A European Science Mission to Planet Mars with Orbiter and Lander (ESMM)

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1 Scope

This paper focusses on the idea of a small yet advanced mission to planet Mars. Based on studies previously performed (see Ref. [1] through [5] on a cost effective robotic mission and earlier or ongoing contributions to Mars missions) four entities from industry (EADS-ST and SSC) and research (DLR and FMI) have teamed for a joint mission proposal to our outer neighboring planet. The relevant interests of the partners can be ideally combined into a small multi-national mission to Mars called: *European Small Mars Mission (ESSM).*

The contributing partners are:

- EADS Space Transportation GmbH (EADS-ST), Bremen, Germany
- Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Planetenforschung, Berlin-Adlershof, Germany
- Swedish Space Coperation (SSC), Solna, Sweden
- Finnish Meteorological Institute (FMI), Helsinki, Finland

Consultancy is provided by Babakin Science and Research Center (Russia).

A cost effective mission that has a multi mission potential (reflight with minimum modifications) has been assumed. This results automatically in a small platform based largely on already developed elements or even commercially off the shelf available technologies for spacecraft and experiments. Therefore costly development programs for new systems are not foreseen within ESMM, instead, ample time will be devoted to testing and verification to ensure mission success. Clearly, we have learned our lessons from Beagle-2.

The spacecraft (ESSM-S/C) consists of a Mars orbiter (ESMM-orbiter) and a Mars lander (ESMM-lander). Both units will be separated upon arrival at Mars in such a way that monitoring of the critical phases atmospheric entry, descent and landing (EDL) is guaranteed through ESMM-orbiter.

ESMM-lander shall prove Europe's capability to perform a controlled Mars landing and shall deliver a small surface module (the ESMM Mars station) for in-situ research onto Mars. A successful landing on Mars surface and the operation of a research station is cruical for Europe in view of the Beagle-2 failure and shall pave the way to future much more heavy – and hence much more expensive – landing units.

First analysis have proven that a small launcher like Rockot (provider Eurockot) is capable of propelling the 325 kg ESMM-S/C onto escape velocity for a direct injection to Mars in year 2009. Alternatively a launch with Ariane 5 would be possible using the piggy-back capability of the launcher and taking the detour of a Moon and Earth swing-by to Mars (see chapter 2).

2 Mission Requirements and Concept

ESMM shall work fully independent of other spacecraft concerning the communication link ESMM-orbiter, ESMM-lander and the ground segment on Earth. A cooperation with other mission shall however not be ruled out since the communication links will be based on frequency bands and codings common to Mars missions. This enables redundancy on the Earth communication link in case of problems.

The mission design is based on a design-to-cost philosophy the financial frame of which is much more narrow than the one of ESAs Mars Express mission. Our current estimate is 100 M€ for ESMM including launch and operation. This necessitates a lean project structure with an overseable team.

Based on the given cost frame, not only technologies (especially that of ESMM-lander) shall be tested but high-class research near and on Mars shall be carried out. A key mission requirement is the synchronised measurement of selected atmospheric parameters from Mars orbit as well as on Mars surface. This is especially true for the magnetic field and the radiation environment (UV and charged particles) measurement for which relevant experiments are foreseen (see chapter 5).

For the first time, a microwave limb sounder shall probe the Mars atmosphere. A further developed *High Resolution Stereo Camera (HRSC)* will be on board similar to the one providing stunning planetary pictures from the Mars-Express mission. Together with other foreseen experiments such as plasma- and magnetic field research and the radio science experiment, an elliptic target orbit around Mars is foreseen with 200 km by 33000 km peri- and apoapsis respectively, with an inclination near 90° (see Fig.1).

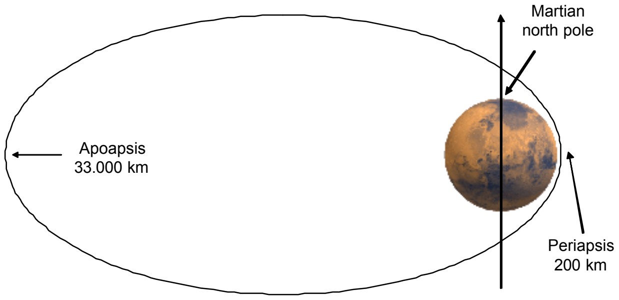

Fig. 1: Target orbit of ESMM-Orbiters during the scientific operational period around Mars

The ESMM-orbiter shall have a minimum life time of one Mars year in Mars orbit. Amongst its scientific tasks, all other typical operational requirements such as experiment orientation and communication with ESMM-lander and the Earth ground station will have to be fulfilled. The data volume to be transferred per Mars day is in the order of a few hundred Mbit (see chapter 6).

3 Launcher and Flight to Mars

Two potential launchers are currently foreseen:

3.1 Use of Ariane 5 ASAP

ESMM-S/C would fly as a piggy-back passenger on a commercial launch of an Ariane 5 but would have to rely on the scheduling of the main passenger (6). Since the launch window for a low energy transfer flight to Mars is limited to about two to three weeks only, problems with the main passenger satellite could seriously jeopardize ESMM already in the early beginning.

Further when using the Ariane 5 ASAP method, a *Moon Earth Gravitiy Assist (MEGA)* method would have to be applied since a direct injection would be too demanding energywise. The MEGA principle is further described in (7).

The clear diameter of the Ariane 5 ASAP container is some 1.5 m and allows a high-gain antenna of about 0.8 m to be intalled on the spacecraft. The useable volume in an ASAP configuration for four payloads is shown in Fig. 2.

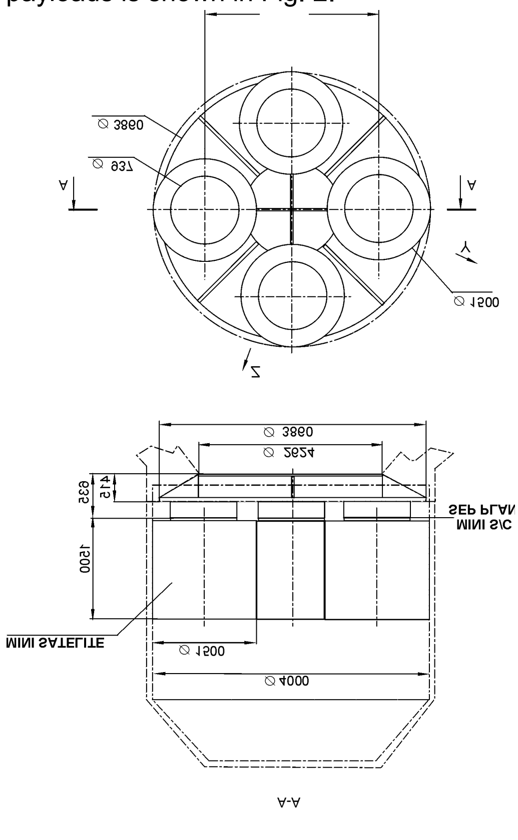

Fig. 2: Configuration scheme of four piggy-back payloads / Mini-satellites on Ariane 5 ASAP

3.2 Use of Rockot

When using Rockot (8) as launcher, ESMM-S/C would be the sole customer which would simplify the launch campaign compared to Ariane 5 considerably. To provide the craft with the necessary escape velocity, an additional booster stage is required. A suitable stage would be the Thiokol STAR 37 FM engine. The critical MEGA swing-by manoeuvre is however not required.

Fig. 3 shows the available payload volume below the shroud. A clear shroud diameter of 2.1 m allows a high-gain antenna of 1.2 m diameter to be installed.

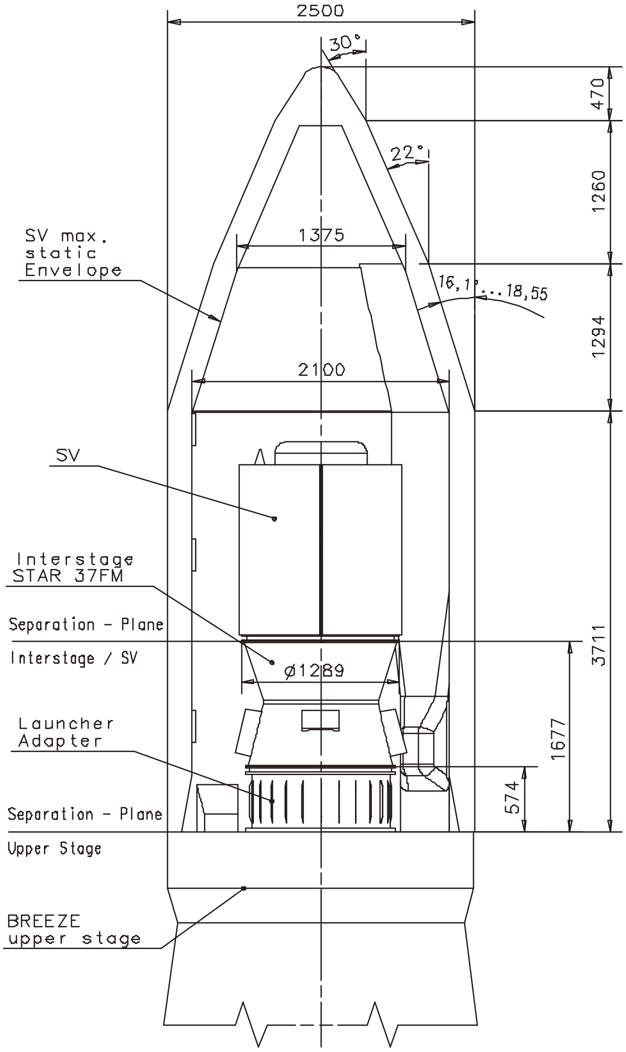

Fig. 3: Rockot upper stage with additional booster stage (Interstage STAR 37 FM) shown with example satellite (somewhat smaller than ESMM-S/C)

3.3 Comparison Ariane 5 ASAP « Rockot

The Rockot is the favorite launcher for ESMM-S/C. The launch is less complicated using a direct injection to Mars avoiding the swing-by method. The more generous volume below the shroud allows a larger antenna diameter of 1.2 m compared to just 0.8 m for the ASAP launch. This allows a gain in the data communication link of 2.25. Since the communication link notorously proves to be a bottle neck -more data are generated than the volume that can be transmitted to Earth- Rockot is the preferred launcher for this reason.

Fig. 4: Launch of a Rockot from Plesetsk cosmodrome

3.4 Delta-V Manoeuvre Using Rockot

Based on a Rockot launch with a STAR 37 FM booster stage providing ESMM-S/C with the required escape velocity, a preliminary mission analysis has been performed yielding the necessary manoevres for velocity correction (delta-V). The required propellant masses have been calculating assuming a bi-propellant propulsion system using MMH and MON.

The results given in Fig. 5 are promising since 120 liters of propellant are foreseen.

Maneuver	Delta-V (m/s)	Propellant Mass (kg)
Midcourse 1	50.000	5.100
Midcourse 2	20.000	2.000
Midcourse 3	30.000	3.000
S/C capture at Mars	775.980	86.000
Lander Entry (initial)	28.700	2.000
Lander Separation	0.000	0.000
Periapsis Lifting	11.960	0.700
Apoapsis Lowering	119.910	7.000
Orbit correction	240.000	10.000
Margin		4.200
	1276.550	120.000

Fig. 5: Delta-V and propellant masses required for transfer to Mars

Fig. 6 depicts the orbit manoevres at Mars required for ESMM-lander separation and injection into the final orbit (33000 km apoapsis by 200 km periapsis).

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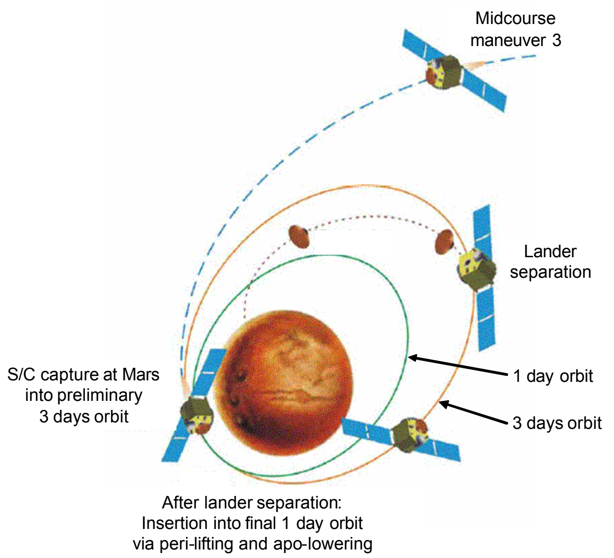

Fig. 6: ESMM-S/C Mars arrival manoeuvre with ESMM-lander release and target orbit of ESMM-orbiter

4 ESMM-S/C and ESMM-Orbiter

Based on a Rockot launch, the ESMM-S/C configuration (325 kg) consists of the ESMM-Orbiter (295 kg) and the ESMM-Lander, mounted on its upper platform and weighing only 30 kg. As shown in Fig. 7, the solar array panels are folded for launch and will be deployed after separation from the launching rocket and the booster engine. Fig. 8 shows the deployed in-space configuration.

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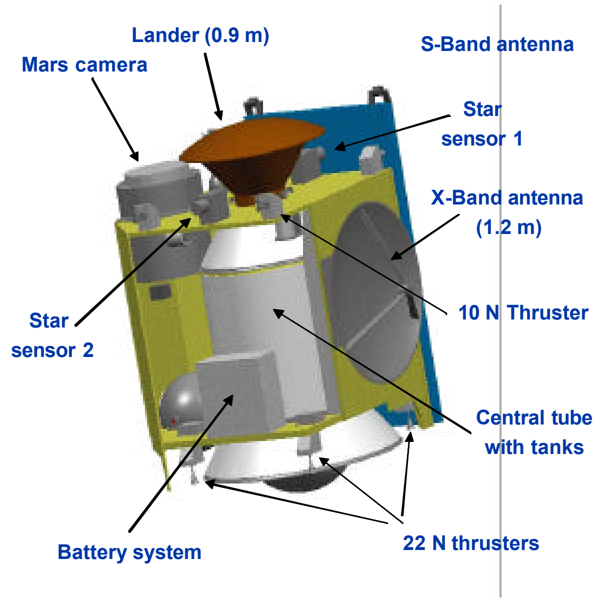

Fig. 7: Launch configuration of ESMM-S/C

ESMM-S/C is composed of the following main elements:

Primary structure, consisting of:

- 1 central tube
- couter cover
- internal platforms
- 1 launch adapter to booster
- 1 separation system for lander

Elements of propulsion system:

- 1 bipropellant tank (MMH and MON)
- 1 Helium pressurant tank
- four 22 N thrusters
- four 10 N thrusters

Attitude sensing and attitude control:

- 2 star sensors
- 2 sun sensors
- 1 inertial platform (IMU)
- 4 reaction wheels

Communication:

- 1 high gain antenna (X-band, Ø 1.2 m)
- 1 single pass antenna (S-band)
- 2 UHF antennas for communication with ESMM-Lander
- related transmitter and receiver

Power supply:

- 2 foldable solar arrays of 2.5 m² each
- battery system
- power distribution unit (PDU)

Payload:

- ESMM-orbiter experiments (30 kg) according to Fig. 10
- ESMM-Lander (30 kg)

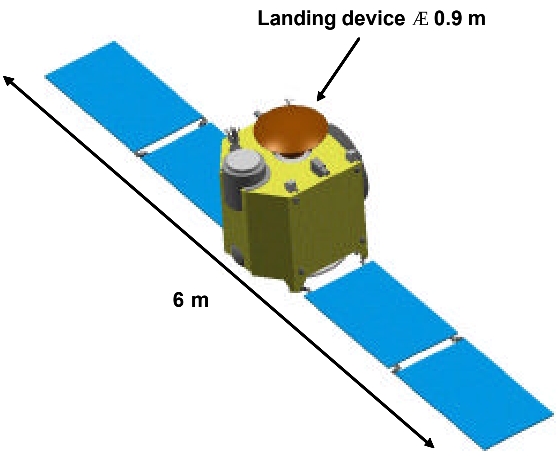

Fig. 8: Flight configuration of ESMM-S/C during transfer to Mars

The mass budget of ESMM-S/C is given in Fig. 9, showing a gentle margin of some 15 kg.

Item	Mass (kg)
Payload	30.000
Lander	30.000
Propulsion S/S	34.000
Communication S/S	16.000
GNC S/S	8.000
Power Supply	16.000
Data Handling S/S	6.000
Structure S/S	44.000
Thermal control S/S	6.000
Fuel (Bi-Propellant)	120.000
Margin	15.000
	325.000

Fig. 9: Mass balance of ESMM-S/C

Item	Mass (kg)
High resolution camera	9.200
Medium-angle camera	1.500
Wide-angle camera	0.300
Digital unit for camera system	1.400
Microwave limb-sounder	7.000
Plasma package	3.000
Magnetometer	0.750
Radioscience	0.500
Dosimeter	1.500
Margin	4.850
	30.000

Fig. 10: Payload experiments of ESMM-orbiter

5 ESMM-Lander

The ESMM landing device (EDL subsystems and Martian station) weighs only 30 kg overall. It is very similar to the Micro-Mars landing device which was presented at the IAC 2003. In comparison to the Micro-Mars landing device (16 kg) the ESMM landing device is an enlarged version due to higher masses for payloads (1.55 kg) and necessary subsystems. The foreseen payloads consist of two packages: A German DLR package and a Finnish package. Both packages are to study parameters of the Martian atmosphere like temperature, wind speed, magnetic field and radiation environment (table x). The sensors are very robust and are not demanding concerning power, thermal conditions, avionics, etc. Once landed on Martian ground an immovable small station (8 kg) carries all the payloads.

The subsystems which are needed for the EDL mission phase weigh 22 kg. To monitor the 6 minutes lasting descent phase an acceleration sensor will be used. Whenever possible there should be a line of sight between the descending landing device and the orbiter. This allows the immediate transmission of the sensor values insinuated that there is no blackout within the communication link.

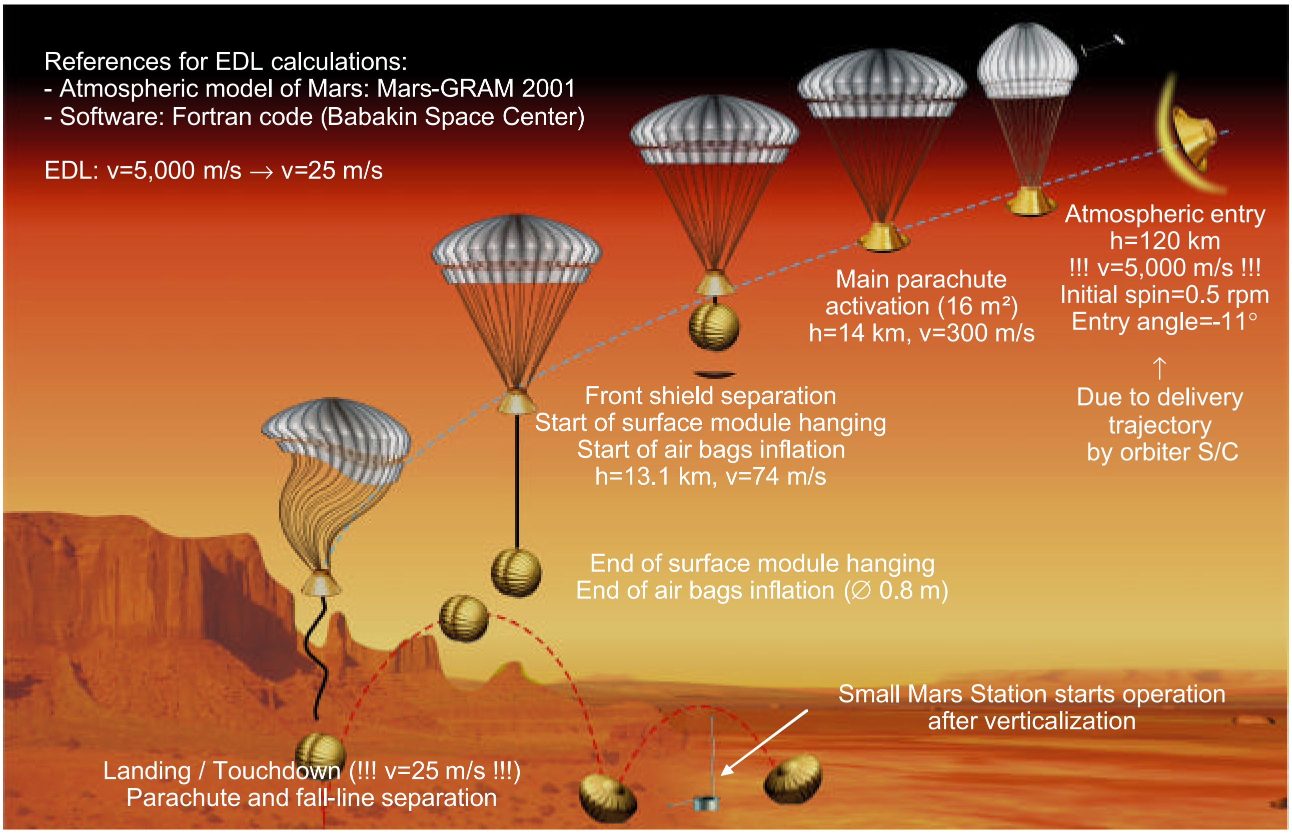

Fig. 11: *Entry, Descent, Landing* mission phase of ESMM-lander

Fig. 11 illustrates the mission phases *Entry, Descent, and Landing* of the ESMM-lander units. Fig. 13 shows an overview of all relevant subsystems. The draft design of the ESMM-lander unit is given in Fig. 12.

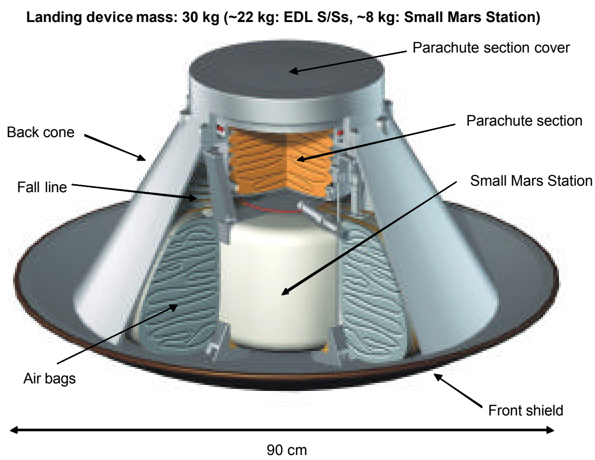

Fig. 12: Design of ESMM-lander

Concerning the relevant re-entry technologies, the following classical subsystem elements are foreseen:

- rigid aerodynamic heat shield
- parachute system
- airbag

Item	Mass (kg)
Martian station	8.000
Aerodynamic shield	4.500
Parachute system	6.000
Air bags	5.000
Fall line	1.200
Shadow part of thermal protection	0.800
Back cone	0.800
Pyrotechnic devices	0.500
Onboard cable network	0.400
Margin (EDL-Monitoring S/S, ...)	2.800
	30.000

Fig. 13: Subsystems of ESMM-lander unit

6 ESMM-Mars Station

After several rebounds of the airbags, the mars station comes to a rest and the airbags are depleted. The mars station deploys, thereby automatically erecting to a position as shown in Fig. 14. Communication with ESMM-orbiter will be in the 430 MHz band. A 150 mm by 150mm patch antenna is foreseen for this purpose

A small boom is foreseen for the camera head and to place the magnetomete at a sufficient distance to the electrical systems of the Mars station.

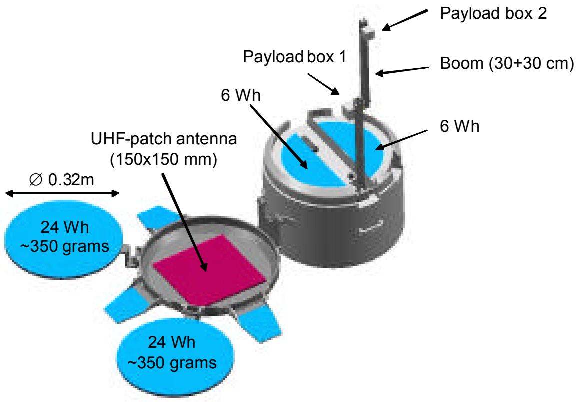

Fig. 14: Fully deployed ESMM-Marssstation

The solar cells can also be seen in Fig. 14, where 48 Wh of energy are generated per Martian day via 2 circular solar cell discs each of 32 cm diameter. Additional solar cell exposed surfaces generate a further 12 Wh of energy. A total of 60 Wh of energy is hence available per Martian day to drive the subsystems and experimental equipment of the Mars station as listed in Fig. 15.

directly payload-related: 1.55 kg

Item	Mass (kg)
Avionics	0.400
Transceiver	0.400
Antenna	0.300
Thermal (coupling RTG↔ battery)	0.300
Magnetometer (DLR)	0.150
Radiometer (DLR)	0.100
Dosimeter (DLR)	0.250
Camera (DLR)	0.100
Experiment Electronics (DLR)	0.250
Atmospheric sensor package (FMI)	0.700
Battery (rechargeable, 2 items)	0.450
Solar Panels (2x0.35kg + 0.10kg)	0.800
RTG (optional)	0.400
Cabling	0.200
Structure & Boom(s)	2.000
Miscellaneous / Margin	1.200
	8.000

Fig. 15: Subsystems and payload of the ESMM-Mars station

Energy drain :			
Item	Power usage (W)	Time (h)	Energy (Wh)
Avionics	0.500	24.000	12.000
Transceiver (including antenna)	18.000	0.167	3.006
Antenna	0.000	0.167	0.000
Thermal	1.500	8.000	12.000
Magnetometer (DLR)	0.400	8.000	3.200
Radiometer (DLR)	0.150	8.000	1.200
Dosimeter (DLR)	0.300	8.000	2.400
Camera (DLR & FMI)	1.000	0.500	0.500
Atmospheric sensor package (FMI)	0.500	24.000	12.000
Experiment Electronics	0.180	8.000	1.440
			47.746
			~ 50
Energy supply :			
Item	Power input (W)	Time (h)	Energy (Wh)
Battery (rechargeable)			27.000
Solar panel (mean power)			60.000
RTG (optional, electrical only)	0.120	24.000	2.880
			62.880
			~ 60

Fig. 16: Energie supply and drain of the ESMM-Mars station

6.1 Remarks to Subsystems Power and Thermal of ESMM-Mars Station

Critical elements on Mars stations are always the power and thermal subsystems. A landing site near the equator somewhat alleviates these problems, however the expected average temperatures will drop to -70 °C which is low enough to deep freeze critical components as batteries. A remedy could be the introduction of a *Radioisotope Thermal Generator* (RTG) to raise and stabilize the internal temperatures. Therefore it is planned to use a Plutonium 238 based RTG module delivering 204 Wh thermal energy per Mars day (Fig. 17). We therefore hope for a life time of several month for the station compared to just several days without the RTG module.

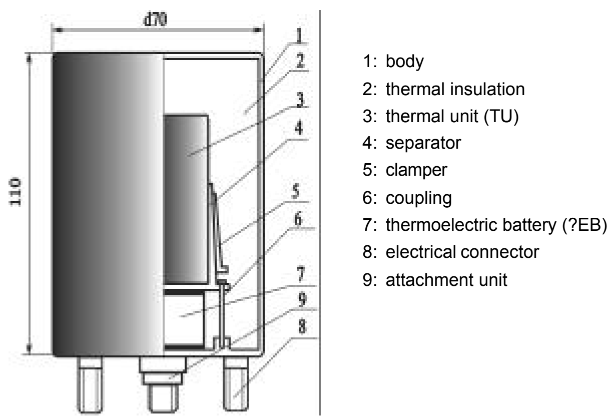

Fig. 17: RTG-module with 204 Wh thermal energy and 2.9 Wh electrical energy per Mars day

shows all foreseen power subsystem elements of the ESMM station

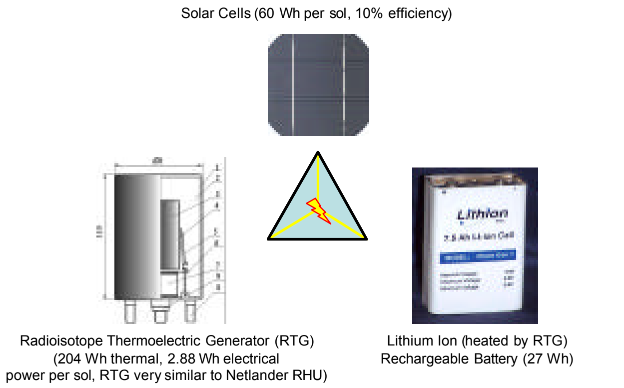

Fig. 18: Foreseen power subsystem elements of ESMM-Mars station

6.2 Data Management and Avionics of ESMM-Mars Station

The data management is performed via a commercially off the shelf micro controller card. Similar solutions have been applied on the NASA *Deep Space 2* mission. A SRAM capacity of 32 Mbit allows for experiment data storage of 9 Mars days, see

Data transfer from lander to orbiter is done at a rate of 8 kbit/s for experiment data and a few house-keeping data of the station. A 10 minutes contact window is therefore sufficient to transfer the data volume of one Mars day rated at 3.5 Mbit. The opposite orbiter to lander transfer rate (commands only) is a mere 20 bits per second.

Space qualified (MIL 1553), but COTS components:

- Similar to *Deep Space 2* electronics and software architecture, but with modified and enhanced memory (SRAM, 4 MBytes) to save and hold data during some sols via history buffer:
  - Experimental data
  - Surface module housekeeping data
  - Imaging data
- Dataprocessing unit:
  - Creditcard-sized OBC
  - Microcontroller-based: 80C51, C167 or similar
  - Common i/o interfaces like RS485, CAN onboard
- Power electronics board
- Memory:
  - SRAM, 4 MBytes = 32,000,000 Bits
  - Needs ~ 8 orbiter↔lander contacts for entired data upload
- Software: C, Assembler

Deep Space 2 microcontroller board (80C51)
low power device: ~ 6mW

Fig. 19: Avionics-S/S and OBDH of ESMM-Mars station

Data volume per Martian day (Bits):

- DLR Experimental data: 00,720,000 (see DLR payloads)
- FMI Experimental data: 02,050,000 (see FMI payloads)
- Imaging data (DLR): 00,180,000
- Housekeeping, Margin 00,550,000

Sum (data per sol): 03,500,000 Bits

SRAM volume (overall): 32,000,000 Bits

→ Data capacity covers ~ 9 Martian days: 9 * 3,500,000 Bits (+ Margin)
→ Data dump per lander↔orbiter contact: 4,800,000 Bites

Data volume per sol = data dump per 10 min orbiter « lander contact

Due to the landing site selection (TBD) of the Small Mars Station and the foreseen orbit of the orbiter there should be one orbiter↔lander contact per sol during the first operational week of the Martian station.
Later possibilities of orbiter↔lander communications depend on line of sight between the two spacecrafts.

Fig. 20: Data volume of ESMM-Mars station and Data transfer to ESMM-orbiter

7 Operation and Communication

The highly elliptical orbit of the ESMM orbiter is a scientific requirement to study planet Mars and his environment from different altitudes. This concerns especially the camera experiment, the radioscience experiment, the microwave limb sounder and the sensors to study Martian plasma and the magnetic field.

To provide electrical power to subsystems and batteries, the ESMM-orbiter must be oriented towards the Sun since the solar arrays are fixed to the spacecraft body. A similar manoever must be performed for communication with the Earth, the high gain antenna needs to be oriented to the ground station.

Therefore a scenario as shown in Fig. 21 has been developed

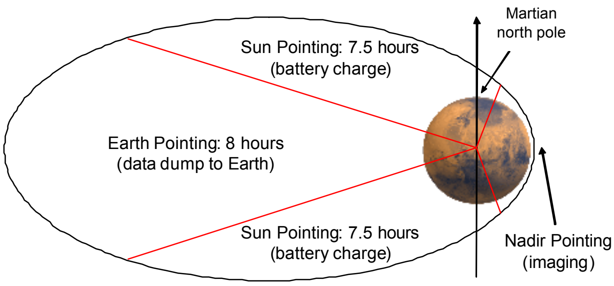

Fig. 21: ESMM operational scenario

The communications infrastructure of all ESMM components is given in Fig. 22.

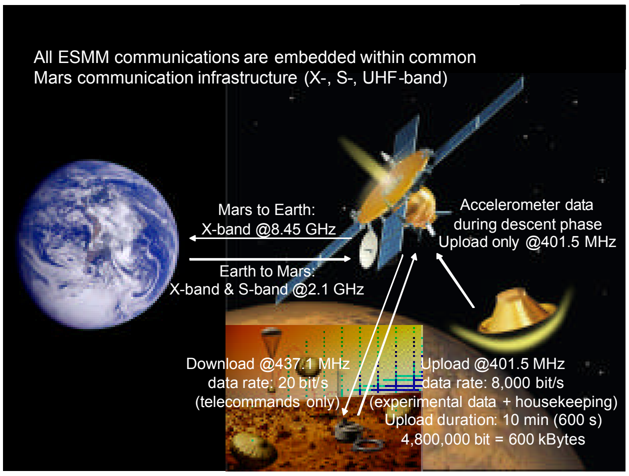

Fig. 22: ESMM communication infrastruktur

Fig. 23 depicts the data rates and volumes at different distances. Ground segment antennas of the 30 m class (ESA Weilheim and New Norcia) are foreseen.

Assumption for ESMM (Rockot launch case):		
Space segment	1.2 m dish, 20 W, X-band @ 8.45 GHz	
Ground segment	30 m antenna (e. g. Weilheim)	
Mars ↔ Earth	0.5 AU (min)	2.6 AU (max)
Data rates	135,000 bps	4,500 bps
1 hour data dump	486,000,000 bits	16,200,000 bits
2 hours data dump	972,000,000 bits	32,400,000 bits
4 hours data dump	1,944,000,000 bits	64,800,000 bits
8 hours data dump	3,888,000,000 bits	129,600,000 bits

Fig. 23: Data volume between ESMM-orbiter and Earth

8 Summary

A proposal for a cost efficient mission to planet Mars has been developed that has all challenges to pave the way for future larger landing missions as *ExoMars* or even a future manned mission.

9 References

[1] G. Neukum, H. Hoffmann, L. Kerstein, B. Bischof, *Kleinsatellitenmission Mikro-Mars*, 53rd International Astronautical Congress, Houston, USA, 2000

[2] L. Kerstein, B. Bischof, H. Renken, H. Hoffmann, U Apel: *Micro-Mars, a small orbiter and lander to planet Mars*, 5th IAA international conference on low-cost planetary missions. Noordwijk, NL, 2003

[3] H. Renken, B. Bischof, R. Ehlers, U. Auster, S. Konstantinov: *Entwurf eines kleinen Landegerätes zur wissenschaftlichen Erkundung des Planeten Mars*, Deutscher Luft- und Raumfahrtkongress, München, 2003

[4] F. von Schéele, U. Frisk, B. Jakobsson, H. Ringstrand, S. Veldman: *A low-cost mission to Mars*, 54th International Astronautical Congress, Bremen, 2003

5] A.-M. Harri, P. Makkonen, J. Polkko, H. Lappalainen, R. Pellinen, et. al: *MetNet - The next Generation Lander for Martian atmospheric Science*, 54th International Astronautical Congress, Bremen, 2003

[6] Ariane 5 ASAP manual, Arianespace, Paris, Internet: http://www.arianespace.com

[7] P. Penzo: *Mission Design for Mars Missions Using the Ariane ASAP Launch Capability,* JPL/NASA, AAS/AIAA Space Flight Mechanics Meeting, Breckenridge, Colorado, USA, 1999

[8] Y. Viertel, P. Freeborn, M. Kinnersley: *The Rockot Launch Vehicle - The successful German/ Russian Partnership in Space Transportation*, 5th IAA international conference on low-cost planetary missions. Noordwijk, NL, 2003

[9] D. Morabito: The spacecraft communications blackout problem encountered during passage or entry of planetary atmosphere, JPL/NASA, IPN progress report 42-150, 2002