

EXECUTIVE SUMMARY

Mars Sample Return Architecture Assessment Study MSRAAS

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1. INTRODUCTION

1.1. Purpose

The objective of this document is to provide the EXECUTIVE SUMMARY of Mars Sample Return Architecture Assessment study led by DEIMOS Space S.L.U. and realised in collaboration with Lockheed Martin UK Amphthil and MDA Corporations. The work has been performed under ESA contract number 4000121990/17/NL/JC.

1.2. Scope

This document provides a complete description of all the work done during the activity and it is self-standing.

1.3. Acronyms and Abbreviations

The acronyms and abbreviations used in this document are the following ones:

AD	Applicable Document	LMUK	Lockheed Martin UK Amphthil
AOCS	Attitude Orbit Control System	LPC	Launch Period Closure
ATV	Automated Transfer Vehicle	LPO	Launch Period Opening
BIPR	Backward Intellectual Property Rights	MAG	Mission Analysis Guidelines
CCD	Contract Closure Document	MAV	Mars Ascent Vehicle
CDF	Concurrent Design Facility	MDA	MacDonald, Dettwiler and Associates
CFRP	Carbon Fibber Reinforced Polymer	MDD	Mission Description Document
CONOPS	Concept Of Operations	MDP	Mission Development Plan
DART	Double Asteroid Redirection Test	MMH	Monomethylhydrazine
DMS	DEIMOS Space	MOI	Mars Orbit Insertion
DOA	Departure Orbit Acquisition	MOM	Minutes Of Meetings
DOF	Degree Of Freedom	MREP	Mars Robotic Exploration programme
DSM	Deep Space Manoeuvre	MRS	Mars Sample Return
EAM	Earth Avoidance Manoeuvre	MSRAA	Mars Sample Return Architecture Assessment
ECSS	European Cooperation for Space Standardization	MSRC	Mars Sample Return Capsule
EDL	Entry descent and Landing	MSRO	Mars Sample Return Orbiter
EIP	Earth Interface Point	NASA	National Aeronautics and Space Administration
ERC	Earth Re-entry Capsule	PDR	Preliminary Design Review
ERV	Earth Return Vehicle	PM	Project Meeting
ESA	European Space Agency	PRA	Preliminary Risk Assessment
ESB	Earth Swing-By	PRR	Progress Reports
ESOC	European Space Operations Centre	PTRSD	Preliminary Technical Requirements Specification
ESTEC	European Space Research and Technology Centre	REQ	Requirement
ESUM	Executive Summary	SCOT	Special Conditions of Tender

FP	Final Presentation	SOW	Statement of Work
FPA	Flight Path Angle	SRR	System Requirements Review
FR	Final Report	TAS	Thales Alenia Space
GAM	Gravity Assist Manoeuvre	TEI	Trans-Earth Injection
GSP	General Study Programme	TMI	Trans Mars Injection
HAO	Handouts	TOA	Target Orbit Acquisition
ITT	Invitation To Tender	TPS	Thermal Protection System
JAXA	Japan Aerospace Exploration Agency	TRL	Technology Readiness Level
LIC	Launcher Injection Correction	WBS	Work Breakdown Structure
LMO	Low Mars Orbit		

2. RELATED DOCUMENTS

2.1. Applicable Documents

The following table specifies the applicable documents that shall be complied with during project development.

Table 2-1: Applicable documents

Reference	Code	Title	Issue
[AD.1]	MREP-ESS-MSRC-MAG-001	Mission Analysis Guidelines	1.0
[AD.2]	ESSB-ST-U-001	ESA Planetary Protection Requirements, issue 1	1.0
[AD.3]	CDF-TN-057	Margin Philosophy Document	
[AD.4]		Ariane 6 User's Manual	0 (May-16)
[AD.5]		Atlas V User's Guide	11 (Mar-10)
[AD.6]		Falcon 9 User's Guide, SpaceX, rev. 2, October 2015	2 (Oct-15)
[AD.7]	ESSB-HB-E-002	Guidelines for the use of TRLs in ESA programmes	1.0
[AD.8]	AO/1-9012/17/NL/JC	Invitation to Tender AO/1-9012/17/NL/JC, "ExPeRT: MSR Architecture Assessment Study"	
[AD.9]		Appendix 1 to AO/1-9012/17/NL/JC, "ExPeRT: MSR Architecture Assessment Study" STATEMENT OF WORK	
[AD.10]		Appendix 2 to AO/1-9012/17/NL/JC, "ExPeRT: MSR Architecture Assessment Study" DRAFT CONTRACT	
[AD.11]		Appendix 3 to AO/1-9012/17/NL/JC, "ExPeRT: MSR Architecture Assessment Study" SPECIAL CONDITIONS OF TENDER	
[AD.12]	MSRAAS-DMS-MAN-MOM-DM1-10	ESA ExPeRT: MSR Architecture Assessment Study - Delta PROGRESS MEETING 1 - Minutes of Meeting	27/11/2017

2.2. Reference Documents

The following table specifies the reference documents that shall be taken into account during project development.

Table 2-2: Reference documents

Reference	Code	Title	Issue
[RD.1]	CDF-167(A)	MSR Carrier, CDF study report	July 2016
[RD.2]	MSRO-TN-ASF-051	Assessment study for a Mars Sample Return Orbiter, Executive Summary	

Reference	Code	Title	Issue
[RD.3]	MSRO-TAS-TN-PRG04-100581563W	Assessment study of a Mars Sample Return Orbiter, Executive Summary	
[RD.4]		Assessment study for a Mars Sample Return Orbiter, Technical data package	
[RD.5]		Assessment study of a Mars Sample Return Orbiter, Technical data package	
[RD.6]		NASA Next Mars Orbiter Mission Overview	1.0
[RD.7]		G. De Zaiacomo et al., "EDL Mission Analysis and Design for High Energy Sample Return Missions" 13th International Planetary Probe Workshop	15 Jun 2016
[RD.8]	SRE-PA/2011.097	ESA Margin philosophy for science assessment studies	2.0
[RD.9]	LKEB-9812-1990	Proton Mission Planner's Guide	7
[RD.10]		https://elvperf.ksc.nasa.gov/pages/Query.aspx	
[RD.11]	AAS 15-632	Ryan C. Woolley* and Austin K. Nicholas, "SEP MISSION DESIGN SPACE FOR MARS ORBITERS"	
[RD.12]		James R. Wertz and Wiley J. Larson "SPACE MISSION ANALYSIS AND DESIGN"	
[RD.13]	MSRAAS-DMS-PTRS-TN02-21	MSRAAS - Preliminary Technical Requirements Specification	2.1
[RD.14]		Attitude Motion and Aerodynamic Characteristics of MUSES-C Reentry Capsule, 2003	
[RD.15]		The aerodynamic Data Base for Asteroid Sample Return Capsule, 2003	
[RD.16]	MSRAAS-LMUKA-MDP-TN03-20	MSRAAS - Preliminary Technical Requirements Specification	2.0

3. TRADE-OFF ANALYSIS

This chapter is intended to present the general trade-off analyses performed for the architecture assessment study of Mars Sample Return (MSR) mission, where particular attention was dedicated to concept (d): this option assumes an independent ESA spacecraft which is independently launched and at Mars performs the full functional set of rendezvous, capturing the OS, bio-sealing, transfer into the ERC and return to Earth. The payload elements on the ESA spacecraft for this option are the capture mechanism, the bio-containment system (incl. BC), the transfer mechanism and the ERC. The variables involved in MSR mission analysis are the ones presented in Figure 3-1, classified per mission phase.

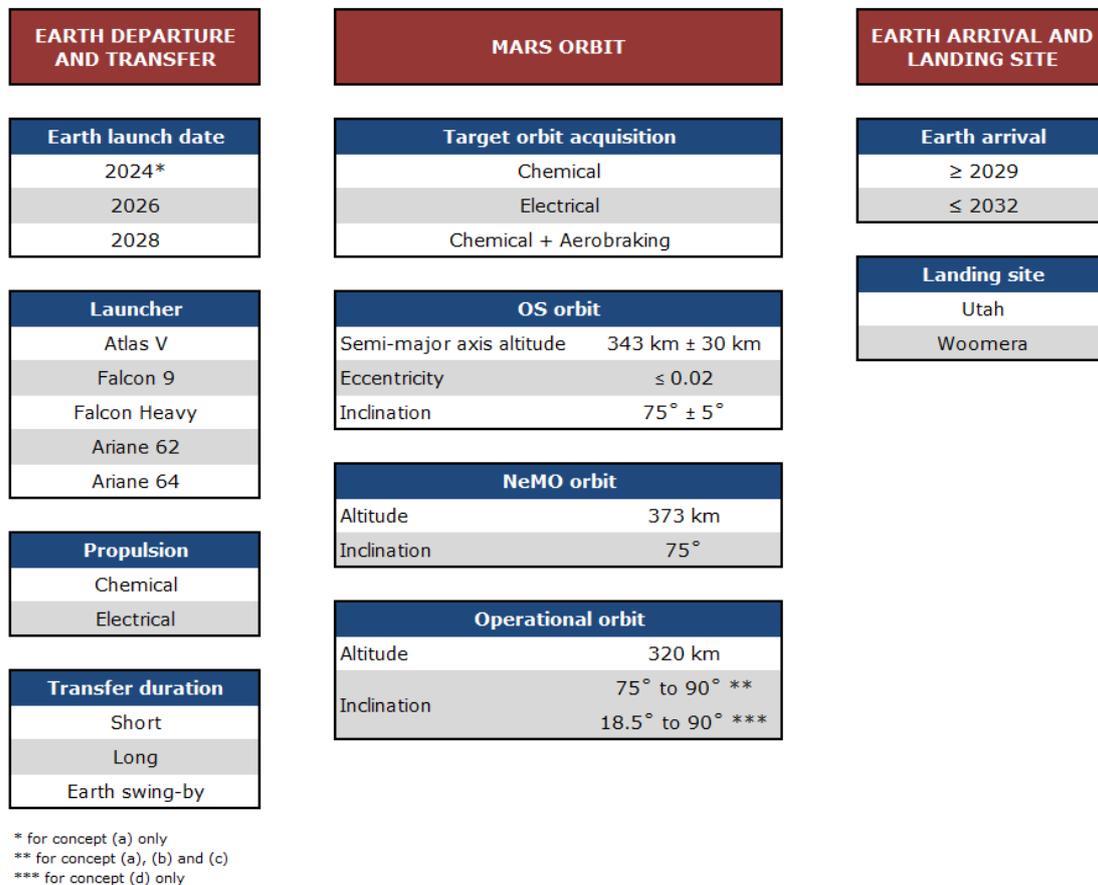


Figure 3-1: MSR design variables overview

3.1. Launchers

The launcher families considered in this study are Ariane 6, Atlas V, Falcon, and Delta IV; in Figure 3-2 it is possible to see all the launchers performance evaluated in the previous sections. For the sake of completeness, it has been highlighted in light orange and light green the range of the required C3 for chemical and electric outbound, respectively.

3.2. Interplanetary Trajectories

The following set of engines has been considered as CH or EP options (Table 3-1) and the correspondent interplanetary trajectories have been computed for all of them.

Table 3-1: characteristics of the considered engines for MSR

		HTAE	T6	NEXT-C	PPS5000	ARM
Engine Type	[-]	Bipropellant	Gridded-Ion	Gridded-Ion	Hall Effect	Hall Effect
Max Thrust	[N]	1100	0.145	0.242	0.31	0.52
Max Isp	[sec]	320	4300	4200	2300	3200
Assumed Isp	[sec]	320	4000	4000	1800-1900	2200-2400
Power at Earth	[kW]	N/A	5	12	5	14
Power at Mars	[kW]	N/A	3	7	4.5	10

3.3. Aero-braking analysis

In order to reduce the amount of ΔV required for the mission, the possibility of using aero-braking in Mars atmosphere to acquire the operational orbit, instead of chemical propulsion, has been explored. A parametric analysis for different values of the ballistic coefficient B has been performed, as it can be seen in Figure 3-3, and more than 1.1 km/s savings in delta-V with respect to a chemical TOA of 1.32 km/s. Additionally the impact of partial aero-braking has been analysed, calculating the DV saving as a function of the amount of time available to perform the TOA manoeuvre.

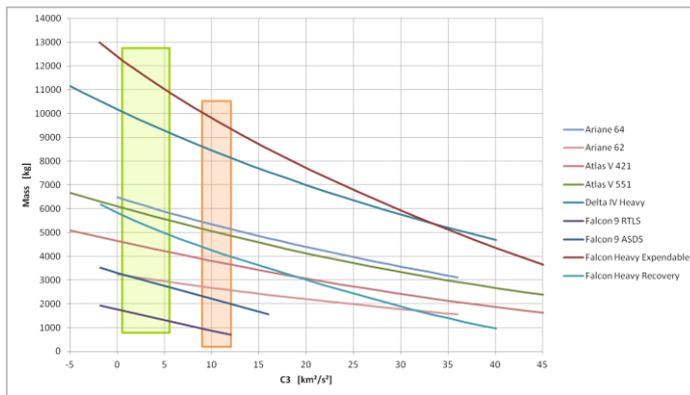


Figure 3-2: Launchers performance summary

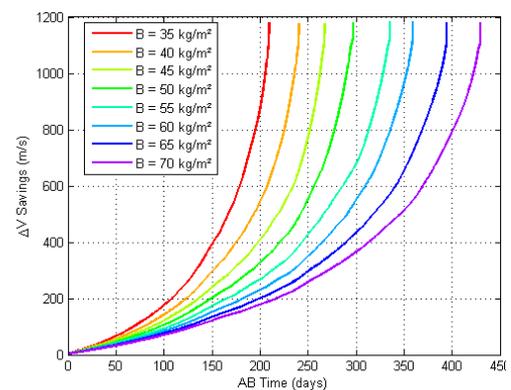


Figure 3-3: Aero-braking parametric analysis

3.4. Mars orbit trade-off

The criteria to trade-off the operational orbit inclination for scenario (d) are summarised in Table 3-2: a polar orbit would offer better performances in terms of Mars high latitudes observation, spacecraft illumination and communications conditions, but it will offer a slower RAAN drift. As a preliminary indication an orbit inclination of 45° is then proposed for concept (d)

Table 3-2: Mars orbit inclination trade-off

Criteria	Low inclination	Mid inclination	High inclination
Arrival and departure declination	-	+	++
RAAN drift	++	-	--
Surface coverage	-	+	++
Revisit frequency	/	/	/
Min. eclipse duration	-	++	++

3.5. Rendezvous operations

A rendezvous analysis has been performed to optimise the mission phase duration and propellant consumption (the resulting trajectory of the final phase can be seen in Figure 3-4). The duration of the optimised approach can be performed in less than 21 days and leads to a reduced DV cost below 40 m/s.

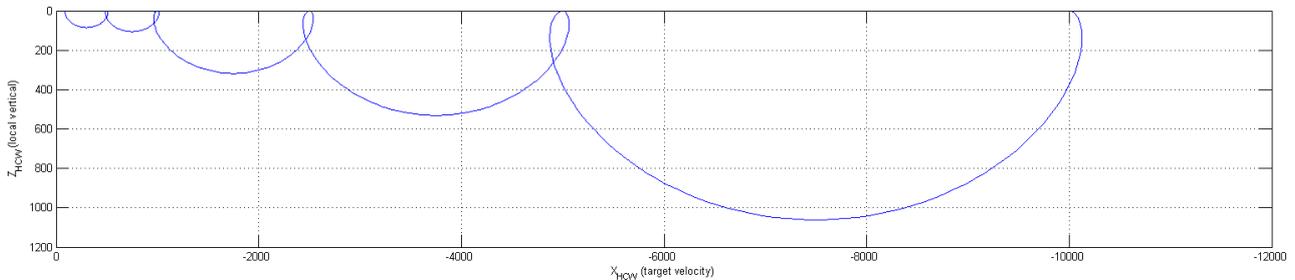


Figure 3-4: Results of the approach analysis from 10 to 0.1 km (plot in m)

3.6. Earth re-entry analysis

Both the Local Entry Corridor (LEC) and EDL performances analyses have been carried out for Utah and Woomera landing sites, considering two possible return scenarios, Chemical and Electric propulsion.

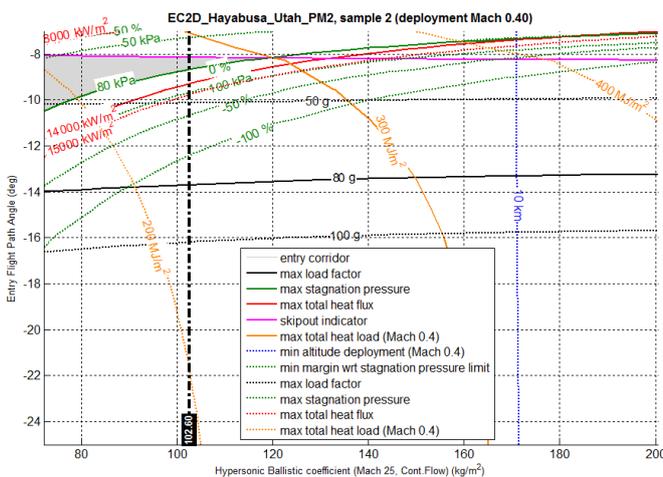


Figure 3-5: 2D LEC plot, Woomera & chemical return scenario

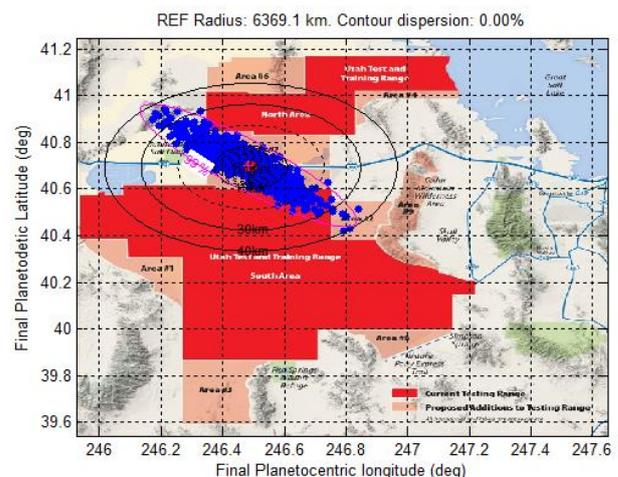


Figure 3-6: Position dispersion at touchdown, chemical return scenario

The main conclusions of the 2D Local Entry Corridor analyses carried out are that Entry Corridor exists in case of Woomera Chemical, Woomera Electric and Utah Electric, but a reduction of the ballistic coefficient or an increase of capsule diameter should be needed for Utah chemical scenario. A 3 DOF Monte Carlo Analysis is carried out for the EDL assessment and the performances in terms of position and velocity dispersion at touchdown are in line with the requirements for all scenarios.

3.7. Propulsion trade-off

One of the most critical aspects of MSRAAS is the selection of the propulsion system that has to consider a full chemical option with our without staging, a full electrical option with our without staging, but also a mixed propulsion system making use of different engines for the different manoeuvres.

The selection of the best solutions is done by an iterative procedure established between Mission Analysis and Spacecraft Design, estimating the feasibility at mass and timeline levels.

4. SPACECRAFT DESIGN

4.1. Payload

Focusing on Option D, which is an ESA only mission, the concept of operations for the payload elements during mission life were identified. Figure 4-1 shows the pre-capture system level configuration of the payload elements. A summary of the payload elements is provided in Table 4-1.

Table 4-1: Summary of Payload Element Mass per Mission Option

Element	MSRAA - ESA Spacecraft Payload Mass			
	A (NeMO)	B	C	D
Mission Option	A (NeMO)	B	C	D
<i>All masses are in kg, and include 30% mass margin (except OS)</i>	w/o Margin	with Margin	with Margin	with Margin
Orbiting Sample (OS)	150	12	12	12
Capture and Sealing System (CSS)		177.8	In NeMO	177.8
Bio-Container (BC)		52	52	52
Transfer Mechanism (TM)			31.2	
Earth Return Capture (ERC)	100	191.43	191.43	191.43
Docking Mechanism (DM)		72	72	
Total	250	506	359	434

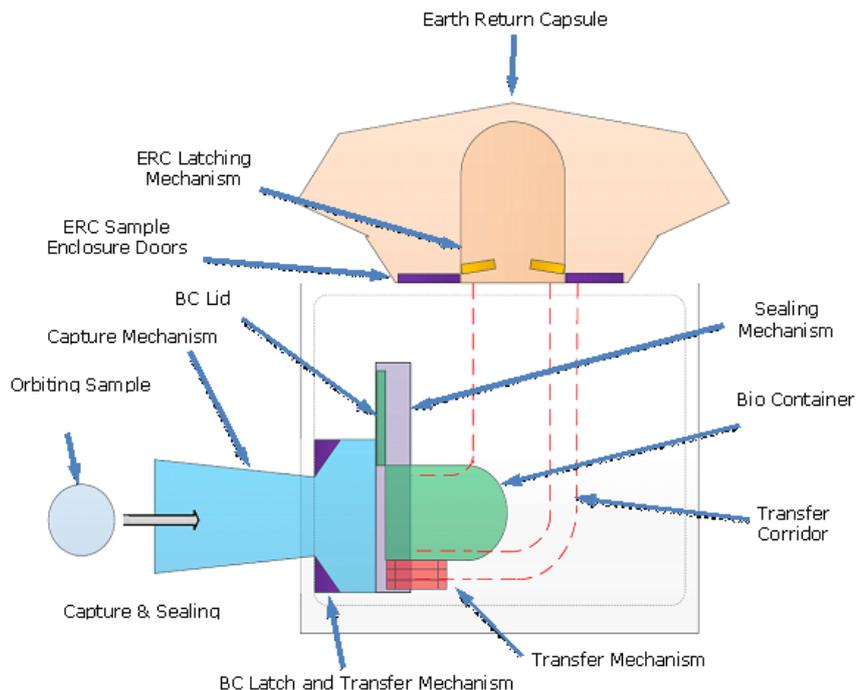


Figure 4-1: System Level Mission Payload Overview (Pre-Capture Configuration, Option D)

4.2. Mass budget analysis

For Concept D of the MSR study Lockheed Martin UK Ampthill Ltd (LMUK Ampthill) have conducted mass budget analysis to assess the feasibility of different proposed spacecraft configurations. LMUK Ampthill have analysed a range of spacecraft configuration options identified by DEIMOS as being feasible from a mission analysis perspective. A full set of results is tabulated in Table 4-2 and colour coded thusly (note that the launcher performances have been approximated, and are commensurate with the tolerances associated with these first-order mass estimates):

- >9000kg
- <9000kg (lifting performance of Delta IV Heavy)
- <5500kg (predicted lifting performance of Ariane 64)
- <5000kg (lifting performance of Atlas 551)

Staging options are considered for MOI, TOA and DOI and are abbreviated with a "Y" or a "N" whether the staging is applied to each manoeuvre or not (i.e. "YYY" is 3 staging, "NNN" is no staging):

Six promising candidates (<5500kg) are identified, where the CSS is ejected:

1. Option 17	Chemical	NYN	4768kg	All Chemical	AB	^ (5306kg)
2. Option 7	ARM	NNY	5066kg	CH EL EL CH	No AB	^ (5307kg)
3. Option 7	ARM	YNY	4923kg	CH EL EL CH	No AB	^ (5134kg)
4. Option 19	2ARM	NNY	5381kg	CH CH EL CH	AB	
5. Option 20	2ARM	NNN	5493kg	CH CH EL EL	AB	
6. Option 20	2ARM	NYN	5136kg	CH CH EL EL	AB	^ (5318kg)

Four of these would remain promising candidates (<5500kg) if the CSS is not ejected, though they will be heavier. Two additional promising candidates are identified with additional SA optimisations:

1. Option 13	NEXT-C	NYN	5074kg	EL EL CH CH	No AB	(after TOA)
2. Option 7	PPS5000	YNY	5462kg	CH EL EL CH	No AB	(after DOA)

LMUK Ampthill has also developed preliminary configurations of the following example options to demonstrate stowage compatibility with the Ariane 64 launch vehicle:

- Option 17 A feasible 2 stage (NYN) all-chemical solution using aerobraking panels.
- Option 20 A feasible 2 stage (NYN) hybrid solution (CH CH EL EL) using a 2ARM engine (i.e. the largest solar array).
- Option 18 A 4 stage (YYY) hybrid solution (CH CH CH EL) using ARM. This is currently over the predicted Ariane 64 launcher requirements but is thought to be one of the tallest stacks due to the high number of chemical stages and has relatively large solar arrays. Consequently, this is shown as an example of a maximum sizing case.

From LMUK Ampthill's analysis, additional important conclusions are as follows:

1. A lightweight (i.e. flexible or semi-flexible) solar array is likely to be a critical technology for any option utilising electric propulsion if an Ariane 64 is the targeted launcher.
2. If future European NGSA technology is assumed, it may be possible to utilise semi-rigid cell technology (as an example, the mass of the promising Option 7 ARM YNY increased by ~500kg to 5455kg using NGSA 2+5 4J33% and therefore remains a promising solution).
3. A preliminary sensitivity analysis showed that for every 1kg increase in CSS mass, total spacecraft mass increased by ~4kg; the precise value will depend on the option chosen.
4. A preliminary sensitivity analysis showed that for every 1kg increase in ERC mass, total spacecraft mass increased by ~7kg; the precise value will depend on the option chosen.

Table 4-2: Nominal mass budget results (with CSS ejection)

Option	1 Stage	2 Stage	3 Stage	4 Stage
1-CH	14355-NNN	8966-YNN		
17-CH	5702-NNN	4768-NYN		
2-T6	15302-NNN	9645-NYN	9416-YYN	
9-T6	14181-NNN	8163-NYN	7886-YYN	
10-T6	9511-NNN	8011-NYN	7734-YYN	
2-ARM	21162-NNN	13137-YNN		
3-ARM	10122-NNN	7889-NYN	7386-YNY	
5-ARM	10550-NNN	7088-NYN		
6-ARM	9195-NNN	7706-NYN	7526-NYY	
7-ARM	5677-NNN	5066-NNY	4923-YNY	
9-ARM	19943-NNN	11649-YNN		
10-ARM	16194-NNN	10332-NYN	9708-YYN	
11-ARM	8491-NNN	6975-NNY	6901-YNY	
13-ARM	8801-NNN	6191-NYN		
14-ARM	7762-NNN	6774-NYN	6678-NYY	
18-ARM	7679-NNN	6554-NYN	6436-YNY	
2-2ARM	26187-NNN	16075-YNN		
3-2ARM	12301-NNN	9514-NYN	8817-YNY	8712-YYY
4-2ARM	10871-NNN	8618-NYN	8403-YYN	
5-2ARM	12871-NNN	8313-NYN	8260-NYY	
6-2ARM	11307-NNN	9400-YNN	9302-NYY	9236-YYY
7-2ARM	6900-NNN	6044-NNY	5861-YNY	
8-2ARM	6292-NNN	5792-YNN		
9-2ARM	34202-NNN	17796-YNN		
10-2ARM	26603-NNN	16432-YNN		
11-2ARM	12273-NNN	9470-NNY	9146-YNY	9039-YYY
12-2ARM	10826-NNN	9433-YNN	8739-YYN	
13-2ARM	12855-NNN	8095-NYN	8044-NYY	
14-2ARM	11270-NNN	9294-NYN	9075-NYY	
15-2ARM	6838-NNN	5835-NNY		
16-2ARM	6059-NNN			
18-2ARM	9381-NNN	7942-NYN	7753-NYY	
20-2ARM	5493-NNN	5136-NYN		
22-2ARM	9326-NNN	8411-NYN	8108-YNY	
2-NEXT-C	18771-NNN	11019-NYN	10702-YYN	
5-NEXT-C	9660-NNN	6767-NYN		
6-NEXT-C	7600-NNN	6770-YNN		
9-NEXT-C	18021-NNN	9364-NYN	8815-YYN	
10-NEXT-C	12775-NNN	9830-NYN	9300-YYN	
13-NEXT-C	7356-NNN	5630-NYN		
14-NEXT-C	5954-NNN			
18-NEXT-C	7512-NNN	6560-NYN		
2-PPS5000	24643-NNN	14499-YNN		
3-PPS5000	11478-NNN	8520-NYN	8021-YNY	7844-YYY
4-PPS5000	10748-NNN	7948-NYN	7748-YYN	
5-PPS5000	12060-NNN	7561-NYN		
6-PPS5000	11253-NNN	8708-NYN	8512-NYY	8458-YYY
7-PPS5000	6783-NNN	5836-NNY	5572-YNY	
8-PPS5000	6456-NNN	5713-YNN		
9-PPS5000	37259-NNN			
10-PPS5000	31784-NNN	19051-YNN		
11-PPS5000	12977-NNN	9524-NNY	8698-YNY	8504-YYY
12-PPS5000	12069-NNN	9190-NYN	8415-YYN	
13-PPS5000	13735-NNN	7830-NYN		
14-PPS5000	12718-NNN	9022-NYN	8759-NYY	
18-PPS5000	8171-NNN	6901-NYN	6705-NYY	
18-T6	6463-NNN	5768-NYN		
21-ARM	9299-NNN	6554-NYN		
22-ARM	9764-NNN	7988-NYN	7793-YNY	7693-YYY
19-2ARM	5980-NNN	5381-NNY		
21-2ARM	10461-NNN	7365-NYN	7179-YNY	
21-NEXT-C	9055-NNN	6534-NYN		
24-2ARM	7801-NNN	7503-YNN	7188-YYN	
22-NEXT-C	7523-NNN	7095-NYN	7043-YNY	
21-PPS5000	12666-NNN	7710-NYN	7464-YNY	
22-PPS5000	12649-NNN	9184-NYN	8732-YNY	

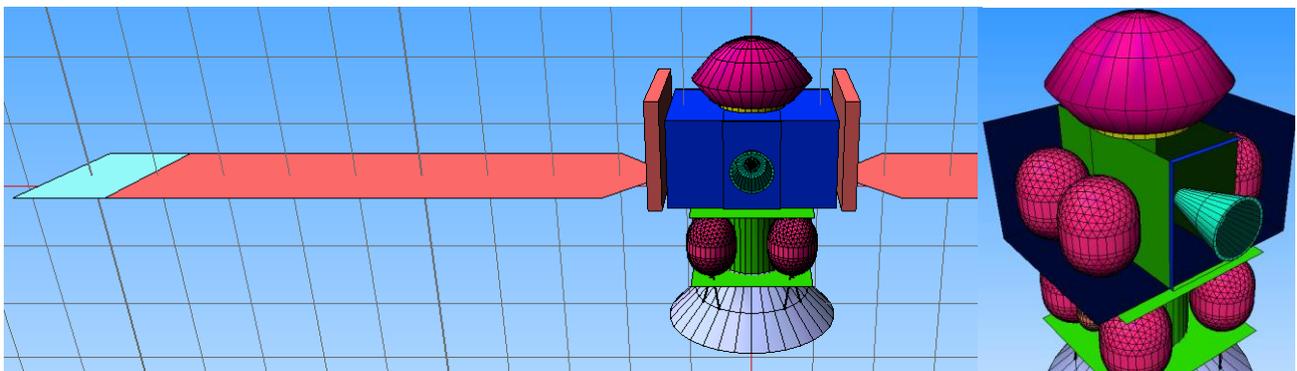


Figure 4-2: Preliminary configuration for Option 17 NYN All-Chemical AB

5. MISSION DEVELOPMENT PLAN

The mission development schedule has been analysed in detail at mission, subsystem and technology level. On the base of this investigation, the following MDP is proposed:

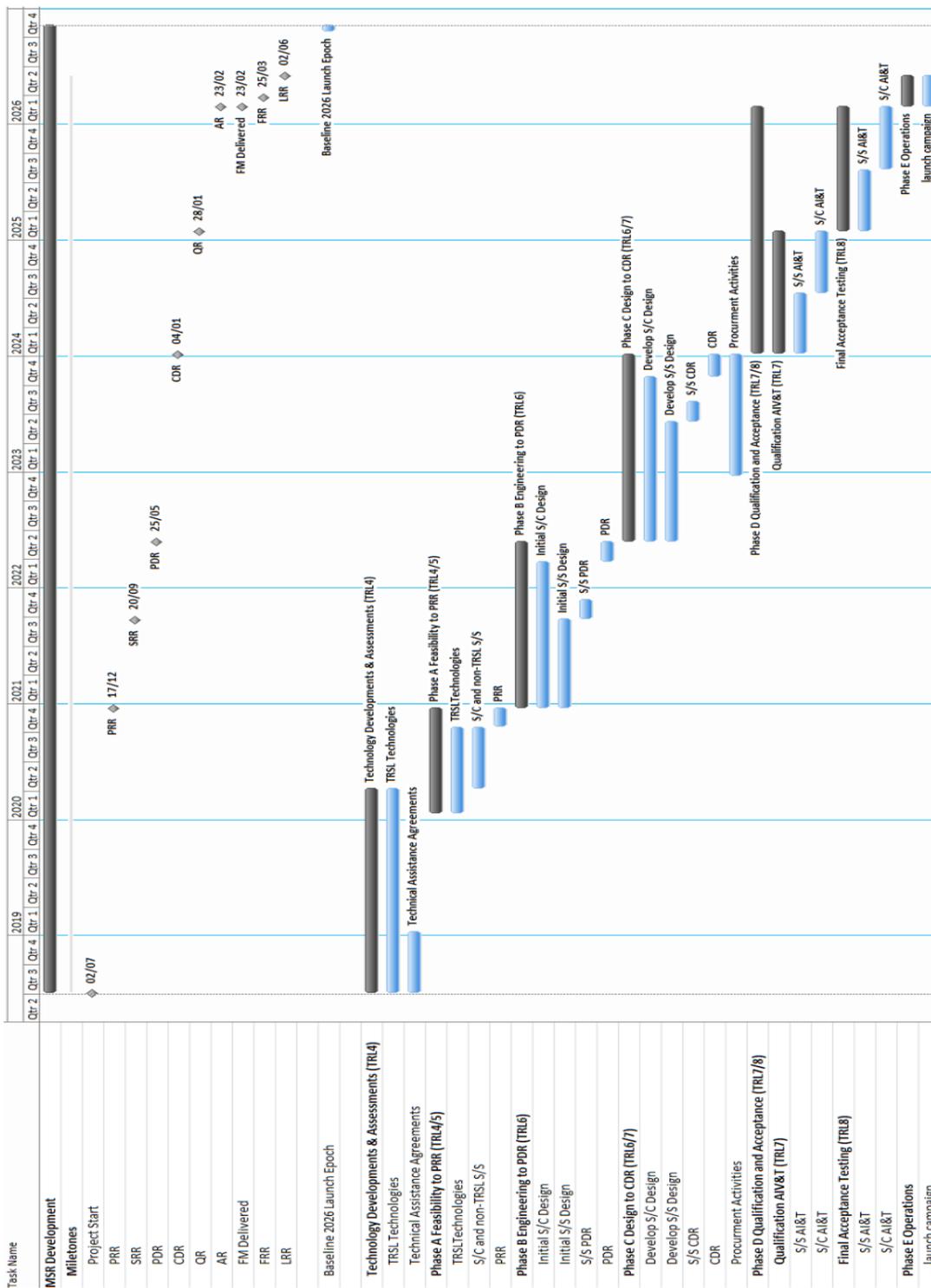


Figure 5-1: Proposed Development Schedule

6. RISK ANALYSIS

For this MSR study a RROA has been conducted to understand the relative risk and opportunity merits associated with selecting different architecture options to achieve the MSR mission. During this assessment, two main categories of major risks/opportunities were considered:

1. Major specific risks and opportunities for the MSRO mission (i.e. not normal satellite risks), which must be highlighted to focus the development of relevant elements as required.
2. Discriminator risks and opportunities between architecture options (i.e. risks whose severity and/or likelihood are dependent on what type of engine is used, whether aero-braking is specified, the level of staging).

The following table summarises both schedule impact and risk/opportunity analysis for the most promising mission options emerged for the timelines and mass budget calculations.

Table 6-1: Summary of promising architecture options

Architecture Option	Wet Mass, kg	Nominal Schedule Impact, months	Nominal Total Risk and Opportunity Value
Option 17 - HTAE - NYN All Chemical - AB - CSS Eject	4768	0	55
Option 17 - HTAE - NYN All Chemical - AB - CSS Retain	5306	0	51
Option 7 - ARM - NNY CH EL EL CH - No AB - CSS Eject	5066	2	88
Option 7 - ARM - NNY CH EL EL CH - No AB - CSS Retain	5307	2	84
Option 7 - ARM - YNY CH EL EL CH - No AB - CSS Eject	4923	2	88
Option 7 - ARM - YNY CH EL EL CH - No AB - CSS Retain	5134	2	83
Option 19 - 2ARM - NNY CH CH EL CH - AB - CSS Eject	5381	5	104
Option 20 - 2ARM - NNN CH CH EL CH - AB - CSS Eject	5493	5	105
Option 20 - 2ARM - NYN CH CH EL EL - AB - CSS Eject	5136	5	103
Option 20 - 2ARM - NYN CH CH EL EL - AB - CSS Retain	5318	5	99
Option 13 - NEXT-C - NYN EL EL CH CH - No AB CSS and SA Eject	5074	5	87
Option 7 - PPS5000 - YNY CH EL EL CH - No AB CSS and SA Eject	5462	2	89

7. SOLUTIONS AND CONCLUSIONS

7.1. CONCEPT (d) solutions

In concept (d) the spacecraft is leaving Earth, arriving to Mars, performing the Orbit Sample capture and bringing it back to Earth. The feasible options emerging from mass budget analysis (§ 4.2) are summarised in Table 7-1:

Table 7-1: feasible mission options after mass budget analysis

		SOL1 Option 17	SOL 2 Option 7	SOL 3 Option 19	SOL 4 Option 20	SOL 5 Option 13	SOL 6 Option 7	
EL ENGINE		/	ARM	2xARM	2xARM	Next-C	PPS5000	
STAGING		NYN	YNY	NNY	NYN	NYN	YNY	
WET MASS [kg]		4768	4923	5381	5136	5074	5462	
LAUNCH		Date 01/11/2026	01/11/2026	01/11/2026	01/11/2026	NA	01/11/2026	
outbound	MOI	Prop	CH	CH	CH	CH	CH	
		Date	03/09/2027	03/09/2027	03/09/2027	03/09/2027		03/09/2027
	TOA	Prop	AB	AB	AB	AB	EL	AB
		Date	06/08/2028	08/05/2028	12/03/2028	21/04/2028		11/06/2028
inbound	DOA	Prop	CH	EL	EL	EL	CH	
		Date	06/09/2028	12/02/2028	12/04/2028	22/05/2028		23/01/2028
	TEI	Prop	CH	CH	CH	EL	CH	CH
		Date	11/09/2028	11/09/2028	11/09/2028	03/10/2028		11/09/2028
ARRIVAL		Date 03/06/2029	03/06/2029	03/06/2029	22/07/2029		03/06/2029	
LATEST RdV		Date 05/09/2028	NA	11/04/2028	21/05/2028		NA	
LATEST MAV		Date 05/08/2028	NA	11/03/2028	20/04/2028		NA	

Nevertheless solutions 2, 5 and 6 are not feasible at timelines level: 1-ARM, NEXT-C and PPS5000 engines are not enough powerful to accommodate the transfers within the mission time constraints. In the first two cases the use of 1-ARM or NEXT-C cannot push about 5000 kg to Mars in less than one year, while, in the third case, the PPS5000 is not able to accommodate the spiralling in and out durations to fulfil the mission time constraints.

The three feasible options both at mass budget and timeline level are:

1. Option 17, full chemical mission with aero-braking
2. Option 19 (CH-AB-EL-CH) with 2 ARM engines
3. Option 20 (CH-AB-EL-EL) with 2 ARM engines

7.2. Conclusions

During the course of the study a significant effort has been dedicated to the explorations of a very high number of configuration architectures for scenario (d), which definition became the main focus of the activity. Several hundreds of options have been analysed with a high level of detail both at mission analysis and mass budget level, to properly identify robust and feasible solutions.

The three of them make use of both staging and aero-braking to reduce the spacecraft wet mass, and they all rely either on chemical propulsion or on a mixed system combining a chemical engine with 2 very powerful electrical thrusters (ARM engines). This result is the consequence of the tight timelines imposed on the mission which do not leave any room to less powerful and more efficient electrical propulsion systems. To accommodate such demanding plan, the mission design is forced to assume certain risk like the ones associated with staging and aero-braking techniques.

The three options are then qualitatively compared with respect to four figures of merit in Figure 7-1:

1. Wet mass
2. Timeline risk, intended as possible overlap with solar conjunctions.
3. Schedule delays
4. Overall risk

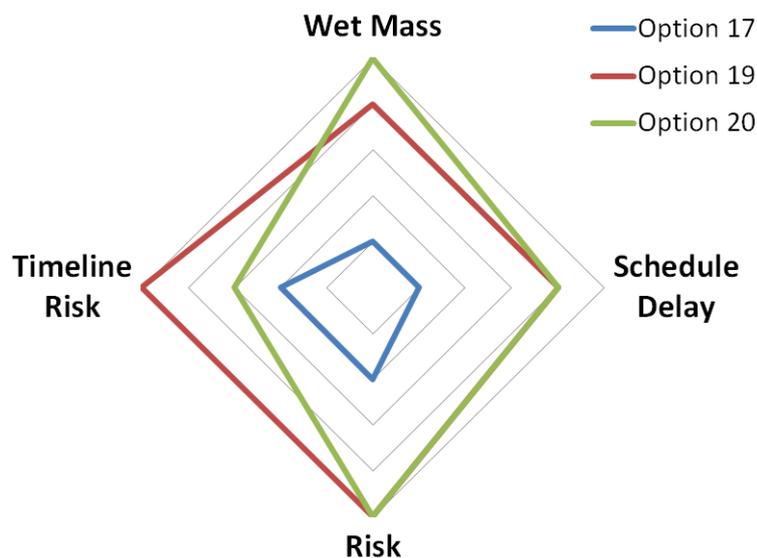


Figure 7-1: comparison of the three feasible solutions for scenario (d)

The outcome of this study shall be considered as a preliminary architecture assessment result to be further refined through a detailed phase-A study for Mars Sample return mission.