AIRBUS

SMALL MISSION TO MARS – ARCHITECTURAL STUDY

Executive Summary | Ref.:SMIMARS-ADSM-RP-1000988283

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OBJECTIVES OF THE STUDY

A Concurrent Design Facility (CDF) study was completed by the European Space Agency (ESA) Human and Robotic Exploration (HRE) Directorate's Exploration Preparation, Research and Technology (ExPeRT) team by April 2020 with the aim of investigating potential small mission architectures that would further ESA Exploration objectives at Mars post-MSR (in the 2030's) or potentially in parallel with MSR (if sufficiently low cost). During the CDF study, three candidate mission architectures were analysed against the following programmatic constraints:

- €125M industrial cost at completion (economic conditions 2022)
- Phase B2 kick-off in either Q2 2023 or Q2 2026
- Phase B2/C/D in ~4 years
- Launch between end 2027 and 2032.

This CDF study was executed by accepting as main mission drivers cost and schedule, and the same priorities have been adopted for the subsequent industrial study. Neither mass, performance nor science return are meant to be programme drivers but, instead, by analysing what can be achieved for a certain cost when there are no initial performance requirements placed on the subsystems. Additionally, a low risk approach on the S/C bus was deemed necessary and therefore the technical baseline had to consider available equipment with high heritage, or at least has a robust development plan through an existing programme such as the Mars Sample Return mission. Although a third mission case for a Mars Hard Lander/Penetrator, was also analysed, it was not included as part of the scope of the subsequent study released for the industry.

In the scope of the Statement of Work released by ESA for this architectural study, the following objectives were requested to be satisfied for this small mission to Mars:

- Critical review of CDF mission architectures and selection of candidate mission architecture.
- Define the technical approach for the platform and equipment provision using a strict design to cost approach including, for example, use of COTS components and redundancy approach
- Describe reuse of company heritage (from equipment to complete platform(s))
- Identify critical technology developments and delta qualifications
- Analyse performance of key subsystems.
- Provide programmatic planning and assumptions on key interfaces
- Identify potential ECSS tailoring that would allow significant simplifications/cost reductions.

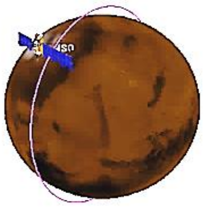
MISSION ARCHITECTURE & TRADE-OFF ANALYSIS

The main drivers for the architectural study that Airbus has undergone along the past 5 months have been:

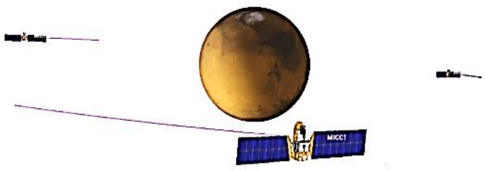
Primary Objectives				
Cost < 125M€ for industrial contribution	*Phase B/C/D Schedule < 4 years*	*Maximize heritage*	*Minimize risk*	*Meet requirements within MRD*

As from requirements, two different mission cases are studied in order to first check feasibility to cope with the cost driver requirement:

Mars Science Orbiter mission, MSO: Single satellite mission, whose main objective is to participate to the characterization of Human landing sites, by means of Mars Observation instruments. The selected orbit is low altitude (~300km). Secondary objective is data relay between Mars surface units and Earth.



Mars Communications Constellation, MCC: Constellation mission made of 3 satellites. Possible orbits are Areostationary or Trans-areostationary. Its main objective is data relay from Mars surface units to Earth. Science is a secondary objective, thus allocation for a small payload is requested.

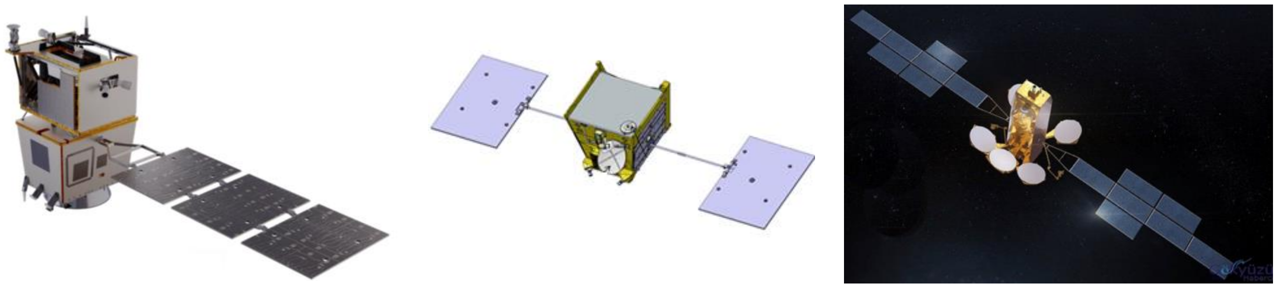


With these two main mission cases in mind, the set of mission architectures analysed along the first month of the study is summarized in the table below:

Definition of Mission Architectures						
ID	**Mission configuration**	**Initial Orbit**	**Target Orbit**	**C3(km^2/s^2)**	**Product Line**	**Propulsion**
MSO-BP1	Science Orbiter	Parabolic / Direct injection	LMO	0	Astrobus Neo	Chemical
MSO-BP2	Science Orbiter	Hyperbolic / Direct injection	LMO	10	Astrobus Neo	Chemical
MSO-EP1	Science Orbiter	Parabolic / Direct injection	LMO	0	Eurostar Neo	Electrical
MSO-EP2	Science Orbiter	GTO	LMO	N/A	Eurostar Neo	Electrical
MCC-EP1	Comms Constellation, 3 identical S/C	GTO	ASO / TASO	N/A	Astrobus SE	Electrical
MCC-EP2	Comms Constellation, mothership + 2 small S/C	GTO	ASO / TASO	N/A	Eurostar Neo + Astrobus SE	Electrical

The following Airbus product lines were analysed along the first task of this project in order to find the most compatible solution in line with the priorities highlighted before; for this design to cost exercise, an ad-hoc platform is rejected from the beginning and the study relayed on product lines that could provide a) complete S/C designs, b) known HW prices based on Long Term Agreements and c) smooth and controlled product evolutions:

- ***Astrobus Neo:*** This platform is the evolution of AS250 (Sentinel 2, Sentinel 5P, SEOSAT/Ingenio) whose first instances are being developed for the High Priority Copernicus Missions LSTM and CRISTAL.
- ***Astrobus SE:*** Small platform fully electrical for LEO missions, evolution from OneWeb. Its first operational mission will be CO3D for CNES
- ***Eurostar Neo:*** Platform designed fundamentally to telecommunications and navigation satellites, evolution from Eurostar 3000 into a more compact and fully electrical solution.



From left to right: LSTM (Astrobus Neo), Arrow (Astrobus SE) & BADR-8 (Eurostar Neo)

A preliminary mission analysis delta V for different alternatives was performed; the results obtained within this first study phase in relation to initial orbit injection and transfer options are summarized in the table below:

Summary of initial orbit injection and transfer options					
Propulsion	**Injection**	**Target**	**ΔV (m/s)**	**duration (y)**	**Comments**
Chemical	C3 = 10 km²/s²	LMO	1300	<2	
	C3 = 7 km²/s²		1800	<2	
	C3 = 0 km²/s²		2300	<2	
	GTO		3100	<2	
	LEO		5300	<2	
Electric	C3 = 10 km²/s²	LMO	6100	1,2	assuming 0,27N and 1200 kg initial mass (*) Figure computed at MAR; at FR the computed transfer time is 3.1 years to LMO h=300km
	C3 = 0 km²/s²		9000	1,6	
	GTO		12700	2,1 (*)	
Chemical	C3 = 10 km²/s²	TASO	2200	<1	
	GTO		4000	<1	
Electric	C3 = 10 km²/s²	TASO	4000	<1	assuming 0,27N and 1200 kg initial mass
	C3 = 0 km²/s²		7000	1,3	
	GTO		10700	1,8	

All mission architectures, based on their respective product lines and for which a preliminary high level architecture was drafted for power, propulsion, avionics and communications were analyzed from several points of view in order to propose one single mission candidate based on the data available before the Mission Architectural Review (MAR). The following aspects were considered:

- ***Cost***: Being cost a key requirement, it is understood that mission architectures with lower industrial cost are preferred w.r.t. others with higher industrial cost.
- ***Schedule***: Similarly as for the previous bullet, the limitation of phases B/C/D to 4 years is assumed as the second key requirement, in line with a fast track space mission..

- ***Mass Margin***: Being mass a critical parameter that drives the whole mission feasibility, the rate between estimated wet mass w.r.t. maximum allowed wet mass for a specific launch configuration has been also assessed, particularly aiming at a dual launch.
- ***Value/Versatility***: Higher mission value is to be assigned for options with higher provision of bus resources (other from mass) for the communications and science payloads (power, downlink data rate…), as well as configurations which provide higher versatility such as using a P/F which could be used for different mission cases.
- ***Transfer Time:*** Maximum allowed transfer time is set to 3 years; shorter transfer times are preferred.
- ***Technical risks:*** Such as not yet qualified equipment, or qualified equipment without flight opportunity so far (and therefore with no information on its behaviour in orbit), % of changes w.r.t. reference platform architecture, risk for obsolescence or higher degree of complexity/amount of in-orbit operations.
- ***Other Programmatic constraints:*** Such as constraining procurement dates (which may impose specific mission schedules in order to be aligned with other ongoing developments), availability w.r.t. stockpiled unit/component batches, need for non-European equipment, expected concurrent workload w.r.t. other ongoing programs, etc.
- ***Operations costs:*** To increase with transfer duration.

From a design to cost point of view, a first trade-off was performed on the two main criteria, i.e. cost and schedule. The following table summarizes the analysis performed for the set of 6 mission configurations:

<table>
<tr><th></th><th>MSO-BP1
(C3=0)</th><th>MSO-BP2
(C3=10)</th><th>MSO-EP 1&2
(2 mission options)</th><th>MCC-EP1
(3 S/C)</th><th>MCC-EP2
(1 M/C + 2 S/C)</th></tr>
<tr><td rowspan="3">Cost</td><td colspan="3">Similar costs. Differences lower than uncertainties at this stage.</td><td colspan="2" rowspan="2">Significant higher cost than MSO.
Attractive prices from low cost P/F no longer valid as reference design would suffer from many changes.
MCC-EP1: 1 PFM (high NREC) + 2 FM > any MSO candidate
MCC-EP2: 2 PFM (small S/C high NREC, big Prop S/S) + 1 FM >> any MSO candidate</td></tr>
<tr><td colspan="2">New product line, two programmes ongoing (LSTM & CRISTAL).
Further opportunities are expected as Airbus shall base new ESA missions on this P/F.</td><td>EP subsystem benefits from telecom prices + other foreseen programmes based on Eurostar Neo.</td></tr>
<tr><td colspan="5">All P/Fs based on product lines. Streamlined procurement , good price references.
Opportunities to get FM prices if aligned with other programmes.</td></tr>
<tr><td rowspan="3">Schedule</td><td colspan="5">Experience in fast track missions (MEX, VEX, CHEOPS)</td></tr>
<tr><td colspan="3" rowspan="2">Several ongoing and near-future programmes based on both reference P/Fs in different countries.
Opportunities for early acquisition of some equipment.
Several teams in Airbus with deep knowledge on both P/Fs.</td><td colspan="2">Significant changes for small S/C w.r.t. ref P/F entail higher systems engineering work, subsystems engineering and PA.</td></tr>
<tr><td></td><td>Two very different S/C developments.</td></tr>
</table>

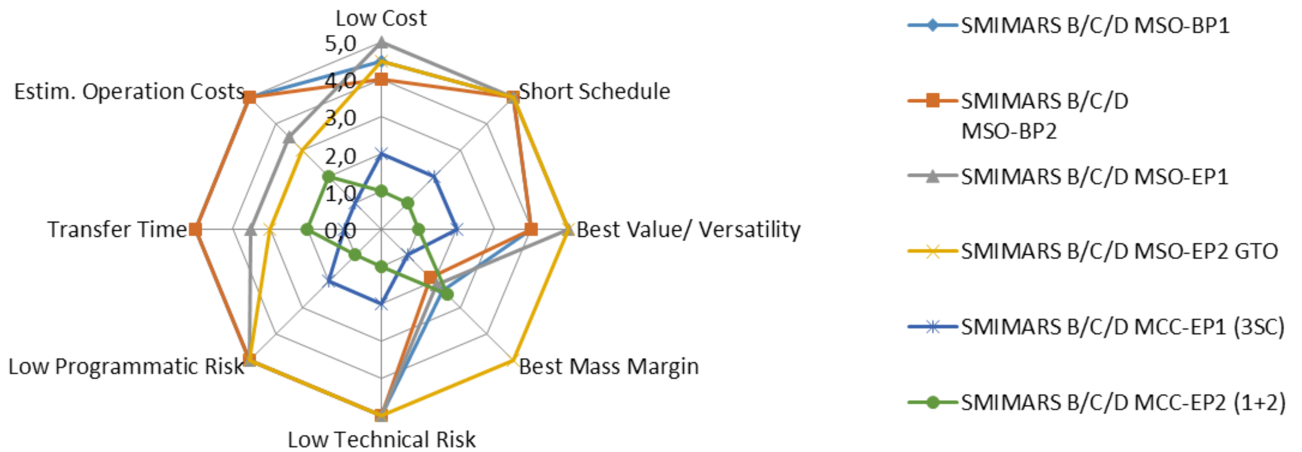
With all the considerations above, the communications constellation mission to Mars didn't seem feasible within current perimeter of programmatic requirements.

A detailed comparison is performed among the 4 MSO configurations, summarized here below; mission architectures have been ranked from 5 to 1, being 5 the best option for a specific criterion and being 1 the worst:

	MSO-BP1 (C3=0)	MSO-BP2 (C3=10)	MSO-EP1 (C3=0)	MSO-EP2 (GTO)
Wet Mass margin	single launch	single launch	single launch	feasible dual launch
Transfer time	< 1 year	< 1 year	~1,5 years	~ 3 years
P/F Versatility	Specific CP S/S design => impact on structure and thermal ctrl.	Specific CP S/S design => impact on structure and thermal ctrl.	Same P/F may fit into two different mission configurations (at the expense of redundancy)	Specific EP S/S based on product line design => impact on structure and thermal ctrl.
Comms, data rate	Common comms S/S. constrained by industrial cost and mass budget.			Higher mass margin, only constrained by cost.
Operations costs	Assumed as optimal for the project		Higher than CP, less than 50% transfer time w.r.t nominal mission lifetime	Highest among all MSO
Technical risks	Solid heritage on CP-based interplanetary missions.		Partial heritage on EP for interplanetary missions, based on Eurostar Neo EP and manoeuvre adaptation from BepiColombo/MSR-ERO	
	P/F based on product line. No new developments expected, only S/S adaptations.			Change in number of EP thrusters
Programmatic risks	AstroBus Neo is reference P/F for ESA missions, further opportunities expected to align procurement plans		Eurostar Neo is reference P/F for telecom and navigation missions, further opportunities expected to align procurement plans	

Mission Case	Low Cost	Short Schedule	Best Value/ Versatility	Best Mass Margin	Low Technical Risk	Low Prog. Risk	Transfer Time	Estim. Operation Costs
MSO-BP1	4,5	5,0	4,0	2,3	5,0	5,0	5,0	5,0
MSO-BP2	4,0	5,0	4,0	1,9	5,0	5,0	5,0	5,0
MSO-EP1	5,0	5,0	5,0	2,1	5,0	5,0	3,5	3,5
MSO-EP2 (GTO)	4,5	5,0	5,0	5,0	5,0	5,0	3,0	3,0
MCC-EP1 (3SC)	2,0	2,0	2,0	1,0	2,0	2,0	1,0	1,0
MCC-EP2 (1+2)	1,0	1,0	1,0	2,5	1,0	1,0	2,0	2,0

The spider web plot below provides information regarding the selection of the mission case; a better candidate is understood to inscribe a regular pentagon with higher area:



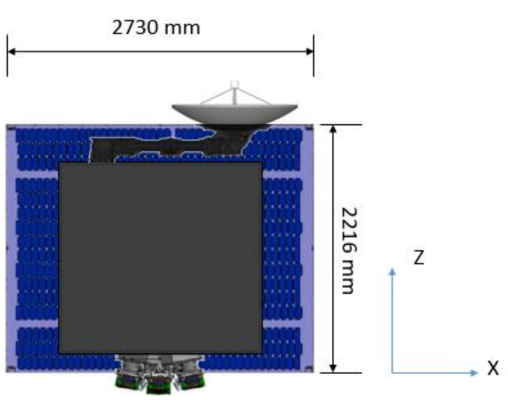
After this exercise, all MSO mission architectures seemed feasible according to the main parameters used for the analysis, using either chemical or electrical propulsion. Given Airbus background in missions to Mars using a chemical propulsion system (all of them feasible so far within current framework in case of a dedicated launch) and in GEO/MEO missions based on platforms with electrical propulsion systems, a Mars Science Orbiter with an electrical propulsion system (MSO-EP2) was selected. Although it was not the one corresponding to the strict minimum cost (as it would correspond to MSO-EP1, an EP based platform released on an orbit for direct transfer to Mars), this solution aimed at a rideshare from GTO, thus allowing for potential minimization of the overall mission costs by aiming at higher launch opportunities.

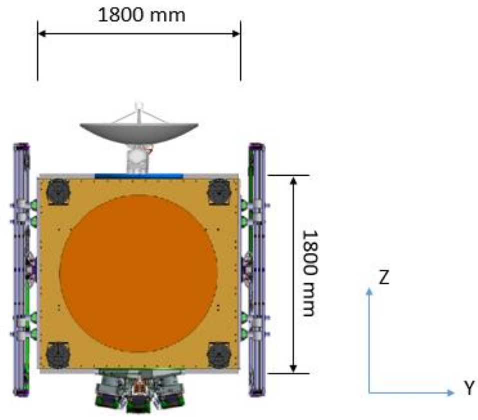
After the full technical assessment, MSO-EP2 consists of a S/C based on Eurostar Neo product line released in GTO, with a remaining available mass for a potential co-passenger of about 1 Tn and a transfer time of 3.1 years for a final LMO with height = 300 km.

SPACECRAFT ARCHITECTURE

The Electrical platform hardware and software selected for SMIMARS is based on a specific reference programme (from now on REF. PROGRAMME) belonging to Eurostar-3000 and Eurostar-Neo product lines, both platform products supporting powerful payloads and featuring a hierarchical FDIR that guarantees maximum mission availability. The selection of REF. PROGRAMME as baseline is due to a higher adequacy in terms of solar array wings and newest development of SW lower layers to cope for PUS-C services. Another advantage of REF. PROGRAMME with respect to Eurostar family is the development of Thruster Pointing Mechanisms compatible with PPS5000 thrusters and high depointing angles. It must be noted that the core of electrical system CMDU and PSR are common for both REF. PROGRAMME and Eurostar family. Three E3000 satellites have demonstrated the ability to successfully manage electrical orbit raising and on-station mode with an electrical propulsion system based on SPT140D, besides PPS5000 is ready to be flown on an Airbus telecom platform by 2022.

The re-use of E-Neo hardware and software ensures a mature design, a safe and secured schedule for SMIMARS development and simple operations. The platform is managed by Airbus as a product line as for Eurostar for which Airbus takes long term maintenance commitment. The adequacy of the Eurostar units with the SMIMARS environment (mainly mechanical, thermal and radiation) is very high as the A62 launcher is already baselined for REF. PROGRAMME and the radiation is similar or better for SMIMARS mission profile (REF. PROGRAMME is in a MEO orbit having to raise the perigee through the Van Allen belts) while the mission duration for E-Neo or REF. PROGRAMME is much higher than for SMIMARS.





The Electrical Platform is based on telecoms heritage from E3000 and Eurostar-Neo (E-Neo) for the Data Handling, Power, Propulsion, and AOCS subsystems.

The communications subsystem is mission specific and SMIMARS shall provide two communications links:

- **Earth – Spacecraft communications**: Uplink (command), downlink (telemetry), and navigation (two-way Doppler, turnaround ranging, differential one-way ranging and regenerative PN ranging) with the 35m ESA Ground Deep Space Network (DSN).
- **Spacecraft – Mars surface communications**: UHF data relay (forward-link relay services and return-link services back) and navigation support services to Mars surface vehicles.

An optimized design has been performed as direct reuse of MSR-ERO communications subsystem did not fit into the cost perimeter. The following elements were included:

X-Band communications units for SMIMARS	
X-Band Transponder	TAS-I IDST (TRL 7 in 2022)
X-Band TWTA	Re-use from ERO
X-Band HGA assembly	Partial re-use from SOLO or down-scale of LAGRANGE HGA
X-Band LGAs	Re-use from ERO
X-Band RF distribution system	Built ad-hoc with off-the-self elements.

UHF communications units for SMIMARS	
UHF Transceiver	From ESA activity "European Orbiter Proximity-1 UHF Transceiver for Mars scenarios" or, alternatively, Electra Radio from NASA
UHF antenna	Re-use from ERO

The following table contains the information on Electrical Platform equipment and its heritage from reuse of Airbus satellites/projects:

S/S	Unit	Current TRL	Delta Dev for SMIMARS (w.r.t. REF. PROGRAMME)	Heritage	TRL @end 2025
PPS	PPS®5000U	8	No change	Propulsion S/S design adapted for SMIMARS (missionization, piping etc) from E-Neo, with all units from REF. PROGRAMME but Xe tank, inherited from MSR-ERO.	
	PPU NG	8	No change		8
	Xenon Flow Regulator	7	No change. Flight-proven valves (TRL9).		7
	High Pressure Transducer	8	No change (US)		8
	Low Pressure Transducer	8	No change (US)		8
	Xenon Storage Tank	6/7	No change		8/9
	Thruster Pointing Mechanism	6	Dev. within reference programme, no change. Flight-proven actuators (TRL9).		9
	Cold Gas Thruster	7	Dev. within reference programme, no change.		9
	Fill & Drain Valves	9	No change		9
	Latch Valve	9	No change.		9
	Pipework	9	Eurostar 3000/NEO. Customization performed for SMIMARS		9

EPS	Power unit	8	Main power bus 100V + 2 secondary buses at 50V & 28V	PSR from E-Neo	8
	Solar Array	9	No change.	REC from REF. PROGRAMME	9
	Battery	7	Adaptation w.r.t. ref. programme, downsizing	Missionization of E-Neo battery (1S14P) w.r.t the one performed for REF. PROGRAMME (different configuration)	7
	SADM	8	Dev. within reference programme, no change.	REC from REF. PROGRAMME	9
DHS	Central Computer	8	PUS-C dev. within reference programme; missionization.	REC from REF. PROGRAMME	8
AOCS	GYRO	9	No change (higher mass than strictly needed)	Same HW as REF. PROGRAMME after removal of MTQ and GNSS. AOCS algorithms are mission specific	**9**
	RW	9	No change (higher mass than strictly needed)		9
	CSS	9	No change		9
	STR	9	No change		9
Comms	X-band TRSP	6 in 2022	IDST, ESA Program GSTPv6 “Integrated Deep-Space & Radio-Science Transponder”	Mission specific, no reuse from REF. PROGRAMME. Partial reuse of units from MSR-ERO. New architecture.	6/7 (TBC)
	X-band TWTA	9	From MSR-ERO		9
	UHF Transponder	2	From ESA project “European Orbiter Proximity-1 UHF Transceiver for Mars scenarios”		7 (TBC)
	UHF USO	9 (US)	TBD if other solutions will be available		9
	UHF antenna	6	Based on MSR-ERO		>=7
	HGA	7	High level of recurrency, based on Lagrange TBC		7
	HGA APMA	7	High level of recurrency, based on Lagrange TBC		7
Harness	Harness	7	Flight proven components & materials	Mission specific design	7
Thermal	Heat Pipes (TBC)	9 (TBC)	Flight proven components & materials	Mission specific design	9(TBC)
	MLI	9	Flight proven components & materials		9
Mechanical	Structure	7	Flight proven components & materials	Mission specific design	7

Main engineering performances are summarized below:

- ***Delta-V budget*** 12725m/s, propellant budget (10% margin) 1440kg and 1575kg considering 35 and 120kg for payload
- **Pointing performances**: Simulations performed considering equipment accuracy for STRs (Hydra) and gyroscope (Astrix 1090)
  APE [15-30 urad], AKE ~10urad, RPE~25urad, RPE [1-25urad], RKE <4urad
- ***Mass budget results:***
  Total Dry mass 1007kg and 1105kg considering either 35 or 120kg for payload
  Wet mass of 2540kg and 2709kg considering either 35 or 120kg for payload
- ***Power and energy budget***
  Power consumption 6360W EOR and 3900W EOL
  Power available [8770W-9720W] @EOR; [4270W – 4500W] @EOL for temperatures [95ºC-57ºC] @EOR and [45ºC-28ºC] @EOL.
- ***Link budget***
  Low rate (LGA) at Mars -> 7.8bps U/L and 10bps D/L
  High rate (HGA) at Mars -> 4kbps U/L and 100kbps D/L @1.1UA; 4kbps U/L and 15kbps D/L @2.7UA;

PROGRAMMATIC APPROACH

The management approach is to be designed with specific focus on cost and schedule perimeters, thus aiming at prioritizing costing and schedule boundaries. Besides a careful project planning and schedule control during the project execution, the following features are to be implemented to secure the successful project end within a specific cost perimeter:

- *Use of existing platform product lines for schedule confirmation and efficiency*
- *A high level of platform recurrence; focus on high TRL with low (delta-) development risk*
- *Programmatic optimization based on ongoing projects*, particularly on REF. PROGRAMME.
- *Advanced development on critical areas along phases A and B*

The engineering approach envisaged for SMIMARS is based on the following pillars:

- *Maximum reuse of avionics and other equipment within the product line,* in spite of other considerations such as mass, performances… to follow a design to cost approach.
- *Systems engineering competences shared among Airbus DS in Spain and France* to profit from experience in fast track and exploration missions respectively.
- *Electrical Platform engineering will reuse REF. PROGRAMME programmatic schema* and therefore will be led by Airbus DS SAS, as well as propulsion S/S engineering.
- *Communications and Payload I/Fs will be centralised in Airbus DS Spain*, as well as the development of mission specific Flight Operations Procedures.
- Centralised AIT in Airbus DS SAU at system level, in parallel with evolved versions of functional disciplines such as CSW and SRDB.

The main changes needed for SMIMARS w.r.t. its reference programme and product line are:

a) **PPS design and xenon tank**: PPS design comes from E-Neo and all units are REC from REF. PROGRAMME with the sole exception of Xenon tank, REC from MSR-ERO. However, specific adaptations of design are needed for SMIMARS mission and P/F configuration => to be done along phase A. No need for earlier procurement.

b) **Battery**: This unit is the same as REF. PROGRAMME with a different battery capacity; preliminary selected is 1S14P (to minimize mass without jeopardize qualification). No specific impact in schedule.

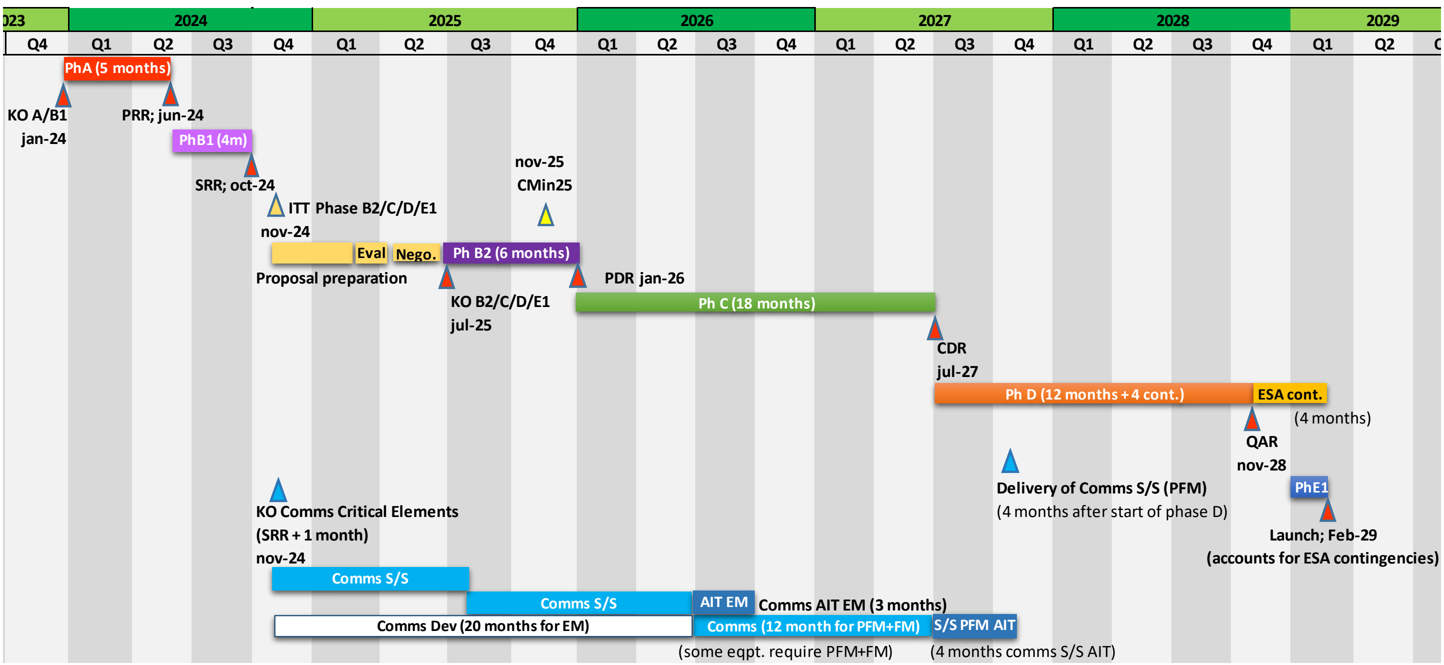
c) **AOCS**: The removal of MTQs and GNSS receiver requires changes in AOCS algorithms and SW, to be considered as part of the overall changes in AOCS modes and algorithms. To be addressed in phase A.

d) **Payload implementation**: Mission specific. One payload is assumed as baseline. Accommodation to be performed from phase A.

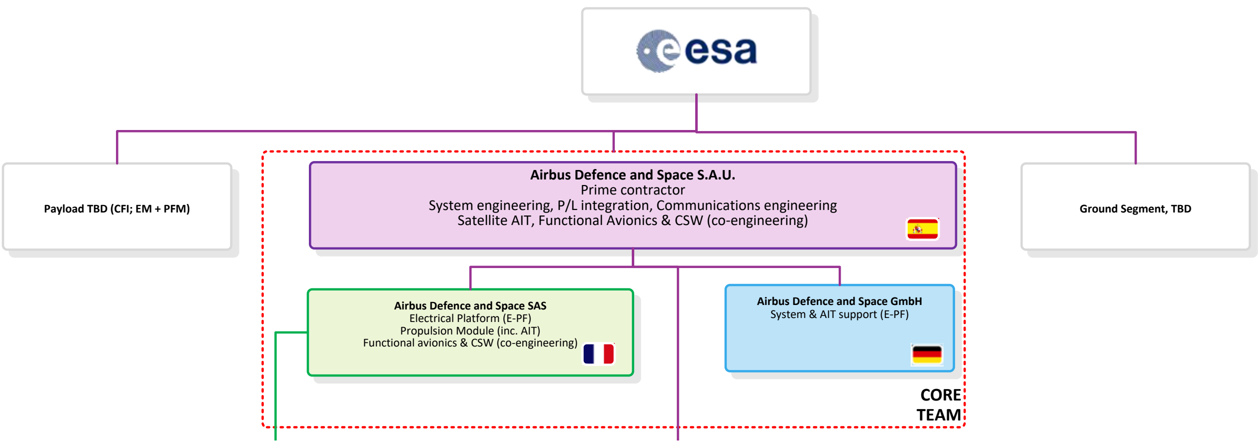
e) **Communications S/S**: Mission specific and new developments included, particularly IDST from GSTPv6 "Integrated Deep-Space & Radio-Science Transponder" (TRL 6 by 2022) and UHF TRCV from "European Orbiter Proximity-1 UHF Transceiver for Mars scenarios" (TRL 5 by end 2023). To be addressed in phase A as this S/S is in the critical path.

f) **Structure, thermal control & harness**: Mission specific design, work initiated in phase A (mainly thermomechanical) and B (detailed thermomechanical + harness)

The following schedule has been designed for current programme:



And the figure below summarizes the core team for the industrial consortium:



The mission architecture selected for this study on a small mission to Mars aimed at the ambitious objective of meeting all the defined requirements for a science orbiter while keeping cost boundary. Additionally, it aimed at analysing the feasibility of rideshare to GTO, thus providing higher flexibility to ESA to find a launch companion for which SMIMARS would play a secondary role as co-passenger. While not all requirements could eventually be fully met, the resulting mission architecture offers some interesting features such as release from GTO and low development risk.

Fast track missions require optimized procedures for management, configuration control and PA; equipment with flight heritage should undergo a light EQSR process; milestones must be handled on a very executive manner and that includes the design of the travel plan. Missions with a short development schedule favour low team rotation in both prime and ESA teams, which enhances fast and accurate decision making times and processes. Product lines help to achieve short development times and keep low technical risks, as well as a controlled cost.

The presented technical and programmatic baseline has been deemed the best way to minimize the overall mission costs. The proposed baseline is slightly non-compliant with the required cost cap. Nonetheless, this platform provides:

- Very high reuse level of E-NEO / REF. PROGRAMME platform, which results in low development risk.
- Long term HW stability and smooth equipment evolution.
- Feasibility for rideshare to GTO together with a typical telecommunications satellite on A64
- Additionally, further savings on extra FMs could allow for 3 identical S/Cs to be launched altogether and provide real time data relay from surface missions on Mars at mid latitudes at an optimal overall cost.

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