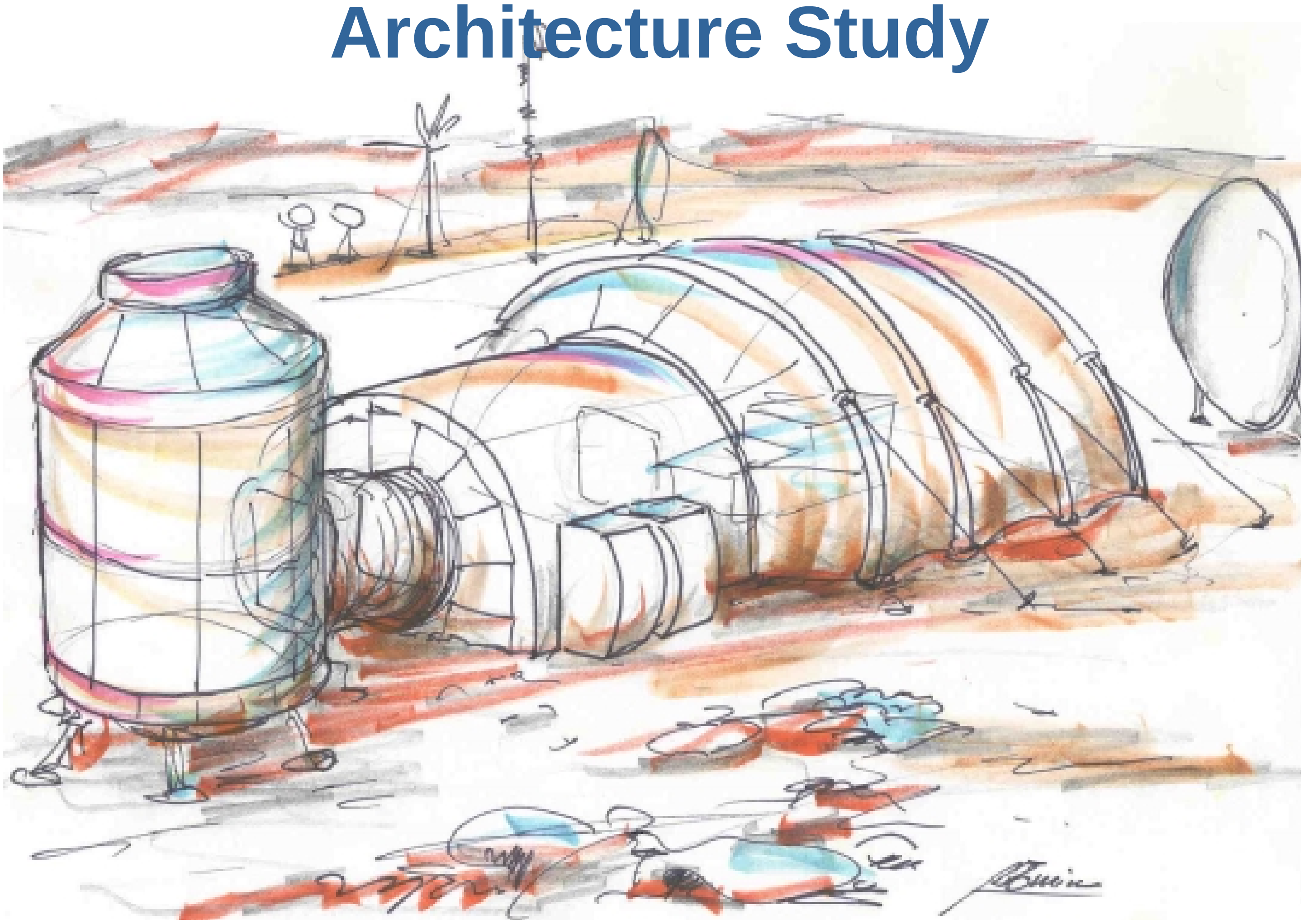
European Mars Missions Architecture Study



Executive Summary

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Title

EUROPEAN MARS SYSTEM ARCHITECTURE STUDY

Executive Summary

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SUMMARY

This Executive Summary summarizes the approach, rationale and main results of the European Mars Mission Study. It includes:

- A recall of the reference mission scenario,
- a description of the transport and lander system and key drivers, of the five candidate missions with a focus on MPL and ISRU, the two reference missions,
- an overview of the necessary technology
- the programmatic aspects for the two reference missions

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1 INTRODUCTION

During the last decades, scenarios have been defined to prepare and support a human exploration of Mars. They have each proposed ways, but looking at the challenge, it is clear that a mission to Mars will require a stepped approach with technological innovations and an International cooperation.

Different approaches could be considered for Europe to participate to the International Human Exploration of Mars. One way is to provide self-contained, cooperative missions in scientific, technological or logistics domains. While relying on European heritage, such missions would benefit from European leading innovative approaches and technologies and would complement the International Mission to Mars by appropriate elements.

This study aimed at analysing the European candidate cooperative, but self-contained missions and architectures, and at investigating the relevant enabling technologies. Its covers the identification and analysis of a set of candidate missions and associated architectures, the elaboration of a relevant set of missions, system and subsystem requirements, the identification of enabling and innovative technologies, the analysis of two reference missions.

The study has been performed by Astrium SAS, with Alenia AeroSpazio, Astrium GmbH (with the support of DLR), EADS-LV and EADS CCR.

Two complementary studies have been run in parallel: the definition and design of automation and robotic systems (S56), the definition and design of future power systems (S54).

2 OVERALL MARS MISSION SCENARIO

The overall Mars Mission Scenario is a background on which candidate European missions can be identified and described. It proposes a stepped approach for the preparation and support of manned missions towards Mars, and subsequently describes a logic of successive missions to Mars.

Nevertheless, this overall scenario is driven by some main assumptions, such as:

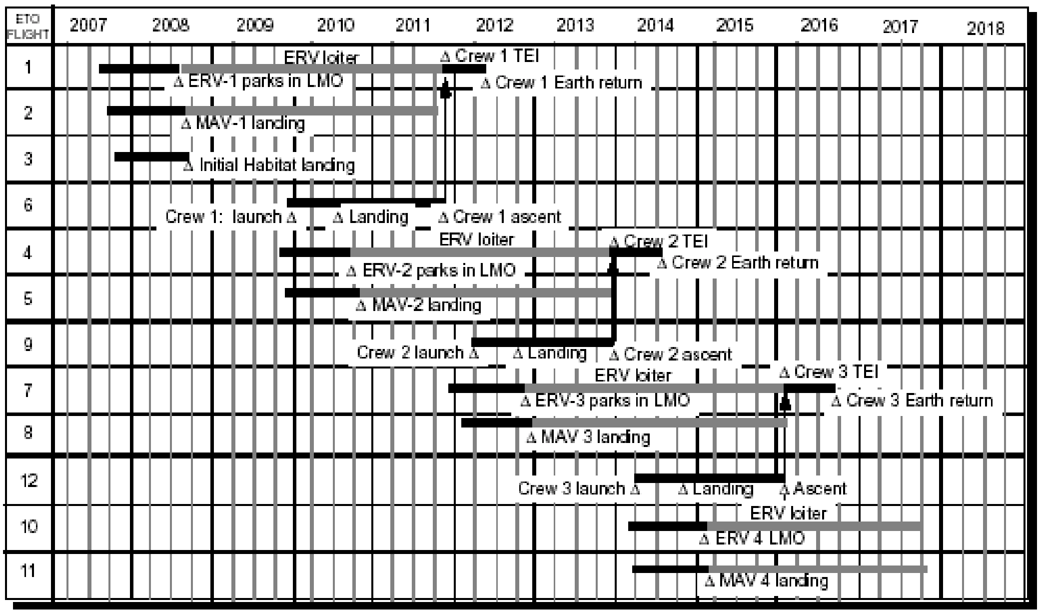
- the type of landing site: a single landing site for the successive manned missions, or a different landing site for each mission. In the first case, an adequate infrastructure could be built.
- Several successive flights, or a single flight for each manned mission
- Long stay versus short stay of crew on Mars surface. A long stay is associated to a short transfer duration. Trade-off is linked to the environment problem (radiation, where are the most severe conditions), and the effect of null or low gravity on the crew.

NASA and Russian have proposed two different approaches.

2.1 THE NASA MARS REFERENCE SCENARIO

The Mars reference scenario proposed by NASA (last version) is illustrated on figure 2.1/1. Obviously, the dates are optimistic, but the logic of the successive missions is interesting and presents the following features:

- Three manned missions are carried out within the scenario, each consisting in two unmanned cargo flights and one manned flight about two years later.
- A single landing site has been selected for the successive missions. It will benefit from an implemented infrastructure
- Long stay of the crew on the Martian surface (nominally 600 days) to take maximum benefit of a long scientific exploration period and to minimise the transfer duration.
- Unmanned and manned missions are planned at the optimum phasing between the two planets: the transit leg for the manned missions is kept to the minimum (180 days)
- “Split strategy”: major elements of the mission are sent independently of each other on a direct Mars orbit: there is independence between cargo missions and manned missions, and the local infrastructure has to be in place and operational before the crew is actually sent.
- Utilisation of a “Magnum” launcher, capable of 80 tons in LEO, together with rendez-vous capability in LEO.



Interplanetary transit	ERV: Earth Return Vehicle
Unoccupied wait in Mars orbit	MAV: Mars Ascent Vehicle
Propellant production and on Mars surface	TEI: Trans Earth Injection
Crew surface operations	LMO: Low Mars Orbit

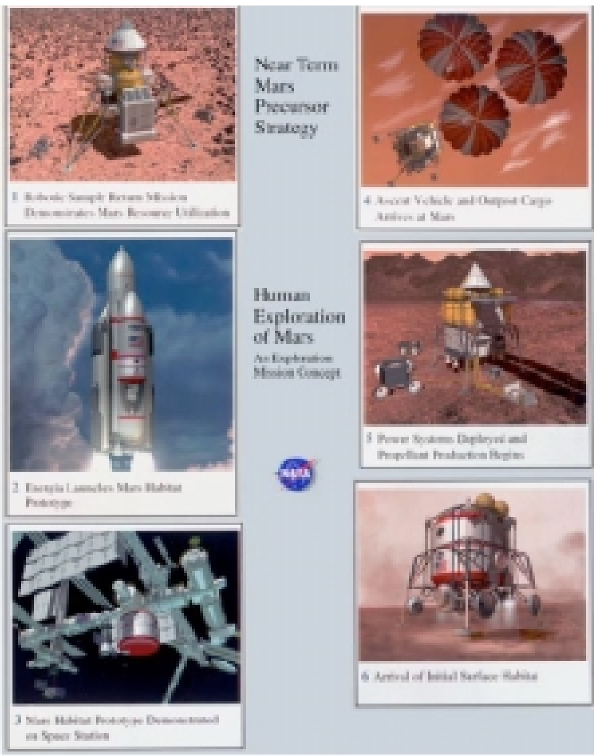


Figure 2.1/1: NASA reference scenario

2.2 RUSSIAN APPROACH (ISTC SCENARIO)

The Russian approach, defined through the ISTC activities, is illustrated on figure 2.2/1. It is different from the NASA one:

- The missions are independent from each other. Each crew does not necessarily return to the landing site of previous mission, limiting therefore the constraints on the landing site.
- A shorter time is spent on Mars surface (60 days maximum) to limit the exposure of crew to radiation. However, the total duration of the mission (Earth-Mars-Earth) is about 900 days in case of low thrust (electrical propulsion), or about 600 days in case of high thrust (nuclear propulsion).
- The mission can be fulfilled by one or two vehicles leaving the LEO. In case of two vehicles (one cargo and one manned vehicle), they are both sent at the same opportunity, and perform rendezvous in Mars orbit.
- Utilisation of launchers of 35t in LEO, with assembly of the vehicles in LEO. This assembly will require several launches.
- In addition, the ISTC activities trade-off a number of issues related to launcher, type of propulsion used during the transfer, the power generation type, etc.

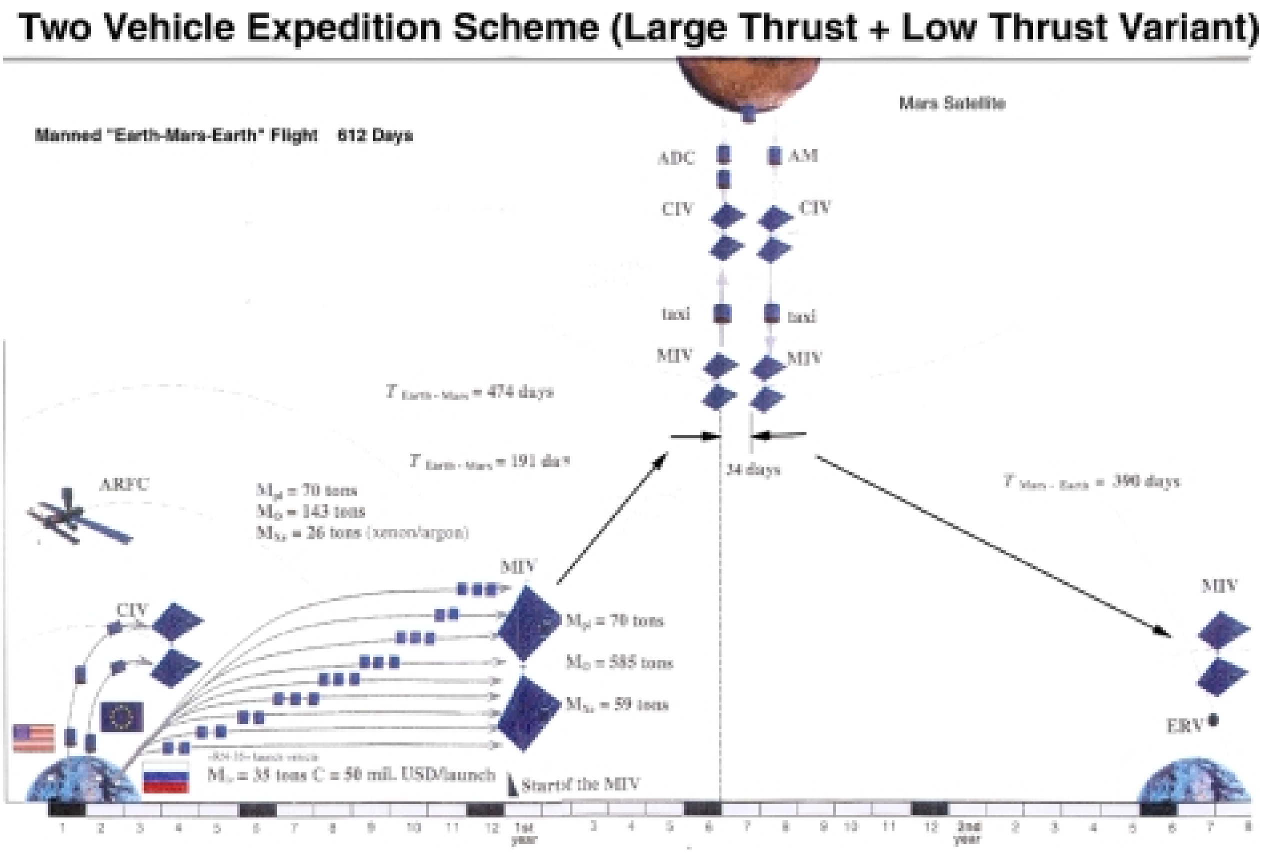


Figure 2.2/1: Russian approach (ISTC scenario)

2.3 PROPOSED OVERALL MISSION SCENARIO

The scenario of human exploration of Mars taken into account relies on the following assumptions:

- A single landing site on Mars for the manned missions
- The implementation of a manned infrastructure to support crew activities and life
- Several flights towards Mars to transport infrastructure elements and crew

This overall scenario is illustrated on figure 2.3/1. It comprises two steps:

- The Step 1 is related to the exploration phase and robotic outpost phase (for the next 10 to 20 years). This step aims to:
  - o Define in details the Martian environment (atmosphere, constituents, e.g. water, …)
  - o Analyse and select the landing sites
  - o Prepare the necessary infrastructure, including technology demonstration
  - o Implement the necessary resources, such as communications, navigation
- The Step 2 is dedicated to the Mars surface operations. It includes the construction, extension and maintenance of the Mars infrastructure, and the continuation of the Mars exploration, from and around Mars

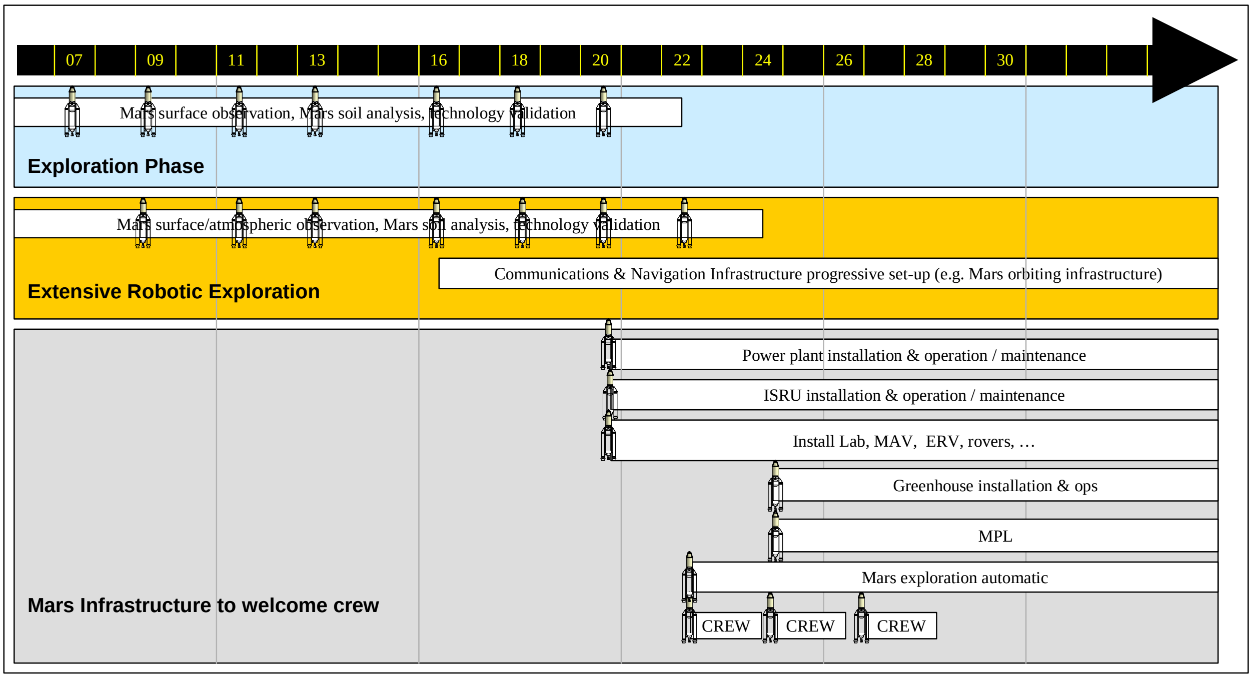


Figure 2.3/1: overall Mars mission scenario

The implementation of the Martian infrastructure on the selected landing site would start in 2020 (first launches) with the installation of an Earth Return Vehicle (ERV) in orbit around Mars, a power plant, an ISRU, a Manned Ascent Vehicle, a pressurised module, rovers. In order to support these implementation missions and later the manned missions, a Mars orbiting communications and navigation infrastructure would be set up.

3 CANDIDATE EUROPEAN MISSIONS AND ARCHITECTURES

3.1 IDENTIFICATION OF CANDIDATE MISSIONS

From the proposed overall scenario, a research of the missions that could be carried out by Europe has been done. These missions have to be co-operative missions, and thus should fulfil some objectives of the International Mars mission, while being self contained in order to be technically and programmatically as independent as possible from the International partners. In addition, a limited budget shall be considered.

Finally, 24 possible mission architectures have been identified and reviewed. They were organised into four categories: logistic / transport missions, Mars surface exploration and evaluation, in-situ resources production capability, support to the manned infrastructure implementation.

3.1.1 Candidate missions

Out of the 24 identified missions, 5 candidate missions have been retained (see figure 3.1 / 1):

- Analysis and evaluation of typical sites, during robotic outpost phase, and analysis of Mars surface and soil from a landing site during Mars surface operations phase with rovers and aerobots.
- Support to the implementation of the Mars infrastructure with a Utility Truck. Such a vehicle allows the ground transport of any element of the infrastructure, and in particular would help the unloading of landers.
- Human exploration of Mars with a Mobile Pressurised Laboratory, capable of reaching area at a long distance from the landing site.
- In situ production of propellant and fluids necessary for the crew life with an ISRU element
- Development and test of closed loop ECLS with a Biology / Greenhouse module.

As illustrated on figure 3.1 / 2, each mission covers:

- the launch and transport phase, including assembly in orbit if necessary, entry into Mars atmosphere, descent and landing on Mars surface. The Mars element is passive during the transport.
- the installation on Mars surface, with the unloading phase which depends on the available infrastructure and will drive the design of the Mars element or lander
- the operational phase on Mars surface, where the Mars element is active; it includes the operations, on the landing site or on a remote working site, and the maintenance of the Mars element at the landing site.

An overview of a generic mission architecture is shown on figure 3.1 / 3. This architecture is driven by the mission objectives and is defined around two main poles: the Mars surface element and the associated transportation system, which are dependent each other.

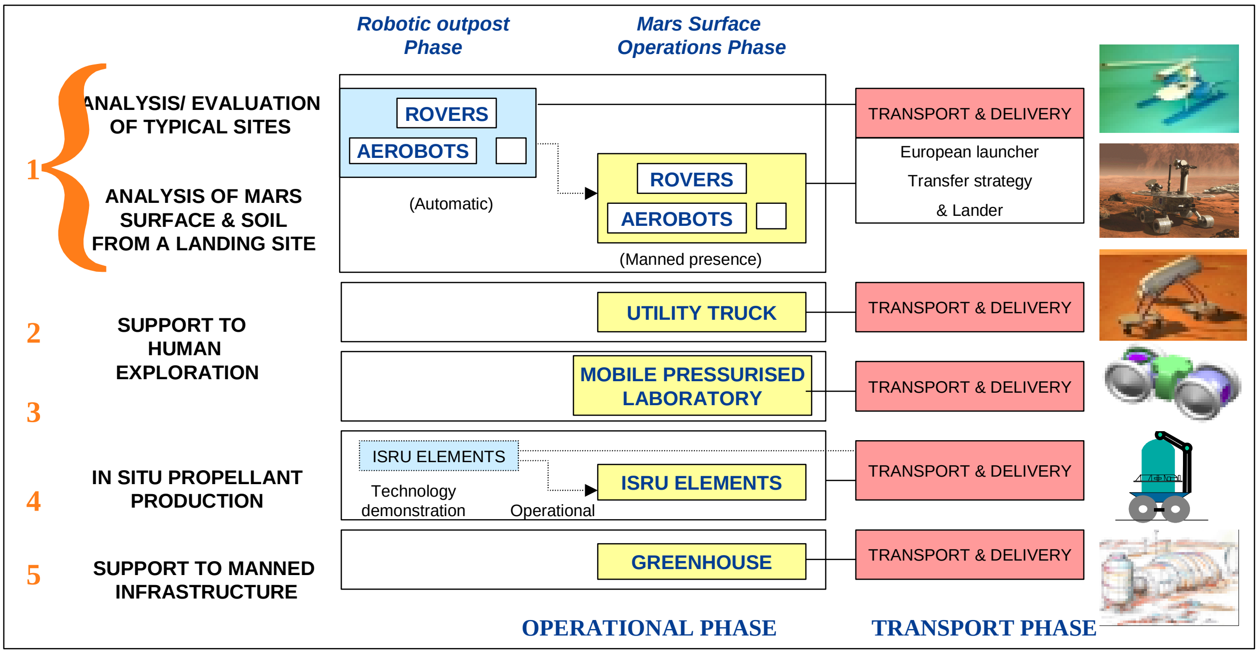


Figure 3.1/1 : Candidate European mission architectures

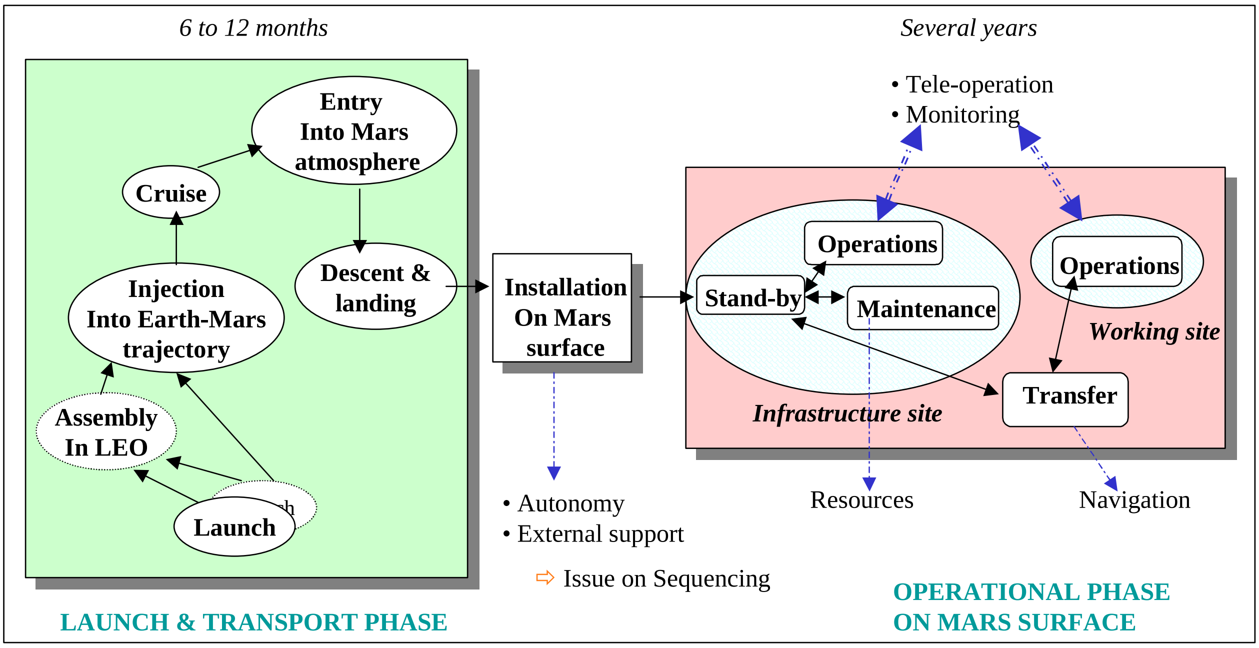


Figure 3.1/2: Main mission phases

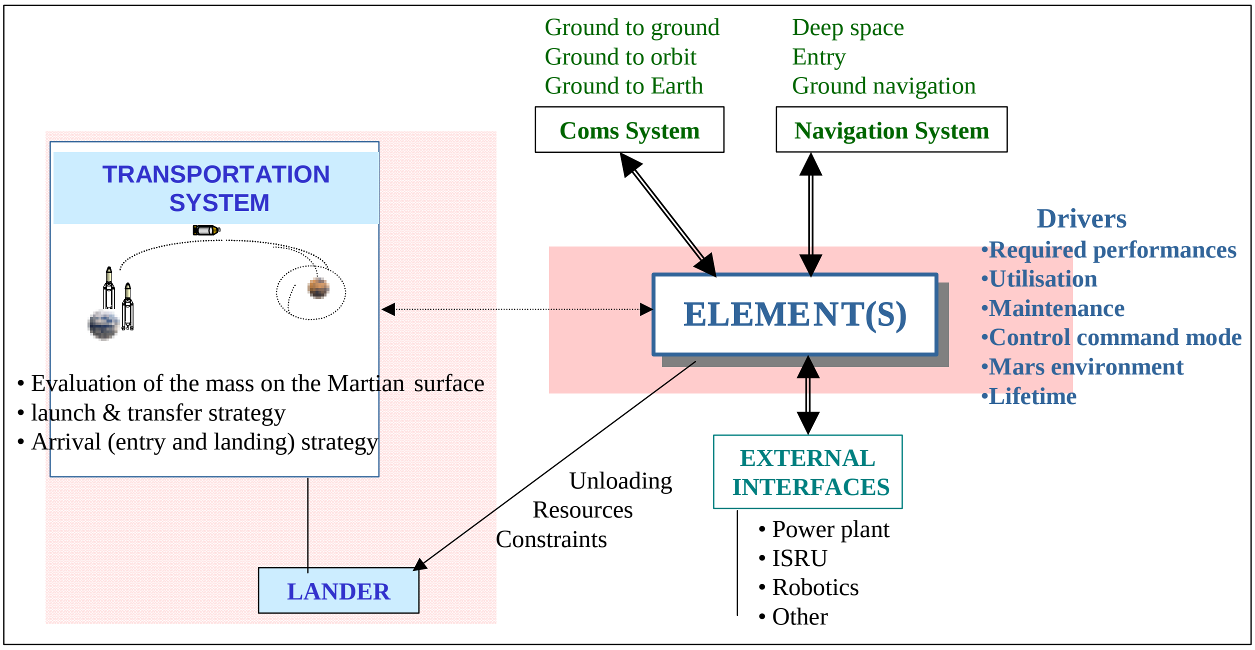


Figure 3.1/3: Mission architecture overview

External interfaces with power plant, ISRU, or robotics could be necessary during maintenance. The communication system, supporting the Mars element operations, would be a priori orbiting around Mars, but ground infrastructure could also be considered with the problem of installation.

The transportation system includes the launcher, the Earth to Mars transfer module, and the lander (with aeroshell). The mass deliverable on the Mars surface relies on the launch and transfer strategy, Mars entry and landing strategy, type of propulsion. The unloading of the Mars element could be supported by available robotics (like Utility Truck), or carried out autonomously. That has a high impact on the design of both the Mars element and the lander.

3.1.2 Mars environment constraints

The Martian environment characteristics are as follows:

- Gravity: 3.725 m/s^2
- Average temperature: from –63°C to + 120°C in south hemisphere, mid summer, and about –100°C in south pole, mid winter
- Average atmospheric pressure: 5.6 mb
- Average solar radiation: 589 W/m^2
- Atmosphere: 95% CO_2, 3% N_2, 1.6% Ar, no H_2

Global Mars dust storm are sparse, but one or more regional dust storm may occur in a year. During a storm, there is an increase of temperature, increase of opacity and reduction of solar radiation. The Mars wind depends on the area, but can be up to 15 m/s during a storm. The Mars surface presents mountains (up to 26 Km high), valleys (up to 7 Km deep). It is stony and sandy.

3.2 TRANSPORT AND LANDER

The transport system design is linked to the type of Mars surface elements, and subsequently the selection of technologies and strategies may vary according to the candidate mission. Clearly, the selection of launcher, the propulsion for the transfer module, the Mars entry strategy, the design of lander and the size of the Mars element are part of an iterative process.

3.2.1 Launcher

The candidate missions shall use as far as possible an existing European launcher, that means the European launcher (called AR++) that will be operational at the time of the missions (typically 2020). The assumed performances of this launcher are:

- Capacity in GTO: 16 tons
- Capacity in LEO (500 Km): between 32 and 37 tons, function of the inclination
- Capacity for a Mars single direct launch at Mars entry: 8to 10 tons
- Fairing size: 5m diameter maximum, 17 m maximum height (no change in the fairing size with respect to AR5)

It is assumed that no specific European heavy launcher will be developed only for the Mars mission.

If the total payload to be launched (Mars element, lander, transfer module) exceeds the capacity of one AR ++, it could be possible to use two AR++ and performs an assembly in orbit. This assembly could be done in LEO via a rendezvous between the two parts, or at the ISS. Nevertheless, a maximum of two AR++ will be used for a mission.

If the Mars element design is not compatible with the AR++ performance or size, the mission will rely on an International heavy lift launcher

3.2.2 Transport scenario

The scenario for transporting Mars element to Mars is illustrated on figure 3.2/1.

The injection on the Mars transfer orbit is driven by the propulsion system of the Transfer Module. The type and level of boosts, to be done for leaving the Earth orbit, will depend on the strategy for Mars entry. Three types of propulsion system have been considered: biliquid, cryogenic and nuclear thermal. In fact, the trade-off is mainly between the cryogenic and the nuclear thermal propulsion for the candidate missions. The nuclear thermal propulsion allows to minimize the mass (or increase the mass at Mars surface), but presents risks.

Other propulsion system like electrical propulsion or solar thermal propulsion would lead to a different scenario: quasi continuous thrust, long duration before leaving Earth orbit and need for large solar arrays in case of electrical propulsion. Nevertheless, they have not been analysed.

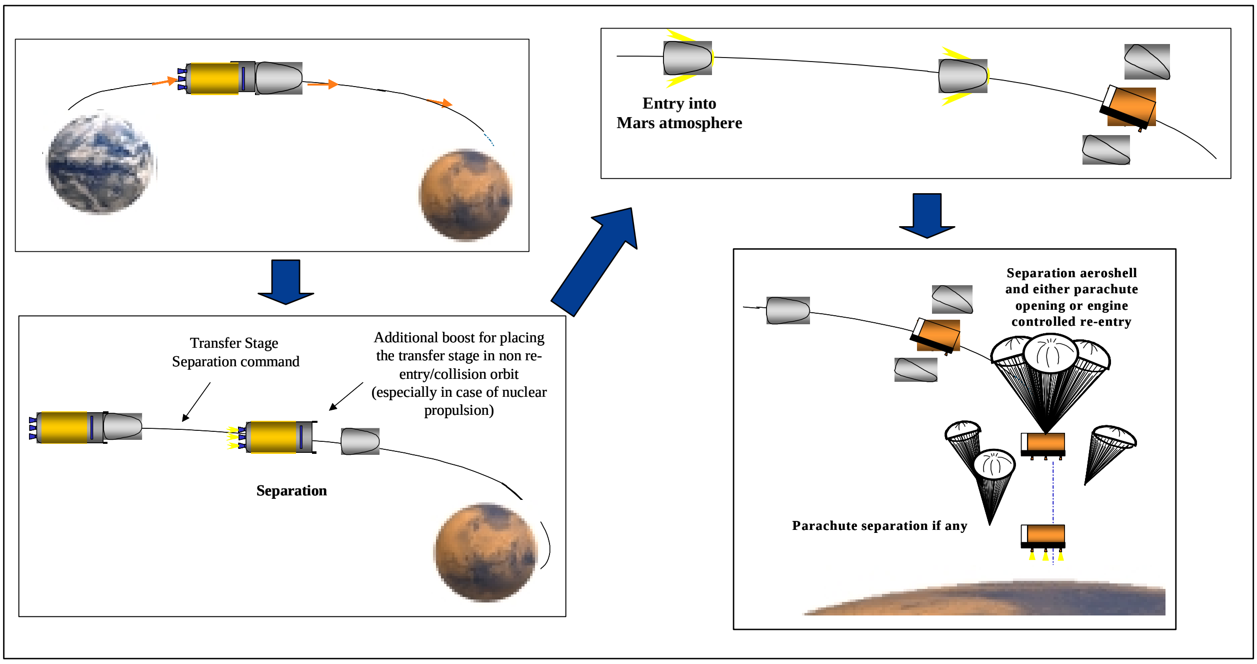


Figure 3.2/1: Scenario for transport to Mars

The transfer module includes the main propulsion system and a resource module providing all the necessary resources (power, telemetry, control-command, etc) to itself and to the lander and the Mars element. It has to ensure the main boosts, but also a few corrective boosts along the transfer-to-Mars trajectory. The separation between the lander-payload and the transfer module can be done when approaching Mars (as assumed in the scenario illustration); it can also occur after the last main boost (once on the transfer trajectory), but, in that case, only the propulsion module is separated and the resource module shall have the capability for corrective boosts. The solution may depend on the type of propulsion and possibly the Mars entry strategy.

The transfer module (or resource module) is separated anyway when approaching Mars. The lander is activated and shall provide resources to the Mars element. The transfer stage could have to be placed in a non entry/collision orbit, specially in case of nuclear thermal propulsion.

Different strategies can be considered for the Mars entry: direct entry, aerocapture, aerobraking. The direct entry is very challenging, as assuming that the hyperbolic trajectory is crossing the Mars atmosphere at an altitude sufficiently low to allow the capture of the vehicle by the Mars atmosphere followed by the landing (while aerocapture assumes the capture of the vehicle followed by a circularisation in a low Mars orbit). This strategy requires a very accurate navigation for the atmosphere entry point and entry corridor, but also for the landing. It allows to maximise the mass of the Mars element. The entry trajectory (flight path angle, entry duration, heat load, etc) is depending on the lander and aeroshell type and on the Martian atmosphere model. The objective of the entry trajectory is to meet the parachute opening conditions.

The descent and landing phase starts at the parachute opening conditions (typically 10 Km altitude, 600m/s). Depending on the mass and size of the lander-Mars element, the mode of braking during descent can be traded off: parachute, propulsion, compromise parachute followed by propulsion. The aeroshell has to be partly or fully separated before starting the braking manoeuvre. The parachute, if any, has to be opened at supersonic speeds; needed surface, opening of multiple canopies, storage during several months are the main features of the parachute system. This phase is characterised by the required precision landing (typically one Km from the Mars base), which can need a controlled descent. A collision avoidance capability, together with a manoeuvre ability is necessary to avoid rocks or other obstacles on the soil.

3.2.3 Lander aspects

The lander has to provide the Mars element with the protection during entry (aeroshell), the power during descent, landing and post landing until the element is unloaded or autonomous, propulsion with attitude control, braking thrust and control, GNC for precision landing, communication with both in-orbit communication system and Mars ground system.

Different sizes and configuration of lander have been reviewed, depending on the mission. Two types of aeroshell have been considered: a Viking type and a biconic type (see figure 3.2/2 ad 3.2/3). The Viking type, having a low ballistic coefficient and a large surface, seems more robust, but, for large payloads, requires a size which exceeds the AR++ fairing. For most of the missions, an inflatable or a deployable heat shield would be necessary to cope with 5m diameter. The aeroshell shape is linked to the entry trajectory: thus, for a biconic type a long entry trajectory with a low flight path angle at the beginning of the entry will be necessary to allow for the adequate braking, with a penalty in term of error propagation.

The power subsystem is required to provide power during 20 h (direct entry and post landing). It is based on the use of primary batteries with high efficiency.

The GNC subsystem would include a high precision navigation, based on optical sensors and appropriate star sensing, during Mars approach in order to cope with the required precision at entry. At high altitude, it uses a high precision autonomous navigation based on optical (not preferred due to troubled atmosphere specially in case of dust), radar (ground beacons to be installed earlier) or orbiting navigation system (GPS like). At lower altitude, an autonomous vision navigation and piloting for safe landing in rugged area, together with a controlled capability for obstacle avoidance could be used.

The selection of the type of lander and aeroshell will be done for each mission.

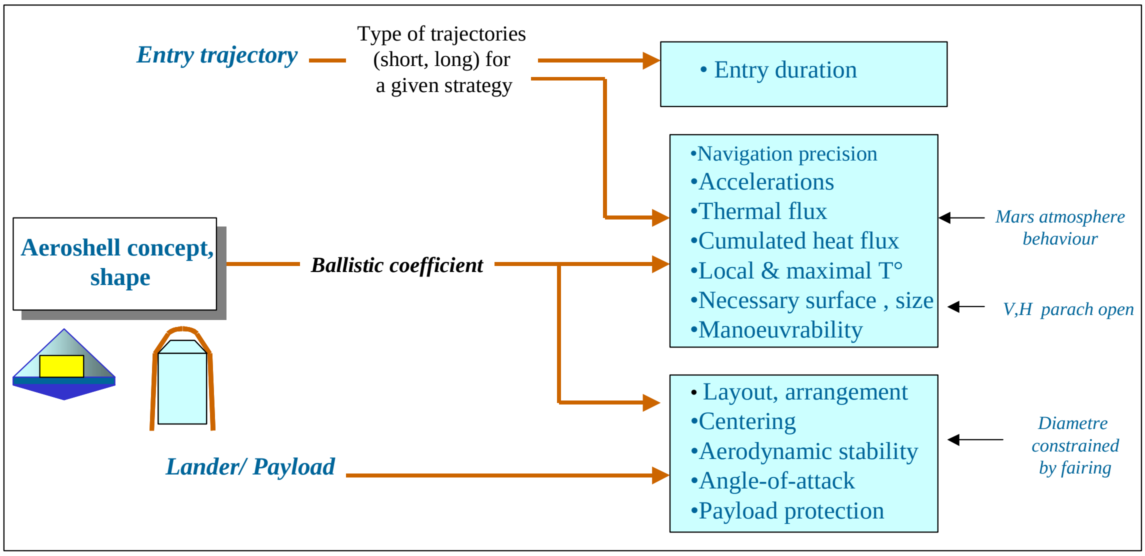


Figure 3.2/2: Key features of the lander

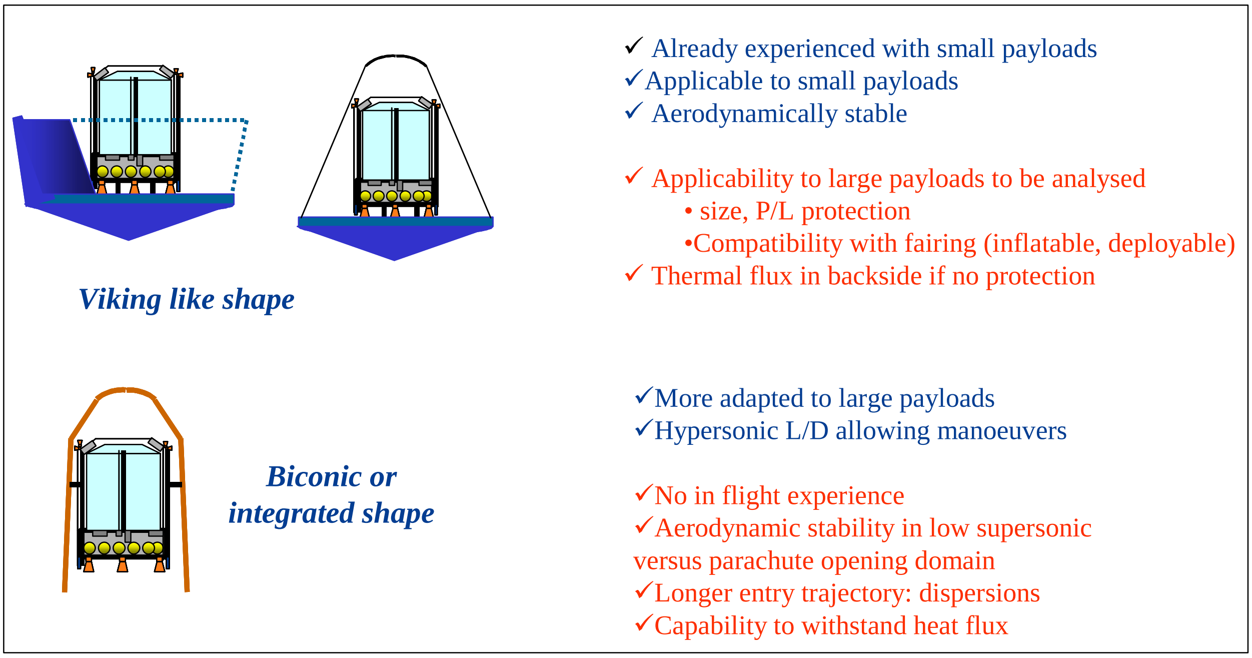


Figure 3.2/3: Alternative shapes for aeroshell

3.3 ROVERS / AEROBOTS

The rovers and aerobots are small and automatic vehicles that can be used both in robotic outpost phase and in the human exploration phase.

In robotic outpost phase, they will allow the analysis of the Mars environment (surface, soil and atmosphere) and will support the examination of potential landing sites. They may be pre-programmed to carry out various types of mission autonomously or tele-commanded from the Earth to conduct activities and analyses requested by the principal scientific investigators. The data retrieved from the analyses and measurements will be stored and, if required, compressed and/or pre-processed, and transmitted via the lander and/or satellite relay system to Earth. The vehicles are also expected to help the verification of technologies for future robotic and human exploration programmes.

In the human operations phase, both rovers and aerobots will be used to assist the crew in getting scientific data out of range of the astronauts or from regions considered hazardous. Rovers will also be used for inspection purposes, i.e. to determine damage to surface elements, perform leak checks, etc.

The mission may rely on one or several rovers and aerobots. Different sizes of rovers could be envisaged. Indeed, the rover may be employed for a dedicated purpose (sampling, inspection, etc) or perform multi-disciplinary tasks.

3.3.1 Launch and transport

The mass of the set of elements ranges from 300 Kg down to a few Kg. The heaviest set of elements (300 Kg) requires the launch of a payload of about 7500 Kg, including the heat shield (accounting for about 600 Kg), being of Viking or Cassini shape, the lander (for about 300 Kg), the lander propellant (for about 150 Kg), the transfer module (the TMI mass, fully loaded with storable propellant, is about 6400 Kg).

The launch is feasible on an AR++, even potentially on a dual launch as a GTO passenger. The utilisation of cryogenic propulsion for the transfer module would lower the TMI mass down to 5.5 tons, but would require additional technology development (long duration cryostorage).

3.3.2 Scenarios

Several options may be considered for the use of rovers and aerobots, as illustrated on figure 3.3/1:

- Basic scenario: Rovers and aerobots are operating in different sites, and are autonomous in term of resources. The data resulting from the exploration are sent to Earth via communications infrastructure.
- Enhanced scenario: Rovers and aerobots are still operating in different sites, but rovers can benefit from in situ resources for power reloading. Data still sent through communications.
- Sample return scenario: the rovers can return Mars samples to a sample ascent vehicle located in the landing site. In addition, rovers can benefit from in-situ resources.
- Human Exploration scenario, with necessary infrastructure for rovers maintenance and sample return to Earth. The rovers could be autonomous or tele-operated by the crew.

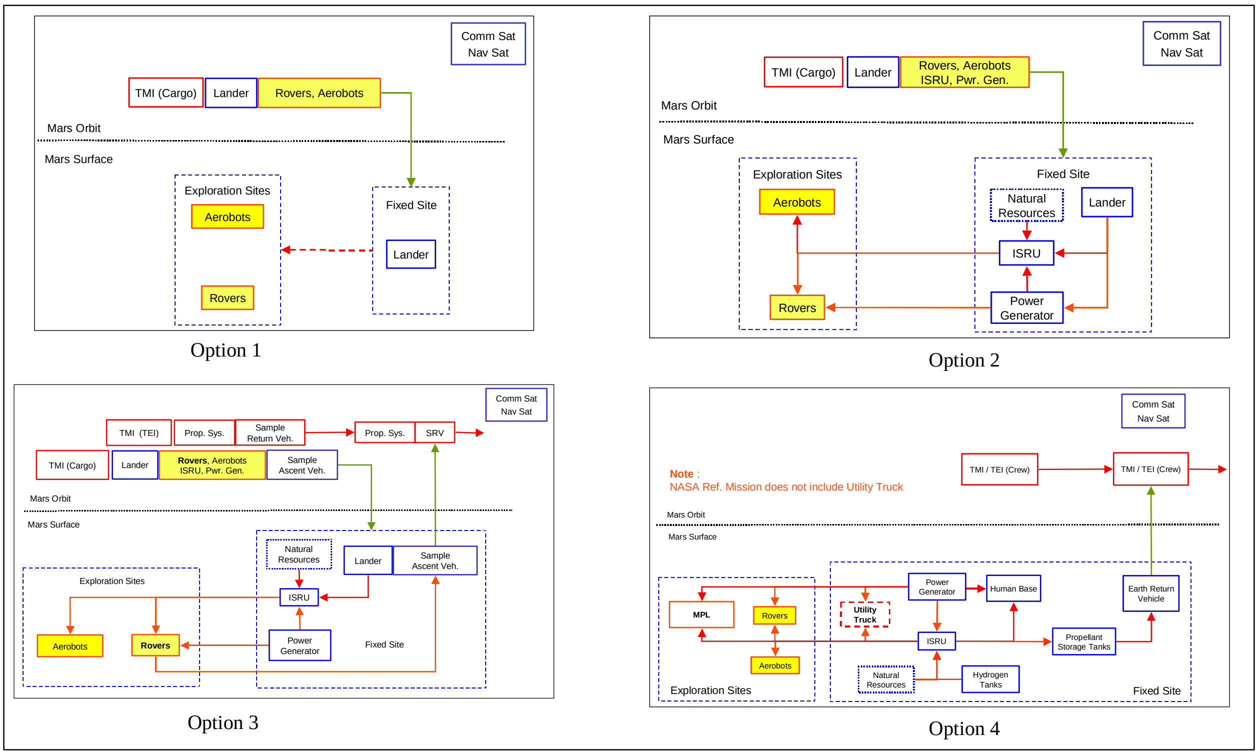


Figure 3.3/1: Possible scenarios for the use of rovers and aerobots

3.3.3 Rovers

Three classes of vehicles foreseen for mission to Mars have been defined:

- rover, with a 150 Kg maximum fully equipped mass and a 100 Km maximum range
- mini-rover, with a 15 Kg maximum fully equipped mass and 10 Km maximum range
- micro-rover, with a 5 Kg maximum fully equipped mass and 40 m maximum range

Their primary characteristics are summarised in the table 3.3/1. Examples of rovers are shown on figure 3.3/2.

3.3.4 Aerobots

The design of aerobots is strongly influenced by the very low density of the Mars atmosphere (consequently the very low Reynolds number, the sound speed, the reference altitude), the very low temperature, the non combustible atmosphere, the wind profile, the stony and uneven surface of unknown firmness and the dusty atmosphere. Several types of aerobots can be considered: balloons, airship, autogyro, helicopter, etc. They are illustrated on figure 3.3/3, and their main characteristics are summarised in the table 3.3/2.

Requirement	Rover	Mini-Rover	Micro-Rover
Primary function	Transport of scientific instruments from stationary lander to points of scientific interest (autonomous operation)		
Max. fully-equipped mass (kg) Scientific equipment mass (% of max. fully-equipped mass)	150 30	15 30	5 30
Stowed envelope dimensions (L x W x H mm)	TBD	650 x 500 x 200	300 x 200 x 200
Cross country ability : min. ground / chassis clearance (mm) trench traverse capability (mm) gradient climb capability (deg)	 300 300 25	 100 100 25	 100 100 25
Max. range from landing site Max. speed	100 km 10 km / sol	10 km 5 m / h	40 m 5 m / h
Max. power demand (W) Max. data transmission rate (M bit / sol)	TBD TBD	10 TBD	3 1
Climatic conditions	Martian ambient		
Scientific equipment deployment	Between horizontal and vertical		

Table 3.3/1: Main requirements for the different classes of rovers

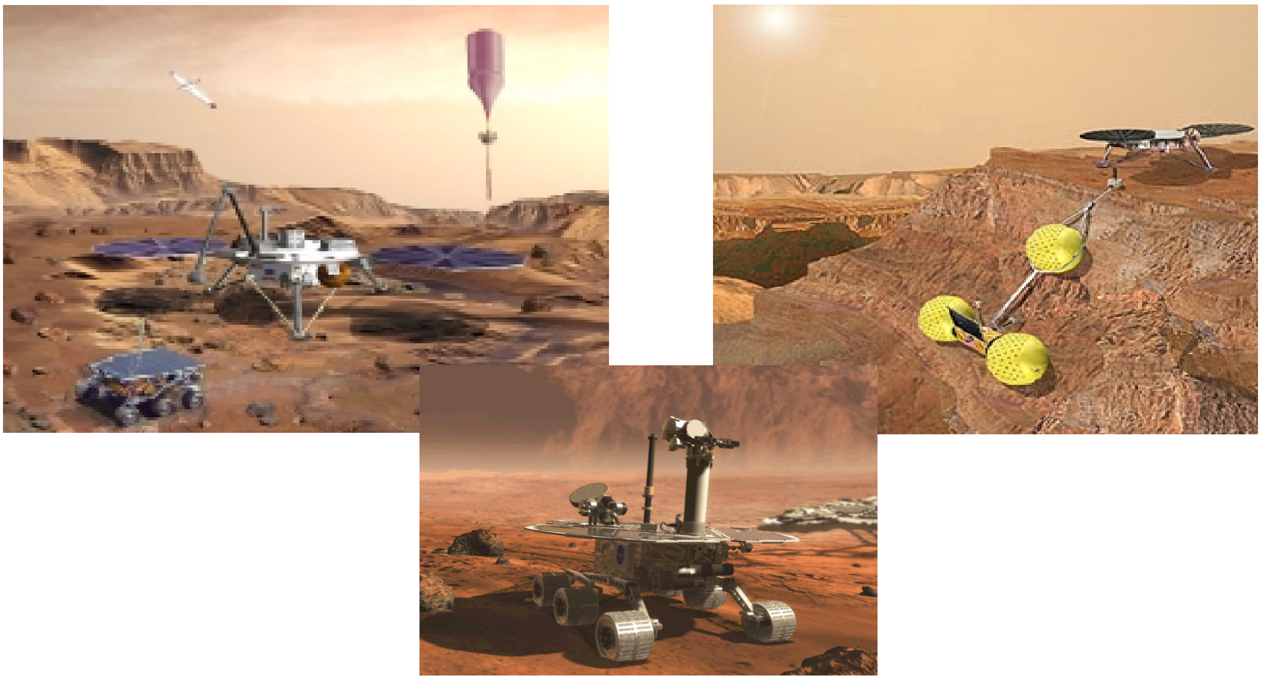


Figure 3.3/2: Illustration of rovers

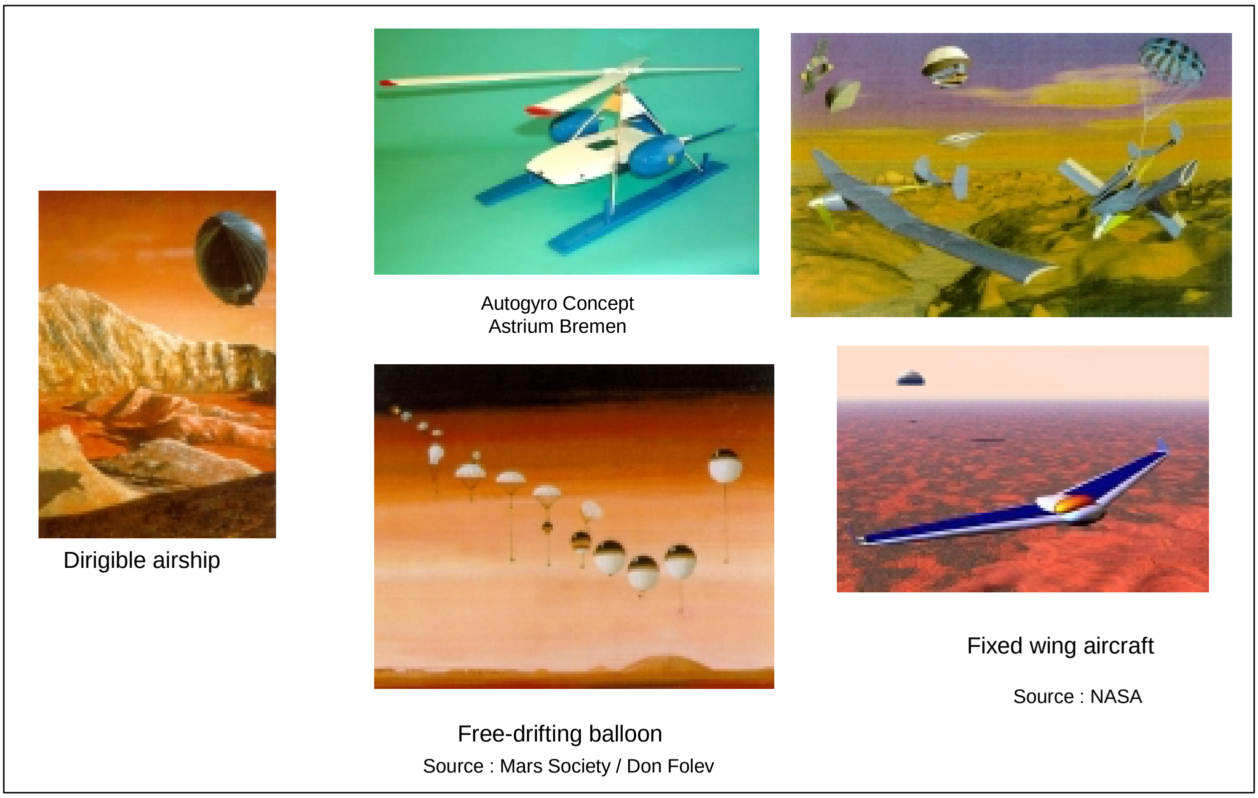


Figure 3.3/3: Illustration of types of aerobots

Type of aerobot	airship	balloon	fixed-wing aircraft	helicopter	autogyro
Flight altitude (km)	0,1 < H < 20	0,1 < H < 10	0,1 < H < 0,5	0,1 < H < 0,5	0,1 < H < 0,5
Flight duration	days / years	days / years	hours	hours	hours
Manoeuvrability	low	none	high	very high	high
Controllability	controllable	not controllable	controllable	controllable	controllable
Take-off site	surface	atmosphere or surface	atmosphere or surface*	surface	surface
Landing site	surface	surface	surface*	surface	surface
Source of energy for propulsion system	sun or atmosphere	atmosphere	sun or atmosphere	atmosphere or surface materials	atmosphere or surface materials
System complexity	relatively simple	simple	complex	very complex	complex

*) only with aid of vertical landing / take-off device

Table 3.3/2: Main characteristics of different classes of aerobots

3.4 UTILITY TRUCK

The Utility Truck is an unpressurised mobile element aiming at assisting with the construction of the human base. It will be used for the recovery of Mars base elements after landing, for erection and assembly of Mars base elements, for surface operations required for removing and transporting surface materials.

3.4.1 Mission scenario

The mass of the UT has been initially evaluated to 7.5 tons. Further analysis tended to show that a lighter element could be envisaged. However, the analysis of the launch and transport phase has been made with the 7.5 tons figure.

The Utility Truck requires the launch of a payload of about 68 tons in LEO, including the heat shield, the lander, the lander propellant and a cryogenic Transfer Module (for about 48 tons, fully loaded). The launch could be feasible with two AR++, but would require a complex assembly in orbit. The UT with heat shield and lander can be launched on one AR++, provided that their implementation under fairing is compatible with the available volume. But the TMI mass is beyond a single AR++ capability, and subsequently has to be divided into two parts, one part launched with UT/lander, the other one alone. This is a key technical challenge: how to split the cryogenic propulsion module in two parts, then assemble them in orbit, and how to keep the cryogenic propellant in orbit (first launch) while waiting for the second launch and assembly. This problem could be solved with a lighter UT or with the use of an International heavy launcher. During the transport phase, the UT is in passive mode, receiving power and telemetry resources from the transfer module or from the lander.

After landing on Mars surface, the UT is in vertical configuration. The UT should be one of the first elements of the base infrastructure to be installed, together with the power plant and the ISRU.Therefore, the unloading of the UT shall be done autonomously, by UT itself and/or with the support of lander. The figure 3.4/1 illustrates the unloading sequence.

A key point of the unloading sequence is the electrical power needed by UT. Indeed, the proposed design of UT relies on the use of fuel cells for the power supply. However, it is not planned to fill the cryogens tanks of the UT at launch, due to the transport duration and associated storage problems. Consequently, the UT will preferably be equipped with a battery pack sized for the unloading and other operations necessary before it is connected to the ISRU for cryogens replenishment. This solution impacts the UT mass and requires the installation of ISRU before or simultaneously with the UT.

Once installed on Mars surface, the UT may be either in dormant mode (including fuel cells replenishment), or in operational mode when there is a mission. A UT mission includes the transfer to the working sites or back (maximum distance 10 Km), and the operations on the site (unloading, assembly, etc). The transfer can be done fully loaded or unloaded. The figure 3.4/2 illustrates the possible tasks of the UT and also the possible UT configurations (in particular the twin configuration).

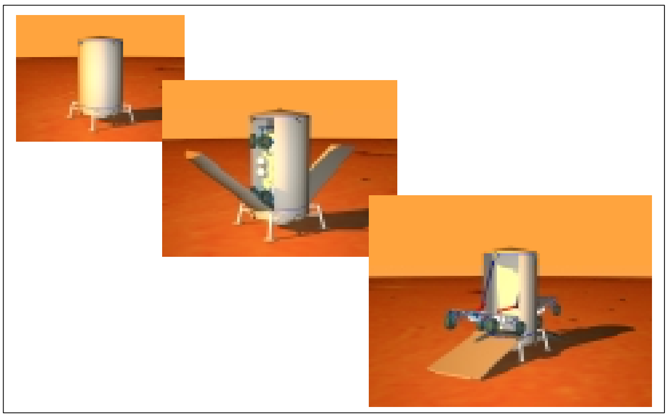


Figure 3.4/1: Unloading sequence of UT

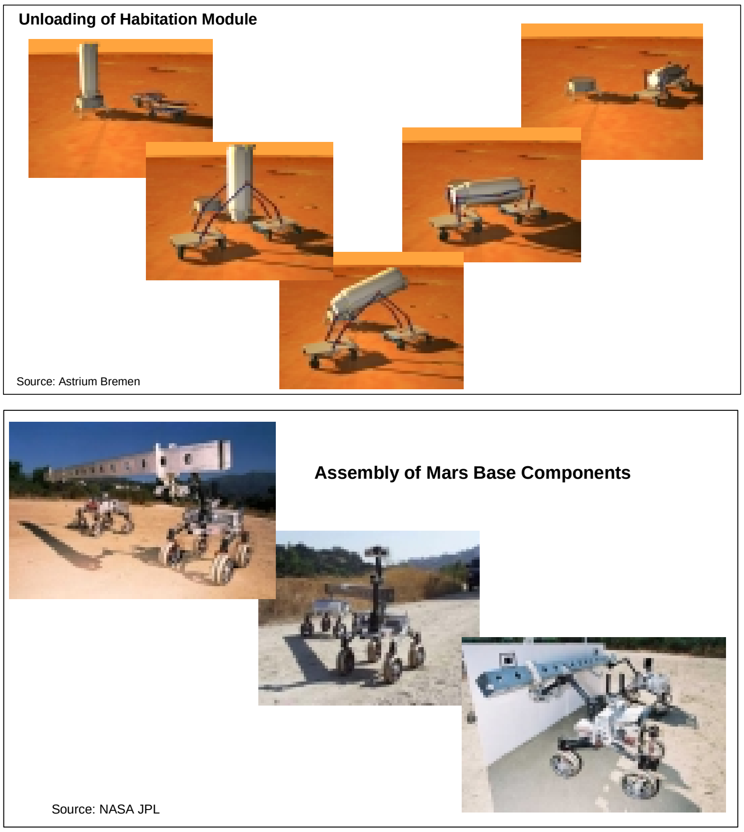


Figure 3.4/2: Illustration of UT tasks

3.4.2 UT concept

The following UT requirements have been established:

- The maximum fully equipped mass is 7500 Kg. The hoist/lifting capability without tipping is also 7500 Kg.
- The maximum lifetime with maintenance is 600 sols

- The cross country ability, when fully loaded, is 10 kPa foot print contact pressure, 800 mm minimum ground/ chassis clearance, 15° gradient climb capability.
- All the operations shall be done within an area of 10 Km. The maximum speed is 1 Km/h.
- The UT could be tele-operated from Earth via communication network or lander, or remote controlled from a Mars base, or proximity controlled by astronaut in EVA suit.

The UT configuration is illustrated on figure 3.4/3. The proposed configuration consists of two identical elements (twin configuration).

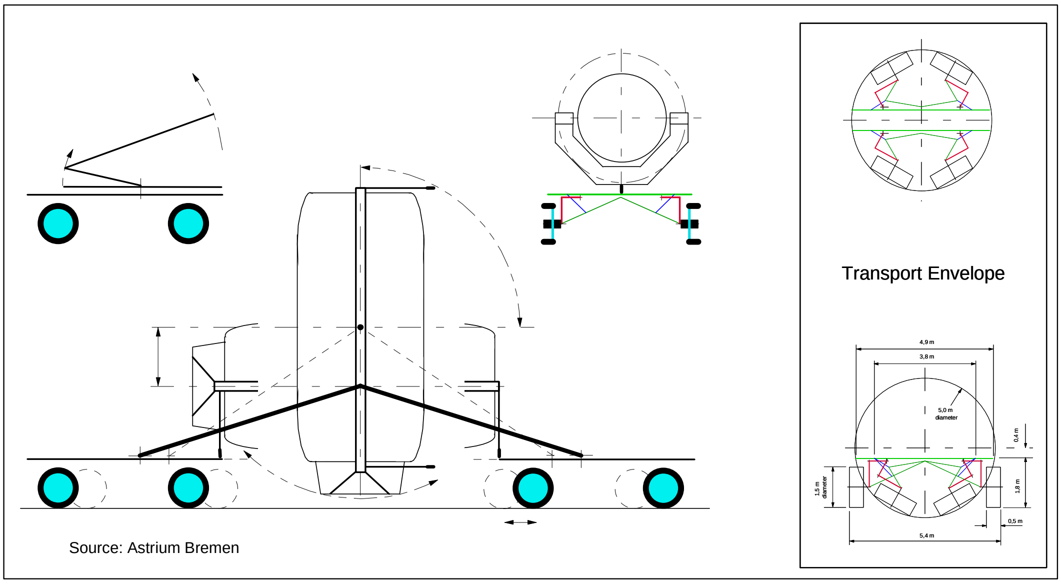


Figure 3.4/3: UT configuration

The UT mass is about 5 tons, among which about 300 Kg of consumables (Oxygen, Hydrogen).

The power subsystem relies on of fuel cells which are sized for a mission, as illustrated on figure 3.4/4. At the end of the mission, they have to be replenished at the Mars base (connection to ISRU or power generator). The locomotion system, which is also a key point, is identical to the one described for MPL.

The UT has to interface with the launcher and lander, ISRU, communications and navigation network.

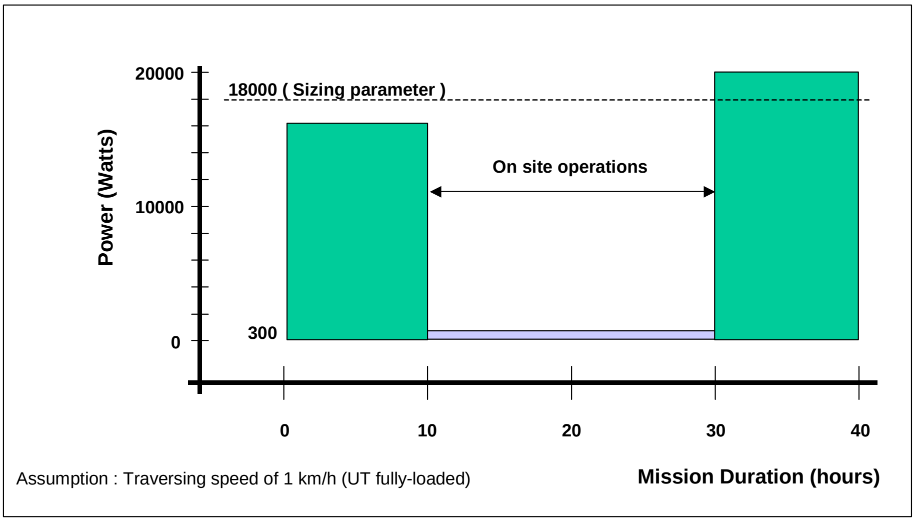


Figure 3.4/4: Baseline mission for power budget

3.5 MOBILE PRESSURIZED LABORATORY

The mobile pressurized laboratory provides the astronauts with a degree of mobility that allows them to explore the Martian surface well outside the confines of the main base. Therefore, it will be used for:

- the scientific exploration of regions of Mars at large distances from the main base. These excursions will take several days, during which the astronaut will also be able to undertake extra vehicular activities.
- preliminary and extensive analyses of investigations made of the Martian surface and environment explored during the pressurized rover's mission using onboard laboratory equipment.
- an emergency habitat (safe haven).

3.5.1 Mission scenario

The MPL will be used during the Human Exploration Mission phase, when the crew will be present. It will be delivered after the first crew has landed. The mission scenario is illustrated on figure 3.5/1.

Launch and transfer

The MPL will preferably be launched by an International heavy launcher (e.g.Magnum). Indeed, its size complemented by the lander and aeroshell exceeds the upper limit of the AR++. In addition, the mass of the transfer stage, lander and MPL (more than 74 tons, for a 7.5 tons MPL) is not compatible with two AR++ launches. However, the updated mass of the MPL (5.5 tons) has solved the mass problem.

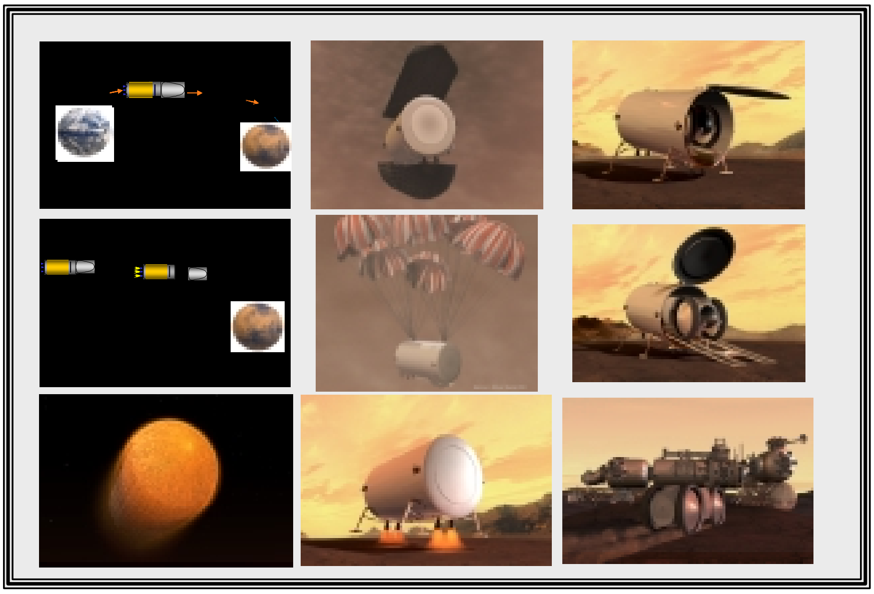


Figure 3.5/1: Illustration of the MPL mission scenario

Descent and Landing

The lander and MPL will be braked during the descent either with parachute, or with propulsion system. The MPL can land, as illustrated on figure 3.5/2, either in horizontal configuration or in vertical configuration. The choice of the configuration for landing depends on the accommodation analysis (lander + MPL size+aeroshell+parachute), on the trajectory analysis and centering problem and on unloading aspects. Thus, the horizontal configuration allows for a ramping system to be deployed while the vertical configuration requires mechanisms to unload MPL before deploying the ramp.

Unloading

The figure 3.5/2 illustrates the unloading sequence in case of horizontal configuration landing. The lander could be used as a shelter for the MPL. The unloading operation can be done by remote control by the astronauts at the main base, by on-board MPL autonomy, by the astronauts themselves driving the MPL to the main base, or by robotic systems. The unloading operations require electrical energy on-board the MPL (except support by a robotic system), which has been transported without fuel cells reactants for minimizing transported mass. One solution is to fit battery on board the MPL for these operations.

Normal mission

The MPL will be employed for scientific exploration purposes and have a crew of at least two astronauts. It is designed to perform an excursion away from the main base of up to 20 Martian days, of which 10 days would be spent at the desired location site.

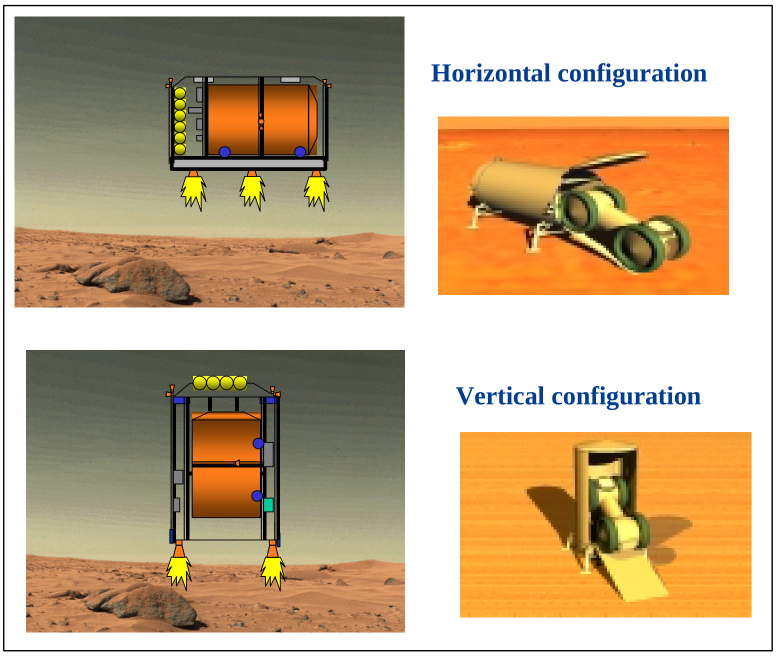


Figure 3.5/2: Possible MPL landing configurations

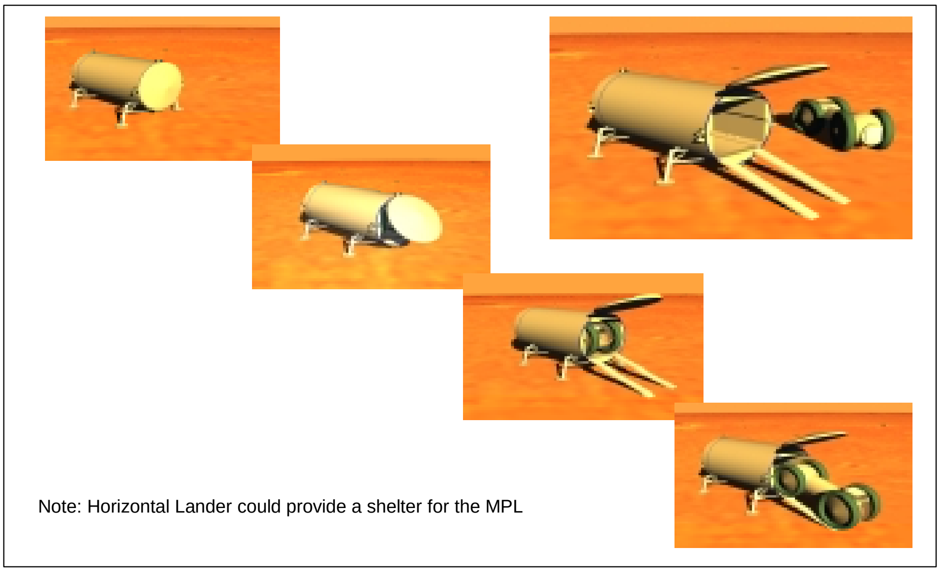


Figure 3.5/3: MPL unloading sequence, horizontal landing configuration

Lander

A wrapping envelope as aeroshell (biconic like) is preferred due to the size and mass of the MPL. This shape favours a long entry trajectory. The design of the lander is adapted for an easy unloading.

The propulsion subsystem has to be operative from end of parachute phase, or from end of atmospheric entry phase if propulsion braking is used in order to ensure a controlled descent. In the last case, the propulsion has to provide a thrust level in order of 200 to 300 kN. A typical configuration with 4 engines (50 to 80 KN) is proposed.

The mass of the lander is estimated to 12.5 tons (including 3.5 tons of aeroshell and 6 tons of propulsion).

3.5.2 MPL concept

The MPL has to meet the main following requirements:

- The maximum fully equipped mass is 7500 Kg
- The MPL shall accommodate 2 astronauts in normal mission mode, and 6 astronauts in safe haven mode
- The normal mission duration is 20 sols (among which 10 sols of operations on site), while it is sized for 7 sols in safe haven
- The maximum range is 500 Km, the maximum speed 5 Km/h and the required energy 1300 kWh
- The MPL shall have a 20° gradient climb capability
- The Laboratory volume shall represent at least 25% of the total pressurized volume.

MPL configuration

The MPL configuration is shown on figure 3.5/4.

The overall layout and size of the vehicle are defined by the launcher payload envelope constraints, the crew habitation requirements and the power requirements. The launcher constraint led to minimize the envelope diameter of the MPL (5m) and keep its length within 10 m. In order to maximize crew habitability volume within this envelope and provide sufficient height for the astronauts while walking and working inside the MPL, a dumb-bell shaped vehicle with large diameter wheels was adopted. An analysis of the locomotion system revealed that the use of large wheel diameter reduced the vehicle's overall power requirements and consequently the size of the fuel cells system. The proposed configuration allows both the centre of mass and astronaut surface EVA access points to be located closer to the Martian surface.

The robotic devices are installed alongside the externally-mounted science facility, which is located in the middle of the MPL.

Astronaut access to the main base is via the airlock hatch integrated in the upper surface of the "driving cabin". The dimensions of this hatch are compatible with the NASA standard airlock designed for ISS. The selected location of this hatch requires the exit port of the main base elements to be above the MPL. Alternative hatch locations are possible if necessary.

In addition, the stringent requirements to avoid planetary contamination and consideration of surface EVA preparation have led to provide a larger volume for the astronaut to prepare himself for surface

EVA prior to leaving and re-entering the vehicle.

The resulting size of the MPL is a transport envelope diameter of 5 m, assuming inflatable wheels, a length of 9.5 m, a width of 4.5 m and a height of 3.8m.

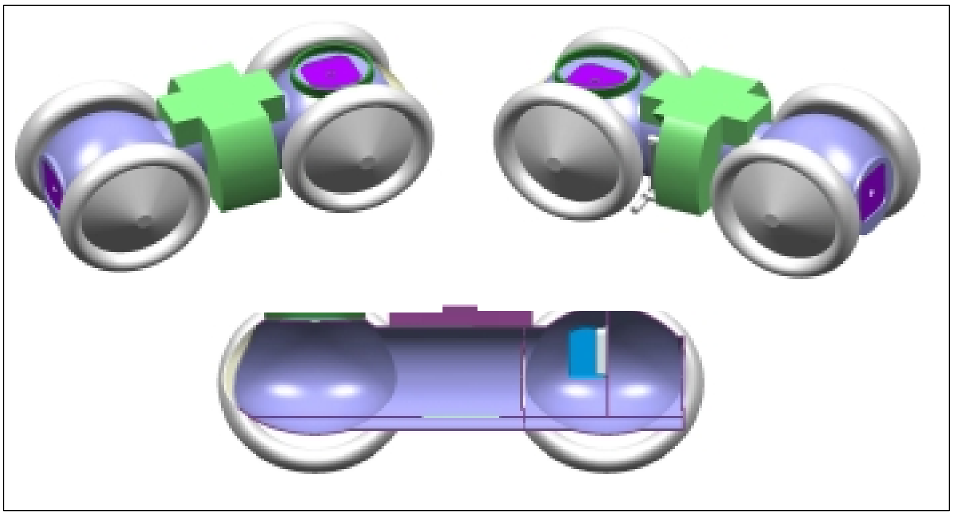


Figure 3.5/4: MPL configuration

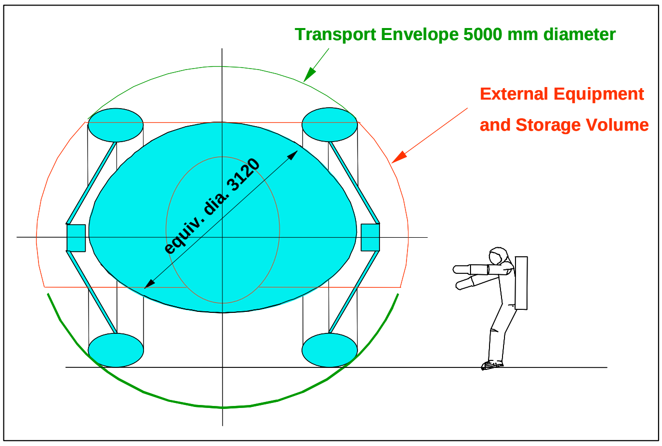


Figure 3.5/5: MPL configuration: sizing parameters

Budget

The MPL mass is about 6500 Kg, among which 1050 Kg of consumables: around 500 Kg for O2 and H2 for fuel cells, the remaining mass for water, O2 and N2 for crew, buffer gas and food. The figure 3.5/7 shows the rate of consumables consumption along a typical mission of 20 sols. The vehicle is delivered at the Martian surface without the consumables, as they will already be available at the Martian base. The landed mass is approximately 5500 Kg.

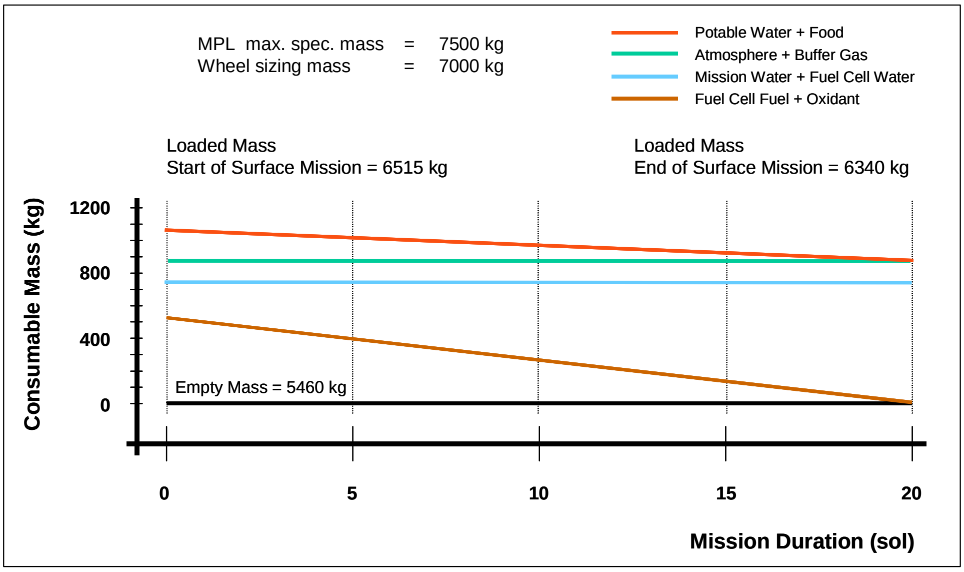


Figure 3.5/7: Evolution of the MPL consumables along a mission

Crew accommodation

The crew will be provided with all facilities needed for a 20 days mission: shirt sleeve environment, food, hygiene and sleeping facilities. The primary structure will be designed to provide protection from radiation hazards. The stringent contamination requirements have led to propose a different form of surface EVA airlock, with integration of the EVA suit. It is proposed to use a modified form of the Russian Orlan space suit which allows access to the suit via astronaut's life support back pack. The back pack itself together with a secondary door will thus function as the airlock. The volume enclosed by the closed back pack and secondary door can be more easily decontaminated. In this situation, the EVA suit remains in an outside chamber and does not have to be decontaminated. The sequence of events for EVA is shown on figure 3.5/8.

Vehicle locomotion subsystem

The MPL will be propelled by four large, independently electrically-driven and suspended wheels. The tyres may be inflatable or of wire mesh form. The undeformed wheel diameter is 3.8 m. Analyses associated with the design of the wheels indicate that power savings can be achieved by selection of large diameters and by eliminating the need for wheel grousers. In particular, without wheel grouser, a 4 kNm drive torque per wheel is required for a 20% slip, and the required combined axle power during cruising (5 Km/h, 5% slip) is 8.7 kW not accounting for the drive train losses.

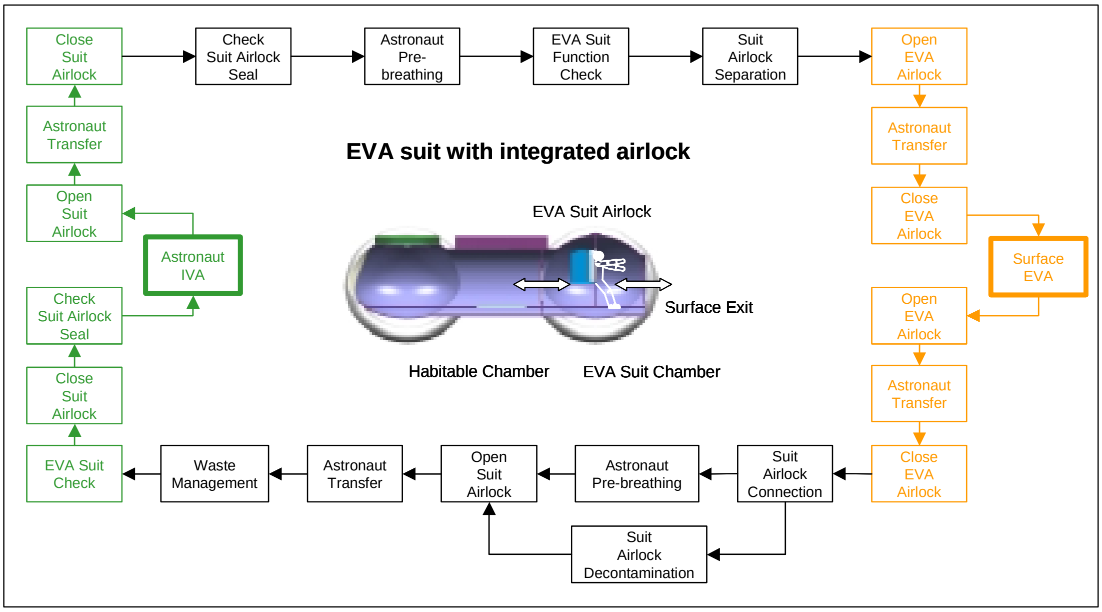


Figure 3.5/8: Surface EVA suit airlock concept: sequence of events prior to and after EVA

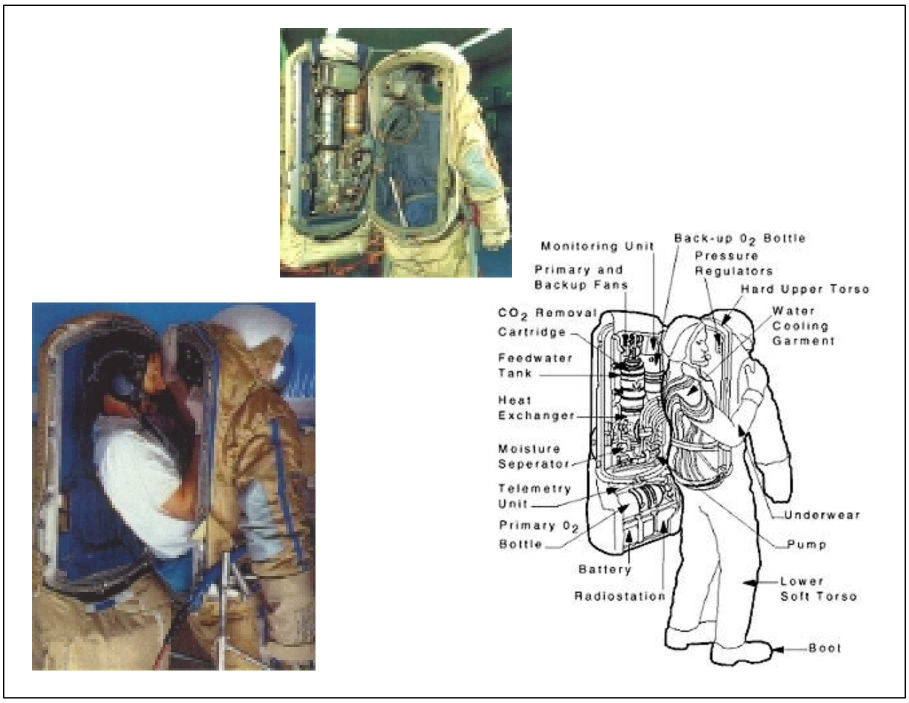


Figure 3.5/9: The basis for the surface EVA suit airlock concept: the Russian Orlan suit

Power subsystem

The power consumption profile shown on figure 3.5/10 has been used to size the power sources. The vehicle subsystems require 600 W throughout the surface excursion, and the locomotion subsystem requires a maximum of about 8.7 kW during the driving period, assumed to be 10 hours per day. To avoid this intermittent use of fuel cells, the MPL could be driven automatically during night time using automatic navigation with on-board self mapping and obstacle avoidance, or could be remote controlled by astronauts at the main base.

The power subsystem relies on the use of fuel cells as main power source. PEM (Proton Exchange Membrane) fuel cell technology is proposed. It combines hydrogen and oxygen and produces waste water. It is sized for a mission (520 Kg dry mass estimated), and reactants have to be replenished at the Mars base. Utilisation of mixed power source could be considered: PEM fuel cells for locomotion, batteries (or other fuel cell system) for essential subsystems and possibly for required power after landing.

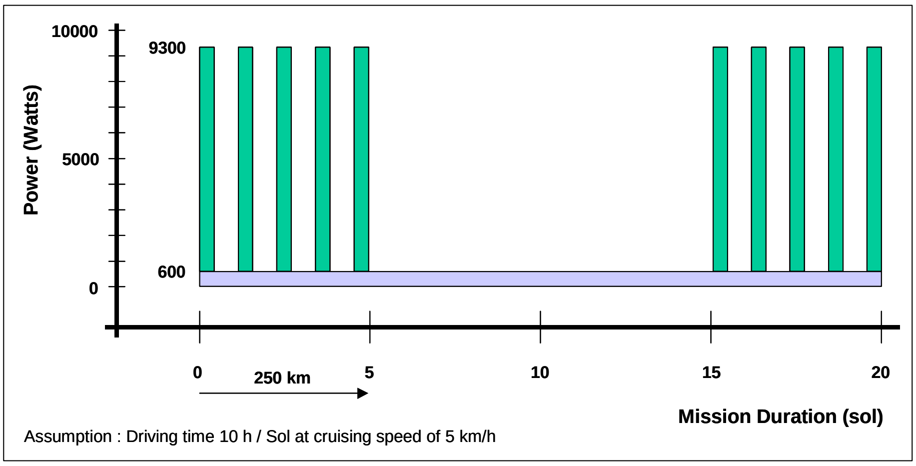


Figure 3.5/10: MPL baseline power demands (20 day mission)

3.6 BIOLOGY/GREENHOUSE MISSION

The Biology/Greenhouse mission has the following objectives:

- Science: exobiology payload to understand the origin, evolution and distribution of life in the universe, and payload for in-situ sample analysis
- Technology: dedicated payload for biology technology testing
- Application: food production (vegetables) for the crew, payload for food preparation and storage, closed environment life support system

3.6.1 Mission scenario

The Biology/Greenhouse module will be launched by an International heavy launcher, and transferred to Mars either by European vehicles (transfer module, lander), or as part of the International mission.

Indeed, the mass of this module (11 tons) would require the launch of a payload of at least 80 tons, which exceeds the capacity of AR++.

Once landed, the Biology/Greenhouse module has to be transported to and assembled with the main base. The proposed baseline is to use a dedicated Mars infrastructure element (e.g. Utility Truck) to unload and install the module.

3.6.2 Biology/Greenhouse configuration

The Biology/Greenhouse is composed of two distinct segments, as shown on figure 3.6/1:

- A rigid segment, for the accommodation of the support systems and biology payloads
- An inflatable segment for the accommodation of plant growth devices

The facility will be directly connected to the Mars habitat base. No external walkways are envisaged to reach the Biology Greenhouse from the Habitat (internal interfacing hatch).

The primary structure shape could be cylindrical or semi-cylindrical. The choice of the semi-cylindrical shape is related to the capability in this case to reproduce more easily the earth 1-g conditions, while the cylindrical shape could require the introduction of dedicated internal baseplate to reproduce a sort of ground passageway. Figure 3.6/1 and Figure 3.6/2 show respectively a pictorial view of the Biology Greenhouse half-cylindrical shape and of the Biology Greenhouse full cylindrical shape.

The implementation of the redundancy levels for the different functionalities of the Biology Greenhouse depends on the requirements (failure tolerance, etc). In particular, the redundancy of the EPS and C&DH functions depends on the Mars infrastructure elements architectural implementation, respectively Mars power plant and Habitat segment command and control functions. Nevertheless, two redundant paths are anyhow foreseen at now for these functions.

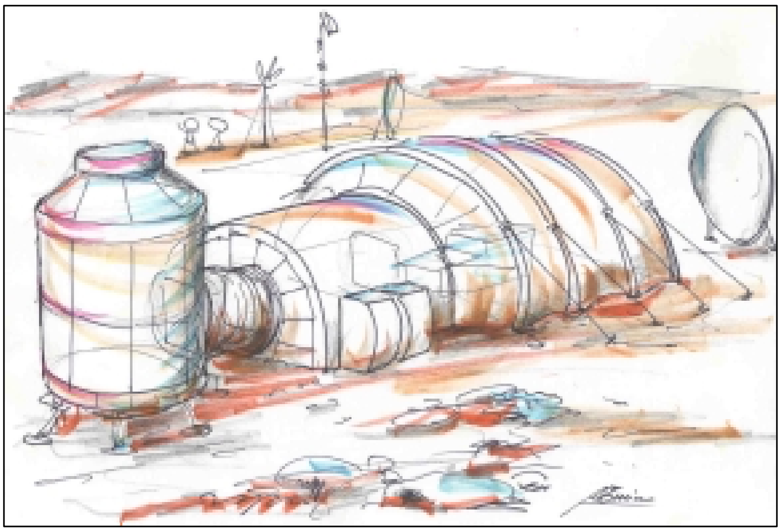


Figure 3.6/1: Biology/Greenhouse connected to the Habitat

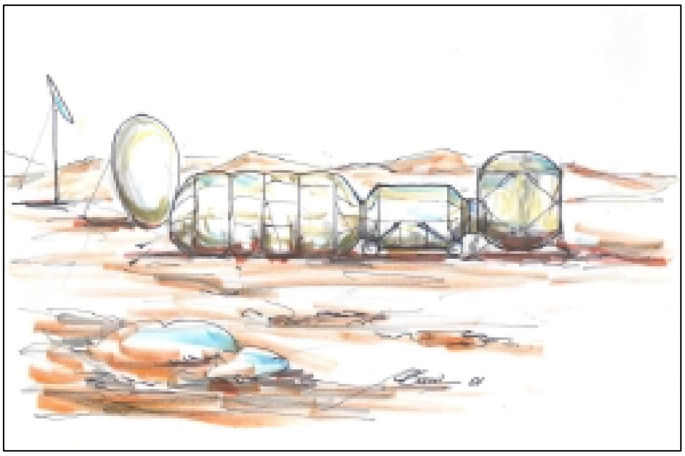


Figure 3.6/2: Illustration of Biology/Greenhouse in cylindrical shape

The interfaces of the Biology/Greenhouse with the other elements are summarized on the figure 3.6/3. Apart the transport vehicles, the Biology /Greenhouse is permanently connected to the power plant for getting power, to the ISRU for Nitrogen, oxygen and water, and to the Habitat segment for data and air. The mass of the Biology/Greenhouse module is around 11 tons, and the necessary power is between 8 and 15 kW.

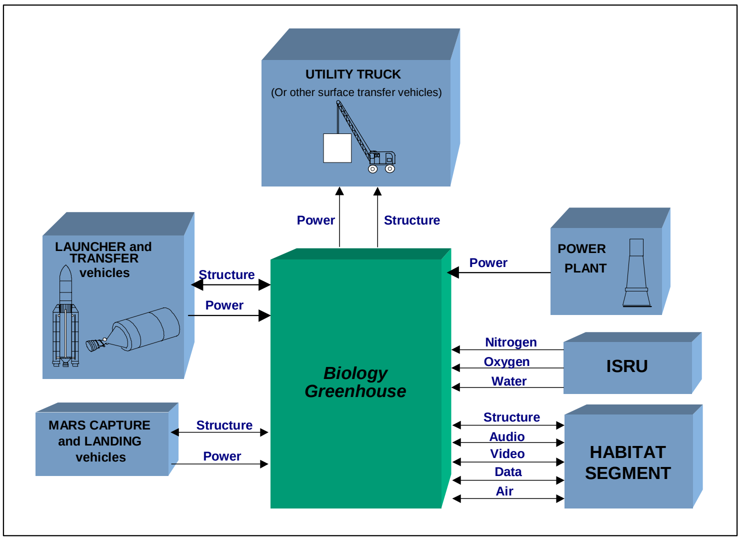


Figure 3.6/3: Biology/Greenhouse interfaces

3.6.3 Utilisation

Biology payloads

The rigid segment will accommodate internal biology payloads and an external exobiology payload:

- The Biology technology payload will accommodate the instruments necessary to test advanced biology technologies on Mars.
- The food production payload has the scope to support the greenhouse food production and to test new food treatments technologies. It will accommodate dedicated systems for fresh food treatment, dry food preparation, food cooking for both experimental and production purposes, food storage capability. The prepared food will properly supply vitamins and minerals.
- The sample analyser payload shall accomplish in-situ sample analyses (food properties, soils composition, atmosphere analyses).
- The Mars crew health payload will contain the necessary equipment to monitor crew health (e.g. microbial identification systems, incubator, defibrillators, medicine support kits, etc..) and to analyse the crew life support systems performances (e.g. concentration of volatile organic compound, cosmic ray flux, water samples) during permanence on Mars.
- The trash and waste management payload shall collect trash and wastes and shall study potential advanced regeneration and distribution systems. It is oriented to the collection of the waste water and waste nutrients arriving from the Greenhouse with the scope to produce potable water.
- The module will accommodate an external payload to carry out exobiology experiments on the Mars soil without the risk of internal contamination.

Greenhouse role

The Greenhouse architecture will implement a hydroponics growth system (figure 3.6/3). The plants are grown with their roots in an aerated solution providing the nutrients, oxygen and water required for growing. The greenhouse photosynthetic system provides natural bioregenerative system inside the greenhouse segment; plant growth allows food production and in the same context atmosphere regeneration. This system allows an ample root area oxygen distribution, a minimisation of the clogged irrigation nozzles and cleaning of culture, a good roots reproduction, a good performances in reduced atmospheric pressure conditions. But it requires more equipment for controlling the system. Broad Beans, Broccoli, Buttercup Lettuce, Cauliflower, Lollo Rosso Lettuce and Parsley look as promising candidate edible plants for hydroponics systems.

Besides producing food, the Greenhouse unit constitutes moreover the core of a (partially) Closed Environmental Life Support System. A partial CELSS system performs all the basic functions of a life support system based on a natural cycle regenerative process providing basic and continuous life-support requirements such as food, drinking water, cleaning water, and breathable atmosphere, by using plants as the central recycling component for waste. Sterilisation and purification systems for water and air should prevent any potential problems of corrosive fungi.

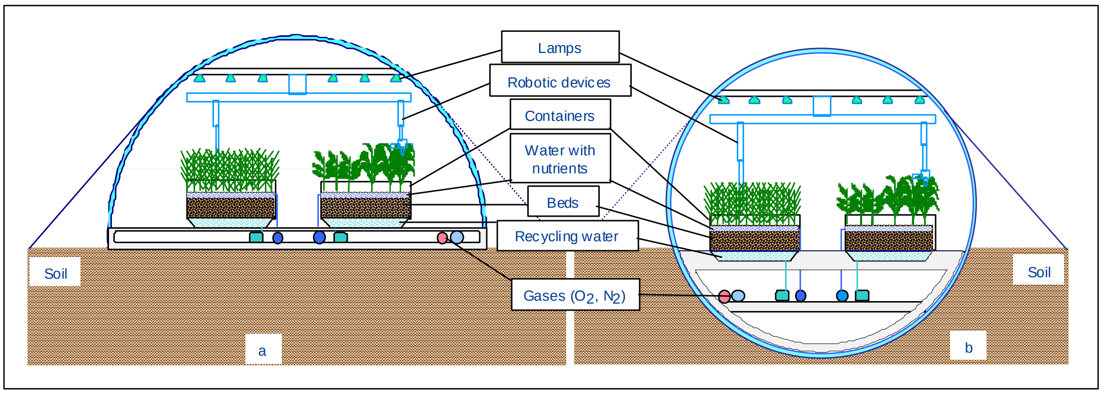


Figure 3.6/4: Hydroponics plant growth

A qualitative, simplified example of the Greenhouse role in such a CELSS is reported in Figure 3.17.

The functions accomplished by a CELSS system are the

- CO_2 reduction and removal, O_2 generation/supply
- Trace contaminant/ Micro-organism monitoring and control
- Atmosphere composition control
- Water recovery and management
- Waste management
- Food storage and preparation

Such a system is conceived to receive a supply of make-up nitrogen, water, hydrogen and oxygen from ISRU and is capable to realise a bioregenerative support system closed at 90 ÷ 95%.

The Greenhouse has a CO2 partial pressure in the order of 1 kPa to guarantee the plant growth and the crew temporary habitability. The temperature is controlled between 22°C and 30°C. The illumination level is between 300 and 600 lux and the terrestrial day-night cycle is reproduced.

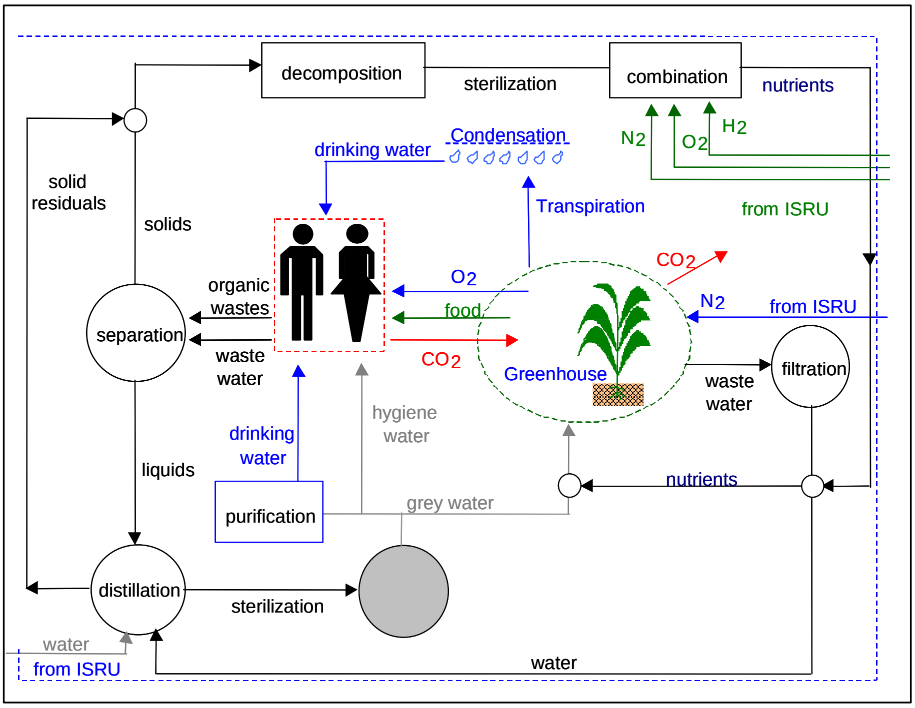


Figure 3.6/5: Closed Environment Life Support System

3.7 IN SITU RESOURCE UNIT (ISRU)

The objective of the ISRU mission is to produce propellants and life support consumables using local resources (namely the atmosphere and the soil) on Mars for the Mars base element and the Mars ascent vehicle.

3.7.1 Mission scenario

The first ISRU facility shall be installed on the surface of Mars more than a year (~ 15 months) before the first crew departs from the Earth, in order to produce the required propellants and the water, oxygen and nitrogen for Life Support System before the crew start the interplanetary trip. A possible sequence of events is depicted qualitatively in the figure 3.7/1. Once installed on the Mars base, the ISRU mission is to ensure the production of propellant and of life support consumables.

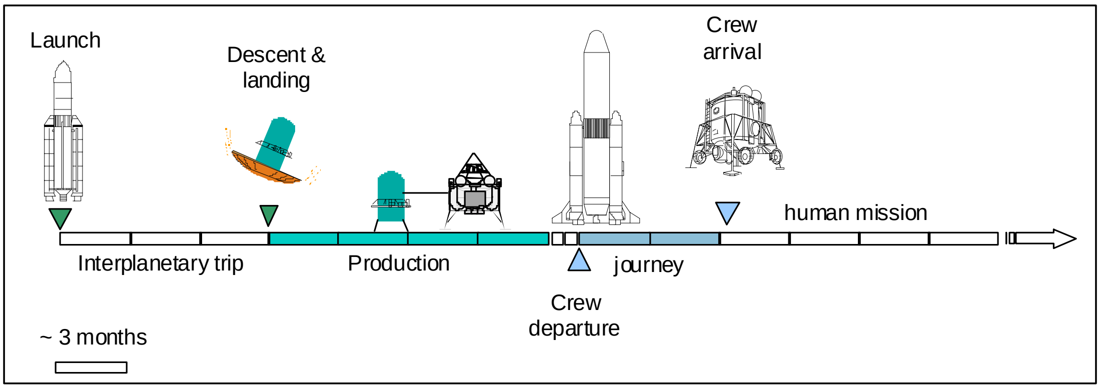


Figure 3.7/1: Illustration of ISRU mission scenario

Launch and transport

The ISRU with its lander and the transfer stage could be accommodated within one AR++. Indeed, the diameter of ISRU and aeroshell is at the minimum 4m, depending on the type of aeroshell, and the length is about 7m. The mass of a cryogenic stage (23 tons) and the lander with ISRU (about 12t) are compatible with a single AR++ launch. On top of these elements, the mission would also require additional tanks for O2 and CH4 storage on the Mars surface. These additional structural elements would be provided either by Europe or by International partner, but would anyway need an additional launch.

The aeroshell shape could be a Viking like, but inflatable or deployable as requiring about 8 m diameter, or a biconic type.

A vertical configuration at landing is proposed. The ISRU will be installed on a plate on the lander. It will not be activated until it is on its operational site.

The lander mass would be about 8.2 tons, for a 4tons ISRU.

Installation

The unloading and installation would be carried out with the help of a Utility Truck. As alternative, a self mobile lander could transport it to the operational site, with subsequent impact on lander design. Another option would be to have the ISRU towed by a rover from the landing site to the final site, assuming that the lander or ISRU is equipped with wheels and the lander with unloading devices. Adequate robotic systems (utility truck, rovers, etc) will be necessary to ensure the installation of and connection with the fluid and gas lines and electrical lines.

Propellant and life support consumables production

The ISRU has to produce the propellant (methane and oxygen) necessary for the Mars Ascent Vehicle, which will carry the astronauts from the Mars base to the low Mars orbit. The MAV tanks refilling shall be completed before the first crew leaves the Earth. Taking into account assumptions on the MAV (total

ΔV= 5650 m/s, Isp = 374s, crew capsule mass around 5600 Kg and a 15% structural coefficient for the propulsion module), 32 tons of propellant have to be produced.

The ISRU facility shall also supply those consumables necessary to support the permanence of the crew on Mars: breathable oxygen, potable and hygiene water, buffer gases (nitrogen, argon). The estimation of the needed production is based on six crewmembers staying on Mars for about 600 days. A key point is the storage of the produced consumables. Storage tanks are necessary and shall be delivered on the Mars base before starting the production.

The table 3.7/1 summarizes the required products to be supplied by the ISRU plant for a crew mission.

Product	Function	**Required quantity (metric tons)**
Methane	Propellant	**7**
Oxygen	Propellant	**25**
Oxygen	Life support (breathing)	**5**
Water	Life support (hygiene, drinking)	**24**
Nitrogen	Life support (atmosphere make-up)	**4.5**

Table 3.7/1: Estimated quantities of propellants and consumables to be produced by the ISRU plant

The nominal reference lifetime for the ISRU facilities (primary and backup) envisages the capability of producing the required propellants and consumables for three crewed missions (as planned in the proposed mission scenario), over an entire mission period of 15 years. Such a lifetime period envisages repair, maintenance and replacement of parts performed by crew during their missions.

3.7.2 Feedstock hydrogen

The ISRU facility relies on the Sabatier reaction, which combines hydrogen and carbon dioxide to produce water and methane. The process requires an initial amount of hydrogen. The water can then be electrolyzed in order to produce oxygen and hydrogen that can be recycled in the process. Besides, in the Sabatier process, there is an overproduction of methane; the pyrolysis of the methane in excess gives additional hydrogen to be recycled in the reaction.

Other processes than water electrolysis can be used to produce oxygen: CO2 electrolysis (direct production from Martian atmosphere) or Reverse Water Gas Shift which requires an initial quantity of hydrogen.

Therefore, there is a need for Hydrogen, which is not available in the Mars atmosphere and thus has to be imported from Earth. The amount of feedstock hydrogen to be transported from Earth depends on the quantity of oxygen and water to be produced, and on the process selected to produce additional oxygen.

A first estimation shows that about 4.5 tons of H2 are necessary if all the oxygen is produced by water electrolysis, or 1.75 tons are necessary if all the oxygen is produced by CO2 electrolysis.

That arises two problems: the transport and the storage of the hydrogen. The estimated 4.5 tons represents a volume of about 64 m3 of liquid hydrogen. Then, the cooling of the hydrogen during the trip to Mars and on Mars will require a huge amount of energy (several tens of kWh depending on the cryocoolers efficiency).

An alternative would be to transport water to Mars for electrolysis. In order to get 4.5 tons of hydrogen, at least 40 tons of water have to be transported. The power required for the electrolysis of water would be in the range of 25 to 30 kW. It is in the same range as the power requirement expected with the advanced generation of cryocoolers. The main critical issue of this option is the huge quantity of water to be transported. The presence of water on Mars, provided it is reachable, would drastically improve this issue.

3.7.3 ISRU facility architecture

ISRU elements

The scheme of the ISRU facility is shown on figure 3.7/2.

The main elements of the ISRU system are:

- The atmosphere/filter compressor
- The extraction system for buffer gases
- The CO2 electrolysis system
- The Sabatier reactor
- The Water electrolysis system
- The Reverse Water Gas Shift
- The methane-vapour separator
- The methane pyrolysis
- The dryers and condensers
- The liquefiers (cryocoolers): methane and oxygen could be liquefied by a common cryogenic system; hydrogen needs to be maintained at 20°K.

External interfaces

The ISRU facility interfaces with the following elements:

- The Mars Ascent Vehicle, which will store the produced propellant inside its tanks. MAV should be present on Mars when the ISRU starts the production
- The power generation plant, for power supply and associated electrical lines

- Dedicated storage tanks, to store life support consumables
- Pipelines connections, to transport propellant from ISRU to MAV, and life support consumables to the storage tanks and Habitat elements
- Feedstock hydrogen, to supply the Sabatier reactor
- Communications infrastructure

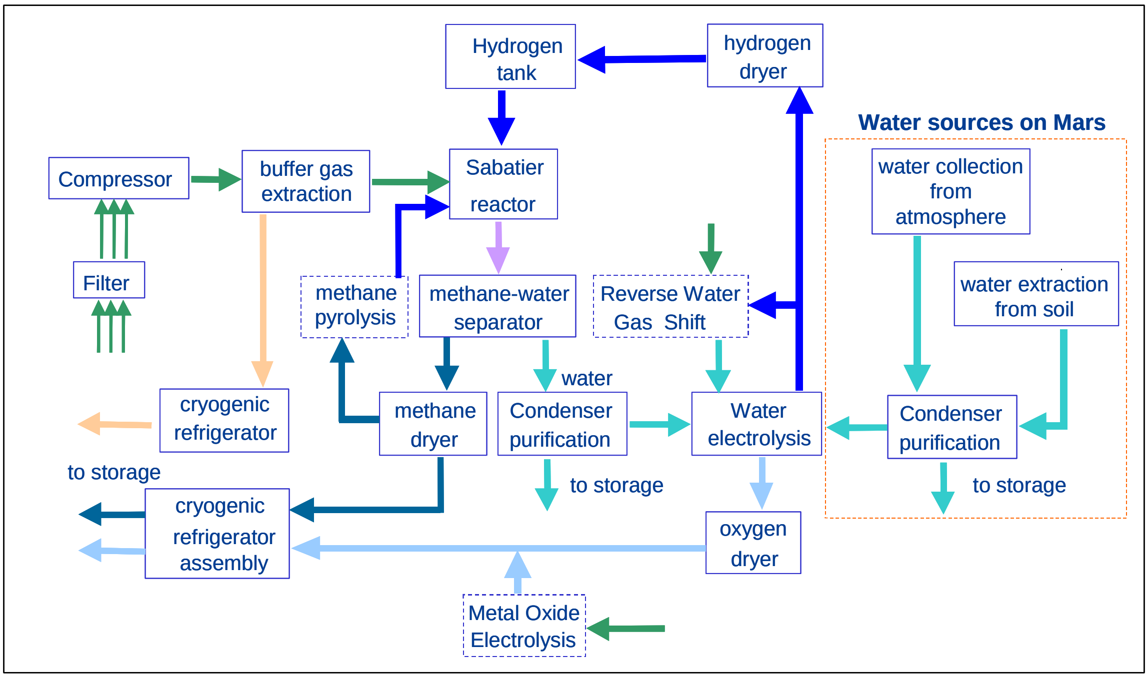


Figure 3.7/2: Scheme of the ISRU facility

Performances

It is assumed that the ISRU facility shall be capable to produce the required propellants and consumables in 12 months, with further 3 months allowed for contingency. The methane and oxygen are produced from Sabatier process and water electrolysis. The nitrogen is got from the carbon dioxide (about 167 tons of CO_2 must be processed to extract 4.5 tons of nitrogen).

The table 3.7/2 reports the production rate for continuous nominal operations over 12 months.

The power and mass budget of the ISRU facility are given in the table 3.7/3. Many of the ISRU components are still at prototype/development level; therefore, some figures have been extrapolated assuming reasonable improvements in the future, and it has been preferred to indicate a range rather than a point value.

Product	Production rate (kg/hour) (12 months)	Notes
Methane	0.84	Propellant
Oxygen	3.5	Propellant and breathable
Nitrogen	0.52	From Mars atmosphere
Water	4.9	Part of the water is electrolysed to produce oxygen
CO_2	19.4	Compressed Mars atmosphere

Table 3.7/2: Required production rate for the ISRU supplied items

The ISRU power demand may depend significantly on the adopted strategy (e.g. to use the liquid hydrogen for liquefying the oxygen). Considering reasonable technology improvements in the next future, the total power requirement for ISRU should be kept around 40 kW. The total ISRU mass should be around 4 tons or less.

Item	Power (kWe)	Mass (kg)
Compressors	7.2 - 15.5 (sorption)	950 - 1150
Filters	0.8 - 1.5 (1)	100 - 150
Sabatier reactor (s)	startup (2)	150 - 200
Water electrolysis	11.5	300 - 350
CO_2 electrolysis	11.2 - 13.8	100 - 150
Methane-water separator	1.7 (NASA DRM)	709 (NASA DRM)
Hydrogen separator	0.5 (NASA DRM)	52 (NASA DRM)
Methane pyrolysis	5	1200
Oxygen & Methane liquefier	4.4 - 6.3 (3)	470 - 1800
Nitrogen liquefier	1.3 - 2.6	50 - 200
Total	**43.6 - 58.4**	**3980 - 5940**

(1) Cyclone filters and electrostatic precipitators (2) the process, exothermic, requires only startup power ; reactor cooling with high-temperature, liquid metal heat pipes
(3) Liquefaction & storage

Table 3.7/3: Preliminary ISRU power and mass budget

Critical aspects

The ISRU preliminary design has identified the following critical aspects:

- The uncertainty in the knowledge of the Mars environment: amount of water, soil characteristics, Martian dust, wind

- The large amount of power required for the storage of feedstock hydrogen
- The long term performance and reliability of equipment and technologies to be proved
- The high degree of autonomy and automation required
- The resistance, efficiency and reliability of materials operating in harsh environmental conditions (thermal cycling, corrosion, etc)
- The equipment survivability to launch, descent and landing loads

3.7.4 Open issues

The following issues can affect significantly the whole ISRU mission:

- The presence of water on Mars, which would minimize the need from hydrogen from Earth
- The storage of liquid hydrogen on Mars
- The use of liquid hydrogen to liquefy the methane and / or oxygen
- The storage of breathable oxygen and nitrogen

4 TECHNOLOGY INVENTORY

Each candidate mission architecture relies on innovative technologies or on significant improvement of consolidated ones. These technologies cover a wide range of domains, some being specific to a mission, others being common to several missions. The table 4/1 gives the list of identified technologies and their applicability to the different missions.

Among this list of technologies, a screening of existing literature has been done for nine specific themes: aerobraking and aerocapture, aeroshell concept, soft landing systems, inflatable structures, closed loop life support system, techniques for high data transmission in deep space, navigation for entry, atmosperic flight and precise landing, Mars ground environment and atmosphere model and simulation, and in situ resources utilization.

4.1 TECHNOLOGIES FOR TRANSPORT AND LANDERS

All the technologies related to Transport and landing are of prime importance if Europe wants to master a full mission to Mars.

The key drivers for the selection of technologies are to save mass while ensuring performances (in order .to maximise the mass of payload on Mars within launcher constraints), to transport and land large payloads and to ensure the fulfilment of requirements, specially for navigation and high temperature material.

Two technologies have been considered for the transfer stage propulsion: cryogenic system or nuclear thermal system. The propulsion technology is a key driver for the achievable mass of payload and the selection of launcher. It impacts the performance and the implementation under fairing.

The cryogenic technology is mastered in Europe. The key point is the storage of cryogenic propellant for a long duration (how to minimize the cryo evaporation). It becomes less critical in case of a single Ariane ++ launch and the separation of propulsion module after the main boosts for placing the vehicle in Trans Mars orbit. Lightweight H2 tank would be used to save mass.

The nuclear thermal system provides higher performances. However, the safety and environment aspects constitute a critical point. Besides, this is a new technology to be developed in Europe.

The aerocapture and the direct landing are new and attractive techniques. The aerocapture was initially part of Mars Sample Return mission. They allow a gain in mass and in entry duration (impact on energy). They are challenging in terms of trajectory accuracy, especially as far as entry corridor and navigation precision are concerned. They have impacts on the aeroshell shape, the entry trajectory and the thermal/mechanical loads. They require a good knowledge of atmospheric properties and gravity models.

The aeroshell shape is driven by the payload size and mass and by the fairing volume. It is closely linked to the entry trajectory. Two types of aeroshell shape could be considered. The Viking like aeroshell is too large with respect to AR++ fairing for most of the payloads, rover/aerobot mission being the exception. It may require two specific technologies: an inflatable aeroshell, for which the current experience is limited to small payloads, and a deployable aeroshell, to be developed. The wrapping aeroshell (typically biconic aeroshell) is better adapted to large payloads. It has to be developed.

Technologies		Rovers	Aerobots	MPL	UT	ISRU	Greenh	Lander	TMI	
Element transport & propulsion										
Aerocapture/aerobraking system								X		
Aeroshell concepts for large payloads								X		
Lightweight descent system								X		
Soft landing systems								X		
Propulsion for TMI								X	X	**Propulsion studies**
Structure materials										
Lightweight high temp material for aeroshell								X		
Inflatable large aeroshell/ heat shield								X		
Inflatable structures		X	X				X			
Large thermal shock resistant material							X			
Lightweight Al-Li tanks						X				
Regenerative Life Support System										
Closed loop life support system				X			X			
Advanced sensors for atmosphere contamination control				X			X			
EVA										
Lightweight, maintainable suit & portable LSS				X						
Contamination control measures				X						
Small, efficient portable cooling/ heating system				X						
Operations										
Automated system control		X	X	X	X	X	X	X		
Fine control manipulators		X	X	X	X	X				
Thermal control										
Thermal control for cryogenic fluids long term storage				X	X	X				
Long life cryocoolers						X				
High reliability cryogenic pump (O_2,CH_4,N_2)						X				**S54 domain**
High efficient lightweight thermal control		X	X	X	X	X	X	X		
Lightweight high perfo insulation material		X	X	X	X	X	X	X		
Power generation & storage										
High density energy storage (battery, etc)		X	X	X	X	X	X	X		
High performance micro fuel cells		X	X	X	X	X	X	X		
Long life regenerative fuel cells				X	X					**S54 domain**
High efficient solar cells		X						X		
Advanced heat-to-energy conversion system		X		X	X					

Table 4/1: List of identified technologies

Technologies		Rovers	Aerobots	MPL	UT	ISRU	Greenh	Lander	
Surface/ atmospheric mobility									
Aerodynamic			X					X	
Surface traction system		X		X	X				AROMA domain
Power transmission for locomotion		X		X	X				AROMA domain
Motors lubricant (long term use)		X	X	X	X				AROMA domain
Large vehicle locomotion system				X	X				AROMA domain
Aerial propulsion system			X						AROMA domain
Steering/control system		X	X	X	X				AROMA domain
Dust control/filtration		X	X	X	X	X			AROMA domain
Simulations									
Simulations & training facilities		X	X	X	X	X	X	X	
Mars atmosphere model		X	X	X	X	X	X	X	
Mars ground (terrain) simulation		X	X	X	X	X	X	X	
Communications									
High data rate transmission on Mars surface		X	X	X	X	X	X	X	
High data rate transmission Mars-to-orbit		X	X	X	X	X	X	X	
High gain small (patch?) antenna		X	X					X	
Data compression information		X	X	X	X	X	X	X	
GNC/ DMS									
Precise autonomous navigation on Mars		X	X	X	X			X	
Precise navigation for entry								X	
Precise navigation for descent & landing			X					X	
System tolerant to failure & environment		X	X	X	X	X	X	X	
Autonomy technology		X	X		X			X	
Miniaturisation rad hard electronics		X	X	X	X	X	X	X	
In situ operations/instrumentation									
Carbon dioxyde electrolyser material						X			S54 domain
Long life Sabatier reactor						X			S54 domain
Advanced reverse water gas shift generator						X			S54 domain
Long life CO2 electrolysis reactor						X			S54 domain
Long life CH4 pyrolysis reactor						X			S54 domain
Sample collection & storage device		X	X	X	X		X		AROMA domain
Rock/soil coring device		X		X	X		X		AROMA domain
Resources extraction process & chemistry		X							AROMA domain
Advanced sensor & robotics		X	X		X				AROMA domain
Micro-robotics/ robots		X	X						AROMA domain
Dust free optics		X	X	X	X				AROMA domain

TABLE 4/1: List of identified technologies

For the descent system, the parachutes, or the parafoils, have already been used. The system has to be opened at supersonic speed level. The key features are the necessary large size and the storage duration before opening.

Two technologies can be considered for the soft landing system. The damping (airbag) system has already flown, but the feasibility of large airbags has to be assessed for the relevant size and mass. The skid system includes mechanisms and damping items which have to be developed.

The navigation is a key technology of the aerocapture and landing accuracy requirements. These requirements are new with respect to current missions. Vision based navigation, using optical sensor, could be considered for approach and autonomous and robust aerocapture monitoring. Such a system is to day in study. An autonomous vision navigation and piloting or use of a GPS like system could be considered for safe landing. Collision avoidance system, based on autonomous navigation, is also a necessary technology for identification and avoidance of rocks and other obstacles.

Although only applicable to transfer stage and lander, these technologies are a prerequisite for all the proposed missions, as far as the mastering of the transport and landing remains a European objective. Most of these technologies would be applicable for other planetary missions.

4.2 CLOSED LIFE SUPPORT SYSTEM

The closed life support system technologies are a prerequisite to support long space human missions (on Mars or other planets). They are applicable to the MPL and to the Biology/Greenhouse proposed missions, and more generally to the Mars base Habitat. It is a further step development of that being implemented in ISS program. Main areas of investigation concern a more compact systems, bio-regenerative life support systems, air revitalization/atmosphere composition control and monitoring systems, water recycling and quality control, solid waste management.

4.3 SURFACE MOBILITY

The surface mobility gathers different type of technologies. The aerodynamic in Martian atmosphere and the aerial propulsion system concern only the aerobots. The locomotion system is related to the MPL, the Utility Truck and, for some technologies, the rovers. Large vehicles, like MPL and UT, needs very large diameter wheels with inflatable or mesh-type tyres. Large wheels lead to reduce the traversing power demands. The wheels and/or tyres should have variable stiffness which is automatically matched to the surface hardness.

4.4 OPERATIONS, COMMUNICATIONS, GNC/DMS, POWER

Communications technologies are applicable to all the proposed missions. Indeed, the transmission to Earth of a maximum of information, and especially of images will result in the need of high data rate communications, with adequate technologies in term of antenna, data compression, type of link (optical, etc). Likewise, communications between elements and Mars base, in particular in case of remote control by the crew on the Mars base, will call for a high rate communications via ground or in orbit infrastructure.

Automated processing and control is a way to reduce the crew workload, maximize the safety controls, or work in absence of crew. It is applicable to most of the missions. For Greenhouse, the technologies are more oriented to client-server architecture, distributed architectures, real time software architectures, vehicle diagnostic systems.

A precise autonomous navigation on Mars is a pre-requisite for the mission with a mobile element (MPL, UT, rover).For instance, the MPL requires an autopilot to relieve the astronaut workload during day and night. Required technology is further development of that currently used in the aircraft industry and being investigated by the automobile in regard to traffic control. System tolerant to failure and environment will be necessary with regard to the long mission duration, the delay for ground control intervention, the environment. Miniaturisation of radiation hardened electronics is also a way for the mass reduction.

Power generation and storage is a critical technology for all the missions, specially for the mobile elements on Mars. High density energy storage source, and in particular high performance micro fuel cells, are the technologies considered for the MPL, the UT and the rover. Indeed, for MPL and UT, a high level of energy is required for an operational mission (out of Mars base), and solar cells solution would lead to too large surface due to the low solar energy received on Mars surface. Besides, these cells would be refilled.

4.5 STRUCTURE, THERMAL CONTROL

Lightweight structures have to be implemented to gain mass. In particular, lightweight high temperature material would be used for aeroshell. They could benefit from the development which will be done for Reusable Launch Vehicle. Likewise for lightweight Li-Al tanks for ISRU. Inflatable structure is a key technology for the Greenhouse, but could be used also for rover or aerobot.

The thermal control for long term storage of cryogenic fluid is a necessary technology for the transport and storage of Hydrogen. High efficient lightweight thermal control and lightweight high performance insulation material are also technologies applicable to all the missions.

4.6 IN SITU OPERATIONS AND INSTRUMENTATION

Most of the ISRU technologies are well consolidated on Earth. They however have not yet been proven for long time in space. The following list, not exhaustive, includes some technologies to be implemented and/or improved: low power long life coolers, long life water electrolysis system can have multiple use, while high efficiency Reverse Water Gas Shift, Oxygen production from CO2, methane pyrolysis are applicable to Mars mission.

Instrumentation necessary for the Mars exploration concern the sample collection and storage device, the rock/soil coring device, the resources extraction process and chemistry, the advanced sensor and robotics, the dust free optics which are applicable to several missions, like rover/aerobots, MPL, UT.

5 DEVELOPMENT PROGRAMME

A development plan has been defined for two candidate missions: the MPL mission and the ISRU mission. This development plan is driven by the scenario of International mission (figure 2.3/1) and by the planning of implementation of the successive Mars base elements.

5.1 MPL MISSION

The MPL is needed when the crew is present on the Mars surface. It is assumed that the MPL is used by the second and third crew. It will then be launched in 2025.

The overall planning of the MPL mission development is given on figure 5.1/1.

The development of critical technologies has to be started between 2005 and 2010. The technologies related to MPL, mainly the surface GNC, the fuel cells, the locomotion, the ECLS closed loop or the surface EVA have to be started early. Testing and validation of these technologies could be done on ground or benefit from the ISS. The MPL phase B will start in parallel to the end of technologies development.

Lander key technologies concerns the direct entry (or aerocapture according to the selected option), the navigation for both entry and accurate landing, the aeroshell (shape, aerodynamic, material), the descent system (in particular due to size in case of parachute) and the landing systems. The model of Mars atmosphere and Mars ground would be periodically refined thanks to the vehicle flying to or orbiting around Mars. Three flight demonstration missions have been identified for navigation related to direct entry, aeroshell (demonstration of a reduced scale aeroshell shape with representative TPS material or dedicated demonstrator performing an Earth re-entry with a representative trajectory.), navigation for accurate landing. The Aurora mission planned in 2016 could be the basis for lander technology demonstration.

The development of the nuclear propulsion technology, if this technology is selected, is also critical and will be probably a long duration development. The planning proposes to start around 2006, but an earlier starting could be necessary.

Mission and system studies have to be led in parallel to the technology development in order to define and precise the mission, the elements, the expected performances, and finally the requirements on the technologies. It will be also necessary to keep coherent the definition and development of the MPL and of the lander and transfer module, and to decide on the launcher.

It is assumed that the feasibility of the mission and of the elements will be verified at the end of the phase B.

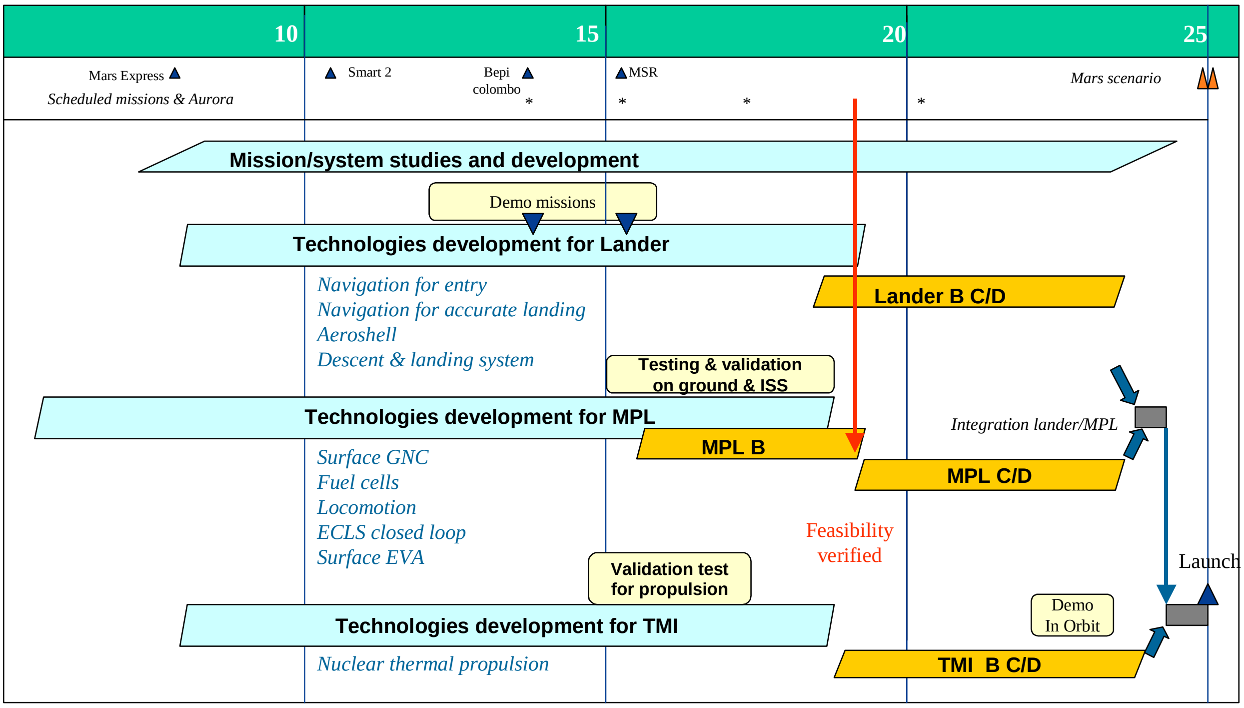


Figure 5.1/1: Development programme for MPL mission

The complexity of the MPL mission makes very difficult to evaluate its cost range.

A Rough Order of Magnitude of 4700 M€ has been evaluated, which includes the system activities and AIT, the critical technologies development, the MPL development and one flight model, the lander development and one flight model, the TMI development and one flight model and the launch, assuming an existing launcher.

In addition, the following assumptions have been taken into account:

- Nuclear propulsion for the transfer module (TMI), but the nuclear thermal propulsion technology is developed on other programmes. Only applicability to TMI of already developed technology is considered.
- Use of an International Heavy Launcher (HLLV) for the launch of the MPL together with the TMI. This launcher is used at recurring cost.
- For in flight demonstration, the critical technologies are assumed included as passenger
- No development of flight spare has been included
- The development of surface EVA and tools, the scientific facilities/equipment integrated in the MPL are not included

The figure 5.1/2 shows the sharing of this ROM cost into the main contributors.

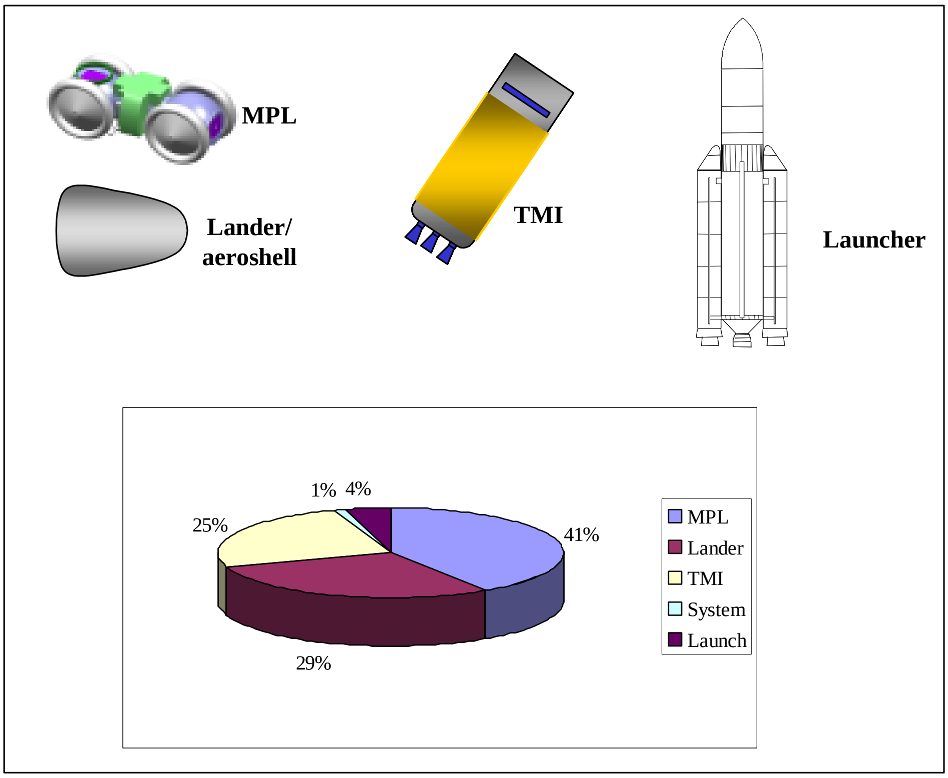


Figure 5.1/2: Elements of the MPL mission and cost sharing

5.2 ISRU MISSION

The ISRU mission appears to be a strategic European contribution as it provides the key technology and equipment for the production of propellant and various gases for pressurised environment. It has to be delivered at the beginning of the Mars infrastructure implementation, and thus would be launched by 2020.

Different steps are required to develop the technologies and to validate the involved chemical/physical processes prior to send the overall facility to Mars.

The overall planning of the ISRU mission development is given on figure 5.2/1.

To meet the launch date objective, predevelopment of critical technologies, both for ISRU plant and lander, have to be started early, even since beginning of 2003. More of the ISRU technologies are well consolidated on Earth; however, they have not been proven for long time in space. Further more, they will have to operate in full autonomy, under heavy conditions. Thus, technologies to be implemented or improved the cryo coolers, the Reverse Water Gas Shift, the CO2 electrolysis, the methane pyrolysis, the water electrolysis, the miniaturised equipment. A demonstration programme, to reduce the risks, shall include the test of integrated ISRU facility at laboratory conditions, ground tests under simulated Mars environment conditions, facility tests on board ISS and Mars robotic precursor missions, as shown on Figure 5.2/2. Lander key technologies are identical to those of the MPL mission (direct entry or aerocapture, navigation for both entry and accurate landing, aeroshell, descent and landing system. The demonstration missions are needed earlier, and could benefit from the Aurora mission planned in 2013.

The development of the element themselves (ISRU plant, lander, TMI) could start later, with a PDR around 2015. Meanwhile, system activities should be started in order to prepare adequate requirements for the technologies development and prepare the main choices for the different elements of the architecture.

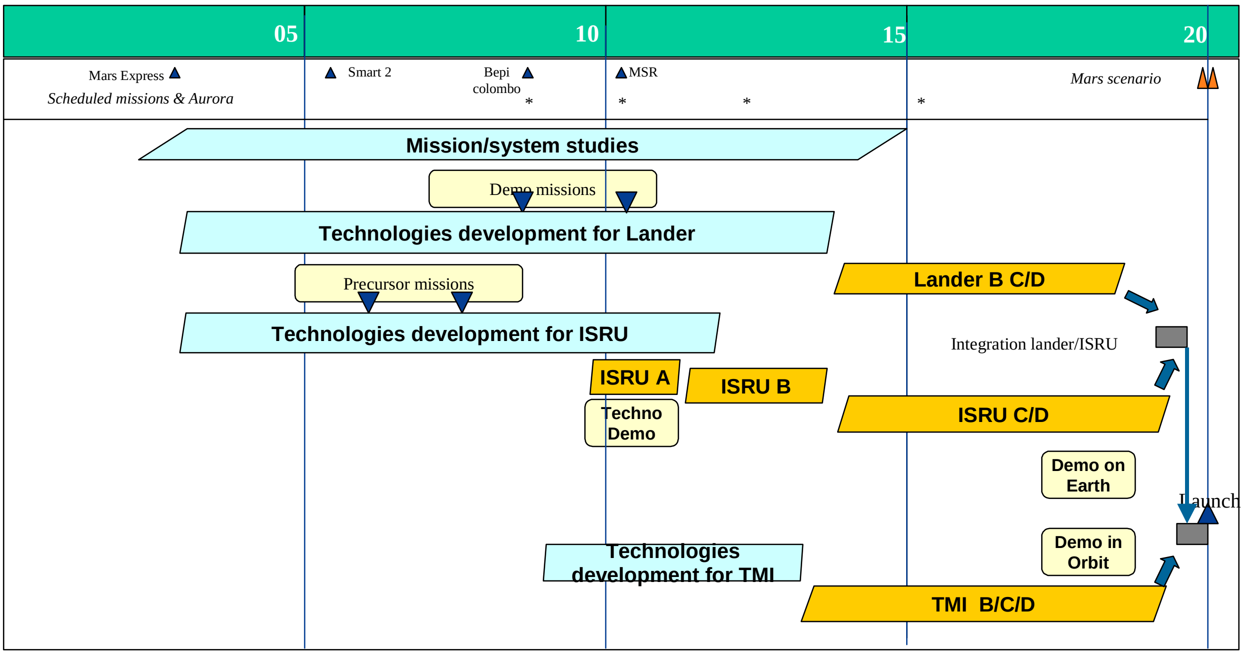


Figure 5.2/1: Development plan for the ISRU mission

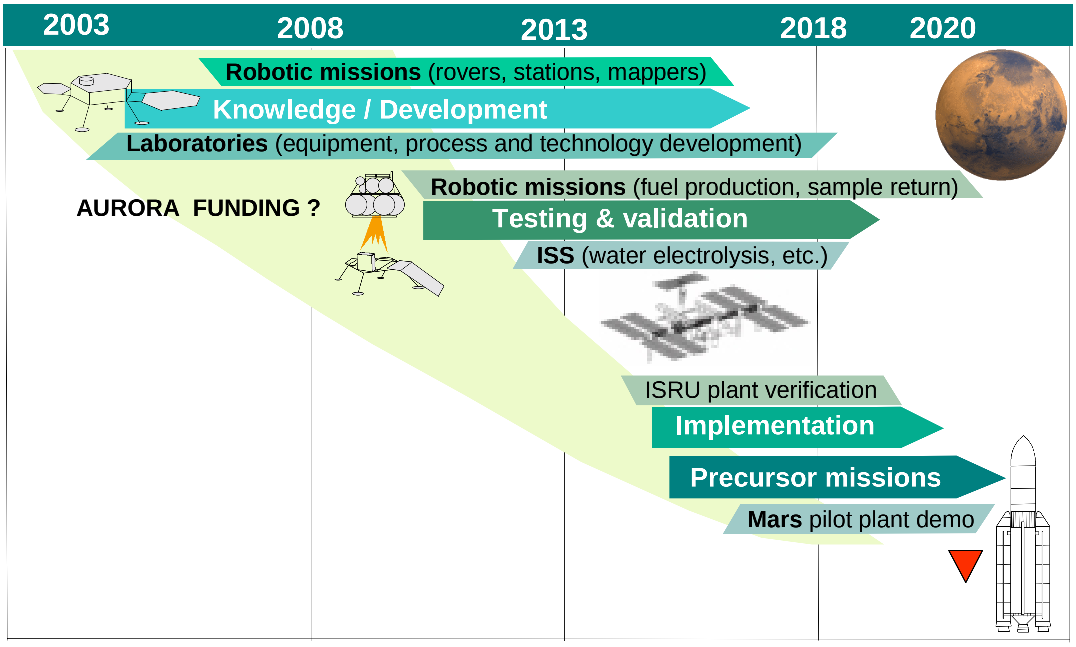


Figure 5.2/2: Road map for ISRU development

The complexity of the ISRU mission makes very difficult to evaluate its cost range.

A Rough Order of Magnitude of 3100 M€ has been evaluated, which includes the system activities and AIT, the critical technologies development, the ISRU development including on ground and in orbit tests and payload on-board a Mars robotic mission, the lander development and one flight model, the TMI development and one flight model and the launch, assuming an existing launcher.

In addition, the following assumptions have been taken into account:

- The transfer module is based on cryo propulsion, but cryostorage is developed on other programmes
- Use of a single AR++ launch
- For in flight demonstration, the critical technologies are assumed included as passenger
- No development of flight spare has been included

The figure 5.1/3 shows the sharing of this ROM cost into the main contributors.

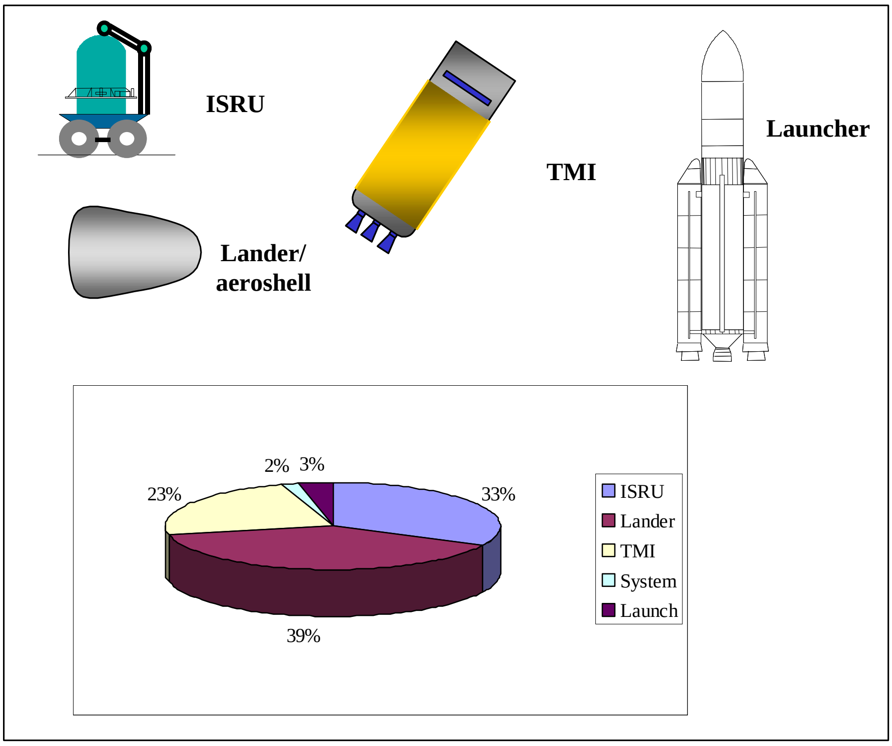


Figure 5.2/3: Elements of the ISRU mission and cost sharing

6 CONCLUSIONS

Several candidate European self contained and cooperative missions have been identified: missions with scientific objectives and missions dedicated to services, missions based on vehicles and missions based on fixed elements. These candidate missions offered a wide range in terms of size, technical complexity and challenging technologies. These missions have been identified in the frame of a reference mission scenario assuming the implementation of a Mars base and three manned missions towards this Mars base.

The system architectures associated to these missions rely on key technologies. A part of these technologies are not yet mastered in Europe, and their development (or acquisition) is a pre-requisite to the missions. The existing or in development technologies need to be adapted to the Mars environment.

The transport system is challenging for such large elements on Mars. The European launcher existing at that time, which has been considered in the study, is applicable to "small" payloads (up to 4 to 5 tons on Martian surface, depending on size). The transfer stage is based on cryogenic or thermal nuclear propulsion, each having constraints and limitations. Thus, the use of an International Heavy Launch Vehicle is necessary for large payloads, but has to be developed. Nevertheless, the study assumed a maximum of two AR++ launches for a mission, with an assembly in LEO in case of two launches. Alternatives based on LEO assembly with several launches and on new propulsion type (electrical, solar,..) for injection in MTO have not been studied. Such solutions would lead to a long transfer duration, but the elements which have been studied do not have strong requirements on the transport duration.

The approach for the entry to Mars still needs to be analysed, as being a key driver for the architecture design and performances. This approach shall consider the strategy for entry to Mars (direct entry, aerocapture, …), the aeroshell shape for large payloads and associated technology, the type of entry trajectory, the descent system (parachute, controlled descent, …).

The operations of Mars elements rely on local Martian infrastructure. Thus? The unloading of the elemnt from lander ands transport to Mars base will require an autonomous system, with impacts on lander and element design, if no infrastructure is available. Power is supplied by the Mars base power plant, even if an autonomy of several days is implemented on vehicles. Likewise, tanks (typically for fuel cells) will be refilled at Mars base. Communications and possibly navigation network will benefit to all elements.

The transport and storage of Hydrogen, which is quasi non available in the Mars atmosphere, is a key point common to most of the missions, and in particular for the ISRU plant. Transport from Earth and storage could be done as cryogenic H_2 (problem of cooling), or as water (energy for electrolysis). Availability of water on Mars could solve part of the problem.

Demonstration missions will be necessary to prepare these missions. They could be technology demonstration taking opportunity of automatic missions (on Moon or Mars), technology demonstration on ISS or dedicated demonstration missions on Earth (ground or re-entry).

The range of 2020-2025 for the missions, as assumed in the study, seems optimistic with respect to technology and transport system availability.

Automatic exploration missions are necessary from now in the coming years to get a better knowledge of the Mars environment and resources and on the possible sites for crew landing. This is a pre-requisite step (robotic outpost) to prepare the strategy for the manned mission and the implementation of necessary infrastructure.

In parallel, technology effort should be conducted to allow Europe to be a real player in a Mars International mission.

7 STUDY DOCUMENTATION

Technical Note N°	Reference	Title	Date
TN1	01/IO2/EMMA/001/CC	Mission Scenarios, Architectures and Requirements	02/02/01
TN2 (TN1b)	01/IO2/EMMA/003/CC	Mission Scenarios, Architectures and Requirements (update)	18/12/01
TN3	02/SZ2/EMMA/007NT/CC	Technology inventory	20/07/02
TN4	02/IZ/EMMA/004TN/CC	Architectural Design of Reference Missions	31/05/02
TN5	02/SZ/EMMA/006TN/CC	Development Programme	09/07/02
Executive Summary	02/IZ/EMMA/006TN/CC	Executive Summary	30/07/02

8 ACRONYSMS

AR:	Ariane Launcher
CCR:	EADS Common Research Centre
CD&H:	Command and Data Handling System
ECLS (CELSS):	Environment Closed Loop System (Closed Enviroment Life Support System)
EPS:	Electrical Power System
ERV:	Earth return Vehicle
EVA:	Extra Vehicular Activity
GNC:	Guidance, Navoigation and Control
GPS:	Global Positioning System
GTO:	Geo Transfer Orbit
HLLV:	Heavy Lift Launcher Vehicle
ISRU:	In Situ Resource Unit
ISS:	Interantioanl Space Station
ISTC:	International Science and Technology Centre
LEO:	Low Earth Orbit
LMO:	Low Mard Orbit
MAV:	Mars Ascent Vehicle
MEO:	Medium Earth Orbit
MPL:	Mobile Pressurized Laboratory
PEM:	Proton Exchnage Membrane
TEI:	Trans Earth Injection
TMI:	Trans Mars Injection (Stage)
UT :	Utilisty Truck