Mars Weather Network

Executive Summary

Prepared by:	*Mars Weather Network Study Team*	
Checked by:	*Saturnino Val Serra*	*System Engineer*
Approved by:	*Jeremy Fielding*	*Study Manager*

This document was produced under the terms of ESA Contract No.4000138882/22/NL/MGu/my.

CONTENTS

1 INTRODUCTION

The Mars Weather Network Mission is a key precursor mission to future human exploration planning which consists of two orbiting spacecraft and four Lander together these will provide a comprehensive understanding of weather patterns at Mars.

This pre-phase-A study was kicked-off in July 2022 for a 9-month contract, with two progress meetings in December and February, culminating in a mission design review in 2023.

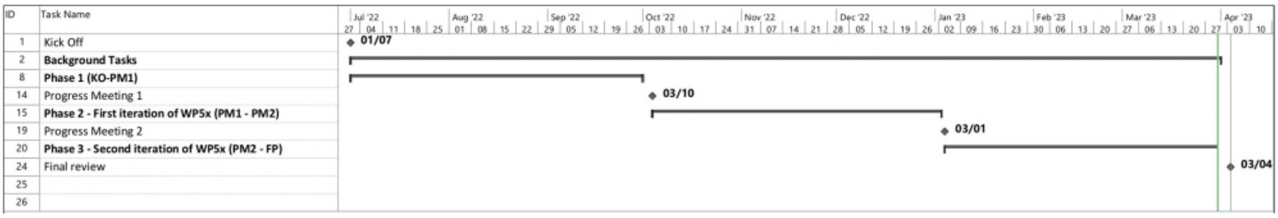

Figure 1-1 : Study Schedule Overview

The first activities focussed on reviewing the requirements and performing mission analysis to present a baseline mission timeline and arrival strategy, along with the compilation of a reference architecture for the mission. Following PM1, the focus was moved towards addressing system level trades and producing a more detailed description of the different elements of the mission. The final phases of the study iterated this design activity and consolidated the findings, along with key areas of focus which were identified during PM2.

The study team was led by Airbus (Stevenage), where the focus of the Lander development activities were also performed. The focus of the development activities for the Orbiters was performed by Airbus (Toulouse). Arianegroup (Les Mureaux) provided expertise on the Entry, Descent, and Landing system, and the Open University (UK) provided payload and scientific support, with further support from Leicester University.

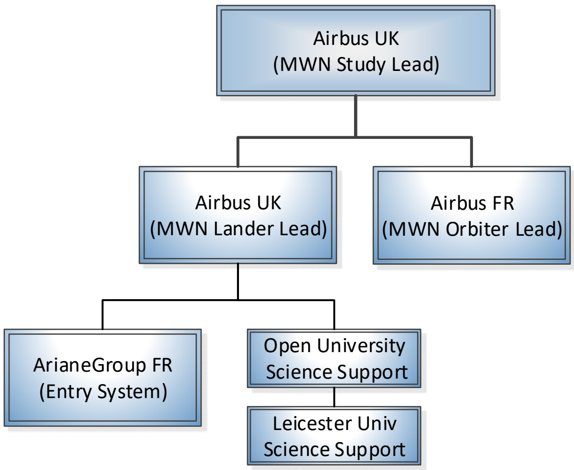

Figure 1-2 : Study Teaming Diagram

2 STUDY ACTIVITIES

The work performed within this study can be broadly considered to come under one of the five following activities, the outcomes of which are presented in the corresponding subsections of section 3.

2.1 Mission Analysis

The activity started by looking at the range of potential trajectories which could be adopted in order to deliver the various elements of the mission into their correct operational locations either on the surface, or in orbit and with the correct mission phasing. The mission requirements provided as inputs to the study provided clear boundaries within which to constrain a preferred solution based on the many factors identified.

2.2 Reference Mission Architecture

Working in parallel with the mission analysis, and considering the findings of this work, a mission architecture was compiled to address the key elements of the mission, the interactions between them, and the timelines of their operations through a series of mission level trade-offs. Preliminary budgets were compiled to capture initial expectations for mass, power and data production for space element in the network.

2.3 Space Element Designs

The concepts outlined in the architecture assessment were iterated to form a baseline design for each element of the mission (Orbiter-A, Orbiter-B, the Lander Carrier Module, and the Descent Module, including the Lander). This involved trading off numerous different design elements, and drawing on equipment heritage and experience from numerous relevant missions, studies, and developments across the team.

2.4 Model Based Systems Engineering

These type of early phase studies have historically been performed prior to introducing a more structured Model Based System Engineering approach later in the development cycle however, in this case, the MBSE approach has been adopted from the start. This activity sought to formalise the design process from the start in order to identify weaknesses in the design and provide a single point of truth for the design baseline.

2.5 Supporting Elements

A programmatic assessment was performed to address the overall timeline of the mission development and to highlight any key issues within the design and development process, based on the mission scenario presented.

An assessment of the potential for commercialisation was performed in respect of leveraging commercially available mission elements to enhance performance or to reduce cost or schedule. This activity also sought out commercial routes to funding the mission is a less traditional way through the sharing of costs, risks, and potential rewards.

At the end of the study, a costing exercise was performed for the baseline elements of the mission, however this is not addressed further within this executive summary.

3 STUDY OUTCOMES

3.1 Mission Analysis

The outcomes of this activity are presented in MWN-ADS-SYS-TN2-1000002 and summarised hereafter.

Mission analyses were performed to identify the best trajectory for the given conditions. Taking account of the baseline requirements, and with certain assumptions applied, the following scenario was identified.

Mission Phase	Orbiter-A	Orbiter-B	Carrier Modules (4-off)
Launch	April-2033 (dual launch with Orbiter-B)	April-2033 (dual launch with Orbiter-A)	October-2032 (all 4 Carrier Modules share 1 Launch)
Cruise Duration	7 months	7 months	28 months
Deep Space Manoeuvre	535m/s	458m/s	N/A
Mars Arrival	November-2033	November-2033	February-2035
Orbit Insertion	1145 m/s using chemical propulsion	1227 m/s using chemical propulsion	N/A
Final Orbit Acquisition	November-2034, following 12 months of aero-breaking in combination with chemical propulsion (1451 m/s)	November-2033, using chemical propulsion (628 m/s)	N/A
Mars Entry, Descent & Landing	N/A	N/A	February-2035 (staggered with 1 day between each landing)

Table 3-1 : Mission Profile

Arrival of the Orbiters at Mars is staggered by 8 days, with Orbiter B arriving shortly before Orbiter A, as illustrated in Figure 3-1. Deep Space Manoeuvres are also performed at different times earlier in the trajectory to avoid overlap of ground operations between orbiters.

The landers are timed to arrive at Mars 15 months after the orbiters to ensure that both orbiters are fully operational, allowing for 12 months of aero-breaking for Orbiter-A and to ensure that the weather conditions on Mars are favourable at the point of landing, avoiding the global dust storm season.

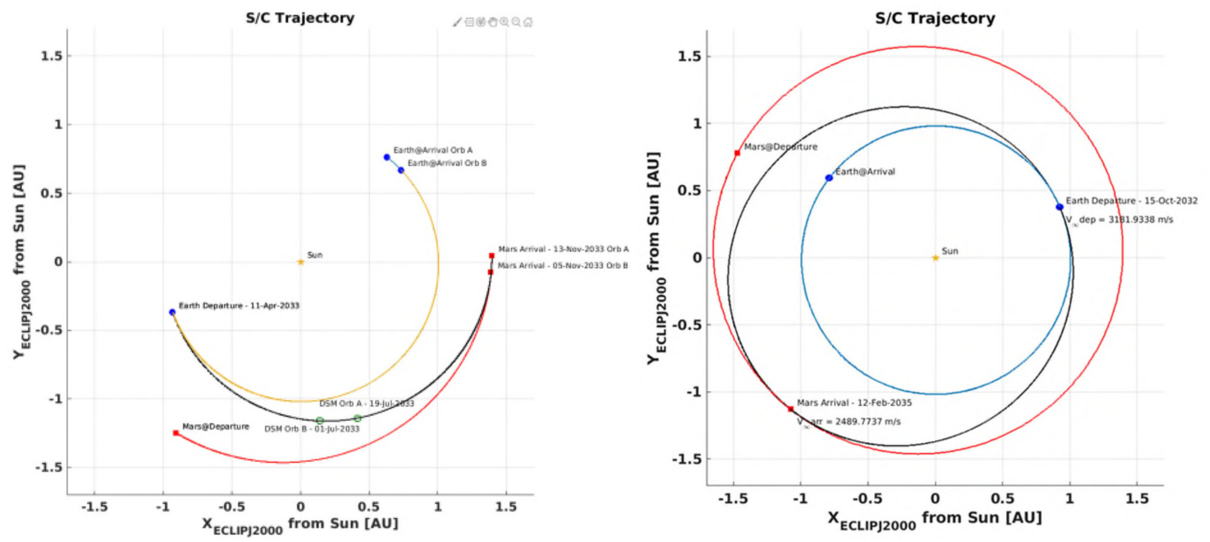

Figure 3-1 : Orbiter A and B **(left) and Carrier (right)** trajectories showing staggered **departure and** arrival dates

3.2 Reference Mission Architecture

The outcomes of this activity are presented in MWN-ADS-SYS-TN2-1000002 and summarised hereafter.

The high level End State Architecture is based on a dual-launch configuration with the four landers (and associated craft) on one launcher and the two Orbiters on a second launcher for a total of 14 space-segment assets:

- 1-off Low Mars Orbiter (Orbiter-A) at around 350km altitude, with repeated global coverage of the surface on a 14 sol cycle
- 1-off Asynchronous Orbiter (Orbiter-B) with a mean altitude of around 17000km.
- 4-off Carrier Modules, each carrying a Lander contained within an Entry Vehicle
- 4-off Entry Vehicles, which contain the landers and protect them during the initial phases of Martian atmospheric entry
- 4-off Landers, which provide self-contained weather stations on the Martian surface configured with three identical Landers placed in a triangle on the surface of Mars between 0-20 degrees North, with an additional Lander approximately 800km to the West

Four carriers each deliver an Entry Vehicle to Mars, staged to give 1 day between landings. Once through the Martian atmosphere, a parachute system is used to slow the descent before the Lander separates from the Entry Vehicle and finishes its descent using thrusters.

Primary communications from the Landers is via the Low Mars Orbiter using UHF Proximity-1, this is then re-transmitted to the Asynchronous Orbiter using K-Band. The Asynchronous Orbiter then transmits back to Earth using X-Band.

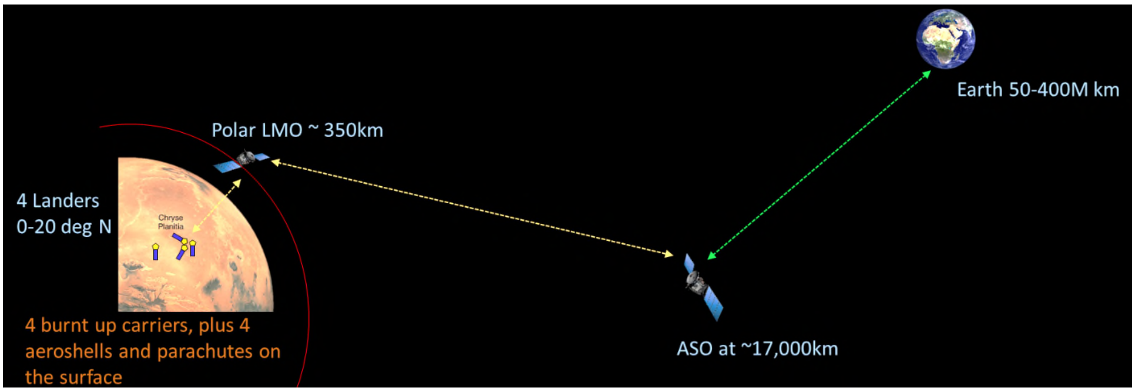

Figure 3-2 : End State Mission Architecture

The two launches are staggered such that the landers arrive at Mars 15 months after the orbiters, allowing for 12 months of aero-breaking for Orbiter-A to achieve its operational orbit. A period of ranging for each carrier is indicated by the orange box which will be followed by corrective manoeuvres needed in order to release of the lander with the best accuracy shortly before arriving at Mars.

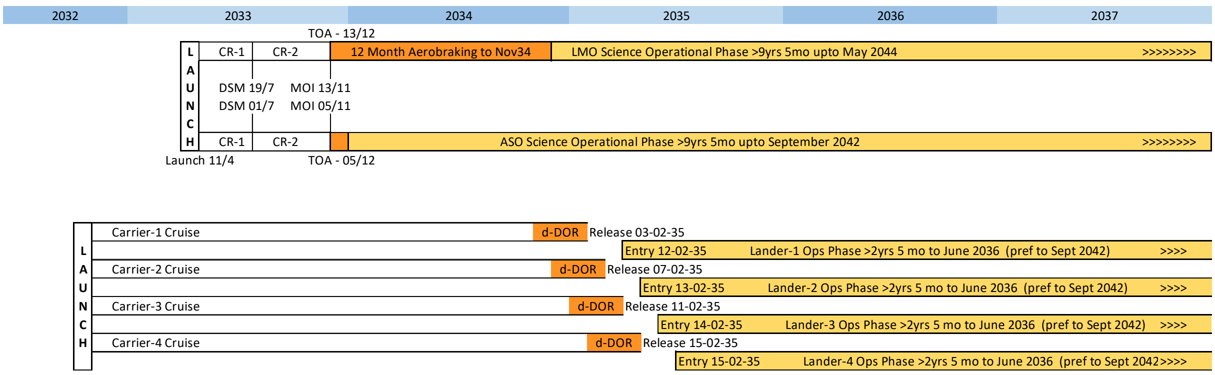

Figure 3-3 : Preliminary Mission Timeline

3.3 Space Element Designs

The outcomes of this activity are presented in MWN-ADS-SYS-TN3-1000003 and summarised hereafter.

Orbiter Designs

Two orbiters are required to perform the necessary scientific functions from Space in support of the Surface payloads, and to provide a global data set to support weather forecasting at Mars.

The orbiters rely heavily on heritage designs within Airbus, drawing much of the structure, propulsion, data-handling and AOCS subsystems from EnVision, and will each be similar in design. The similarity between them helps to reduce the overall development cost, since large parts of the spacecraft will be duplicated, thus negating additional design and testing effort. Despite their similarities, the two spacecraft each have their own unique elements:

MWN	Orbiter-A	Orbiter-B
Orbit	Quasi-Polar 350km	Areosynchronous 17,000km
Payload	Remote Weather Monitoring including Sub-mm sounder, Thermal IR Radiometer, Wind/Aerosol LIDAR, Imaging & Radio Occultation	Remote Weather Monitoring including Thermal IR Radiometer, Imaging & Radio Occultation
Structure	Primary: CFRP central cylinder with Aluminium honeycomb panels adapted from Envision Additional reinforcements to sustain additional loads from dual launch and aerobraking flaps on array	Primary: CFRP central cylinder with Aluminium honeycomb panels adapted from Envision Additional reinforcements to sustain additional loads from dual launch
Dry Mass	1768kg (including 30% system margin)	1368kg (including 30% system margin)
Propellant	1846kg (incl. residuals)	2253kg (incl. residuals)
Power	Solar Array: 25.6m^2, 2 axis mechanism Battery: 3710Whr	Solar Array: 88m^2, 1 axis mechanism Battery: 5680Whr
AOCS	2 Coarse Sun Sensors (Internally redundant) 2 Inertial Measurement in cold redundancy Star Tracker: 3 Optical Heads in hot redundancy 4 Reaction Wheels in hot redundancy	
Communications	1 fixed nadir UHF Antenna Steerable K-band Antenna 2 low gain X-band antennas 1 Medium gain X-band antenna	1 fixed nadir UHF Antenna Steerable K-band Antenna 2 low gain X-band antennas 1 steerable high gain X-band antenna
Data Handling	OBC, Remote Interface Unit, Solid State Mass Memory, Payload Data Handling Unit	
Propulsion	Bi-propellant, 16x 10N Thrusters, 1x 1kN main engine, 2x propellant tanks, 1x oxidizer tank	

Table 3-2 : Summary of Orbiter key design features

Figure 3-4 : Orbiter A and B configuration Overviews

Carrier Design

The Carrier baseline design makes use of the Lander sub-systems where possible to reduce mass, resulting in a Carrier which is dominated by a propulsion system and a substantial structure but little else – the Lander providing all control functions during cruise. By reducing the mass of the carrier in this way, it is possible to adopt an architecture with four separate Carriers, where each carries a single Lander, which results in a more accurate delivery to Mars.

Mars Weather Network Carrier (4-Off)	
Structure	Provisionally aluminium honeycomb box structure however needs detailed design as structure optimisation recognised to be critical
Dry Mass	788kg (including 30% System Margin)
Propellant	192kg (including residuals)
Power	1.5m^2 Body Mounted Array Battery: None (Uses Lander battery)
GNC	1 Coarse Sun Sensor (Internally redundant) Star Tracker: 2 Optical Heads in hot redundancy Inertial Measurement provided by Lander
Communications	2 Low Gain Antenna 1 Medium Gain Antenna
Data Handling	Provided by Lander IABS
Propulsion	Monopropellant, 8x 20N thrusters, 1x propellant tanks, 1x pressurant tank

Table 3-3 : Summary of Carrier key design features

The Carrier incorporates a structural element to support the launch loads of the Entry Vehicle, and auxiliary equipment needed to allow the Lander to function including an external radiator, a solar array, and external antennas.

As indicated below in the launch configuration diagram, each pair of carriers sits back to back with no mechanical link between; this concept reduces the complexity of the inter-carrier separation phase, but at the expense of a limitation of lateral stiffness of the stack.

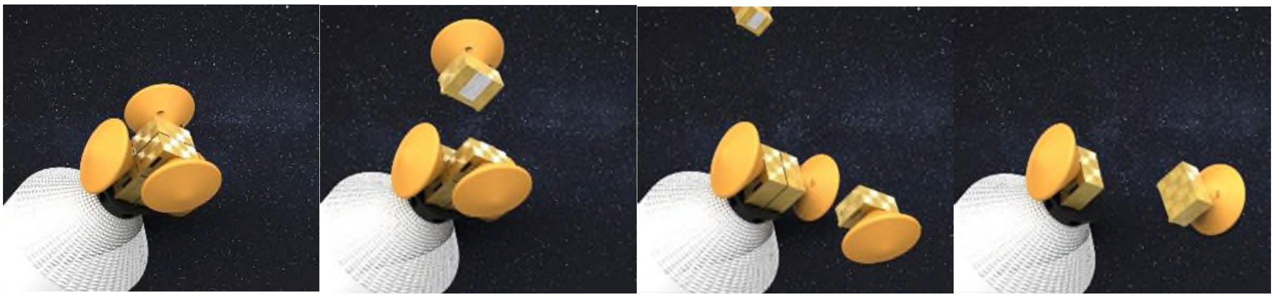

Figure 3-5 : Carrier launch configuration and deployment sequence

Entry Vehicle Design

The Lander is protected during entry from aeroheating by a front-shield and a back-shell. The heat-shield consists of a CFRP-aluminium honeycomb sandwich primary structure which is covered in a layer of bonded tiles.

The front shield consists in a 70° blunt capsule inherited from former Viking and all subsequent US missions that provides a first deceleration stage in the tenuous Martian atmosphere from around 125 km altitude down to around 10km altitude where the descent system is initiated.

The front-shield aeroshape remains unchanged from previous missions to ensure maximum heritage, however the rear-part is slightly modified in order to optimize the lander accommodation and centre-of-mass, without jeopardizing the above aerodynamic performances.

Mars Weather Network Entry Vehicle (4-Off)	
Structure	Carbon Fibre Composite Honeycomb Shell
Thermal Protection	Norcoat Liege
Dry Mass	392kg (Including 30% system margin)
Power	Pilot: 2.4m Disk-Gap-Band (DGB) Drogue: 15m Disk-Gap-Band (DGB)

Table 3-4 : Summary of Entry Vehicle key design features

Figure 3-6: Aeroshell Configuration Overview (heritage from ExoMars 2016)

Lander Design

Each Lander is carrier to Mars by its own Carrier module, which provides the space functions needed to support it during cruise. During entry, the Lander is protected inside the aeroshell until it is released from the back shell to perform its powered descent. Once landed on the surface, the Lander deploys a solar array, and payloads before entering its fully operational state.

The Lander separates from the Carrier Module during descent and lands under the power of its' thrusters. Compliant legs aid its' landing on the uneven terrain while avoiding the use of hazard avoidance manoeuvres. These articulated legs allow the platform the be elevated well above the surface to minimise the build-up of dust on the solar arrays, and to ensure maximum altitude for the weather payload.

The upper panel provides a thermally isolated panel for the external payload to be consolidated onto. The weather payload is concentrated on an elevated boom, which in turn is appended to the rigid CFRP camera mast. This provides additional height and isolation for the weather payload.

Mars Weather Network Lander (4-Off)	
Payload	Weather Monitoring (Temperature, Pressure, Wind Speed etc)
	Seismometer, sub-surface temperature probe, Radio Science, Camera
Structure	2m Hexagonal CFRP Honeycomb panel with vertical shear walls incorporating the Warm Electronics Box, and mounted directly to Landing gear and Propulsion system
Dry Mass	442kg (including 30% System Margin)
Propellant	53kg (including residuals)
Power	2 x 2.6m^2 linearly deployable arrays using Azurspace 3G30 cells with a linearly actuated dust clearing device operating on a 15 day cycle plus a Small body mounted panel Battery: 2.2kWhr
GNC	1 x Astrix 1090A Inertial Measurement Unit with supplemental accelerometers CCD Sun Sensor
Communications	2 Low Gain UHF Antennas (Prox-1 to low mars orbiter or other available relays)
Data Handling	Fully Integrated Avionics Box System encapsulating all electrical equipment
Propulsion	Monopropellant, 12 x 400N thrusters, 3x propellant tanks, 1x pressurant tank
Thermal	Gas-gap warm enclosure houses all sensitive equipment 30W Radio-isotope Heater Unit provides all platform heat

Table 3-5 : Summary of Lander key design features

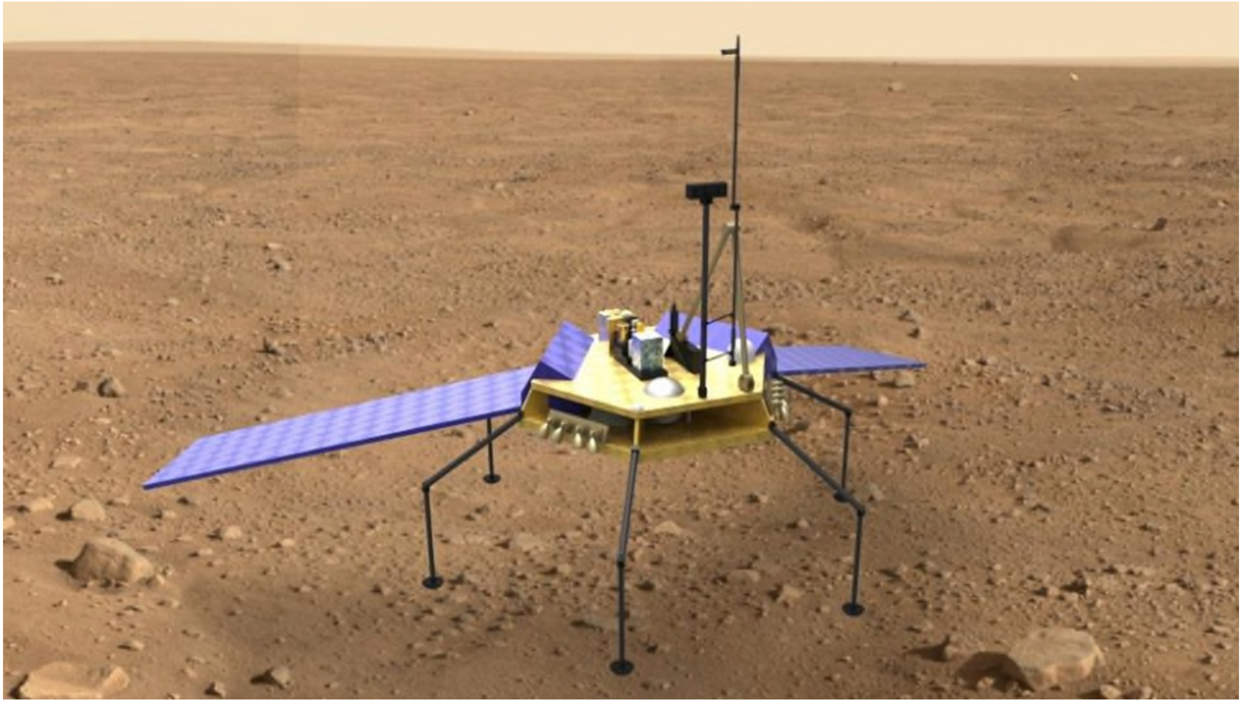

Figure 3-7 Lander Configuration on Mars

3.4 Model Based Systems Engineering

The outcomes of this activity are presented in MWN-ADS-SYS-TN6-1000006 and summarised hereafter.

The MBSE activity concentrates on the modelling of the architectures of the mission systems. This definition is related to the mission, operational, functional, and logical architectures, each providing incrementally more detailed information about the mission and the systems, and serving as starting point for the next layer. Requirements are allocated to the architecture elements to ensure compliance.

Following the identification of the mission phases and operational concepts, the system functions are derived and properly mapped to the operations, providing a high level of confidence that all major system functions are identified. Finally, the selection of logical components is performed, in order to identify the main subsystems and units to realize the functions, without considering the details of the technical implementation.

The MBSE approach is therefore focused on four main architectures, each described in a subsequent section in this document. The model helps monitor the progress on each layer, highlighting the elements to focus on.

1. Mission
2. Operations
3. Functional
4. Logical

In this framework, the system engineering activity is followed in a top-down fashion (i.e., from mission to logical). For instance, it would not be beneficial to develop the functional layer in great detail if the operational layer is not well described. Once complete, the model can be shared with the customer by exporting it in HTML format.

3.5 Supporting Elements

The outcomes of this activity are presented in MWN-ADS-SYS-TN4-1000004 and summarised hereafter.

Commercialisation

Commercialisation aspects have been examined both in terms of the industrial approach to building the mission and the subsequent exploitation of data produced by the space-segment

Industrialisation possibilities include Public-Private Partnerships, where the initial non-recurring costs are supported by an institutional partner, while the expansion of the constellation is supported by the successful commercial exploitation, and a commercially funded development, whereby the development is funded by a commercial entity which either receive substantial grant from an institution to cover the initial investment or an institution become an anchor-customer.

The final product of the Mars Weather Network will mainly consist of weather / temperature data and forecasts, potentially providing landing weather forecast for other missions, along with the possibility to use Orbiter-B as a communications relay or backup for other missions.

Programmatics

Programmatic considerations have been given to the industrial setup for the programme and whether, considering the large scope of work, it should be structured with dual prime contractors; a provisional product tree and implementation schedule has also been defined along with the identification of programmatic risks, critical items and cost drivers.

The ultimate program of work is heavily dependent on the model philosophies applied to the different elements:

- the commonalities between orbiters A and B should permit for a STM-PFM(Orbiter-A)-FM(Orbiter-B) approach
- assuming the Carrier Modules remain (nearly) identical then a STM-PFM(CM1)-FM(CM2,3,4) approach is also likely
- Similarly for the Landers, a STM-PFM(L1)-FM(L2,3,4) approach could be adopted with the addition of an Electrical Test Bench to ensure robust development of the flight functional chains.

This document was produced under the terms of ESA Contract No.4000138882/22/NL/MGu/my.

4 SUMMARY AND CONCLUSIONS

This pre-phase-A study has reviewed the Mars Weather Network at a mission, architecture, system, and sub-system level. The core elements of the mission baseline identified in the study include four identical Landers, four identical Carriers, and two Orbiting spacecraft which share considerable commonality between them despite their different requirements. The level of commonality across the platform has been encouraged in order to constrain the potential cost of the mission.

Because of the breadth of the activity, which included an assessment of four distinct spacecraft, the level of definition is naturally lower than may normally be expected of a similar more constrained study, however the approach has been to focus on the most critical parts of the mission, and give less bandwidth to the more common elements.

Mass budgets for each mission element have been compiled, and with all margins included, the total launch mass can be seen to be close to the capability of the baselined dual-launch using two Ariane-64 Evo launch vehicles. As the level of definition increases, so the mass budget is expected to be eroded, however there should be no doubt that this will be a large and challenging mission.

A number of mass saving opportunities have been identified including relaxing the operational mission timeline constraints to extend aero-braking, optimising the Carrier structure design to be more efficient, and further optimisation of the Lander power modes in order to reduce power and volume of the Lander and Aeroshell.

This study has also examined commercial and programmatic aspect of the mission, identifying possible re-sale opportunities for the data it would gather along with how best to distribute such a large scale mission amongst industry, including the possibility of one prime for the orbiters and a second prime for the carriers and landers.

Overall the mission can be seen to be viable within the primary objectives, however a limited number of exceptions to the mission requirements are identified below, and extremely valuable in supporting all future missions. Whether future missions are within the operational lifetime of the weather network or not, they will certainly benefit from an increased understanding of weather at Mars which will be derived from this mission. This may be for surface operational reasons (available solar power or temperature) or for atmospheric modelling to ensure a safe entry upon arrival.

Req. ID	Requirement Text	Compliance	Comments
R-M-MIS-0030	The first science data to be obtained in the operational phases of the orbital and surface elements shall be returned in the nominal launch scenario no later than May 2034 (TBC).	NC	With the proposed launch scenario for the landers, the landers will be on Mars surface in February 2035 (nominal) / 2037 (backup). Refer to TN2 Sections 4.3 and 4.4
R-M-MIS-0040	The first science data to be obtained in the operational phases of the orbital and surface elements shall be returned in the back up launch scenario no later than May 2036 (TBC).	NC	
R-M-LAS-0010	The FAHRENHEIT mission shall use the Ariane 64 Evolution launch vehicle for all mission launches, with launch vehicle performance assumptions given in [AD8], from Kourou, French Guiana as nominal.	PC	Compliance with Ariane 64 EVO performance is not obtained with the Carrier + EV baseline Refer to TN3 Section 7.5
R-M-LAS-0030	The FAHRENHEIT mission shall be compatible with a nominal launch date in 2033.	PC	With the proposed baseline, the orbiters will be launched in the 2033 (nominal) / 2035 (backup) launch opportunity whereas the carriers/landers will be launched 6 months earlier, in 2032 (nominal) / 2034 (backup). Refer to TN2 Sections 4.3 and 4.4
R-M-LAS-0040	The FAHRENHEIT mission shall be compatible with a backup launch date in 2035.	PC	
R-S-OPS-030	Surface science data shall be available (if selected for downlink) on ground within 1.5 sols (TBC) of acquisition.	PC	NC only during extreme weather conditions Refer to TN3 Section 8.4

Table 4-1 : Exceptions to mission requirements

This document was produced under the terms of ESA Contract No.4000138882/22/NL/MGu/my.

DOCUMENT CHANGE DETAILS

ISSUE	RELEVANT INFORMATION/INSTRUCTIONS
1	First Issue
2	Updated for initial MDR Comments and evolutions in the referenced documents
3	Updated post MDR to align Summary tables & Mass values to budget update

DISTRIBUTION LIST

INTERNAL	EXTERNAL
Configuration Management	ESA Configuration Management