SAMPLE FETCHING ROVER (SFR) FOR MSR

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ABSTRACT

In this paper the Sample Fetching Rover (SFR) design is presented. The main objective of this study is the assessment of a lightweight rover with high mobility and fetching capabilities, developed in the frame of the Mars Sample and Return (MSR) Mission.
Sample Fetching Rover (SFR) will navigate and transverse to the location of a sample cache deposited by previous rover mission, retrieve and carry the sample cache in order to deliver it to the Mars Ascent Vehicle within the SFR timeline (180 sols). As a potential alternative to the aforementioned nominal mission scenario and in order to mitigate the risks involved in relying on another surface asset to collect the samples (e.g. failure of the previous rover or cache deposition) the alternate SFR design is able to acquire soil samples from the surface/underground while travelling along its landing site and deliver them to the MAV within the MSR surface operations timeline. The Sample Fetching Rover studied in the frame of this contract could be part of the MSR Lander Mission (originally foreseen for 2024). An alternative nominal mission scenario where the SFR is landed separately from the Mars Ascent Vehicle and by a Mars Precision Lander is also possible.
The design is constrained by several stringent requirements: <u>Mass & Envelope</u> (<100kg with goal set to 60kg, 1m x 1m x 0.7m stowed envelope), <u>High Mobility</u> (travel a straight line distance of 15km in 110 locomotion sols), <u>Reliability</u> (loss of SFR would mean the loss of the entire MSR campaign).

This activity (assessment study and preliminary design) has been entirely funded by the European Space Agency Mars Robotic Exploration Preparation (MREP) programme. The consortium is composed by Thales Alenia Space (prime contractor), supported by MDA for Locomotion and Mechanisms, SCISYS for Software and Autonomy, SEA for Planetary Protection and Joanneum Research for Navigation/Localisation.

1. INTRODUCTION

This paper is prepared according to the activities executed by Thales Alenia Space under the "Study of a sample fetching rover for MSR" ESA contract, which are mainly devoted to establish a detailed preliminary design of the SFR rover substantiated by subsystem, operational concept and environment analyses.
The aim of this work is to assess the rover capabilities and to provide the preliminary design of a highly mobile and lightweight rover (<100kg class), building on current European technology (i.e. ExoMars rover) or new technology developments able to achieve TRL 5 by 2014/15.
All required subsystems have been evaluated and designed, focusing on the investigation of the critical elements and design drivers as well as on enabling and enhancing technologies.

2. WHY SFR?

The Mars Sample Return (MSR) campaign and especially the Sample Fetching Rover role are briefly described in this section.
The MSR campaign is based on an international MSR scenario aiming at returning 500g of Mars samples to the Earth in order to allow for intense analyses only possible in Earth-based laboratories by state-of-the-art analysis instrumentation. The current considered MSR campaign architecture is based on a campaign of three missions plus a facility for Mars Sample handing on Earth:

- a caching rover mission (2018 or later), which selects and acquires the sample inside the cache for later pickup
- An MSR Lander mission (2024) which searches and retrieves the cache, places it inside the orbiting sample (OS) container and launches it into a low Mars orbit
- a MSR Orbiter Mission (2022), which searches and captures the OS, places it in a bio-container and brings it back to Earth
- A Mars Sample receiving facility which retrieves the bio-container for delivery to the Sample Receiving Facilities for samples unpacking, before distributing them to the science community

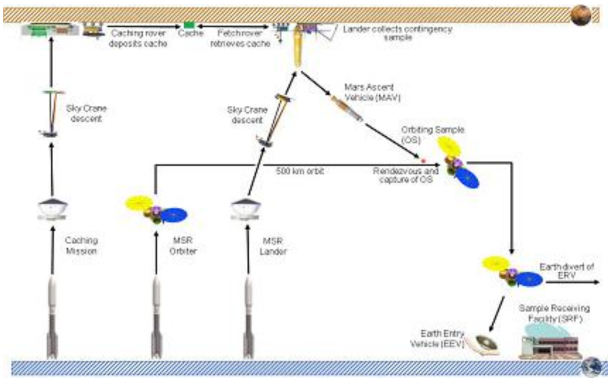


Figure 1 – MSR Campaign Architecture and SFR Role (Ref. Proposed MSR Campaign Description (PMCD), D-66014_Initial Release 30/06/2010, NASA)

The Sample Fetching Rover (SFR) is part of the MSR Lander mission (nominal scenario). Alternatively to ensure that the MSR architecture is not driven by the potential mass growth of the MAV, the activity also considers an alternative mission scenario where the SFR is landed separately from the MAV platform by an additional Mars Precision Lander (MPL), as potential 5th mission element. In this alternative mission the MAV launch timeline and aforementioned operational reference scenario is maintained.

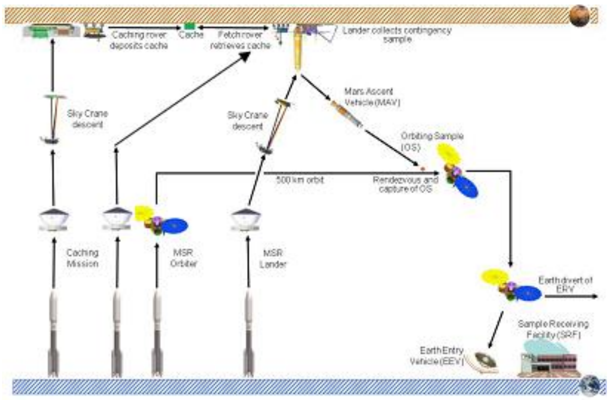


Figure 2 – MSR Campaign Architecture – Alternative with Mars Precision Lander (Ref. Proposed MSR Campaign Description (PMCD), D-66014_Initial Release 30/06/2010, NASA)

SFR will be a lightweight rover with high mobility capabilities and highly reliable (robust to electrical and mechanical failures). SFR will navigate and transverse to the location of the sample cache deposited by previous rover mission, retrieve and carry the cache in order to deliver it to the MAV within the SFR timeline.
As a back-up to the aforementioned nominal and alternative mission scenarios and in order to mitigate the risks involved in relying on another surface asset to collect the samples (e.g. failure of the previous rover or cache deposition) the SFR will itself acquire soil samples from the surface/underground while travelling along its landing site and deliver them to the MAV within the MSR timeline

3. WHAT TO DO

3.1. Nominal Reference Mission

In this scenario the SFR is proposed to be landed together with the MAV platform or by the MPL (alternative scenario) and the following operational reference scenario shall be taken into account:

- ➢ Departure from the landing point (Mars Lander or proximities in case of MPL)
- ➢ Cache maximum distance = MSR Lander or MPL landing accuracy (**7,5km semi-major axis**)
- ➢ Operations:
  - The rover will navigate and transverse from its landing site to the location of a sample cache deposited on the Martian surface by a previous rover mission (e.g. Max-C 2018 MSR mission element)
  - The rover will retrieve and carry the sample cache by using a Cache Acquisition System (CAS)
  - Return to the MAV and possible manipulation of the collected samples

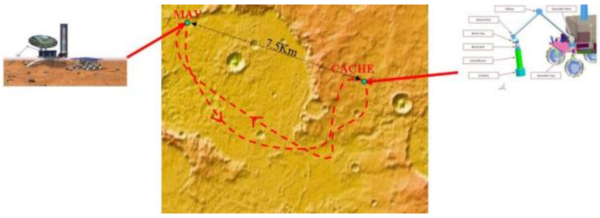


Figure 3 – SFR Nominal Reference Mission

3.2. Backup Reference Mission

In this scenario the SFR is proposed to be landed together with the MAV platform or by the MPL and the following operational reference scenario shall be taken into account:

- ➢ Departure from the landing point (Mars Lander or proximities in case of MPL)
- ➢ Operations:
  - Identification of the target location by using the PanCam
  - Travel to the target location
  - Target verification and confirmation by using the PanCam
  - Sample Acquisition by using the Sample Acquisition System (SAS)
  - Return to the MAV and possible manipulation of the collected samples.

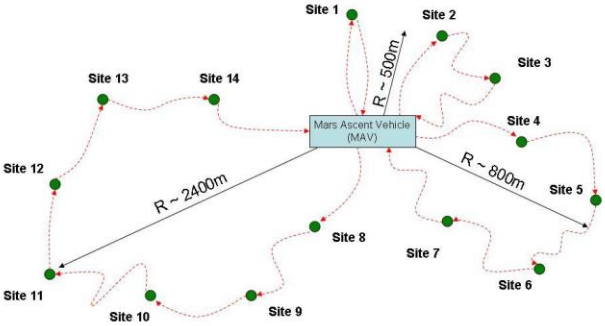


Figure 4 – SFR Backup Reference Mission

4. WHEN & WHERE

The SFR was designed to operate at a range of latitudes between 5° South and 25° North and the surface mission start on arrival date (September 2025) and to last 180 sols.

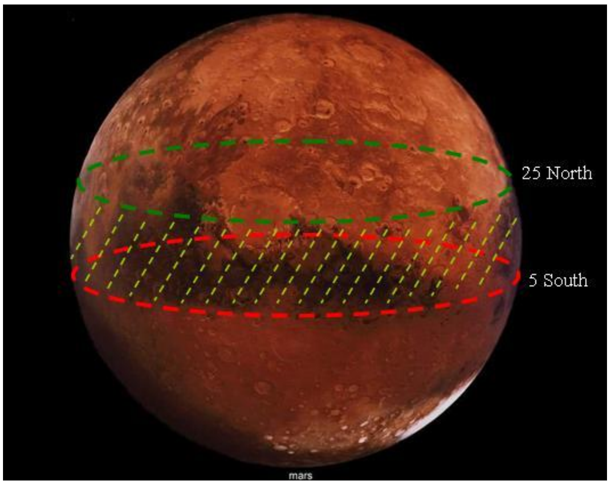


Figure 5 – SFR Landing Latitude

During the mission lifetime an atmospherically optical depth profile based on ESA/NASA statistical observations has been used and which will vary from 1 to 1.5 (first five months of the mission OD=1 and OD=1.5 for the remaining 3 months). The slight opacity of the atmosphere will affect the power generation capabilities of the rover directly by decreasing the Solar Flux reaching the Solar Arrays and indirectly by the incremental deposition of dust on the Solar Panels.
Moreover in the current scenario (arrival Sep 2025) during the rover lifetime a solar conjunction will happen, leading to almost 30sols of no communication with Earth.

The Solar conjunction and the OD profile split the timeline in four parts:

- From **Sol 0** to **Sol 111**: High power availability, thus core phase for Locomotion.
- From **Sol 112** to **Sol 142**: No communication due to solar conjunction, the SFR is kept in a safe condition on the Mars Surface collecting housekeeping data and periodically uploading it to the MSR Orbiter.
- From **Sol 142** to **Sol 149**: Medium power availability before OD change.
- From **Sol 150** to **Sol 180**: Low to very low power availability.

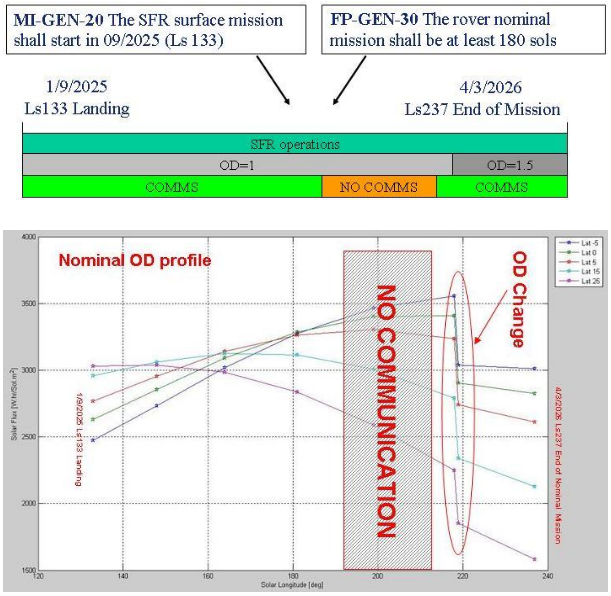


Figure 6 – SFR Mission Lifetime

From the above considerations it is clear that the Locomotion Sol distance shall be sized according to the power availability, in order to minimise as much as possible the energy loss. Moreover the mission should be accomplished before sol 112, in order not to increase too much the solar array area to support locomotion with OD 1.5.

5. SFR DESIGN DRIVERS – Small Fast Reliable

5.1. Mass & Envelope (Small)

A target mass of 60kg-class rover for the platform and payload including margins was required at the beginning of the study. A final mass of 82kg has been reached at the end of the preliminary design phase. While for the majority of the subsystems the mass and volume can be tailored to the application according to the size of the rover, this does not fully apply for a number of the rover parts, in particular:

- **Locomotion**: for a wheeled rover, the capability to overcome an obstacle of a certain height depends on the wheels diameter and the suspension travel; therefore, in general a smaller rover will be more limited in terms of capability to overcome obstacles, as well as in terms of operative range although it can more easily navigate between rocks.
- **Deployment Mechanisms**: The small envelope required lead to the need of deployment mechanisms (e.g. mast, SA, Locomotion).

- **Avionics**: the equipment in charge of functions such as data handling and communications, but also power management, localisation and navigation are not, or only partially, scalable according to the size of the rover, considering that the required functionality are the same or similar independent of the size of the rover (e.g. communication with the relay Orbiter; autonomous localisation and navigation; etc.)

Therefore the very low target mass is in contradiction with the high mobility and reliability needed for the SFR.

5.2. High Mobility (Fast)

Autonomous Navigation is a key capability for the Sample Fetching Rover, which will have to travel on the Mars surface more than any other rover so far. SFR locomotion, GNC and power systems are strongly affected by the type of terrain the rover faces. The main terrain characteristics have been fixed and a terrain model (DEM) has been generated in order to allow the sizing of the Locomotion SS (through careful definition of maximum negotiable slopes and discontinuities) and perform traversability and path analysis.
The following main terrain characteristics have been analysed and modelled according to Exomars terrain specifications (where applicable) and the ESA and NASA state of the art on the subject:

- Slopes distribution
- Rock size and distribution

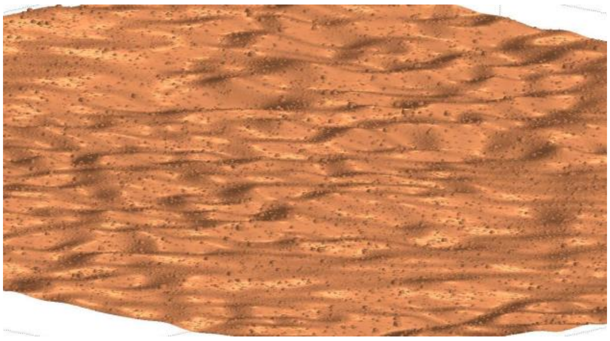


Figure 7 – SFR Terrain Model

No details on the soil properties have been applied to the SFR Terrain Model, since this characteristic is taken in account separately in order to derive the worst cases conditions for the Locomotion SS.
Based on the internal R&D outcomes TAS-I has developed a tool for the SFR Study with the following objectives:

- **Traversability Analysis**: evaluate the Traversability score of the Digital Elevation Map created as for Figure 7, allowing the sizing of the locomotion subsystem (slope and discontinuities negotiation capabilities). This analysis led to the decision to have discontinuities threshold of 18cm and slope threshold of 20deg, in order to have at least 70% of the DEM navigable.

Traversability Analysis: evaluate the traversability score of the SFR Digital Elevation Map, allowing the sizing of the locomotion subsystem (slope and discontinuities negotiation capabilities)

Parameters: Obstacle Grow Factor [m]	Parameters: Discont. Threshold [m]	Parameters: Slopes Threshold [deg]	Non Navigable Area [%]	Navigable Area [%]	Average Cost [0..255] 0 simple 255 difficult	Note
0.71	0.10	10	71.1	28.9	184	
0.71	0.10	15	69.2	30.8	178	
0.71	0.10	20	68.9	31.1	175	
0.71	0.15	10	47.2	52.8	169	
0.71	0.15	15	41.4	58.6	146	
0.71	0.15	20	40.4	59.6	135	SFR baseline at proposal
0.71	0.17	10	41.0	59.0	166	
0.71	0.17	15	33.8	66.2	139	
0.71	0.17	20	32.3	67.7	123	
0.71	0.18	10	38.6	61.4	165	
0.71	0.18	15	30.7	69.3	137	
0.71	0.18	20	29.0	71.0	119	
0.71	0.20	10	34.4	65.6	163	
0.71	0.20	15	25.3	74.7	133	
0.71	0.20	20	23.0	77.0	111	
0.71	0.25	10	28.2	71.8	161	
0.71	0.25	15	17.5	82.5	129	
0.71	0.25	20	13.9	86.1	102	
1.5	0.5	20	6.4	93.6	96	Actual ESA/NASA Exomars capabilities (caching rover)

(*) Obstacles are grown of half rover dimension in order to have a Map in the Configuration Space

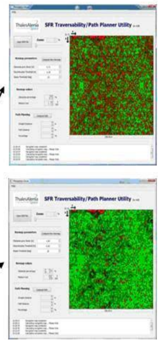


Figure 8 – Traversability Analysis

- **Path Analysis**: evaluate the ground track distance VS straight line distance for the SFR, allowing the computation of the approximate distance value to be travelled by the SFR to reach the edge of the landing ellipse (7.5km straight line) and return back to the MAV (7.5km straight line). From the analysis it was possible to calculate for SFR the ratio between the ground track distance and straight line distance (due to the obstacle avoidance), equal to 1.4.

Path Analysis: evaluate the ground track distance VS straight line distance for the SFR, allowing the computation of the approximate distance value to be travelled by the SFR to reach the edge of the Landing ellipse (7.5Km straight line) and return back to the MAV (7.5Km straight line)

The selected Navigation Map is the one built with the following baseline parameters in order to have at least 70% of navigable area (SFR assumption):
Obstacle Grow Factor 0.71 m (half rover diagonal)
Discontinuities Threshold 0.18 m
Slopes Threshold 20 deg

DEFINITION **Path Bending factor**: the ratio between the Ground Track Distance and the Straight line distance between start and goal coordinates

RESULT Using field D* path planner the Path Bending Factor for SFR is 140%

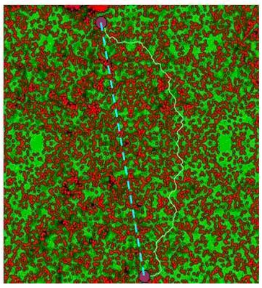


Figure 9 – Path Analysis

All these system level analyses lead to the definition of the mobility requirements as follows:

- travel 21km (10.5km to reach the cache + 10.5km to return to the MAV) to complete the mission
- Locomotion SS shall be able to withstand at least a discontinuity of 0.18m and a slope of 20deg.
- perform the mission before the solar conjunction (Sol 112)

The key features of the SFR design related to mobility in order to satisfy the above requirements are shown in the following table:

SFR Navigation capabilities:

- Discontinuities Threshold	0.18 m
- Slopes Threshold	20 deg
- Continuous Navigation	
- Closed Loop Navigation Speed	55 m/h
- Ground Track Distance	21 Km
- Avg. Distance x Sol	~210 m/Sol

Figure 10 – SFR mobility key features

5.3. Reliability (Reliable)

Rover design shall provide single-fault failure tolerance, since the loss of SFR in the assumed scenario would mean the loss of Mars Sample Return campaign primary objective. A careful detailed design was needed on Locomotion and Avionic Subsystems to find the best redundancy solution for the SFR or in the unfavourable case, estimation of the degraded performance.
Moreover in case of an anomaly not recoverable automatically or a missed communication (i.e. no communication with the Orbiter in a communication timed window) the rover is required to switch to Safe Mode. This mode has to be supported during the entire mission for at least 14 sols in every condition (even local dust storm with OD = 2). The rover is ready for a communication with the Orbiter (communication RX chain always ON during night and day), waiting instructions from ground. As shown later this mode is power demanding and together with the high mobility requested drives the size of the solar arrays.

5.4. Planetary Protection & Contamination Control

SFR is part of the MSR mission which corresponds to a mission of Category V restricted Earth return

- Restrictions on return of Martian contaminated HW to Earth
- SFR will not return, but issues must be kept in mind

Therefore for the SFR forward contamination of Mars, the Category IVb requirements are applicable:

- Low bioburden and bioburden density
- Very highly controlled sample handling equipment

The SFR subsystems which are involved in the acquisition and delivery of samples (or cache of samples) to be used for life detection must carry a bioburden of < 30 spores at a density of < 0.03 spores / m^2, or meet levels of biological burden driven by the nature and sensitivity of the particular life‐detection experiments. AIT of SAS / CAS must me done in a very highly controlled environment

- e.g. ISO 3 cabinet
- Precision cleaning of contact surfaces

Permanent Biobarrier to be removed on Mars are considered as design baseline for SFR.

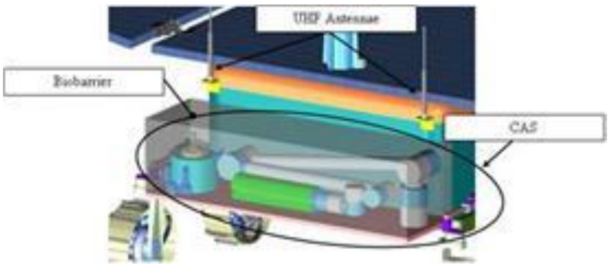


Figure 11 – CAS with Biobarrier

The elements of the SFR not involved in sample / cache acquisition and handling shall carry a biological burden of < $5x10^4$ bacterial spores on exposed external and internal surfaces, this level has been allocated by ESA, and is a portion of the $3x10^5$ surface spores allow for the Lander mission as a whole. Control of individual elements and AIT carried out in a bioburden controlled environment (c.f. Exomars). Each component must be assessed for appropriate bioburden reduction

- Dry Heat Microbial Reduction preferred as the only qualified process
- Other options possible as only surface bioburden needs be controlled (e.g. H_2O_2, IPA wiping)
- Isolation of volumes by HEPA filters to render them "unaccountable" for bioburden.

6. SFR OVERVIEW

The rover configuration here presented represents the optimized solution for the SFR, based on the choice of the best subsystems configurations and system level considerations. X-Band DTE/DFE link equipment (i.e. goal for SFR requirements) is not present, in order to be as much as possible close to the target mass. The SFR has been designed on a RHU-free thermal configuration to simplify the AIV flow removing the need for late access at launch site. The following table shows the final baseline for every subsystem.

Subsystem	Selected configuration
Structure	Main body 660 (length) x 600 (width) x 300 (height) mm made by parallelepiped-shaped CRFP sandwich
Mechanisms	Telescopic Mast + Pan&Tilt Unit and Spring-actuated Solar Array Hinges
Autonomy	Autonomy level E3
GNC	Continuous navigation, perception based on Stereo Vision, standard equipment without Sun Sensor nor LocCam (i.e. NavCam exploiting Navigation and Localisation, IMU). Redundancy is foreseen for NavCam and IMU (only accelerometers). Absolute localisation performed by Ground using Bundle Adjustment technique.
Locomotion	Locomotion formula 6 x 6 x 4 and Exomars 3 bogies suspension system. Linear Deployment Mechanism
Power	Battery: space qualified ABSL 18650NL Solar Array: Area $1.83m^2$, organised in 3 panels (fixed $0.71m^2$ + 2 deployable $0.56m^2$ each) with AZUR 3G30 cells (BoL 29.5% EoL 25.5%)

	PCDU: based on Maximum Power Point Tracking (MMPT) with temp measurement SA Regulator and unregulated bus
Telecommunication	UHF link implemented with 2xmonopole antenna and redundant UHF transceiver (heritage from MREP DUX development) – hot red. during day, cold red. during night
Data Handling	Two Processor Modules (PM) in cold redundancy. Each PM (LEON3 based) includes FPGAs for GNC image processing algorithms
Thermal	Thermal regulation based on an insulated space inside the body, by means of a CO_2 gas gap, where the internal units (heaters, evaporators, passive LHP) are installed. 3 radiators are placed on the external part of the body - RHU-free
Payload	PanCam + Cache Acquisition System (CAS) or Sample Acquisition System (SAS) for back-up mission scenario

Following pictures show SFR main dimensions both in stowed and deployed configurations.

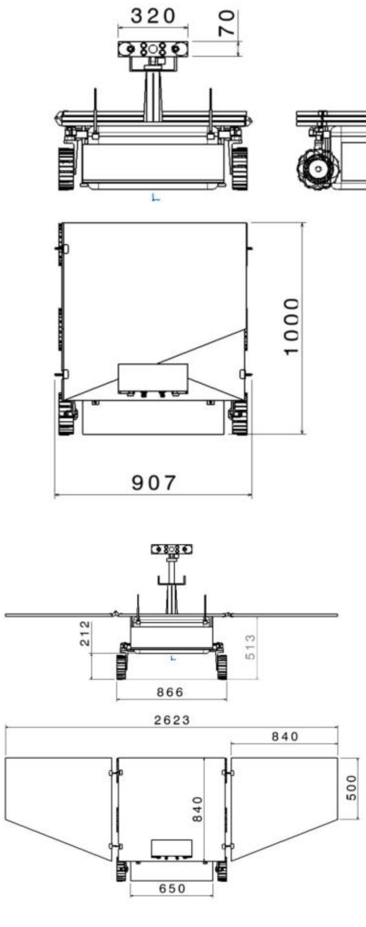


Figure 12 – SFR stowed & deployed configuration (in mm)

SFR is configured with four main modules:

- Rover Body Structure (660 length x 600 width x 300 height mm)
- Locomotion Subsystem
- Mast Assembly
- Solar Array Assembly

Rover Body accommodates the Rover subsystem and electronics equipments. It is made of a sandwich structure with carbon fibre reinforced plastic skins. For thermal needs three radiators have been also mounted outside the body, two on the lateral sides and one on the rear side. In the pictures below are shown the interior and the exterior of the body. Electronic boxes are encapsulated inside a thermal compartment made of aluminium in order to guarantee the correct temperature for each equipment. Besides, to guarantee the thermal requirements the electronic equipments have been mounted on a sandwich panel (aluminium honeycomb + aluminium skins) directly attached to the lateral side of the body by means of an interface with a low thermal conductivity.

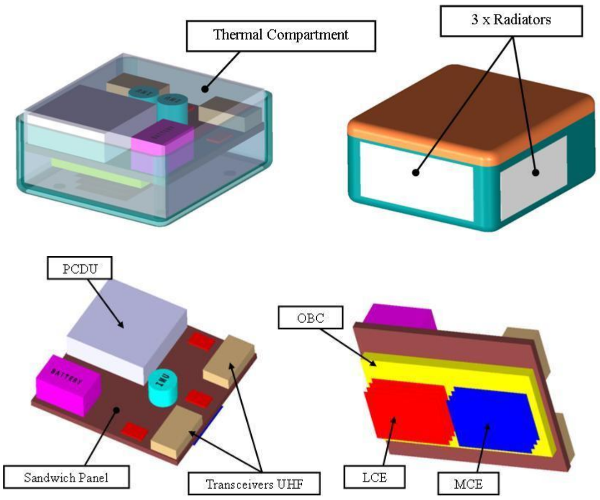


Figure 13 – SFR Body

During Mars operations, the Rover body is supported by a locomotion subsystem comprising 6 wheels driven by electric motors. Wheels are connected in pairs by two structures named “boogies”, two longitudinal boogies are attached on the left and right side of the main body. On the rear side another boogie supports the other two wheels of the Rover.

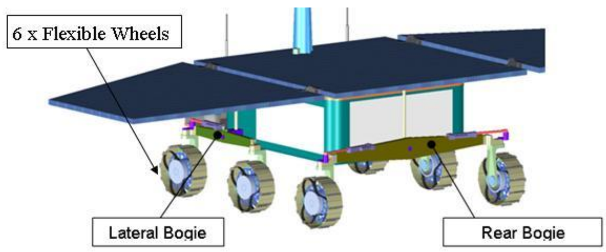


Figure 14 – SFR Locomotion SS

On the front side of the Rover Body dedicated bracket will be developed in order to mount the UHF antennae and the Cache Acquisition System. A Biobarrier structure is also foreseen to protect the CAS, it serves two purposes, planetary protection and contamination control.

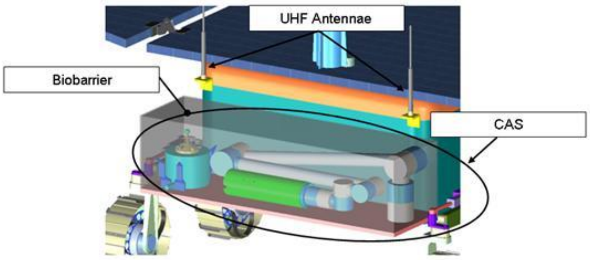


Figure 15 – SFR front side

The mast assembly is mounted on the upper side of the body, it supports two NavCams stereo benches (nominal and redundant), PanCam and one High Resolution Camera. A telescopic tube permits the deployment of the mast from the stowed position to a height approximately of 1.1m above the ground, this is the position that the Rover assume during the nominal locomotion phases on the Martian surface.

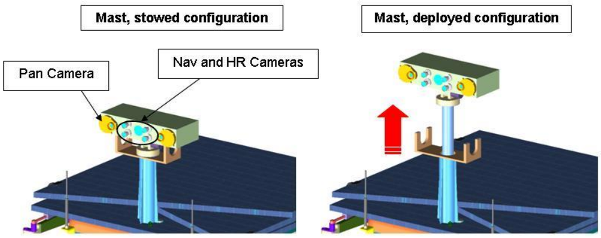


Figure 16 – SFR mast assembly

Finally, the Solar Array comprises a fixed rectangular panel on the top face of the rover body and 2 deployable trapezoidal side panels that are folded out, after the landing on Mars, by spring actuated hinge mechanisms on the lateral edges of the fixed panel.

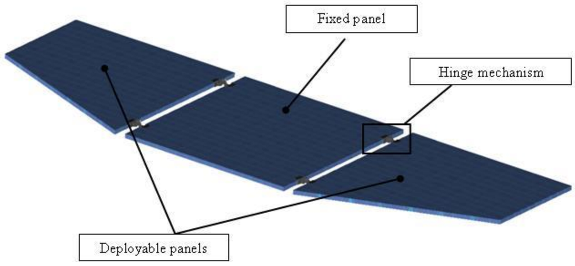


Figure 17 – SFR Solar Array

7. SFR MISSION TIMELINE & FEASIBILITY

As indicated in the previous paragraphs the locomotion sol distance shall be sized according to the power availability, in order to minimise as much as possible the energy loss. Moreover the mission should be concluded before sol 112, in order not to increase too much the solar array area to support locomotion with OD 1.5. The amount of ground track distance which could be travelled by the rover is of course linked to the available power (variable during the lifetime), the solar array area and the power consumption of each subsystem.

Surface Mission Phase	Phase Duration	Activity
Egress and Commissioning	14	Rover egress, functional, and mobility commissioning
Locomotion	X (computed according to SA Area and SS power consumption)	Rover navigation to cache position - 7.5 Km straight line distance, equivalent to 10.5Km ground track distance. Daily travel maximised according to power availability and thermal conditions
Precise approach + Sample cache collection	5	Sample cache precise approach (commanded by ground or mixed target tracking approach) + Rover collects the sample cache using the CAS and stores it in a "safe" position
Locomotion	Y (computed according to SA Area and SS power consumption)	Rover navigation to cache position - 7.5 Km straight line distance, equivalent to 10.5Km ground track distance. Daily travel maximised according to power availability and thermal conditions
Precise approach + Sample cache handover	5	MAV precise approach (commanded by ground or mixed target tracking approach) + Handover of the cache to the MAV (executed by Lander arm)

Figure 18 – Mission Phases Definition

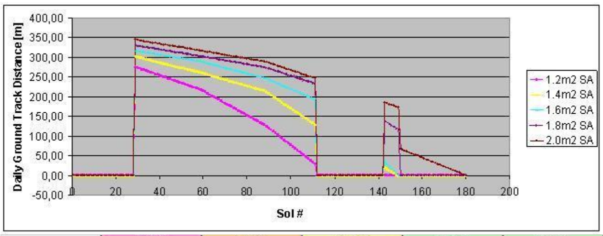
SFR power consumption according to OP Mode

Op Mode	Mehanisms [W]	GNC [W]	Locomotion [W]	Power [W]	Comms [W]	Data Handling [W]	Thermal [W]	Payload [W]	Power Need (+20% margin) [W]	Note
Off	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	Baseline Mode during Cruise. Rover temperature is supposed to be maintained by the Carrier
Self-Test	0,00	0,00	0,00	1,80	0,00	12,50	0,00	0,00	17,16	Entered only during Cruise. Rover temperature is supposed to be maintained by the Carrier
Sleep	0,00	0,00	0,00	1,80	0,00	1,80	7,00	0,00	12,72	Night and Dust Storm with high OD
Standby	0,00	0,00	0,00	9,83	0,00	5,80	0,00	0,00	18,76	This is the basic mode entered by the rover in the morning. Rover is actually doing housekeeping and is ready for operations
Communication (day)	0,00	0,00	0,00	9,83	24,50	10,00	0,00	0,00	53,20	On predefined time windows transceiver will start a communication session. Other operations (e.g. travelling) shall be paused for the communication window. During night communication the communication equipment is in cold redundancy, while during the day it is in hot redundancy
Communication (night)	0,00	0,00	0,00	1,80	23,00	10,00	0,00	0,00	41,76	
Travel	0,00	8,70	28,00	9,83	0,00	12,50	0,00	0,00	70,84	In this mode the rover is travelling
Scientific (CAS or SAS)	0,00	0,00	0,00	9,83	0,00	10,00	0,00	25,00	53,80	In this mode the rover is actuating the Payload (CAS or SAS)
Scientific (PanCam)	0,00	0,00	0,00	9,83	0,00	10,00	0,00	7,31	32,57	In this mode the rover is actuating the Payload (PanCam)
Day-time Safe	0,00	0,00	0,00	9,83	3,00	5,80	0,00	0,00	22,36	This is the mode entered by the rover, during the day, after an anomaly not recoverable automatically or a missed communication
Night-time Safe	0,00	0,00	0,00	1,80	1,50	1,80	5,50	0,00	12,72	This is the mode entered by the rover, during the night, after a sunset with the Rover in Day-Time Safe Mode

As already mentioned the core design driver for the SFR is mobility. The nominal reference mission feasibility has been assessed, based on the power budget presented in the previous page.

Three main requirements have been satisfied to judge mission feasibility:

- REQ1: perform the nominal reference mission within 180 sols, travelling 15km straight line distance (21km accumulated ground track distance)
- REQ2: support the Safe Sol for the entire mission timeline with OD = 2, <u>or until the nominal reference mission objective is accomplished.</u>
- REQ3: support the hibernation sol for the entire mission timeline (180 sols) with OD = 2



	1.2m2 SA		1.4m2 SA		1.6m2 SA		1.8m2 SA		2.0m2 SA	
	7.5+7.5Km Groud Track Distance	10.5+10.5Km Groud Track Distance	7.5+7.5Km Groud Track Distance	10.5+10.5Km Groud Track Distance	7.5+7.5Km Groud Track Distance	10.5+10.5Km Groud Track Distance	7.5+7.5Km Groud Track Distance	10.5+10.5Km Groud Track Distance	7.5+7.5Km Groud Track Distance	10.5+10.5Km Groud Track Distance
Cache approach [Sol]	29 => 59	29 => 74	29 => 55	29 => 66	29 => 53	29 => 63	29 => 52	29 => 62	29 => 51	29 => 60
MAV approach [Sol]	NOT FEASIBLE	NOT FEASIBLE	61 => 92	NOT FEASIBLE	59 => 86	69 => 144	58 => 83	68 => 106	57 => 81	66 => 102
Expected Mission End [Sol]	NOT FEASIBLE	NOT FEASIBLE	97	NOT FEASIBLE	91	149	88	111	86	107
Max Ground Track Distance (not considering cache operations, only travelling) [m]	14354,01		19629,81		22283,51		24872,83		27421,72	

Figure 19 – REQ1 Feasibility Assessment

OD	Sol [#]	Daily Energy Generation [Wh]					Safe Sol Energy Need [Wh]
		SA Area 1.2m2	SA Area 1.4m2	SA Area 1.6m2	SA Area 1.8m2	SA Area 2.0m2	
2	0	552,86	641,34	729,82	840,28	928,76	453,79
2	23	511,76	593,67	675,57	777,82	859,72	449,93
2	45	465,72	540,25	614,79	707,84	782,37	446,56
2	68	412,86	478,93	545,00	627,49	693,57	443,19
2	90	359,96	417,57	475,17	547,09	604,70	439,33
2	113	305,67	354,59	403,51	464,59	513,51	435,48
2	135	254,82	295,60	336,39	387,30	428,08	432,11
2	158	206,01	238,98	271,95	313,11	346,08	428,25
2	180	162,83	188,89	214,95	247,48	273,54	424,88

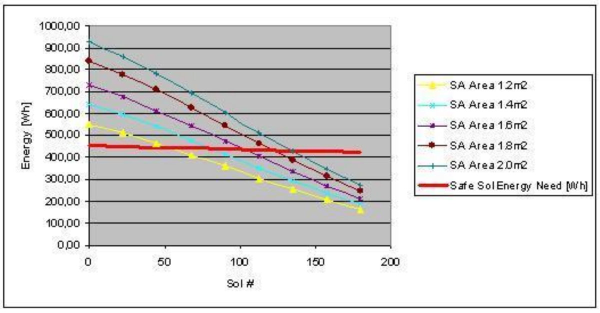


Figure 20 – REQ2 Feasibility Assessment

OD	Sol [#]	Daily Energy Generation [Wh]					Hib. Sol Energy Need [Wh]
		SA Area 1.2m2	SA Area 1.4m2	SA Area 1.6m2	SA Area 1.8m2	SA Area 2.0m2	
2	0	552,86	641,34	729,82	840,28	928,76	223,83
2	23	511,76	593,67	675,57	777,82	859,72	227,19
2	45	465,72	540,25	614,79	707,84	782,37	230,13
2	68	412,86	478,93	545,00	627,49	693,57	233,07
2	90	359,96	417,57	475,17	547,09	604,70	236,43
2	113	305,67	354,59	403,51	464,59	513,51	239,79
2	135	254,82	295,60	336,39	387,30	428,08	242,73
2	158	206,01	238,98	271,95	313,11	346,08	246,09
2	180	162,83	188,89	214,95	247,48	273,54	249,03

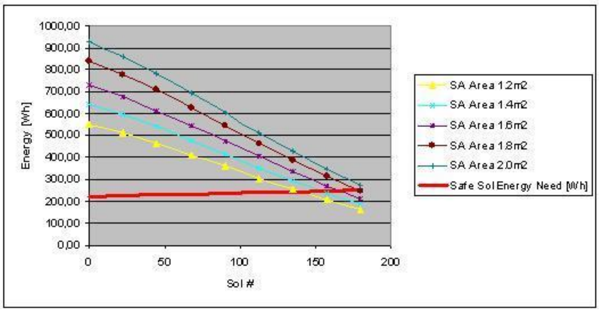


Figure 21 – REQ3 Feasibility Assessment

The nominal reference mission objective, with the current SFR design, can be accomplished before the solar conjunction (sol 111) with a <u>SA area of 1.8m^2</u>, while being safe since the Safe Sol can be sustained for all the 111 sols. The SFR will be however able to survive the entire mission lifetime (180 sols) in hibernation mode (with 2 communications per day).

8. CONCLUSIONS & FURTHER WORK

The Sample Fetching Rover mission feasibility has been assessed and a preliminary design has been provided as an output of this study. During this work, several technologies have been indentified which are needed for the SFR development but which have low Technology Readiness Level (TRL). A priority has been assigned to each of the technologies, with the following meaning:

- **High**: TRL 5 shall be reached by 2014/2015. Critical technology to be developed for SFR since they are part of the design.
- **Medium**: TRL 5 should be reached by 2014/2015. This is considered a goal as would increase rover capabilities, but not a critical technology blocking the SFR development (not baselined).
- **Low**: technologies which should probably bring an increase of rover performances and/or increase of the understanding and confidence on the design and analyses done in this study.

Subsystem	Technology Description	Priority	TRL	Development Status
Mechanisms & Locomotion	Mechanisms working at very low temperatures can increase the operational time and decrease the need of energy at warm up (less heaters). Current goal set to -60deg but SFR findings indicate -80deg as best lower operational	**High**	**4**	ESA MREP E915-002MS: “Mechanisms technologies that operate at very low temperatures”

	temperature.			
	Mechanisms control electronics: A new development oriented to the power consumption optimisation of the ÅAC MCCs is advised, since they can represent the best solution for the mid term future planetary rovers	**Med**	**4**	TRP ESA activity concluded with encouraging results and first breadboard. To be further optimised in a new development to reduce mass and power consumption
	Simulation of wheel-soil interaction for understanding and predicting locomotion subsystem performance on different terrains.	**Med**	**3 / 4**	Two activities already in ESA MREP technology plan. ESA TRP SWIFT activity already running to develop a simulation tool, as well as ESA MREP EXPERTISE foreseen for 2012, to obtain test data for validating SWIFT tool.
	Robotic arm for cache acquisition and transfer or scientific instrument placement	**High**	**3**	ESA TRP DELIAN activity initiated in 2012 to develop lightweight robotic arm for exploration.
Autonomy	Plan Validation - Model-checking approach, supplemented by automated sampling techniques for testing robustness and automated domain analysis techniques to identify inconsistencies and violation of basic constraints.	**High**	**4**	Design heritage in Exomars Technology provision through PMOPS – GSTP – target TRL 5
	Plan Adaption/Replanning - Action centred symbolic AI providing declarative descriptions of the domain and problem model. PDDL or TDL/PDDL mapping	**High**	**4**	Design heritage in Exomars Technology provision through PMOPS – GSTP – target TRL 5. ESA TRP GOAC (Goal Oriented Autonomous Controller – E4) activity outcomes to be evaluated for an autonomy level E3
	Secure Deployment and component orientated test and development - Secure time and space partitioning	**High**	**4**	ESA Integrated modular avionics (IMA) studies
	Ground-based software tools for highly-mobile, autonomous rover mission operations	**Med**	**4**	ESA activities running (IRONCAP, MMI4EXP, 3DROCS)
GNC	Vision Based Algorithms on FPGA: currently vision based algorithms are running on space qualified processors (LEON2) with very poor performances. Next step should be porting these algorithms in HW. Simultaneous Localisation and Mapping (SLAM): SLAM is essential for autonomous vehicles aiming at returning back precisely to the starting point. Currently this algorithm not been implemented and tested for space.	**High**	**3**	ESA MREP E913-001MM: "SPAring Robotics Technologies for Autonomous Navigation (SPARTAN)"
	Bundle Adjustment (BA): BA from Ground links overhead images (including orbital and descent images, if available) with surface images (including rover panoramic images and traversing images) through natural features on the ground and/or remote landmarks. This technique has been studied in the frame of the Exomars project, and has been used by NASA for the MER localisation, but needs further development in Europe in order to reach an higher TRL before 2015. A study in this direction is recommended. Together with field testing.	**High**	**4**	ESA MREP E913-005MM: "Spartan EXTension Activity - Not Tendered (SEXTANT)"
	Time of Flight Cameras (TOF) development for Space: this technology is very promising and extensively used for Unmanned Ground Vehicles but is currently not taken in consideration for Space application. A study on the applicability of this technology to the Space Segment involving the TOF manufacturers is recommended.	**Low**	**3**	ESA Activity initiated for Rendezvous and docking: AO 1-6975/11/NL/MH. Not known activity for Mars characterisation. ESA TRP study on Miniaturised Lidar (MILS) running which could also address the Rover application.
	IMU power consumption: the current space qualified IMU are heavy and power demanding. A development of a lightweight IMU with small power consumption is advised (e.g. MEMS based and integrated in a chip)	**High**	**3**	ESA Activity foreseen: TRP activity IMU on a chip development for 2012
	Soil characteristics detection on-board (e.g. Dangerous soft soil) based on stereo vision	**Low**	**2**	No known activity
Power	Development of high efficiency solar cells (multi quantum cells, diluted nitrides, ultrathin, inverted metamorphic are at research level only) is advised	**Low**	**2 / 4**	ESA MREP activity T903-014EP: "Characterisation of space and terrestrial cells for future Mars lander/rover missions". However for the Martian environment dust degradation represents the biggest weakness (see next point)
	Development of a dust removal device for Solar Arrays is advised	**Med**	**3**	See previous point. NASA developments stopped with the use of nuclear power sources (thermal + electrical). ESA TRP activity T913-008MM: "Dust Unseating from Solar-panels and Thermal-radiators by Exhaling Robot (DUSTER)"
	Battery thermal requirement are the most stringent inside the Rover body. Development of a Battery cell with lower discharge temperature would preserve power during	**Med**	**3**	ESA MREP E903-013EP: "Development of a low temperature Lithium ion battery and survivability tests". It is

	night (smaller battery and SA)			advised to increase the energy density to further increase usability for light weight rovers like SFR
	Development of SA Regulators (Maximum Power Point Tracker with temperature sensors) and PCDU is advised	**High**	**4**	Development foreseen for the Exomars Rover Module. Not known activity in case Exomars program is stopped
Telecommunication	UHF band transponder: modify the transceiver architecture in order to reduce the power consumption during the wait for hail. The use of more power-efficient DC/DC conversion, components and RF power generation are also development directions to be investigated	**High**	**3 / 4**	ESA MREP Study planned: Dual UHF-X Band Transceiver
	Power amplifier: a new generation of solid state RF power amplifying architecture with more efficient power generation would reduce power consumption mass and envelope thus making feasible the implementation of full redundant X-band DTE-DFE Comms architecture via LGA	**Low**	**3**	
	X-band transponder: a dedicated low information-rate transmission and reception architecture (e.g. just using a small set of commands and telemetries code by means of tones) with minimum operating flexibility features would reduce transponder mass and envelope thus allowing a possible rethink on introducing the X-band DTE/DFE link via LGA. Also in this case, as per the UHF transponder, the use of more power-efficient DC/DC conversion, components are also development directions to be investigated			
	UHF antenna: embed the antenna in other elements of the rover (e.g. camera mast if present).	**Low**	**3**	No known activity
Data Handling	Components integration, SoC (e.g. SCOC3) providing reduction of PCB size, mass and power	**High**	**4 / 5**	Dual Core Rad Hard Processor (GR712RC Dual-Core LEON3FT SPARC V8 Processor). SCOC3 system on Chip. Ongoing MREP development (E901-002ED Tailored onboard computer)
	Development of Smart Image Sensors dedicated to Navigation and / or Localisation	**Low**	**4**	This is considered an option in case MREP SPARTAN breadboard does not meet requirements. Also running ESA
				VisNAV study maybe addressing this.
Planetary Protection	HEPA filters have a very low TRL in Europe. A development of this technology is critical.	**High**	**3**	No known activity
Operations	On Earth Rover Test Campaigns are advised to familiarise with Rover operations, simulating communication constraints	**High**	**3**	European experience on Rover commanding & operations is very low (pending Exomars approval). Not ESA funded activity foreseen but MARS2013 "Morocco Mars Analog Field Simulation" under organisation by the Österreichisches Weltraum Forum. ESA TRP Sample Acquisition Field Experiment with a Rover "SAFER" foreseen for 2012.

Figure 22 – SFR needed Technology Developments

9. ACKNOWLEDGEMENTS

The SFR Phase A study reported in this paper has been entirely funded by the European Space Agency (ESA) under MREP. We would like to specially thank Pantelis Poulakis (ESA) and Sanjay Vijendran (ESA) for the precious technical support.

Thales Alenia Space would like to gratefully acknowledge its subcontractors for the outstanding work done:

- **MDA** (Howard Jones) for Locomotion and Mechanisms
- **SCISYS** (Roger Ward, Mark Woods) for Software and Autonomy
- **SEA** (Michael Guest) for Planetary Protection
- **Joanneum Research** (Gerhard Paar) for Navigation/Localisation