploration missions. In particular, it shall be identified which missions such technologies could enable which are today considered not feasible.
- Review the related technological elements available in Europe, and assess their maturity for a relevant mission application. The required key technologies shall be identified, existing solutions be assessed and any required delta-development be identified. The expected technological limits shall be identified.
- Perform a trade-off on the various concepts considering the expected benefit/interest for future missions and the required development effort and risks.
- At system level the following aspects will have to be considered: Packing, configuration, aerodynamic stability, potential separation strategies.
- The technologies to be specifically assessed shall include high temperature fabrics, deployment and inflation mechanisms and integration of the TPS material.

The heatshields used so far for entry probes of planetary exploration missions are based on a thermal protection system on a rigid structure. The heatshield typically also acts as hypersonic decelerator. While its dimension is typically limited by geometrical constraints, like e.g. the fairing of the launcher, enlarging the hypersonic decelerator would allow to significantly reduce the ballistic coefficient and thereby the loads experienced by the heatshield during the atmospheric entry.

Deployable and inflatable heatshield concepts have therefore moved in the focus of interest in recent years. Such technology might enable future planetary exploration missions which are not feasible today, e.g. increased landed P/L masses or currently unreachable (higher altitude) landing sites on Mars.

**Deliverables**

Study reports (technological review, mission & application assessment, trade-off)

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 1-2 | **Target TRL:** | 3-4 | **Application Need/Date:** | 2018 |
| **Application Mission:** | Future planetary exploration missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8079, T-7906, T-7879, T-8142 | |

**Consistency with Harmonisation Roadmap and conclusion:**

Consistent with D/TEC technology roadmap

**Standard kinetic models for CO2 dissociating flows**

| | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T918-006MP |
| **Title:** | Standard kinetic models for CO2 dissociating flows | | |
| **Total Budget:** | 500 | | |

**Objectives**

The objective of this activity is to provide an ESA standard model for Mars entry chemistry. As a first step, the study will focus on pure $CO_2$ reactions, including relaxation of internal degrees of freedom (vibration,...)

**Description**

Mars atmosphere consists in a mixture of $CO_2$ (approximately 95%), $N_2$, Ar and traces of other species. When a probe enters Mars

| |
|---|
| atmosphere at hypersonic speed, the atmospheric gas mixture is heated and chemical reactions occur (dissociation, ionisation...).<br>The design of the heat shield requires the knowledge of the distribution of heat flux, pressure and shear stress at its surface, that depends on the chemical and physical state of the surrounding gas.<br>Chemical and vibrational rates are needed for the numerical prediction of the flow properties. They are best provided by processing results of numerous tests in kinetic shock tubes. ESA has developed a facility dedicated to this problem.<br>The work shall focus on CO2 pure gas, but the influence of the presence of N2 and Ar shall also be preliminary assessed. It is expected to involve mostly experimental work in shock tube(s), but also numerical and analytical work shall be required:<br>Part of the work shall be to perform by emission/absorption measurements in a shock tube giving ground state and most important excited states populations at high temperature. LIF (Laser Induced Fluorescence) measurements shall also be investigated, for their applicability in such short duration flows.<br>The electronic densities and temperatures shall also be measured.<br>A two spectrometer approach for the emission spectroscopy is recommended, so to identify the important bands, and to investigate particular bands at high resolution.<br>Ab initio calculations (Molecular Dynamics/Schrodinger if required) shall be performed for the most critical chemical rates.<br>The results of the shock tube tests and of ab-initio calculations shall be collected, to develop a high-fidelity chemical and vibrational kinetic scheme for CO2 mixture.<br>Different levels of modelling shall be included in the standard kinetic model developed within this activity, including Collisional Radiative (excited state specific) and State to State (vibrational state specific) data.<br>The final result of the activity is the recommendation of standard chemical kinetics schemes for CO2, with the associated reaction rates and assessment of confidence/uncertainties. |
| **Deliverables** |
| Reports. Experimental data in electronic format (Data Base) and numerical data and associated models also in electronic format to allow future comparisons and/or benchmark tests. ESA standard kinetic models for CO2 mixtures chemistry, ionisation and vibrational relaxation. |

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2023 |
| **Application Mission:** | MREP | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8090, T-8089 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| ATD Harmonisation 2012 | | | | | |

| **Catalytic properties of Ablators** | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T918-004MP |
| **Title:** | Catalytic properties of Ablators | | |
| **Total Budget:** | 500 | | |
| **Objectives** | | | |
| The objective of this activity is to determine the catalytic properties of ablators materials in the VKI Plasmatron facility and to derive<br>corresponding physical models for implementation in CFD codes. | | | |
| **Description** | | | |
| Ablative thermal protection materials are the most critical parts of the thermal protection systems for hypersonic applications that face high velocity (7~10 km/s) atmospheric entry. The thermal protection systems experience very complex interconnected phenomena during a re-entry flight. Their design and improvement require suitable ground testing associated with dedicated measurement techniques. One of the most important measurement techniques is the accurate measurement of material temperature. Further, together with catalycity, emissivity is another important surface properties to be determined. Also, for ablating thermal protection materials, accurate measurement of the recession rate is a critical task for the characterization and proper modelling of the ablative materials. Here is proposed to use optical techniques (such as high speed and/or high-definition cameras) and associated post-<br>processing techniques to calculate the recession rate of the ablative samples exposed to plasma flow.<br><br>Finally, an uncertainty quantification will be performed of both the enthalpy reconstruction and the whole loop enthalpy reconstruction + catalycity identification. An identification of parameters which have a critical impact on the catalycity estimation will be performed. The study would also involve an uncertainty quantification on the gas reaction. In this case the rate constants would be the uncertainty parameters. The existence of correlations between the gas reactions and how the enthalpy or catalycity are influenced by change in the reaction rate coefficients is of large interest. Also, the influence of the diffusion modelling on the identification of the catalytic properties of the material shall be investigated.<br><br>The models employed in the computer codes will be upgraded based on the results of the present investigation. | | | |
| **Deliverables** | | | |
| Reports including test plan, test data, numerical reconstruction and assessment of the results. Experimental data in electronic format | | | |

| | | | | | |
|---|---|---|---|---|---|
| (Data Base) and numerical data and associated models also in electronic format to allow future comparisons and/or benchmark tests. | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2023 |
| **Application Mission:** | MSR, Phootprint and Marco Polo-R | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-7902, T-7897, T-8094, T-8090 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Software Defined Radio Proximity-1 Link Communications Package design Study** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T906-002ET | |
| **Title:** | Software Defined Radio Proximity-1 Link Communications Package design Study | | | | |
| **Total Budget:** | 300 | | | | |
| **Objectives** | | | | | |
| The objective of this activity is to investigate the implementation of a flexible and multimission data-relay communication package based on CCSDS Proximity-1 protocol using software defined radio as the enabling technology. | | | | | |
| **Description** | | | | | |
| The current European proximity-link transceivers (as developed in the previous ESA missions, for instance Beagle) are limited in flexibility as they are based on a low level of integration between the RF and the digital part. Using the Software Defined Radio technology (similar to that implemented by NASA/JPL for the Electra transceiver) allows a higher level of flexibility with the possibility of unit reconfiguration. Using the software defined approach provides the capability to add/change functionality by simply changing the software version. This software upload (software patch) can be done pre-launch or in orbit, which makes the unit very flexible and provides the capability to support multiple missions.<br><br>This multimission approach is particularly interesting in case of an Orbiter with data-relay capabilities and a long lifetime (such as Mars Express). This way it can support different lander missions (European, American and other international space agencies) even the ones it wasn't intended to serve in the first place. Allowing post-launch reconfigurability of the protocol and signal processing functions over the Orbiter lifetime supports protocol updates and provides the possibility to respond to unanticipated mission scenarios. Secondly, by ensuring a standardised and interoperable data-relay infrastructure allows any lander to make use of multiple data-relay assets, thereby increasing the science return while at the same time reducing mass and power requirements on the lander. The ultimate goal would be to equip every science Orbiter with a standardised relay package, taking away some of the technology burden of small lander missions.<br><br>The scope of the activity is to study the implementation of a reprogrammable Proximity-1 transponder based on a software defined radio architecture. The transponder shall support the Proximity-1 protocol in its entirety including support for full duplex operation. The transmit and receive carrier frequencies shall be programmable (by software uploads) to any frequency in the range used by the Proximity-1 protocol (i.e. 390 - 450 MHz). The transponder shall be designed in a modular manner that allows tailoring of the basic transponder to future missions. The proximity-link transponder to be developed shall implement different modes, e.g.only sampling, demodulation, etc. to support the EDL and rendezvous and capture mission modes, it shall also support higher data-rates than those currently available on European hardware, in order to increase the science return. Consideration shall be given to the architecture proposed in order to reduce mass, power and volume envelopes as much as possible.<br><br>The contractor shall implement the most critical functionalities in a breadboard. | | | | | |
| **Deliverables** | | | | | |
| TN's, Final Report, breadboard | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | >2016 |
| **Application Mission:** | MSR, future exploration missions | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8744 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Harmonization Dossier "TT&C Transponders and Payload Data Transmitters" 2012. | | | | | |

| **Software Defined Radio Proximity-1 Link Communications Package design EQM** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E906-007ET |
| **Title:** | Software Defined Radio Proximity-1 Link Communications Package design EQM | | |

| | | | | | |
|---|---|---|---|---|---|
| **Total Budget:** | 2500 | | | | |
| **Objectives** | | | | | |
| The objective of this activity is to develop a qualification model of a flexible and multimission data-relay communication package based on CCSDS Proximity-1 protocol using software defined radio as the enabling technology. | | | | | |
| **Description** | | | | | |
| The activity is a follow on of the TRP activity: Software Defined Radio Proximity-1 Link Communications Package design Study There is currently no equipment available in the European market to cover future missions needs. The Exomars orbiter mission will implement the Electra (CFI provided by NASA). The only proximity-link transceivers was developed for the Beagle misssion, this unit is considered obsolete and was very limited in performance and flexibility.<br><br>Using the Software Defined Radio technology (similar to that implemented by NASA/JPL for the Electra transceiver) allows a higher level of flexibility with the possibility of unit reconfiguration. Using the software defined approach provides the capability to add/change functionality by simply changing the software version. This software upload (software patch) can be done pre-launch or in orbit, which makes the unit very flexible and provides the capability to support multiple missions.<br><br>This multimission approach is particularly interesting in case of an Orbiter with data-relay capabilities and a long lifetime (such as most exploration orbiter missions). This way it can support different lander missions (European, American and other international space agencies) even the ones it wasn't intended to serve in the first place. Allowing post-launch reconfigurability of the protocol and signal processing functions over the Orbiter lifetime supports protocol updates and provides the possibility to respond to unanticipated mission scenarios. Secondly, by ensuring a standardised and interoperable data-relay infrastructure allows any lander to make use of multiple data-relay assets, thereby increasing the science return while at the same time reducing mass and power requirements on the lander. The ultimate goal would be to equip every science Orbiter with a standardised relay package, taking away some of the technology burden of small lander missions.<br><br>The scope of the activity is to implement an engineering and qualification model of a reprogrammable Proximity-1 transponder based on a software defined radio architecture and test it. The transponder shall support the Proximity-1 protocol in its entirety including support for full duplex operation. The transmit and receive carrier frequencies shall be programmable (by software uploads) to any frequency in the range used by the Proximity-1 protocol (i.e. 390 - 450 MHz). The transponder shall be designed in a modular manner that allows tailoring of the basic transponder to future missions. Finally, the proximity-link transponder to be developed shall also support higher data-rates than those currently available on European hardware, in order to increase the science return. Consideration shall be given to the architecture proposed in order to reduce mass, power and volume envelopes as much as possible.<br>Such a unit could also be of interest to scientific missions, planetary missions and Lunar missions requiring a proximity link. | | | | | |
| **Deliverables** | | | | | |
| Technical Notes, EQM, EIDP's | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 6 | **Application Need/Date:** | 2024 |
| **Application Mission:** | MSR Mars OrbiterScience, Exploration, Lunar missions | | **Contract Duration:** | 29 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8744 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Harmonization Dossier "TT&C Transponders and Payload Data Transmitters" 2012. | | | | | |

| **X-Band cryogenic feed prototyping** | | | |
|---|---|---|---|
| **Programme:** | TRP | **Reference:** | T912-005GS |
| **Title:** | X-Band cryogenic feed prototyping | | |
| **Total Budget:** | 600 | | |
| **Objectives** | | | |
| To design an innovative X-Band cryogenic feed to be installed in the future in the Deep Space antennas . G/T in X-Band will be maximised by an integrated design of the feed (receive and transmit in X band) and the cryo- cooled LNA sub- systems | | | |
| **Description** | | | |
| The reception performances of the Deep Space Ground Stations is limited by the noise generated in the front end. Any reduction of this noise will allow to increase the data transmitted or to reduce the required mass and power on the spacecraft transmitter.<br>X band is presently used for the telemetry of all deep space missions and will still be the preferred frequency band for future Mars exploration missions. The existing feed and LNA systems have been designed separately. Therefore, the feed system is operated at room temperature while the LNA is operated at 12 K. The overall system noise temperature is therefore suboptimal due to the insertion loss of the waveguide connection and passive elements at room temperature. In order to increase the mission data return, it would be extremely beneficial improving the present G/T by more than 1 dB. This will be achieved by reducing the loss of the feed system and trying to cryo-cool as much as possible the passive components of the receiver front end (diplexer, polarizer, waveguides, tracking coupler...). The interconnection of the feed and LNA subsystems will be optimised and the cryo-cooler | | | |

| | | | | | |
|---|---|---|---|---|---|
| subsystem will be designed to guarantee a maximum availability and redundancy. The same feed is going to be used for the uplink at 20 kW. A proper study will be conducted to minimise the effect of the high power uplink on the cryogenic subsystem. | | | | | |
| **Deliverables** | | | | | |
| A prototype of X-Band cryo-feed subsystem. | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2016 |
| **Application Mission:** | All future missions in X band | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| No Harmonisation dossier | | | | | |

| **Modelling of the Mars Environment for Future Missions** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E904-005EE | |
| **Title:** | Modelling of the Mars Environment for Future Missions | | | | |
| **Total Budget:** | 400 | | | | |
| **Objectives** | | | | | |
| To develop user-oriented, integrated tools to analyse aspects of the Mars environment required for mission design, including atmosphere, dust, regolith, and radiation. | | | | | |
| **Description** | | | | | |
| Various studies have analysed aspects of the Martian environment, including climate data derived from global circulation models, radiation data derived from monte-carlo studies of cosmic ray propagation in the atmosphere and regolith, and various dust investigations. This activity will review the available models, and develop tools around them that allow easier use in engineering. This avoids that the engineer will have to work with complex tools whose subtleties require considerable effort to work with. Requirements will be established for both the underlying physical modelling, and the engineering tools. | | | | | |
| **Deliverables** | | | | | |
| Engineering tools and associated documentation. | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 37 | **Application Need/Date:** | 2017 |
| **Application Mission:** | All Mars missions | | **Contract Duration:** | 36 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Harwell Robotics Autonomy Facility (HRAF) - Pilot project 1** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E908-001FP |
| **Title:** | Harwell Robotics Autonomy Facility (HRAF) - Pilot project 1 | | |
| **Total Budget:** | 1200 | | |
| **Objectives** | | | |
| The objective is to implement the HRAF core infrastructure and demonstrate, through a pilot project, the value of the facility for the validation of autonomous systems and technologies. This activity is the first in a long-term programme and is funded by the UK through the ESA MREP-2 programme and supported by UKSA. | | | |
| **Description** | | | |
| The development of complex autonomous robotic systems will be critical for future planetary exploration missions. At a minimum, elements of the MSR mission such as Sample Fetch Rover, landing with high precision (and hazard avoidance), autonomous sampling and sample transfer or sample container rendezvous and capture will all require ECSS level-3 autonomy and higher. Although the related technology developments are progressing strongly within Europe, there remains a lack of critical infrastructure to allow validation, verification and integration of autonomy components at the mission level.<br><br>The aim of this activity is to setup a facility that supports the validation of autonomous systems and associated technologies to enable the TRL of technologies to be raised, confidence in performance to be gained, cost estimates to be more credible, and eventually missions to be validated. These will require the use of specialist test facilities including mock planetary surfaces, | | | |

software-based simulation environments and physical field trials in representative environments to provide ground truth.

The aim of this activity is:
Phase 1:
- Define underlying requirements (including prime, academic and Agency input)
- Validation Process Definition
- Define the architecture of the facility (S/W, H/W environment, tools...)
Phase 2:
- Start of Component Engineering
- Integration of core infrastructure elements (including maturation of the EAGLE software tool)
- Prepare and execute a pilot project

The activity is split into 2 phases: Phases 1 ends with a PDR. A successful PDR is the prerequisite for the execution of phase 2. The pilot project will be based on and use results and data from the SEEKER activity and EAGLE simulator development (ESA C21286(2007)).

**Deliverables**

Documentation
Software (Middleware components)
EAGLE update

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 1 | **Target TRL:** | 3 | **Application Need/Date:** | 2015 |
| **Application Mission:** | MSR, Phootprint, Inspire & various | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |

**Consistency with Harmonisation Roadmap and conclusion:**

# Long Term

| European Isotope Production Phase 2 | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E903-015EP | |
| **Title:** | European Isotope Production Phase 2 | | | | |
| **Total Budget:** | 2000 | | | | |
| **Objectives** | | | | | |
| The precursor activity European Isotope Production Phase 1, resulted in the submission of a fully costed 7-year plan leading to the commencement of Am241 radioisotope fuel production at the UK National Nuclear Laboratory. This Phase 2 activity covers the first year of the "Development" task in the 7-year plan. | | | | | |
| **Description** | | | | | |
| Overall objectives of the 7-year plan are as follows:<br>- To complete the engineering development of the previously proposed Am241 production plant at Sellafield in Cumbria, England. The outstanding development areas are: plutonium dissolution, plutonium solvent extraction, americium solvent extraction, plutonium finishing, americium finishing, evaporator operation and solvent management.<br><br>- To develop the previously produced concept design into a fully complete and detailed preliminary design, to be taken through the HAZOP1 safety review process, to a point suitable for immediate use in (future) pre-fabrication design/blueprinting.<br><br>- To continue the evolution of the plant safety case and security (nuclear material safeguards) planning, including continued real-time liaison and iteration with the regulatory authorities.<br><br>Specifically, this 200kEuros Phase 2 activity covers the initial stage of the DEVELOPMENT task which entails:<br>1. Specification, design and procurement of equipment needed for full-scale inactive testing.<br>2. Development of chemical models (computer) for each sub-process.<br>3. Perform maloperations investigations for the solvent extraction processes. | | | | | |
| **Deliverables** | | | | | |
| Deliverables to ESA will be documentary (not hardware), but in many cases will derive from the execution of nuclear engineering trials and experimental rig manufacture/procurement within the NNL Central Laboratory. Detailed deliverables are TBD in the contractor's proposal and subsequent negotiation process. | | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 5 | **Application Need/Date:** | 2016 |
| **Application Mission:** | INSPIRE and other future Mars missions | | **Contract Duration:** | 12 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8933 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| Nuclear Power Systems architecture study for safety management and fuel encapsulation prototype development. | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E903-003EP |
| **Title:** | Nuclear Power Systems architecture study for safety management and fuel encapsulation prototype development. | | |
| **Total Budget:** | 1000 | | |
| **Objectives** | | | |
| To develop the NPS reference architectures for a European ASRG and small RTG, study its accommodation on spacecraft and launcher; to derive the end-to-end requirements including storage, transport and launch safety requirements for the fuel encapsulation and develop its design and start breadboarding and testing of the encapsulation, by using consolidated information from previous and ongoing activities. | | | |
| **Description** | | | |
| This activity aims to:<br>1) Consolidate existing information from ongoing and previous activities (e.g. ExoMars RHU accommodation and T303-040EP Nuclear fuel capsule and aeroshell design study)<br>2) Establish a reference design for a small European RTG and a Sterling RPS.<br>3) Study its accommodation on spacecraft (orbiter, lander, rover, small surface stations) and in the launch vehicle to derive the consolidated end-to-end requirements for the fuel encapsulation under consideration of all required safety issues and overall system aspects. | | | |

4) Investigate and consider all relevant safety and system aspects of the encapsulation from fuel delivery to launch and transfer to Mars.
5) Design the encapsulation and develop a breadboard and perform critical tests

**Deliverables**

Technical data package
- System architecture of (1) Sterling converter RPS and (2) a small RTG
- End-to-End system requirements for encapsulation of nuclear material for space NPSs.
- Summary on space nuclear safety issues related to the encapsulation
- Test report
- Mathematical models

H/W: Encapsulation prototype.

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 2 | **Target TRL:** | 4 | **Application Need/Date:** | 2012 |
| **Application Mission:** | Mars exploration, (>2018) | | **Contract Duration:** | 15 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |

**Consistency with Harmonisation Roadmap and conclusion:**

Consistent with the nuclear power dossier and proposed roadmap

**Nuclear Power Systems architecture study for safety management and fuel encapsulation NPSAFE (phase 2)**

| | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E903-004FP |
| **Title:** | Nuclear Power Systems architecture study for safety management and fuel encapsulation NPSAFE (phase 2) | | |
| **Total Budget:** | 2000 | | |

**Objectives**

Continuation of Phase 1 (E903-003EP) to further develop the NPS reference architectures for nuclear power systems and their safety
aspects in particular for the fuel encapsulation and aeroshell to progress on its design, bread boarding and testing.

**Description**

This activity aims to:
1) Based on the established reference designs for a small European RTG (E903-006EP), the Sterling RPS (E903-009EP) and the heater source encapsulation and aeroshell design (T9303-004EP and E903-003EP) the selected encapsulation technology shall be bread boarded and extensively tested.
2) Consolidation of safety end-to-end requirements for the fuel encapsulation under consideration of all required safety issues and overall system aspects.

**Deliverables**

Technical data package
- Updated End-to-End system requirements for encapsulation of nuclear material for space NPSs.
- Breadboard design
- Updated space nuclear safety issues related to the encapsulation
- Test report
- Mathematical models

H/W: Encapsulation prototyp

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2022 |
| **Application Mission:** | various | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |

**Consistency with Harmonisation Roadmap and conclusion:**

**Radioisotope Heater Unit development (RHU-DEV1)**

| | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E903-020FP |
| **Title:** | Radioisotope Heater Unit development (RHU-DEV1) | | |

| | | | | | |
|---|---|---|---|---|---|
| **Total Budget:** | 1000 | | | | |
| **Objectives** | | | | | |
| Development of a European RHU Phase 1 | | | | | |
| **Description** | | | | | |
| (On-going) activities for the small RTG and Stirling RPS need heater sources in the order of 150 Wth. A RHU typically is in the range of a few Wth only. Encapsulation and aeroshell design might be based in principle on similar technologies used for the RTG/Stiling heat source, but will required specific design solutions for the RHU. | | | | | |
| **Deliverables** | | | | | |
| Technical data package<br>- Design report of a RHU.<br>- Breadboard of encapsulation and aeroshell, use of a heater simulant.<br>- Test report<br>- Mathematical models<br>H/W: Encapsulation prototype | | | | | |
| **Current TRL:** | 1 | **Target TRL:** | 3/4 | **Application Need/Date:** | 2020 |
| **Application Mission:** | various | | **Contract Duration:** | 18 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Safety and aggression tests & demonstrations** | | | | | |
| **Programme:** | ETP | | **Reference:** | E903-005EP | |
| **Title:** | Safety and aggression tests & demonstrations | | | | |
| **Total Budget:** | 2000 | | | | |
| **Objectives** | | | | | |
| To safety test a radioisotope fuel encapsulation system. | | | | | |
| **Description** | | | | | |
| Modern RPS fuel must inevitably conform to the "intact re-entry, intact impact" model, in which the fuel module is robust against launcher and/or re-entry accident. | | | | | |
| **Deliverables** | | | | | |
| Qualification Test Plans, Test Procedures and Test Reports. | | | | | |
| **Current TRL:** | 6 | **Target TRL:** | 6 | **Application Need/Date:** | 2017 |
| **Application Mission:** | Mars exploration, (>2018) | | **Contract Duration:** | 36 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Consistent with the nuclear power dossier and proposed roadmap | | | | | |

| | | | |
|---|---|---|---|
| **Thermoelectric converter system for small-scale RTGs (to ~TRL3/4)** | | | |
| **Programme:** | TRP | **Reference:** | T903-006EP |
| **Title:** | Thermoelectric converter system for small-scale RTGs (to ~TRL3/4) | | |
| **Total Budget:** | 660 | | |
| **Objectives** | | | |
| Demonstrate a low-power thermoelectric power conversion system | | | |
| **Description** | | | |
| Smaller RTG systems based on (several) RHUs (e.g. Russian Angel RHUs with 8 W thermal output (mass ~200g) or US RHUs with 1 W thermal output (mass 40 g)) can be used with thermoelectric conversion to provide electrical energy for long life/low activity measurement and communication for in-situ systems. Typical required electrical power is in the order 500 mW to several | | | |

| | | | | | |
|---|---|---|---|---|---|
| Watts, mission duration 9 to 11 years transfer and at least 1 year of operations. Contract is split into 3 activities:1. Study of the application range and preliminary definition of architecture and interfaces of a thermoelectric converter system for use with small nuclear heat sources (i.e. RHUs). Some competences on this or related subjects have already been developed in Europe through previous studies (funded at individual national level).<br>2. Thermocouple design study for small RTGs. A comprehensive review of modern thermoelectric materials will be conducted. This shall make assessments and trade-offs of the various materials and construction options (including, e.g, n-type, p-type, segmentation and coatings), and make a clear recommendation of the material(s) and thermocouple type to be selected.<br>3. Production of a preliminary breadboard model small-scale thermoelectric converter, using simulated (non-nuclear) heat source. | | | | | |
| **Deliverables** | | | | | |
| Breadboard model small-scale thermoelectric converter, using simulated (non-nuclear) heat source. | | | | | |
| **Current TRL:** | 1 | **Target TRL:** | 3/4 | **Application Need/Date:** | 2011 |
| **Application Mission:** | Mars exploration, (>2018) | | **Contract Duration:** | 15 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Consistent with the nuclear power dossier and proposed roadmap | | | | | |

| **Thermoelectric converter system for small-scale RTGs (to ~TRL3/4)** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | TRP | | **Reference:** | T903-006EP-B | |
| **Title:** | Thermoelectric converter system for small-scale RTGs (to ~TRL3/4) | | | | |
| **Total Budget:** | 660 | | | | |
| **Objectives** | | | | | |
| Demonstrate a low-power thermoelectric power conversion system | | | | | |
| **Description** | | | | | |
| Smaller RTG systems based on (several) RHUs (e.g. Russian Angel RHUs with 8 W thermal output (mass ~200g) or US RHUs with 1 W thermal output (mass 40 g)) can be used with thermoelectric conversion to provide electrical energy for long life/low activity measurement and communication for in-situ systems. Typical required electrical power is in the order 500 mW to several Watts, mission duration 9 to 11 years transfer and at least 1 year of operations. Contract is split into 3 activities:1. Study of the application range and preliminary definition of architecture and interfaces of a thermoelectric converter system for use with small nuclear heat sources (i.e. RHUs). Some competences on this or related subjects have already been developed in Europe through previous studies (funded at individual national level).<br>2. Thermocouple design study for small RTGs. A comprehensive review of modern thermoelectric materials will be conducted. This shall make assessments and trade-offs of the various materials and construction options (including, e.g, n-type, p-type, segmentation and coatings), and make a clear recommendation of the material(s) and thermocouple type to be selected.<br>3. Production of a preliminary breadboard model small-scale thermoelectric converter, using simulated (non-nuclear) heat source. | | | | | |
| **Deliverables** | | | | | |
| Breadboard model small-scale thermoelectric converter, using simulated (non-nuclear) heat source. | | | | | |
| **Current TRL:** | 1 | **Target TRL:** | 3/4 | **Application Need/Date:** | TRL5 by 2015 |
| **Application Mission:** | Mars exploration, (>2018) | | **Contract Duration:** | 15 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Consistent with the nuclear power dossier and proposed roadmap | | | | | |

| **Small-scale RTG development to TRL 5** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E903-007FP |
| **Title:** | Small-scale RTG development to TRL 5 | | |
| **Total Budget:** | 3500 | | |
| **Objectives** | | | |
| Continued development of small scale thermoelectric converter, building upon the conclusions of the parallel precursor TRP activities, and culminating in the manufacture and testing of (non-nuclear, electrically heated) engineering models (EM) of an RTG. | | | |

| **Description** | | | | | |
|---|---|---|---|---|---|
| The development shall build upon the findings and conclusions of the parallel TRP activities "Thermoelectric Converter System for small-scale RTGs" (ref: T903-006 EP).<br><br>An evolved design shall be developed that is fully optimised with respect to the mass-specific power output of the full RTG system.<br><br>Engineering models shall be constructed from fully representative flight materials.<br><br>Functional testing will be performed in the simulated space environment (thermal vacuum / mars atmosphere analogue), and one EM will also be subjected to structural testing, e.g. a generic/typical sine & random vibration test. to determine physical integrity.<br><br>One EM shall be suitable for long-term testing (to be covered under a subsequent contract if required).<br><br>The RTG shall be designed to be fuelled with Am241 heat modules that will be the subject of parallel development activities - therefore close communication between the contracts will be required (i.e. commercial confidentiality is not appropriate)<br><br>The scale (sizing) of the RTG EMs will be effectively quantized by the nature of the Am241 heat module and will be determined by ESA prior to the beginning of the contract. | | | | | |
| **Deliverables** | | | | | |
| RTG EMs and various documents TBD. | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Application Need/Date:** | 2016 |
| **Application Mission:** | Future Mars missions | | **Contract Duration:** | 36 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8933 | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |

| **Thermoelectric converter system for small-scale RTGs (to ~TRL6)** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | | **Reference:** | E903-008EP | |
| **Title:** | Thermoelectric converter system for small-scale RTGs (to ~TRL6) | | | | |
| **Total Budget:** | 3000 | | | | |
| **Objectives** | | | | | |
| Produce an EQM suitable for fuelling with radioisotope material. | | | | | |
| **Description** | | | | | |
| Further thermoelectric converter development, and qualification, within the 2011-2015 timeframe. Shall result in production of an EQM suitable for fuelling with radioisotope material. | | | | | |
| **Deliverables** | | | | | |
| An EQM suitable for fuelling with radioisotope material with test reports. | | | | | |
| **Current TRL:** | 4/5 | **Target TRL:** | 6 | **Application Need/Date:** | 2017 |
| **Application Mission:** | Mars exploration, (>2018) | | **Contract Duration:** | 48 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Consistent with the nuclear power dossier and proposed roadmap | | | | | |

| **Stirling Converter Technology Development phase 1** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E903-009EP |
| **Title:** | Stirling Converter Technology Development phase 1 | | |
| **Total Budget:** | 2000 | | |
| **Objectives** | | | |
| To develop a breadboard model of a Stirling cycle power converter system for use with radioisotopic heat sources. | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Description** | | | | | |
| This contract covers the initial development of a Stirling cycle power converter system for space applications, considering use with radioisotopic heat sources. Electrical output in the ~100 W range. A breadboard will be developed and tested in laboratory conditions (using a simulated, non-nuclear, heat source). | | | | | |
| **Deliverables** | | | | | |
| Consolidated requirements and design documentation. Breadboard model with test reports. | | | | | |
| **Current TRL:** | 2 | **Target TRL:** | 3 | **Application Need/Date:** | 2013 |
| **Application Mission:** | Outer Planets, Mars exploration, (>2018) | **Contract Duration:** | 27 | | |
| **S/W Clause:** | N/A | **Reference to ESTER** | T-8534 | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Consistent with nuclear power dossier | | | | | |

| **Stirling converter development phase 2 to TRL6** | | | | | |
|---|---|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E903-010EP | | |
| **Title:** | Stirling converter development phase 2 to TRL6 | | | | |
| **Total Budget:** | 3300 | | | | |
| **Objectives** | | | | | |
| Continued development of the Stirling converter system, including its interfaces with the radioisotopic fuel, and the spacecraft | | | | | |
| **Description** | | | | | |
| Continued development of the Stirling converter system, including its interfaces with the radioisotopic fuel, and the spacecraft. | | | | | |
| **Deliverables** | | | | | |
| Shall result in production of EQM suitable for fuelling with radioisotope material with test reports. | | | | | |
| **Current TRL:** | 3/4 | **Target TRL:** | 6 | **Application Need/Date:** | 2017 |
| **Application Mission:** | Outer Planets, Mars exploration, (>2018) | **Contract Duration:** | 48 | | |
| **S/W Clause:** | N/A | **Reference to ESTER** | | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| Consistent with nuclear power dossier | | | | | |

| **Combustion chamber and injection technology development** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E919-011EP |
| **Title:** | Combustion chamber and injection technology development | | |
| **Total Budget:** | 2000 | | |
| **Objectives** | | | |
| To conduct the necessary preliminary development work for a high thrust (1000-1500N) engine for planetary science and exploration. | | | |
| **Description** | | | |
| A high thrust apogee engine (HTAE) has been identified as a key technology to provide Europe with an enhanced independent capability for planetary science and exploration.<br><br>Gravity losses on Mars Express (MEX) accounted for around 4 % of the Delta V at orbit insertion. This mission used a classical high reliability apogee motor at 400N thrust level and 321s specific impulse (ISP)<br>The current Exomars (EXM) orbit insertion propulsion relies on a similar single 424N engine with an ISP of 321s. The Mars orbit insertion manoeuvre (MOI) and other manoeuvres bring the total main engine burn time to nearly 6 hours. Furthermore, significant gravity losses are involved in the Mars orbit insertion manoeuvre: 30% delta V or around 300 kg in terms of propellant mass.<br><br>A higher thrust apogee engine, 1.0-1.5 kN or similar, with current State of the art performance (~321s ISP) would be of significant benefit. Such an engine recovers more than half of the losses for an EXM class mission while retaining acceleration levels similar to those seen on Mars Express. This, in turn, increases the spacecraft dry mass available on orbit by a similar amount and hence the payload available for useful science. Further, such an approach leads to a relatively compact and mass efficient propulsion system. | | | |

A classical apogee engine design is considered for the HTAE. The design will consist of:

- Propellant flow control valves
- Injector assembly
- Combustion chamber
- Expansion nozzle
- Heat shield

The overall development requires three phases:
Phase 1 is aimed at the verification, by test, of the key elements of such a design with a particular focus on the chamber and injector technology.
Phase 2 targets the optimisation and finalisation of the design to critical design review (CDR) status.
Finally, phase 3 addresses the qualification of the engine on ground.

The activity outlined here relates to phase 1 of the development.
Phase 1 - of the high thrust apogee engine HTAE development is split into two further sub-phases; A and B.
Phase 1-A is constructed to take the development to a program requirements review (PRR) with a traded concept and supporting analysis confirming the feasibility of the design.
Phase 1-B is split into three development strands for the three key components; valve, chamber and injector. Phase 1-B is designed to demonstrate the feasibility of the injector design and to address chamber compatibility issues with an agreed injector reference design. Further, significant emphasis is placed on the injector and chamber development to allow an initial performance optimisation loop and to give good margins w.r.t combustion stability.
The phase 1 closes with three separate intermediate preliminary design reviews (IPDR) for the Valve Chamber and Injector respectively.

**Deliverables**

Phase 1-A Activities

- Definition of requirements in terms of performance, physical properties and test facilities.

- Definition of options for engine designs.

- Result from trade of engine options based on relevant analysis.

- Initial design and supporting analysis.

- Provision of PRR data pack.

Phase 1-B Activities

- Development of HTAE technical specification.

- Valve technology demonstrator - model design and manufacture.

- Injector technology demonstrator - Design and manufacture of development model injector elements. Testing injectors for the performance optimisation loop.

- Chamber technology demonstrator - Chamber development model design, manufacture including testing with reference injector.

- Provision of I-PDR data packs for valve, injector and chamber .

| | | | | | |
|---|---|---|---|---|---|
| **Current TRL:** | 1 | **Target TRL:** | 3 | **Application Need/Date:** | 2012 |
| **Application Mission:** | All exploration missions e.g. Mars Sample Return (>2016) and following exploration missions | | **Contract Duration:** | 24 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | T-8324 | |

**Consistency with Harmonisation Roadmap and conclusion:**

Consistent with the Technical Dossier - Chemical Propulsion Components (Aim C3)

| **Design, development testing and generic qualification of a High Thrust Apogee Engine (HTAE)** | | | |
|---|---|---|---|
| **Programme:** | ETP | **Reference:** | E919-012MP |
| **Title:** | Design, development testing and generic qualification of a High Thrust Apogee Engine (HTAE) | | |
| **Total Budget:** | 4300 | | |

| **Objectives** | | | | | |
|---|---|---|---|---|---|
| This activity will continue the development, to a generic qualification level, of a High Thrust Apogee Engine for the Robotic Exploration Programme. | | | | | |
| **Description** | | | | | |
| The MREP-funded Combustion chamber and Injection technology development activity, was a first phase aimed at defining a high thrust apogee engine (HTAE) that was a specific fit to Agency requirements for planetary missions and orbit insertion. The HTAE phase 1 targets an ITAR-free design and examines high performance injector design and cost effective high temperature materials developments. The definition of a flow control valve was also included to complete the equipment definition. The phase 1 activity will conclude in 2013 with a Intermediate PDR (I-PDR) for the injector, chamber and valve.<br><br>The follow on Phase 2, which is the subject of this activity proposal, is intended to proceed following a successful close-out of the I-PDR, and is aimed at:<br>- Completion of design Definition<br>o Final loop of injector, chamber and valve development testing as identified in Phase 1B will be performed to finalise injector down-selection for the design of the HTAE including any further optimisations identified.<br>o PDR<br>- Detailed design<br>o CDR<br>- Generic Qualification<br>o Manufacture of EM (generic qualification) batch 2 test hardware<br>o Process qualification for injectors, chamber manufacture and if relevant, chamber material coating process<br>o HTAE Valve development activity - design and manufacture of a qualification model for engine qualification program<br>o Qualification program of engine(s) to TBC specification (generic qualification requirements)<br><br>The Phase 2 will be split into two parts, Phase 2a and Phase 2b as shown below:<br>- Phase 2a (2000kEuros) starting 2013 for a duration of 24 months until CDR<br>- Phase 2b (2300kEuros) starting 2015, for a duration of 18 months until completion | | | | | |
| **Deliverables** | | | | | |
| Documentation, development models, engineering model engine and valve assemblies. | | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 5/6 | **Application Need/Date:** | 2016 |
| **Application Mission:** | INSPIRE, Phootprint, MSRO and other future Mars missions | | **Contract Duration:** | 42 | |
| **S/W Clause:** | N/A | | **Reference to ESTER** | | |
| **Consistency with Harmonisation Roadmap and conclusion:** | | | | | |
| | | | | | |