CapellaDays

INTERPLANETARY SPACE MISSION AS A REVERSE-ENGINEERING BACKGROUND FOR THE CAPELLA ENVIRONMENT

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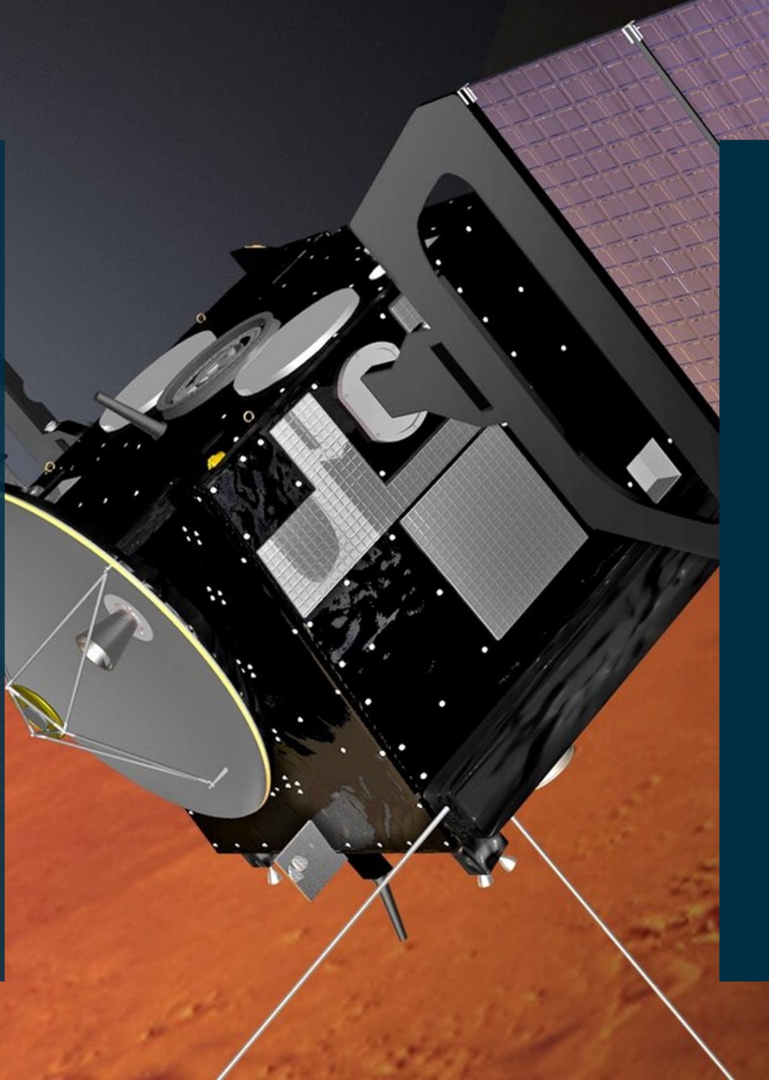
Prosperi Alessio | Rambaldi Riccardo | Tomassi Emanuele

POLITECNICO
MILANO 1863



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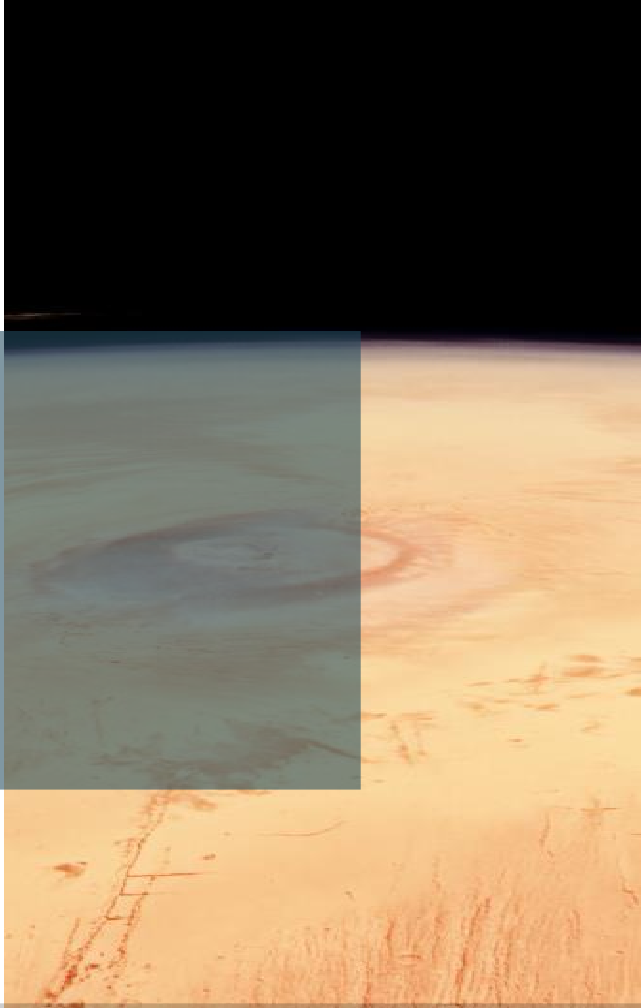
INTRODUCTION

MISSION STATEMENT

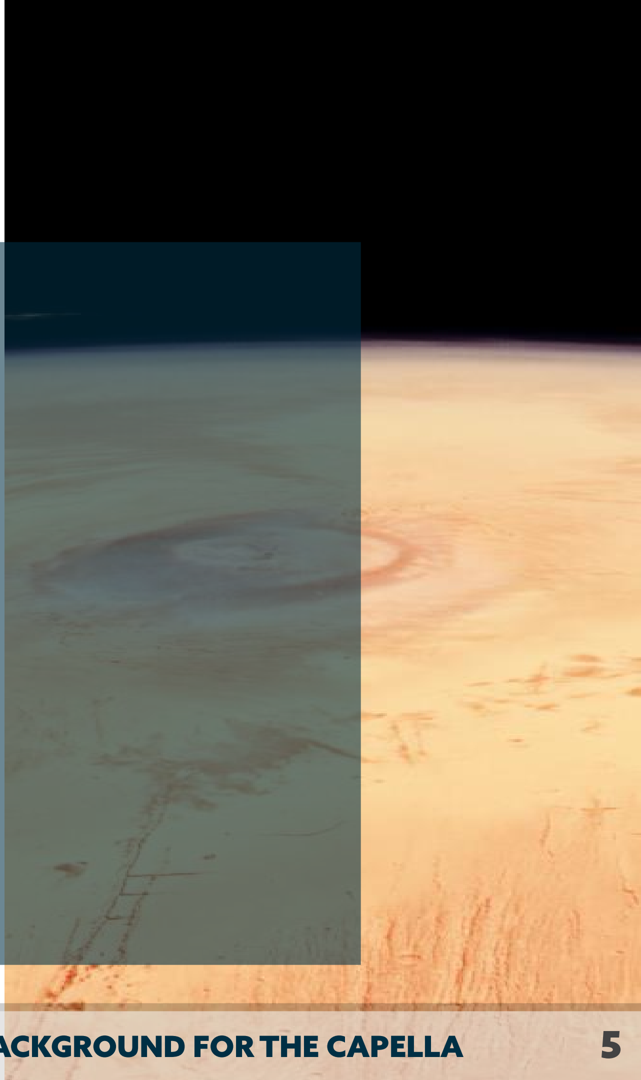
"The Mars Express mission has the objective to monitor all aspects of the martian environment, including the subsurface, surface and atmosphere of the planet, and to take pictures of the Martian moons Phobos and Deimos, in order to search for evidence of extinct or extant life"



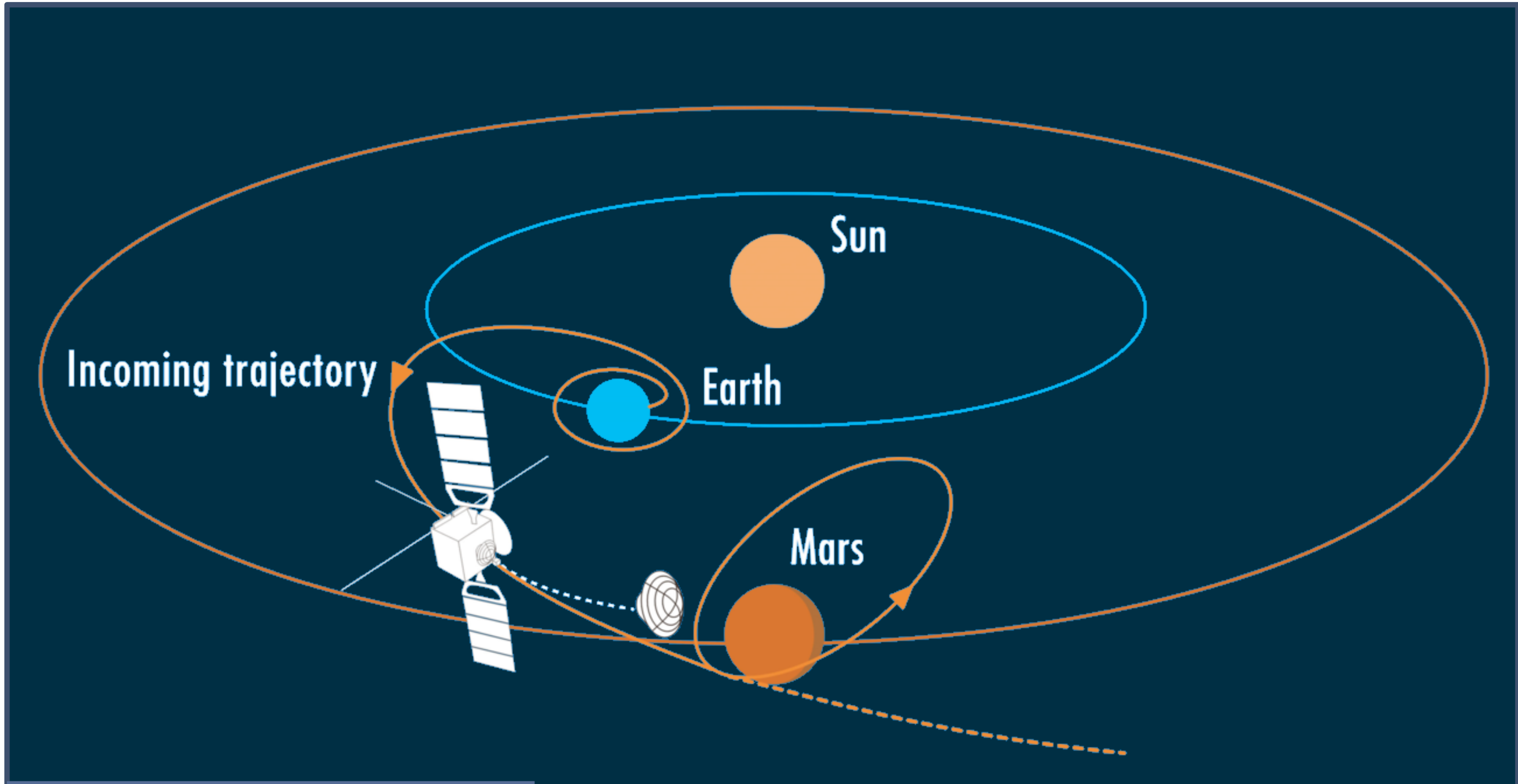
INTRODUCTION

HIGH-LEVEL SCIENTIFIC OBJECTIVES

- Global **mineralogical mapping** of Mars surface
- Study of the global **composition** and **circulation** of the martian **atmosphere**
- Perform **surface morphology** investigation
- Mapping of the **distribution of water** in the upper portions of the crust
- Perform flybys of Phobos and collect images of **Martian moons**
- Perform **in-situ investigation** of the local terrain and rocks
- Characterisation of the **near-Mars plasma** and **neutral gas environment**
- Study of the interaction of the upper atmosphere with the interplanetary medium and **solar wind**

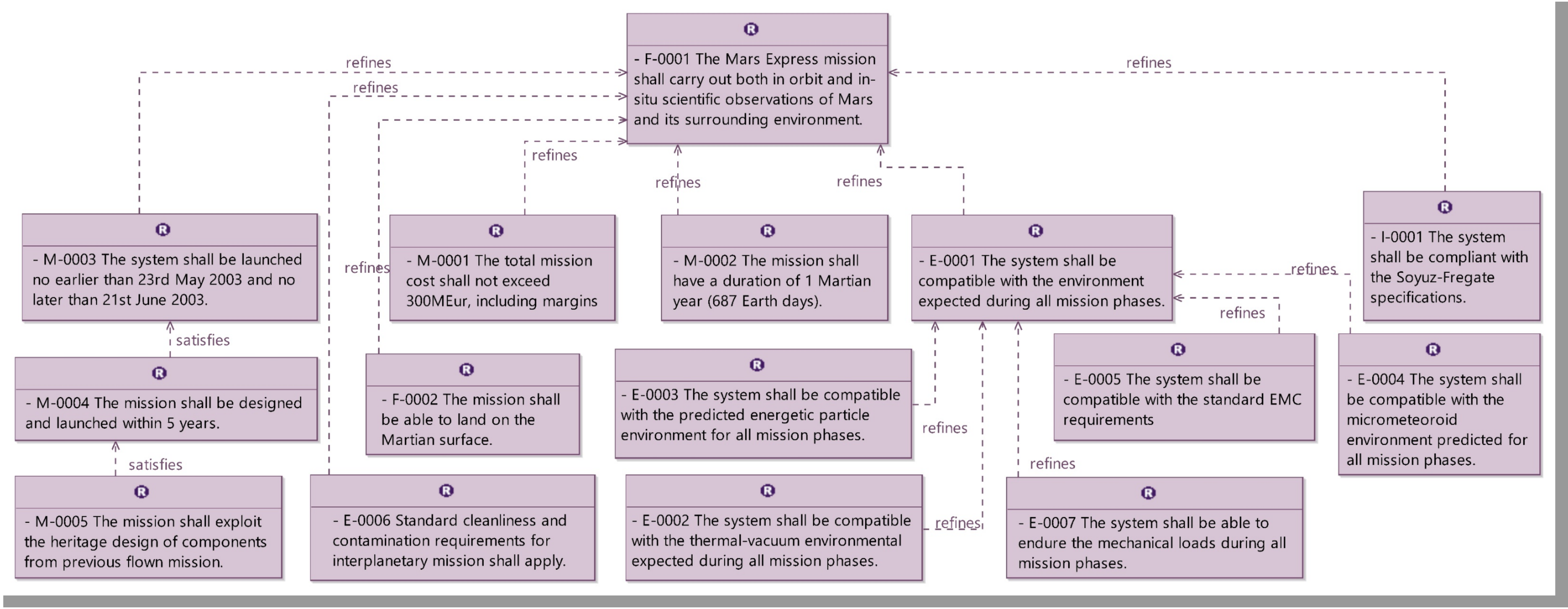


MISSION SUMMARY



Credit: *Illustration by Medialab, ESA 2001*

MISSION REQUIREMENTS



PAYLOAD IDENTIFICATION AD RATIONALE – 1

Perform surface morphology inv estigation

Provide stereo and colour imaging of entire planet at very high resolution in 3D and in full colour

High Resolution Stereo Camera (HRSC)

Obtain near-simultaneous imaging data of a specific site at high resolution, with a long-track triple stereo, four colours and five different phase angles

Perform surface sounding

Mapping of the distribution of water in the upper portio ns of the crust

Perform subsurface sounding

Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS)

Transmit in rapid sequence up to four quasi-simultaneous pulses at one or two different frequencies, and receives the corresponding echoes on the antennas

Study of the global compo sition of the atmosphere

Measure the vertical distribution of CO2, temperature, O3, aerosols, O2 and H2O2

Study of the interaction of th e upper atmosphere with the interplanetary medi um and solar wind

UV observations of the upper atmosphere

SPectroscopy for t he Investigation of the Characteristics of the Atmosphere of Mars (SPICAM)

UV spectrometer and IR spectrometer. Measures the vertical distribution by using stellar occultation and the stellar spectrum recorded above the atmosphere serves as a reference spectrum.

Characterisation of the near-Mars plasma and neutr al gas environme nt

Characterise the environment in near-Mars space through energetic neutral at om (ENA) imaging and local charged-particle measurements.

Analyser of Space Plasma and Energetic Atoms (ASPERA)

Measures the integral ENA flux. Provides ion and electron measurements of hot plasma

PAYLOAD IDENTIFICATION AD RATIONALE – 2

Study of the global composition and circulation of the martian atmosphere

Analyse wavelengths to identify the elements

Planetary Fourier Spectrometer (PFS)

Double pendulum interferometer workin g in two wavelength ranges (1. 2-5µm and 5-45 µm). Gases that have bands in the PFS spectral range: H_2O, CO, O_3, O_2.

Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité (OMEGA)

Mapping spectrometer, with coaligned channels working in the 0.38-1.05 µm visible and near-IR range and in the 0.93-5.1 µm short wavelength IR range.

Radio occultation to sound the neutral Martian atmosphere

Mars Express Orbiter Radio Science (MaRS)

Simultaneous and coherent dual-frequency downlinks at X-band (8.4 GHz) and S-band (2.3 GHz). The radio signals are affected by the medium through which they propagate and by the gravitational influence of the planet.

Study of the global composition and circulation of the martian atmosphere

Measure atmospheric temperature, pressure, wind speed and direction, dust saltation and angole of repose

Global mineralogical mapping of Mars surface

Quantitative and qualitative analysis of sample composition and precise isotopic measurements

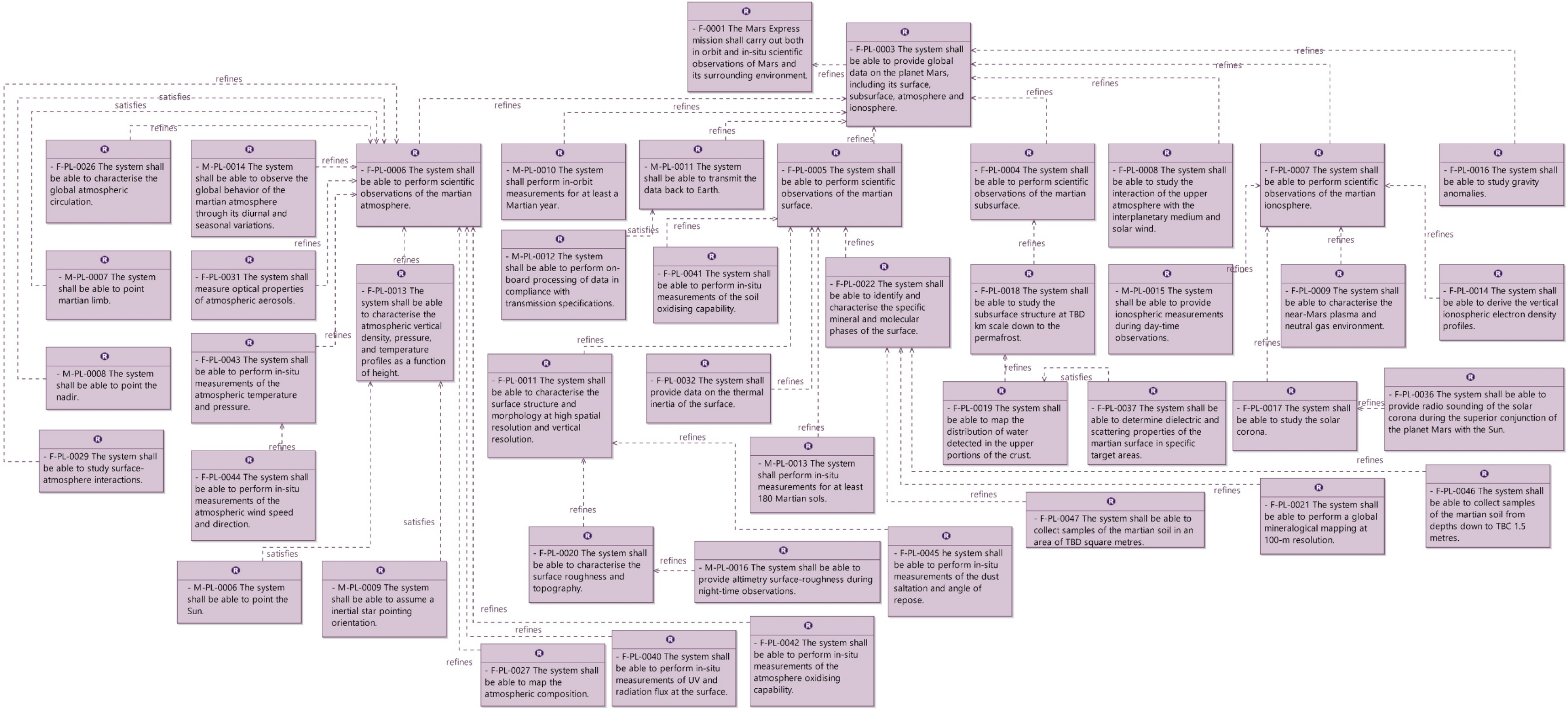
Perform in-situ investigation of the local terrain and rocks

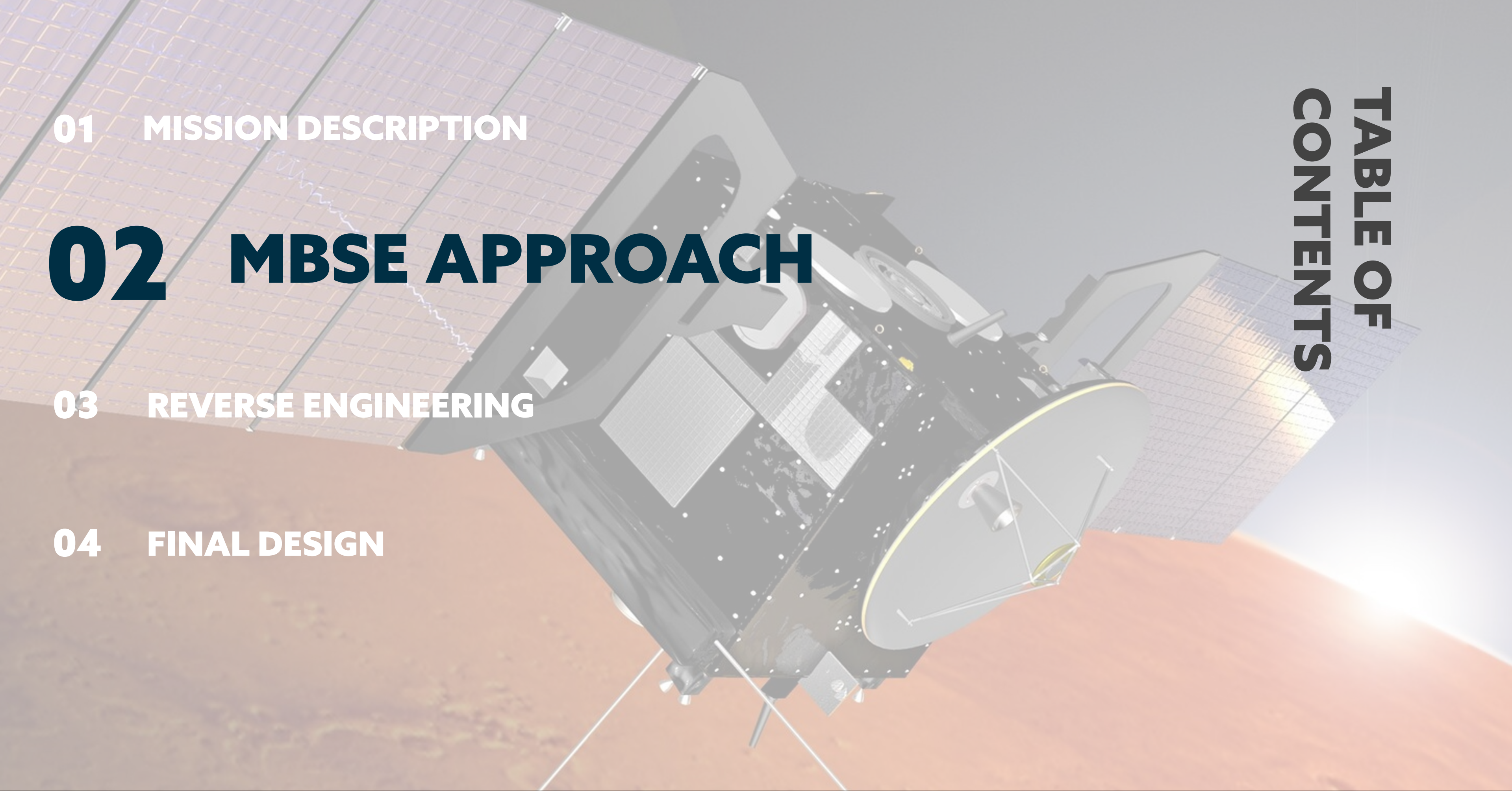
Dedicated tools to sample the surface and subsurface materials

Beagle 2

- Deployable in-situ instrumentation
- Imaging devices
- Field spectrometers
- Sampling tools
- Environmental sensors

PAYLOAD REQUIREMENTS





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Summary of ARCADIA method

Operational analysis

Capture and consolidate operational needs from stakeholders. Identify entities, actors, roles, activities, concepts.
Useful diagrams: OEBD, OCB, OES, OAB

Systems analysis

Identify the boundary of the system, consolidate requirements. Model functional dataflows.
Useful diagrams: CSA, MCB, SFBD

Logical architecture

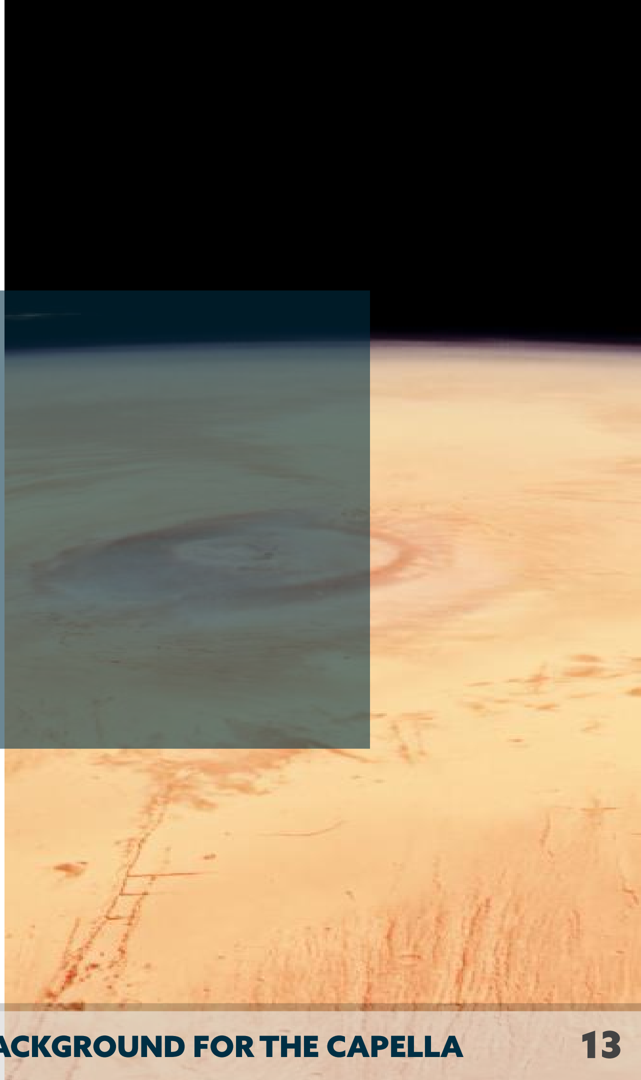
Define how the system will work. Perform a first trade-off analysis.
Useful diagrams: LCBD, LAB, M&S, ES

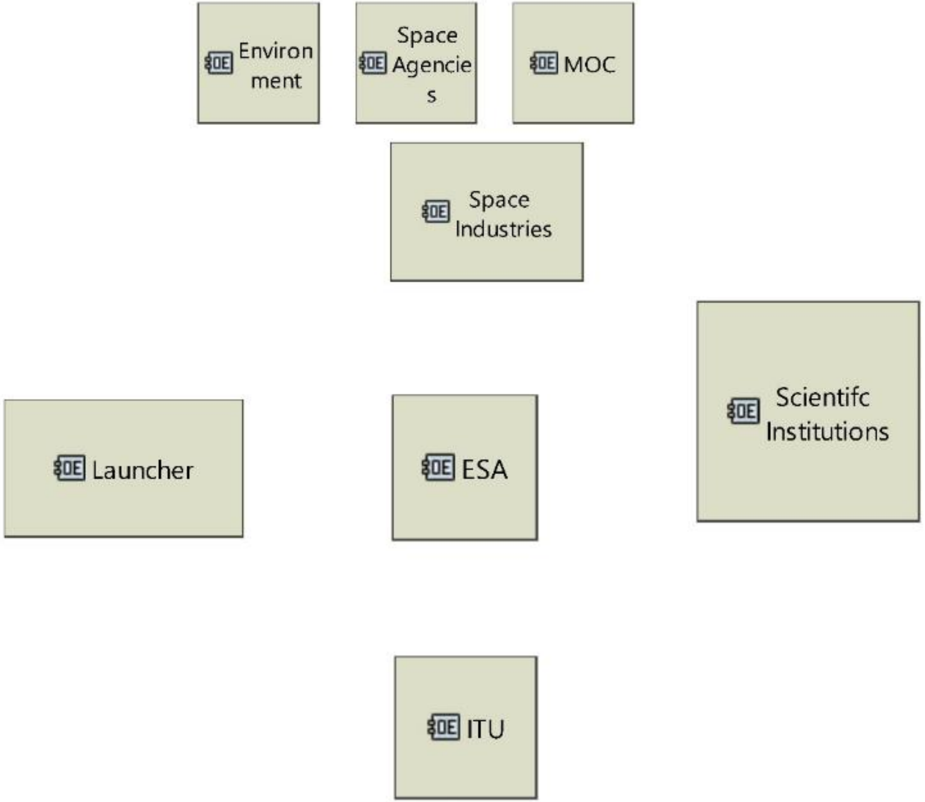
Physical architecture

How the system will be developed and built. Software vs hardware allocation.
Useful diagrams: PCBD, PFB, PAB

OPERATIONAL ANALYSIS

Capture and consolidate operational needs from stakeholders. Define what the users of the system have to accomplish. Identify entities, actors, roles, activities, concepts.

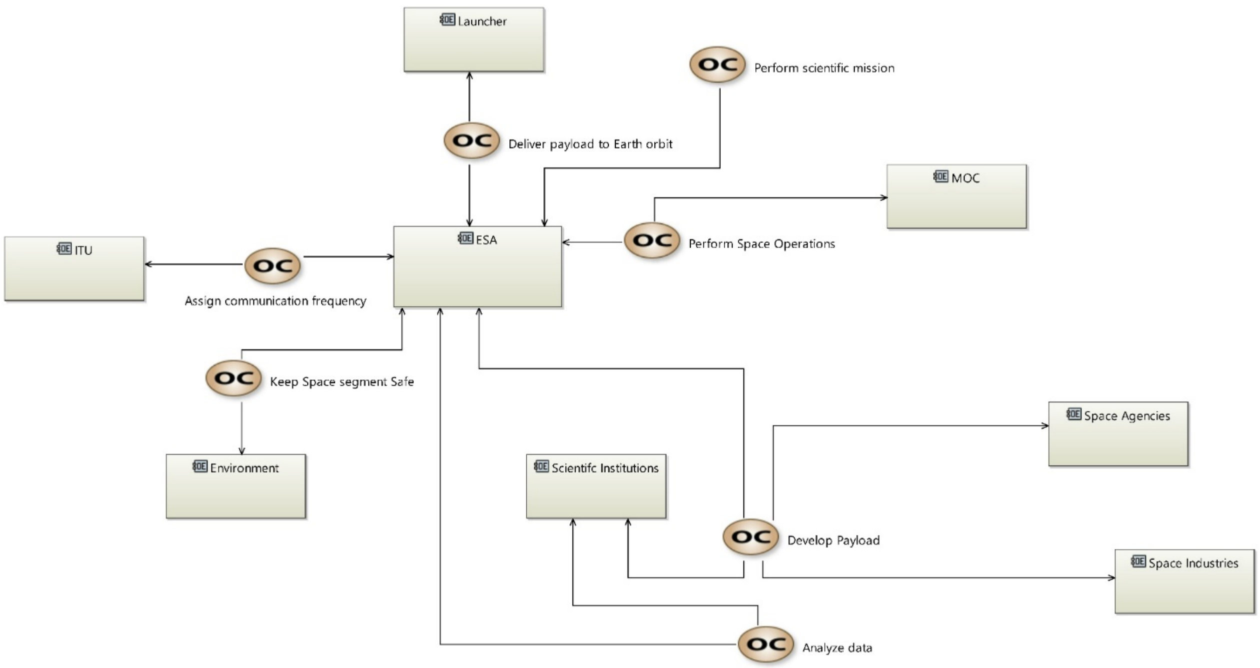




OPERATIONAL ENTITY BREAKDOWN DIAGRAM

Create all operational actors (human stakeholders) or entities (non-human stakeholders), and specify if they are included within themselves

OPERATIONAL CAPABILITIES DIAGRAM



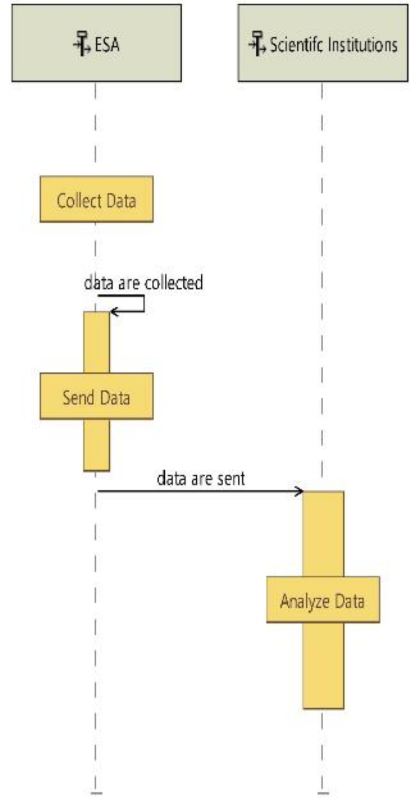
GOAL 1

Create all operational capabilities

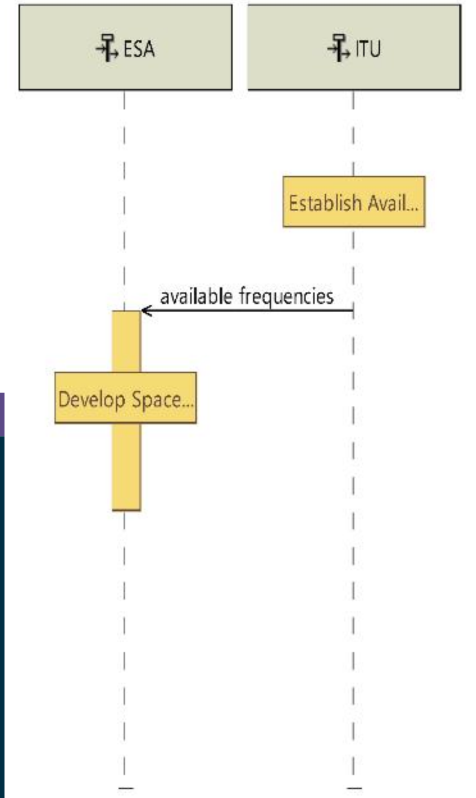
GOAL 2

Specify their relationships with the existing operational entities or actor using Involvement

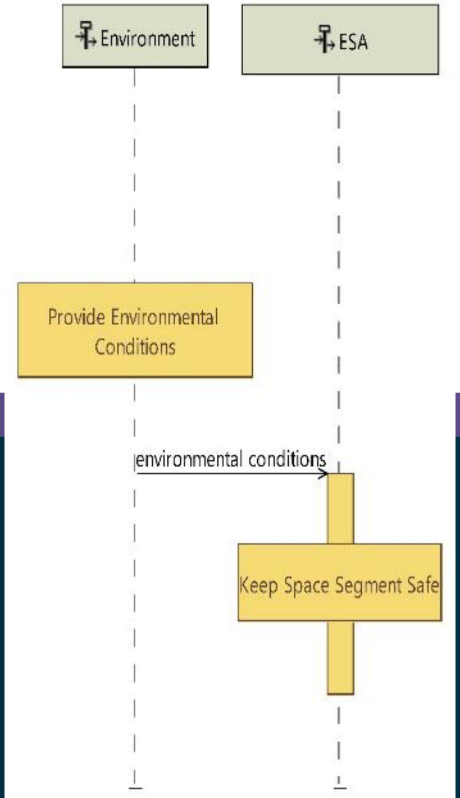
OPERATIONAL ENTITY SCENARIO



[OES] Analyse data

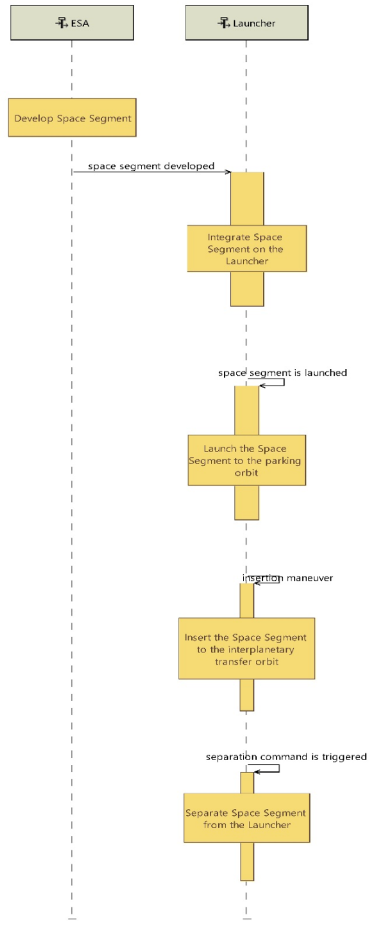


[OES] Assign communication frequency

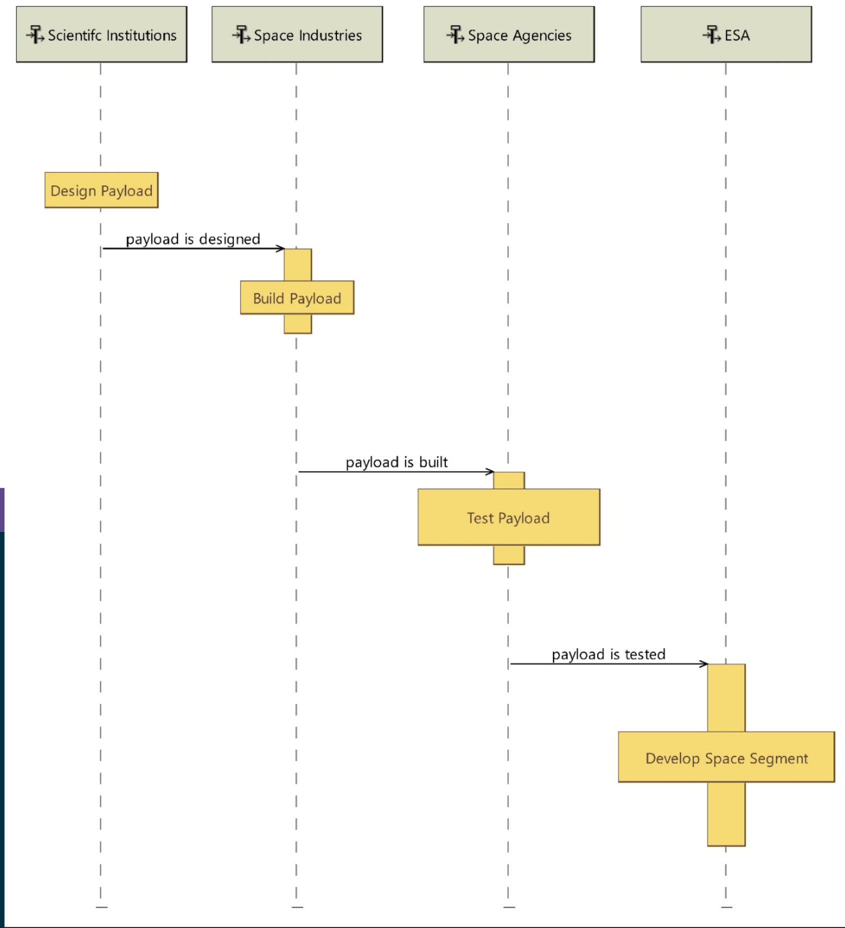


[OES] Keep Space segment safe

OPERATIONAL ENTITY SCENARIO

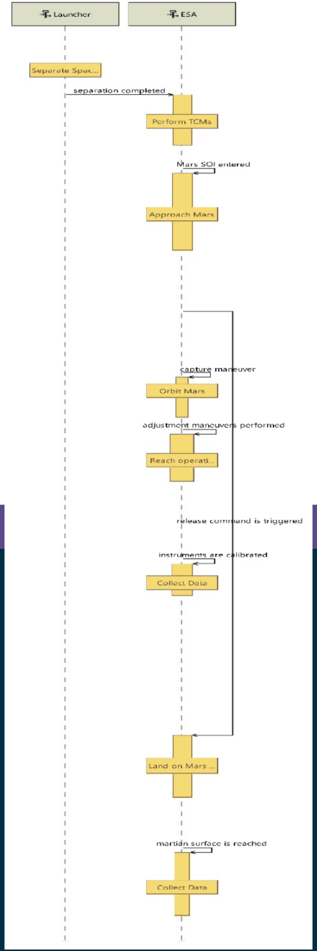


[OES] Deliver payload to Earth orbit

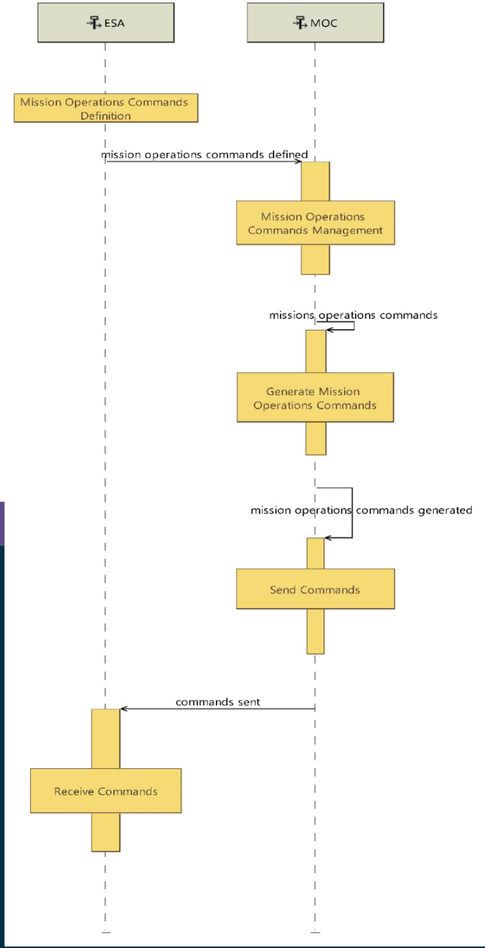


[OES] Develop payload

OPERATIONAL ENTITY SCENARIO

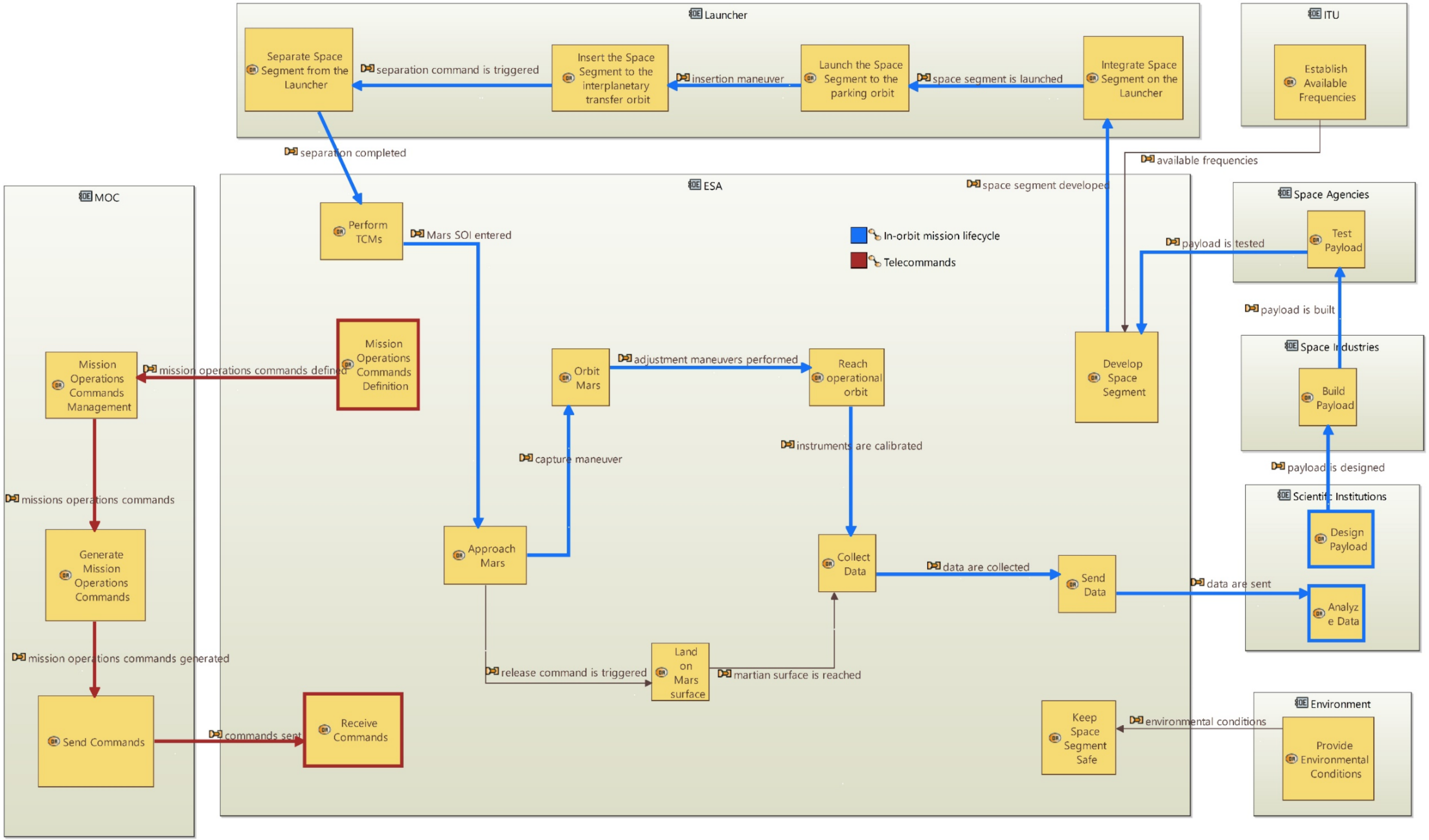


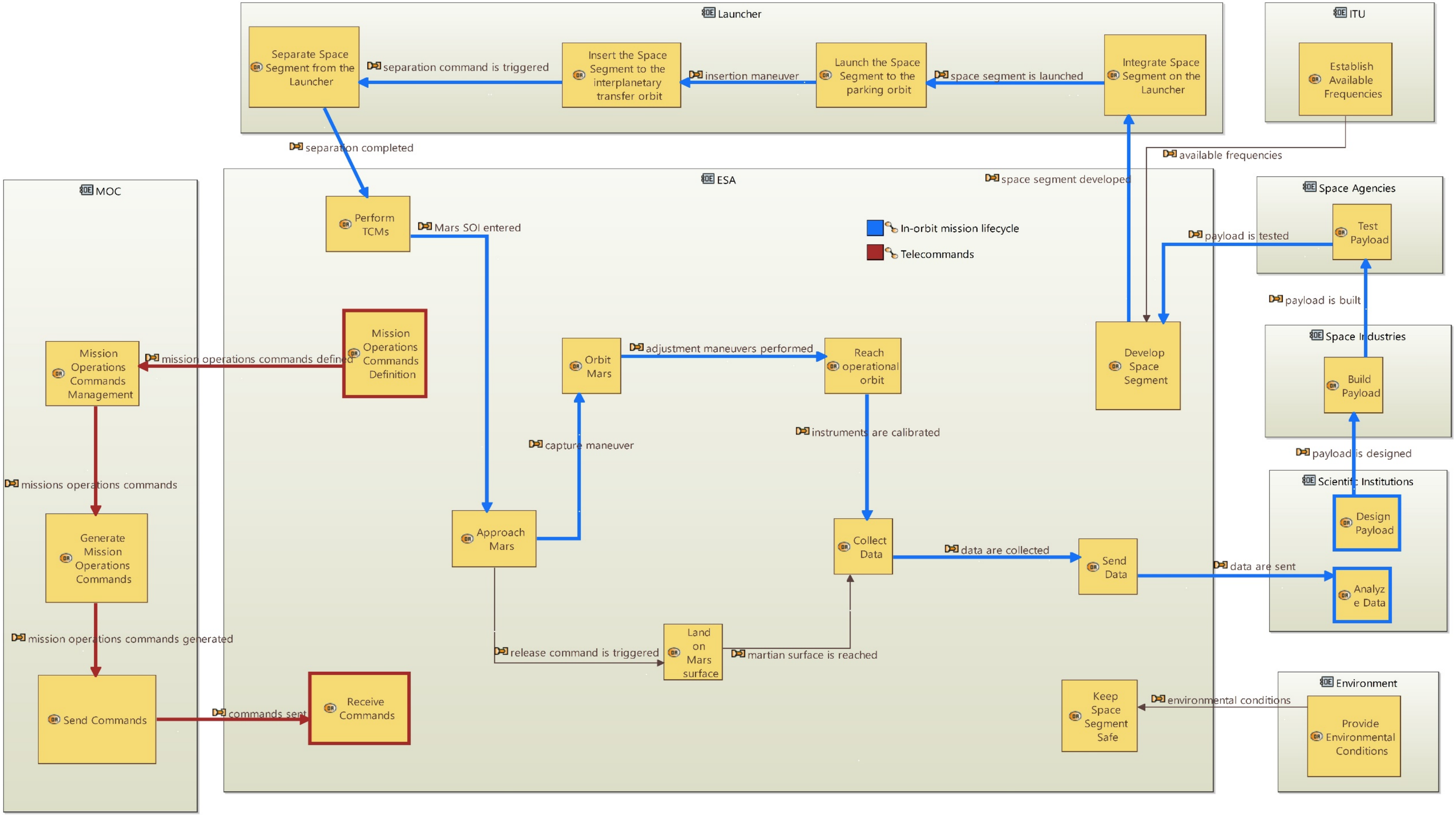
[OES] Perform scientific mission



[OES] Perform Space operations

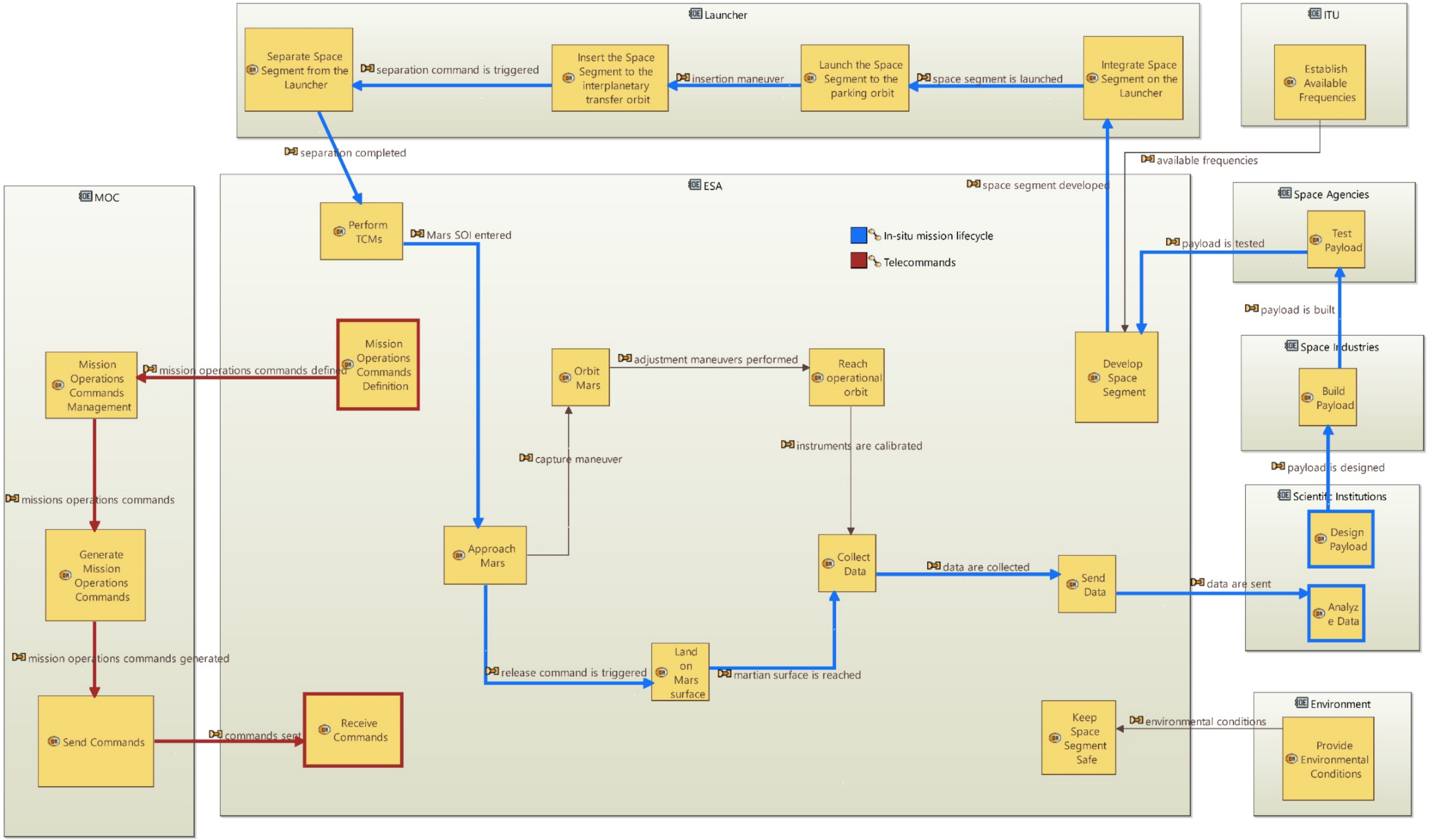
Operational Architecture Diagram

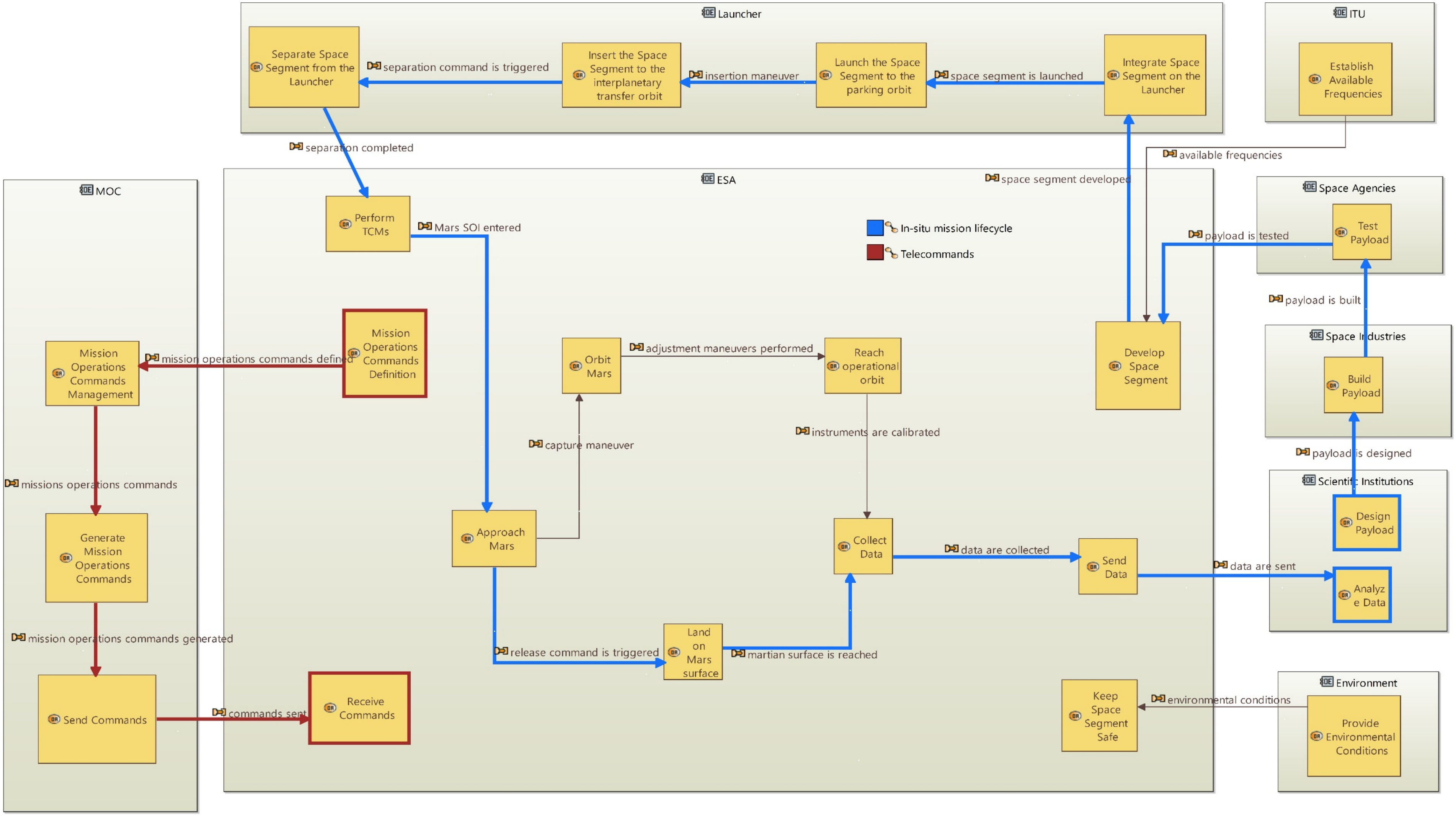




Launcher
Separate Space Segment from the Launcher
separation command is triggered
Insert the Space Segment to the interplanetary transfer orbit
insertion maneuver
Launch the Space Segment to the parking orbit
space segment is launched
Integrate Space Segment on the Launcher
ITU
Establish Available Frequencies
available frequencies
separation completed
ESA
space segment developed
MOC
Perform TCMs
Mars SOI entered
In-orbit mission lifecycle
Telecommands
Space Agencies
Test Payload
payload is tested
payload is built
Space Industries
Build Payload
Mission Operations Commands Definition
Mission Operations Commands Management
mission operations commands defined
Orbit Mars
adjustment maneuvers performed
Reach operational orbit
Develop Space Segment
instruments are calibrated
capture maneuver
payload is designed
missions operations commands
Scientific Institutions
Design Payload
Generate Mission Operations Commands
Approach Mars
Collect Data
data are collected
Send Data
data are sent
Analyze Data
mission operations commands generated
release command is triggered
Land on Mars surface
martian surface is reached
Environment
Keep Space Segment Safe
environmental conditions
Provide Environmental Conditions
Send Commands
commands sent
Receive Commands

Operational Architecture Diagram





Launcher
Separate Space Segment from the Launcher
separation command is triggered
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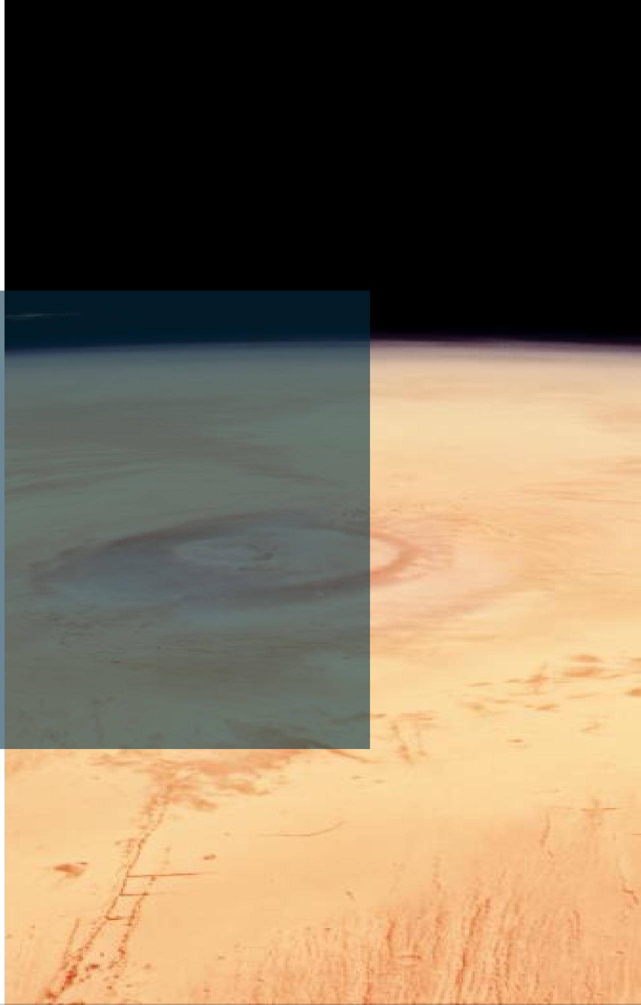
environmental conditions
Environment
Provide Environmental Conditions

SYSTEM ANALYSIS

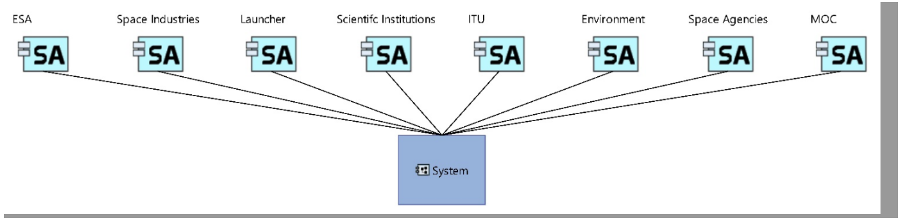
Identify the boundary of the system, consolidate requirements. Model functional dataflows.



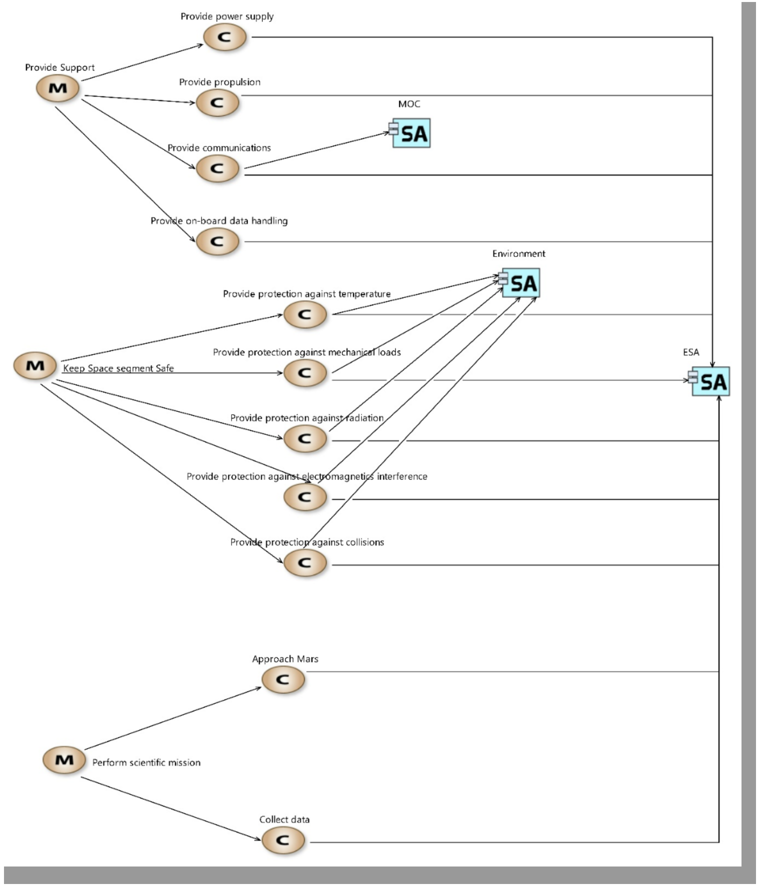
SYSTEM ACTORS & MISSION CAPABILITIES BLANK

CSA - Operational Entities are now transformed into System Actors

MCB – 3 main missions identified, further described by the linked capabilities

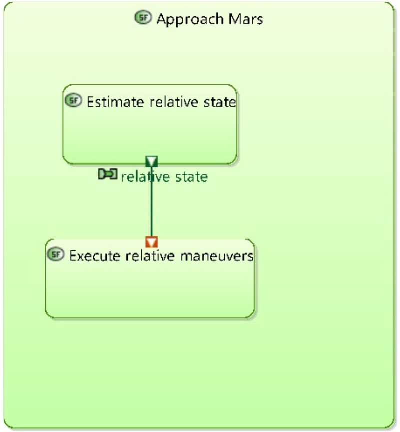


[CSA] System Actors

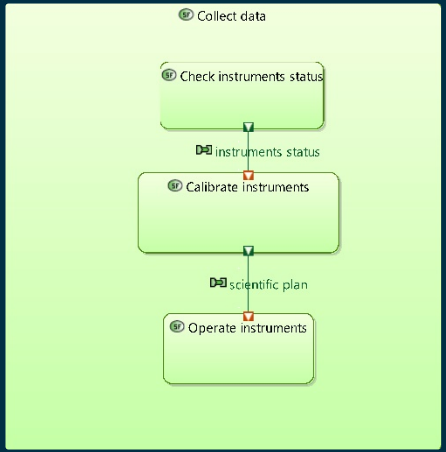


[MCB] Capabilities

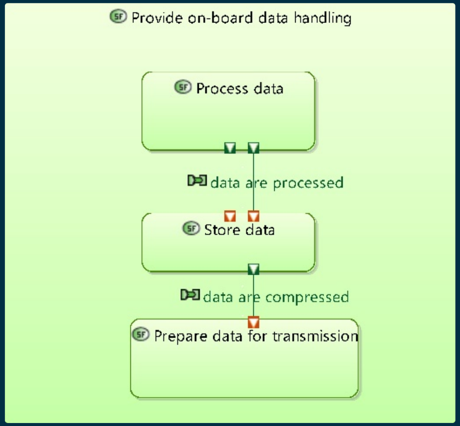
FUNCTIONAL DATA FLOW BLANK [SDFB] - 1



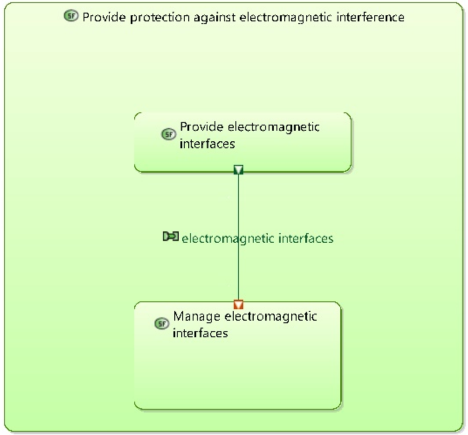
[SDFB] Approach Mars



[SDFB] Collect Data



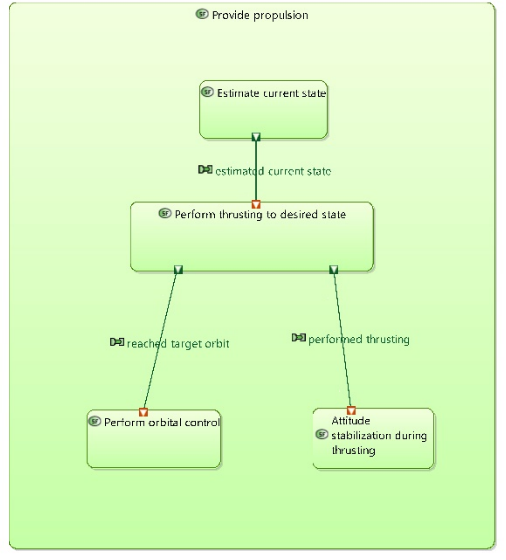
[SDFB] Provide On-Board Data Handling



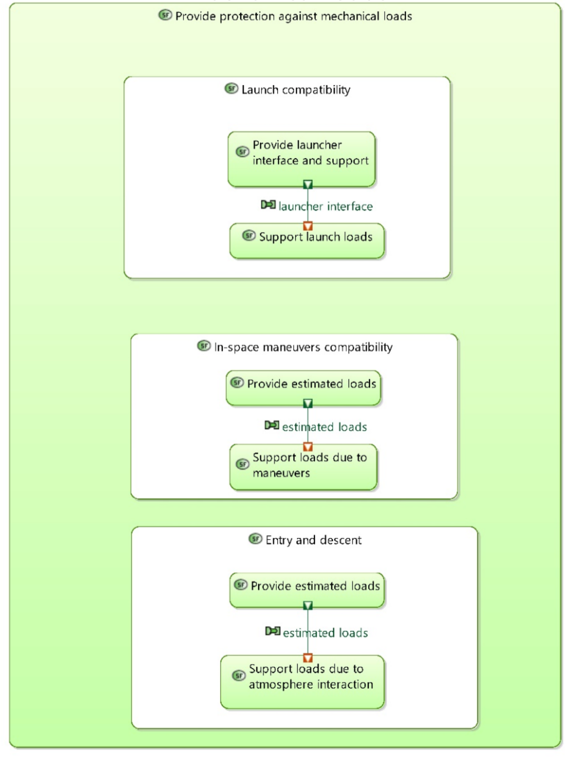
[SDFB] Provide Protection against electromagnetic interference

FUNCTIONAL DATA FLOW BLANK [SDFB] - 2

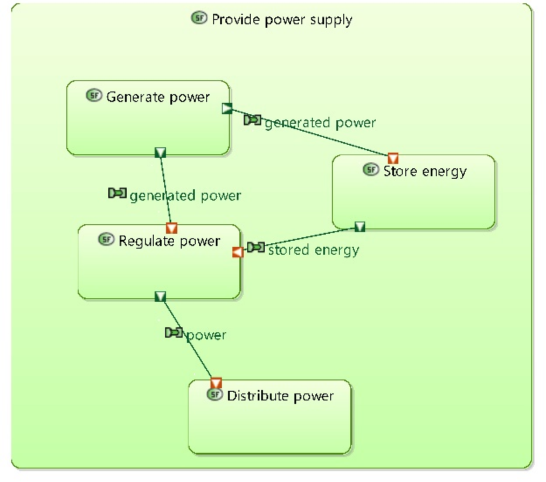
[SDFB] Provide propulsion



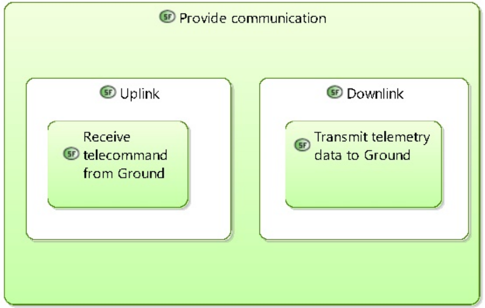
[SDFB] Provide protection against mechanical loads



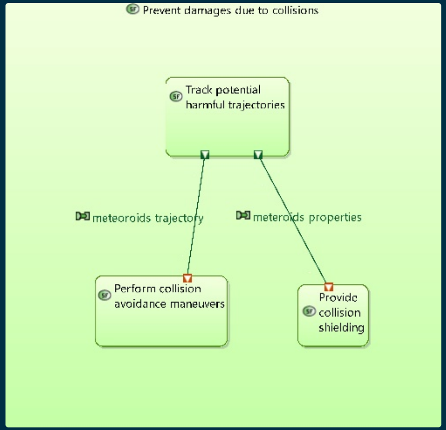
[SDFB] Provide power supply



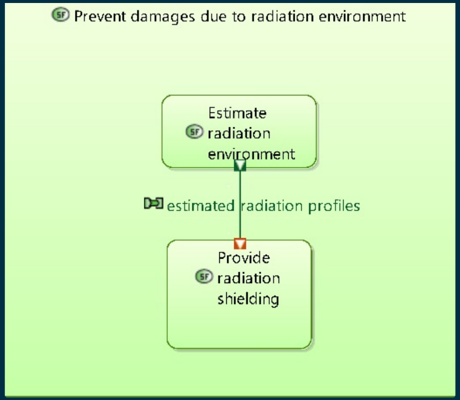
FUNCTIONAL DATA FLOW BLANK [SDFB] - 3



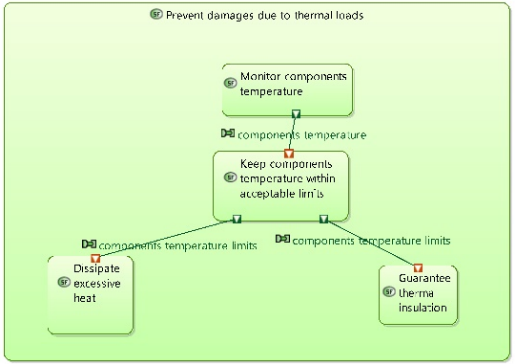
[SDFB] Provide Communication



[SDFB] Provide protection against collision

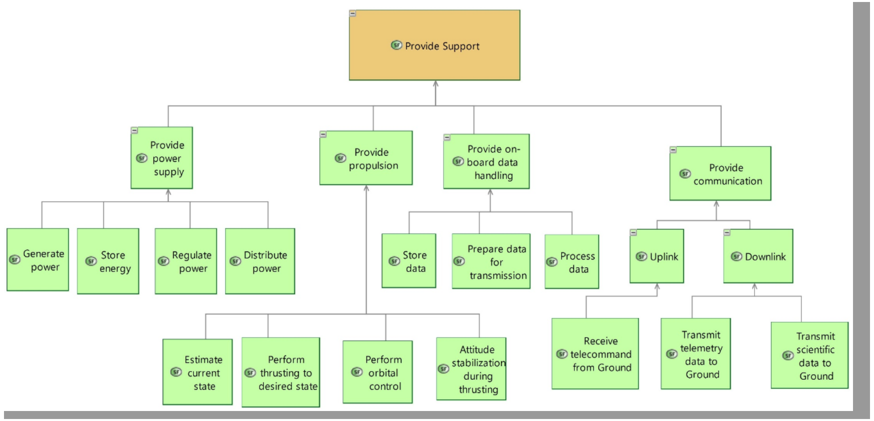


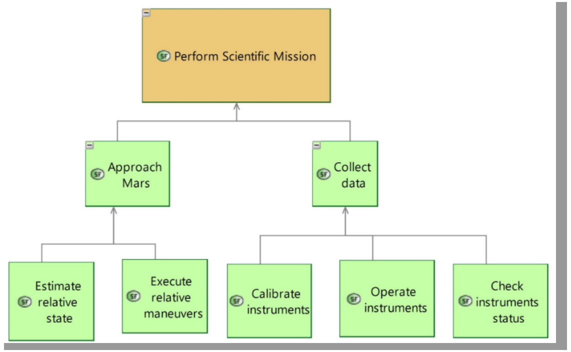
[SDFB] Provide protection against radiation

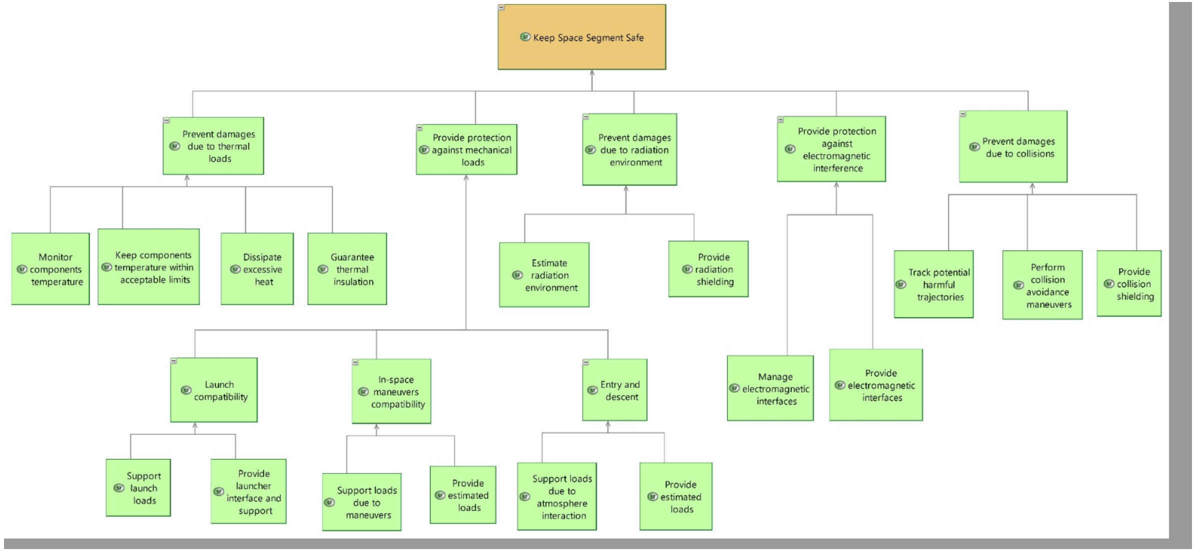


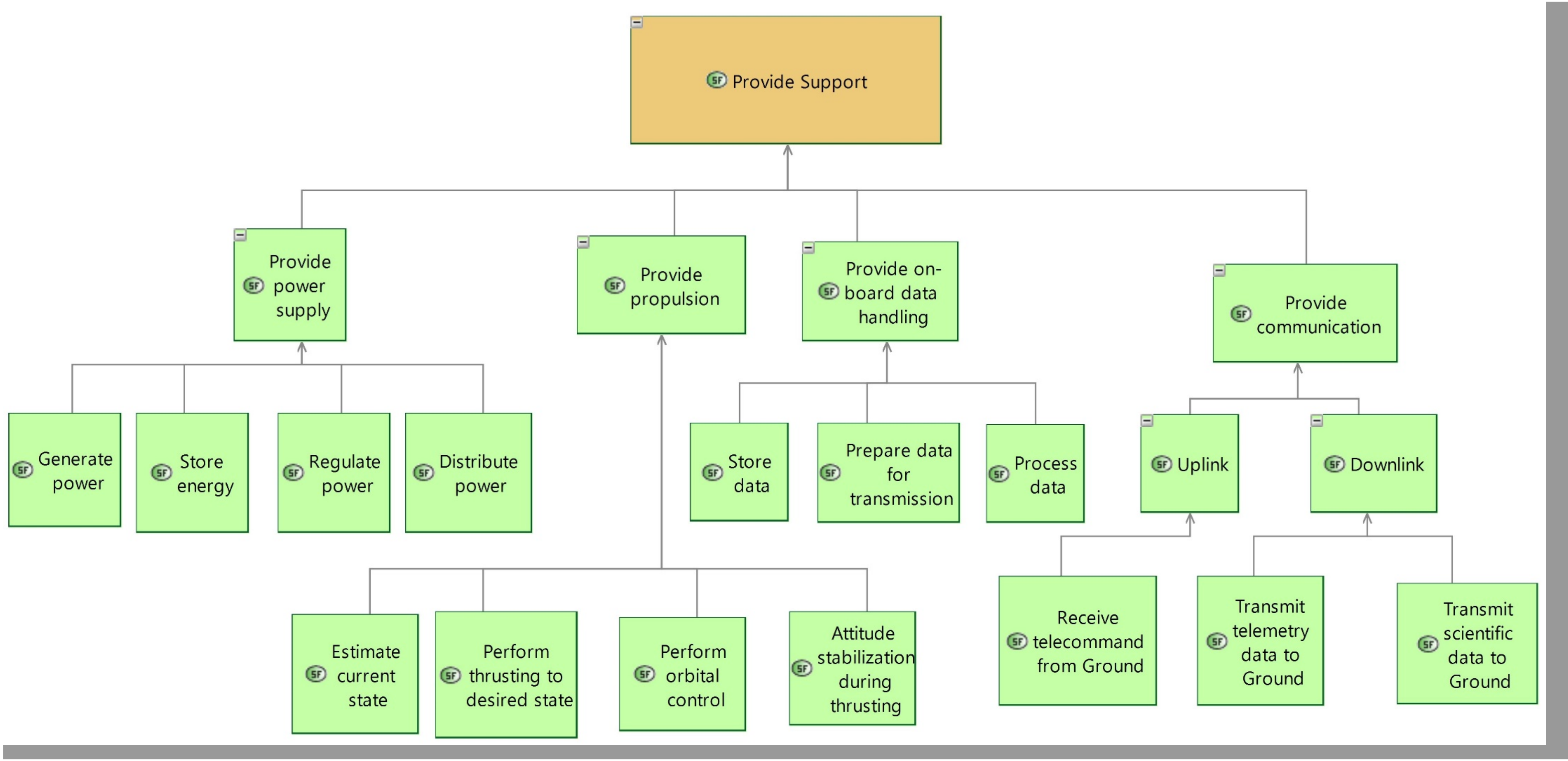
[SDFB] Provide protection against temperature

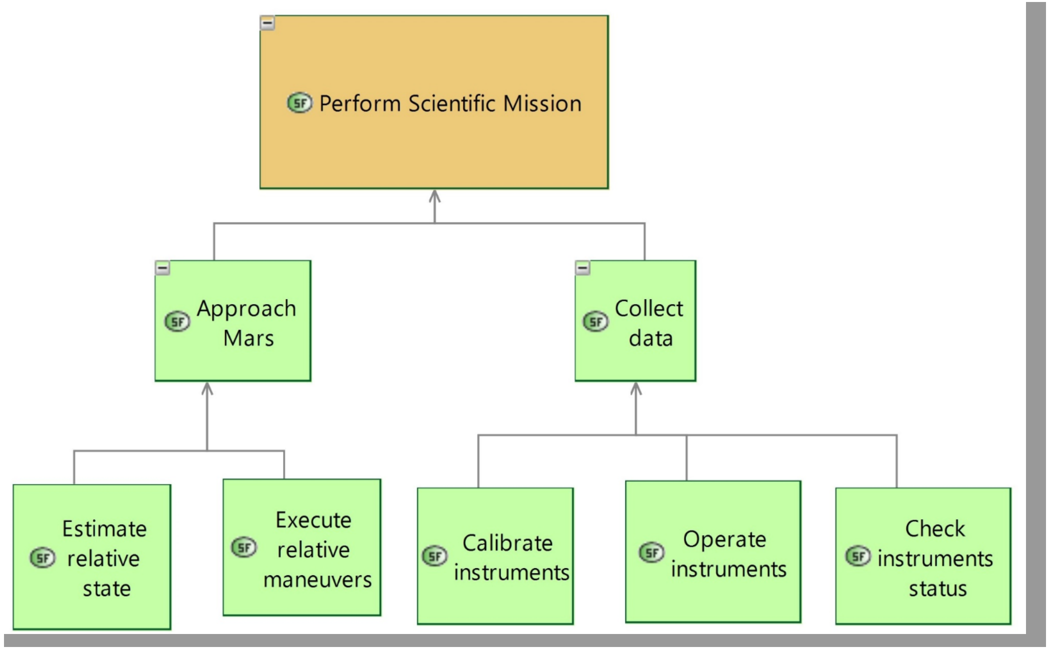
ROOT SYSTEM FUNCTION

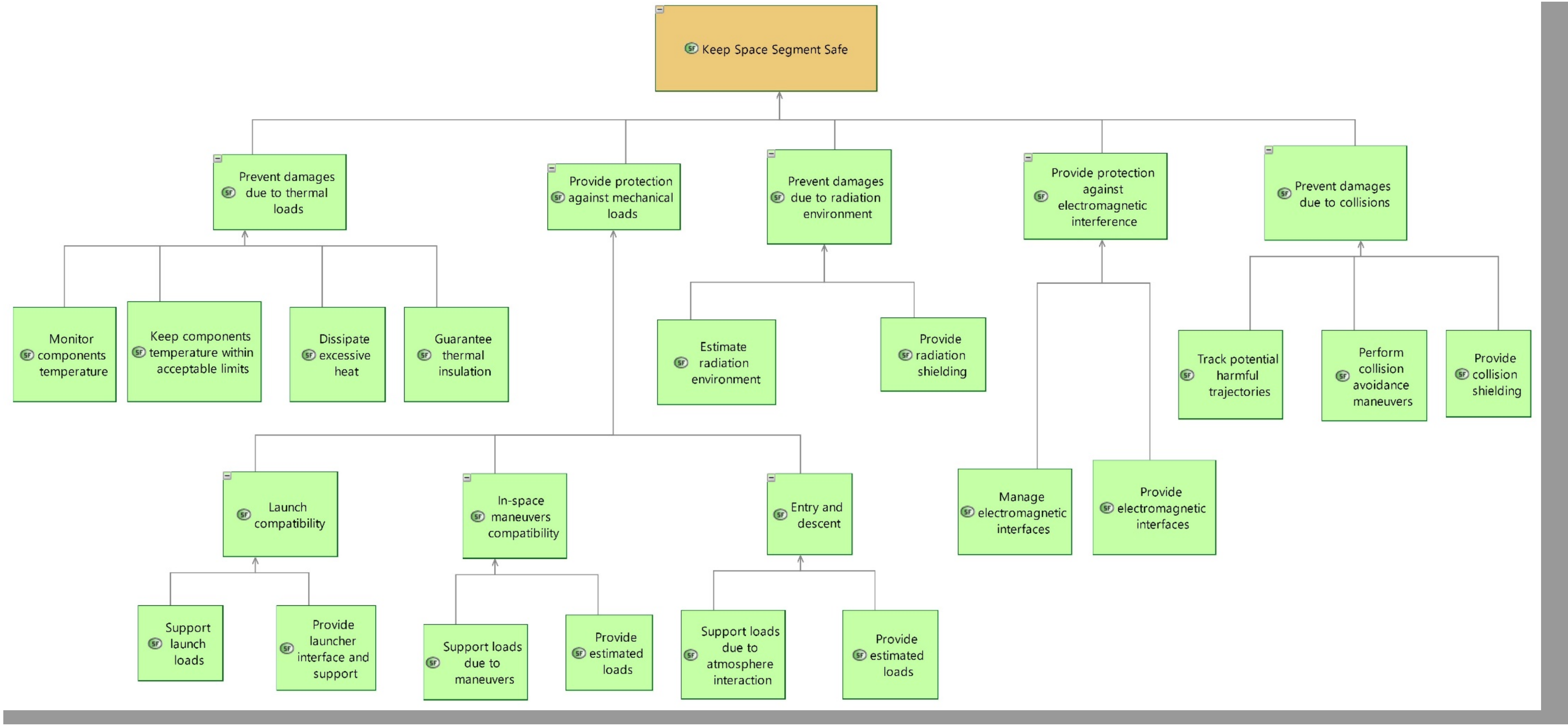


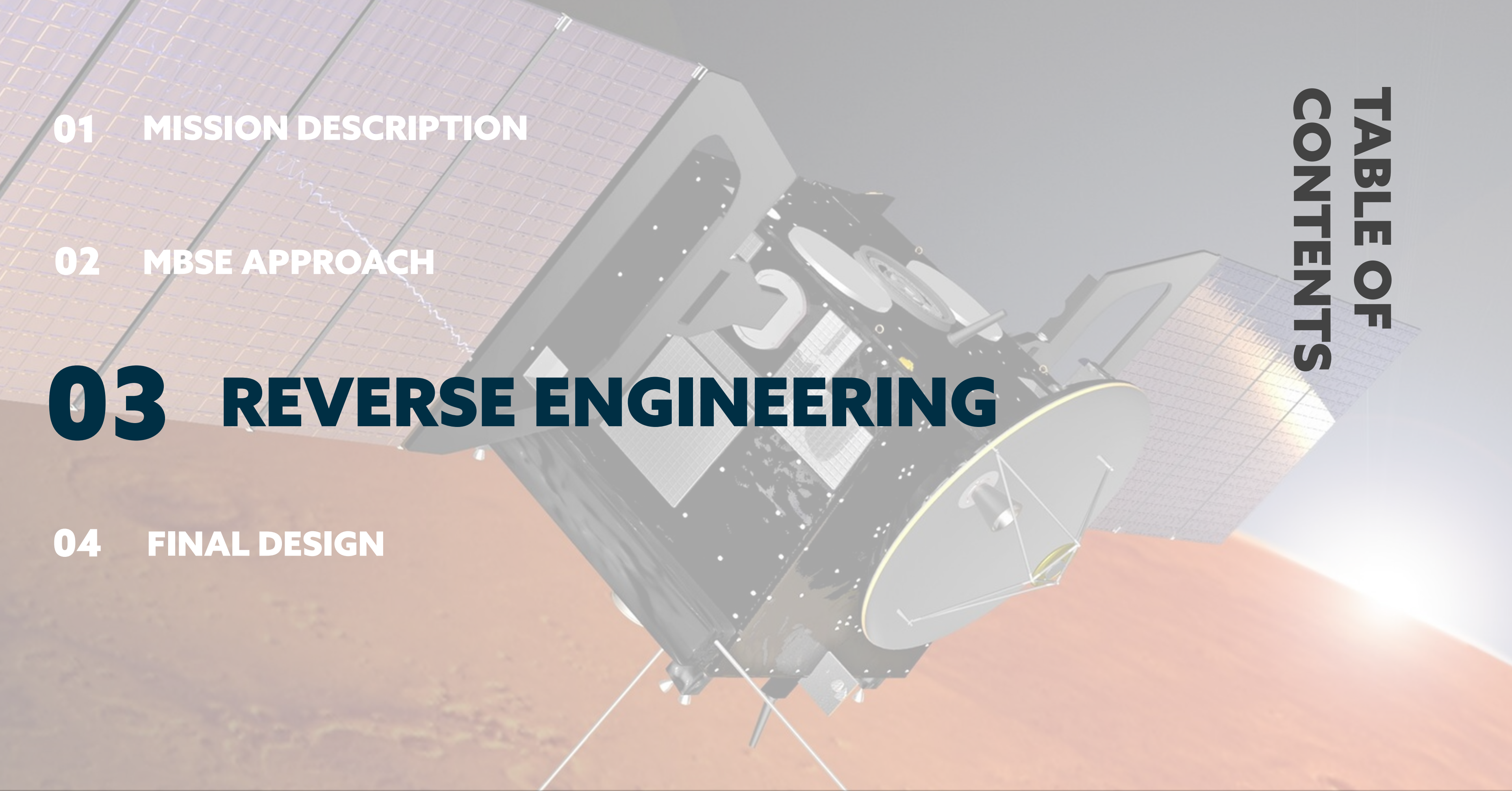





Provide Support
Provide power supply
Provide propulsion
Provide on-board data handling
Provide communication
Generate power
Store energy
Regulate power
Distribute power
Store data
Prepare data for transmission
Process data
Uplink
Downlink
Estimate current state
Perform thrusting to desired state
Perform orbital control
Attitude stabilization during thrusting
Receive telecommand from Ground
Transmit telemetry data to Ground
Transmit scientific data to Ground


Perform Scientific Mission
Approach Mars
Collect data
Estimate relative state
Execute relative maneuvers
Calibrate instruments
Operate instruments
Check instruments status


Keep Space Segment Safe
Prevent damages due to thermal loads
Provide protection against mechanical loads
Prevent damages due to radiation environment
Provide protection against electromagnetic interference
Prevent damages due to collisions
Monitor components temperature
Keep components temperature within acceptable limits
Dissipate excessive heat
Guarantee thermal insulation
Estimate radiation environment
Provide radiation shielding
Track potential harmful trajectories
Perform collision avoidance maneuvers
Provide collision shielding
Launch compatibility
In-space maneuvers compatibility
Entry and descent
Manage electromagnetic interfaces
Provide electromagnetic interfaces
Support launch loads
Provide launcher interface and support
Support loads due to maneuvers
Provide estimated loads
Support loads due to atmosphere interaction
Provide estimated loads



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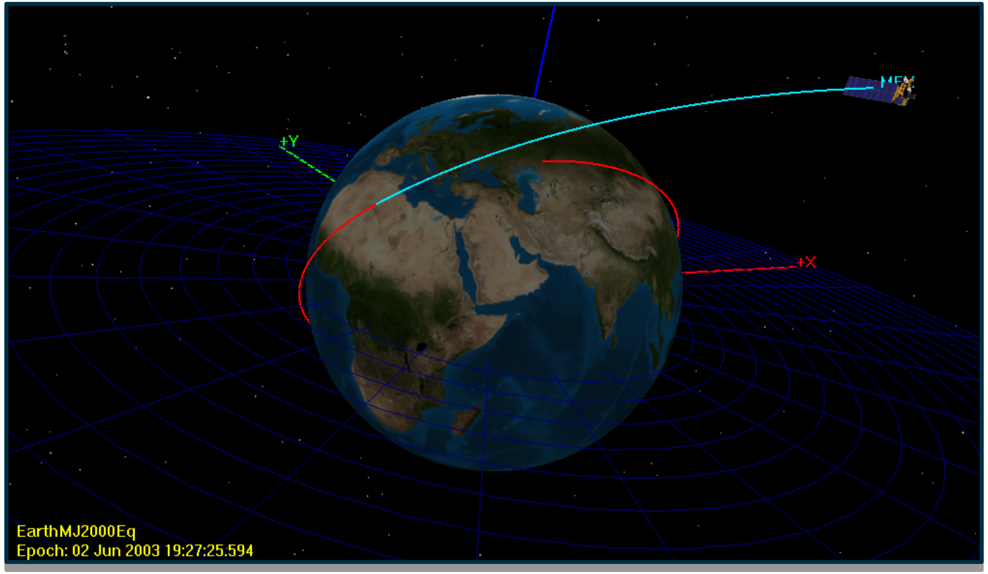
MISSION ANALYSIS
REVERSE ENGINEERING

STEP 2
Retrieve initial parking orbit and escape manoeuvre



STEP 1
Find data from literature:
- **Departure date**
- **Launch site**
- **Launcher user manual**

STEP 3

SMA [km]	6571
ECC	0
INC [deg]	52.11

RAAN [deg]	167.98
AoP [deg]	0
TA [deg]	76.9

NEAR EARTH

MISSION ANALYSIS REVERSE ENGINEERING

STEP 2

Compute the Trajectory Correction Manoeuvres

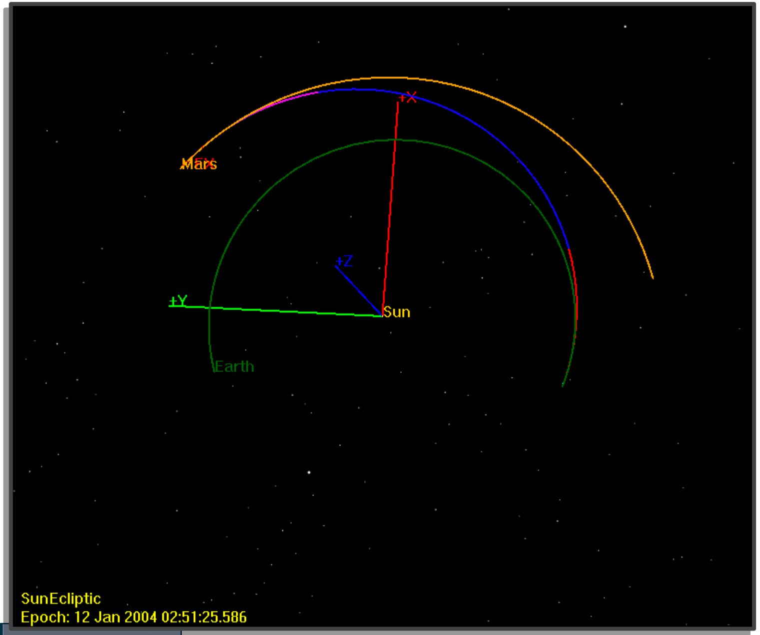
STEP 1

Find data from literature:

- **Number of TCMs**
- **Time between TCMs**
- **B-dot target parameters**

STEP 3

TCM1	0.4974 m/s
TCM2	0.7542 m/s
TCM3	0.4240 m/s
TCM4	0.5777 m/s
TCM5	6.9737 m/s



DEEP SPACE

MISSION ANALYSIS REVERSE ENGINEERING

STEP 1

Find data from literature:

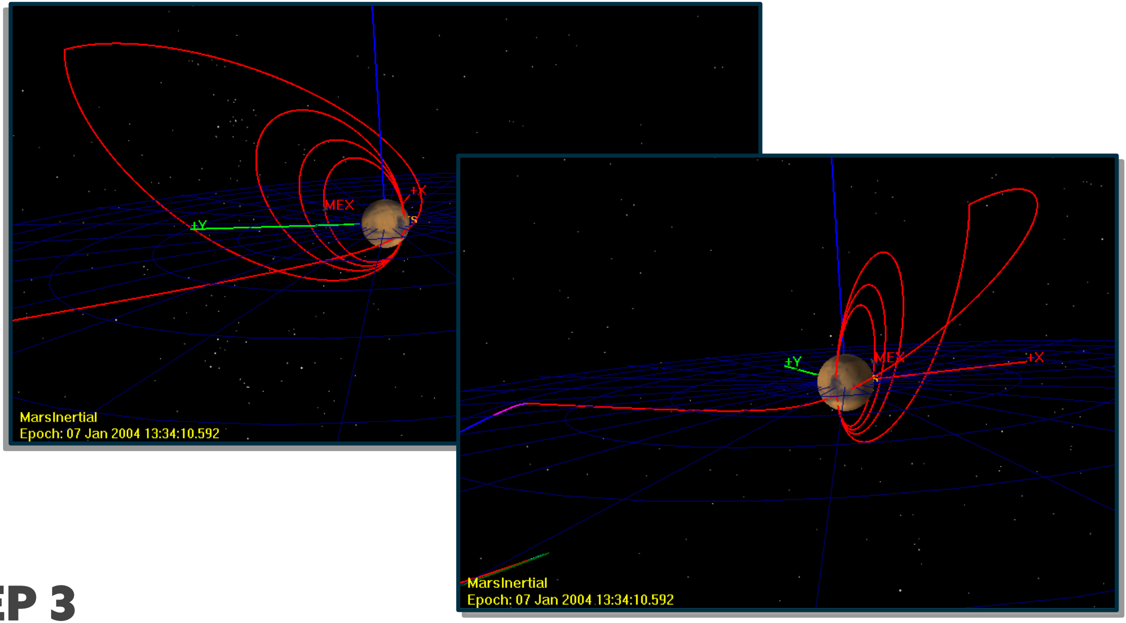
- **Arrival date**
- **Type of manoeuvres executed**

STEP 2

Compute the Mars Orbit Insertion and the shape and plane change manoeuvres

STEP 3

MOI	786.5181 m/s
PLANE CHANGE	102.5880 m/s
APOGEE REDUCTIONS	496.9609 m/s
SK (yearly)	9.0946 m/s



NEAR MARS

MISSION ANALYSIS
REVERSE ENGINEERING

FINAL PARAMETERS ACHIEVED

SEMI-MAJOR AXIS	9391.5584 km
ECCENTRICITY	0.6120
INCLINATION	86.1626°
ANOMALY OF PERICENTER	344.9423°
TOTAL VELOCITY BUDGET	1343.8381 m/s

RELATIVE ERRORS

<0.5%
SEMI-MAJOR AXIS

<0.5%
ECCENTRICIT
Y

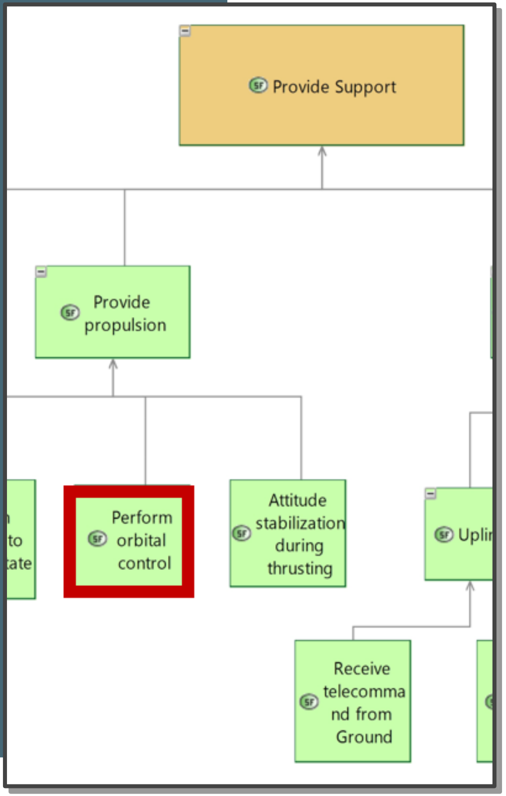
<0.02%
ANOMALY OF PERICENTER

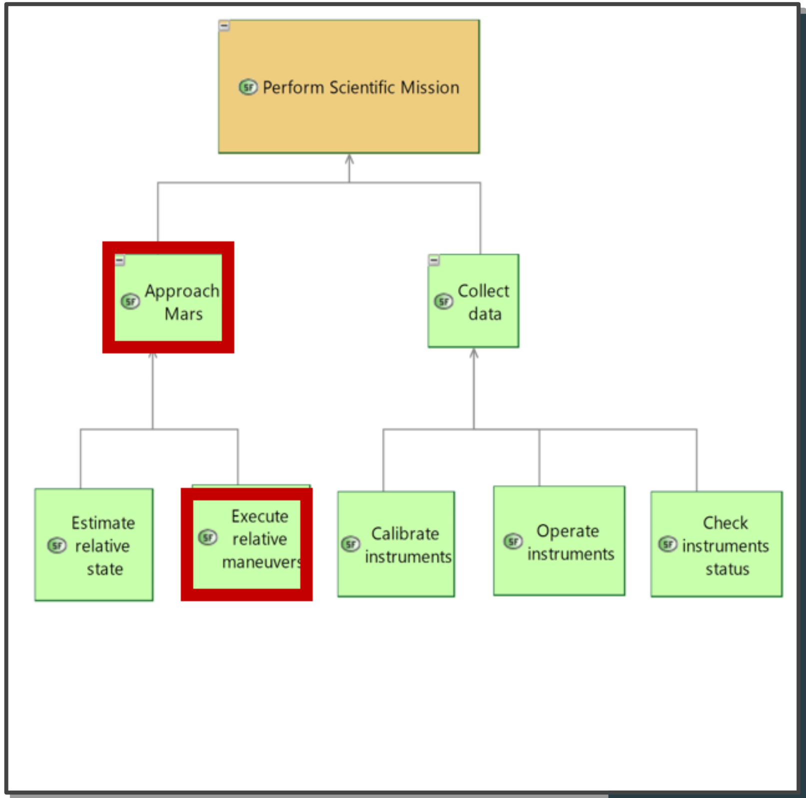
<0.1%
INCLINATIO
N

<0.05%
TOTAL VELOCITY BUDGET

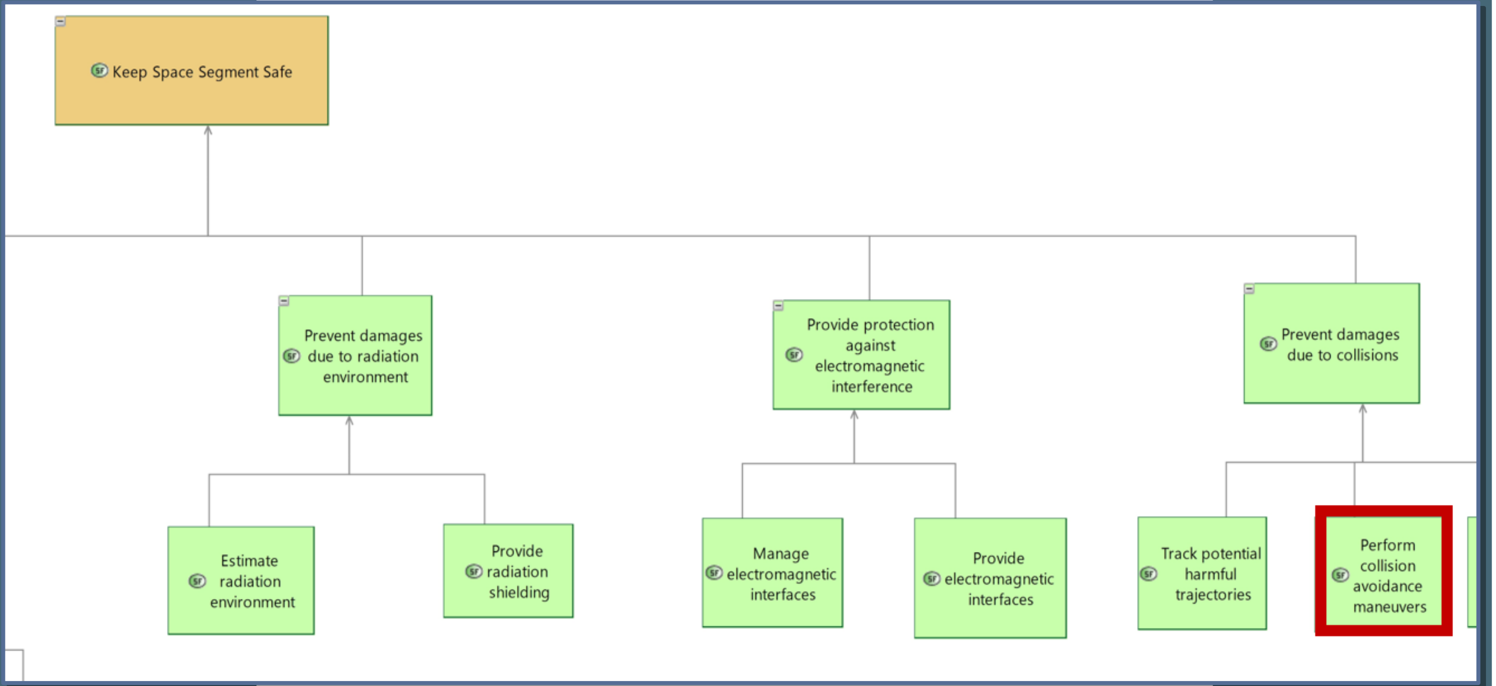
FROM FUNCTIONALITIES

MISSION ANALYSIS JUSTIFICATION





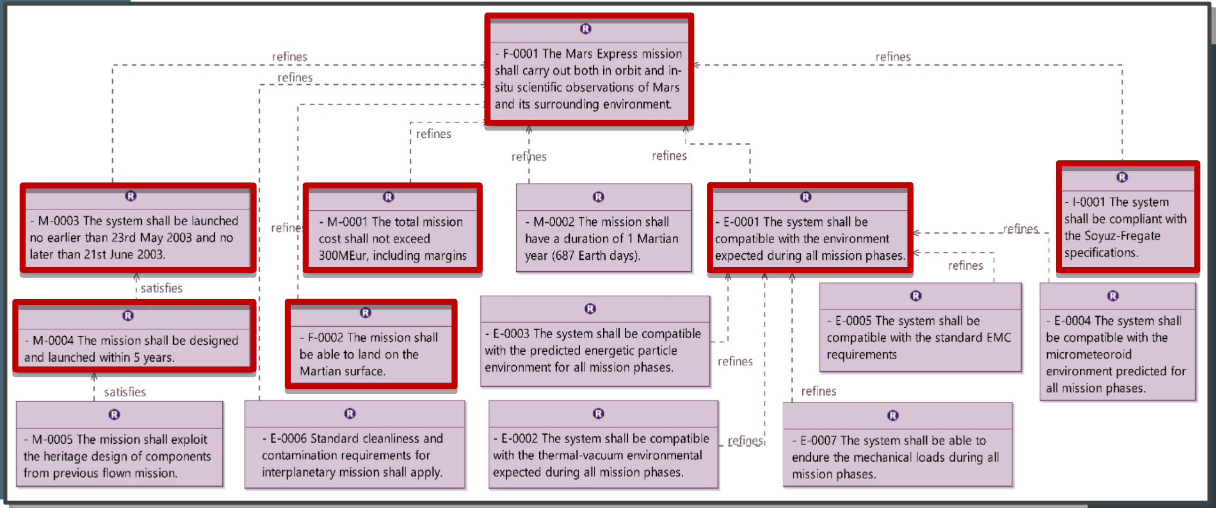
FROM FUNCTIONALITIES



MISSION ANALYSIS JUSTIFICATION

MISSION ANALYSIS JUSTIFICATION

FROM MISSION



FROM MISSION OBJECTIVES

POLAR ORBIT

HIGH ECCENTRICITY

HIGH SEMIMAJOR AXIS

LANDER

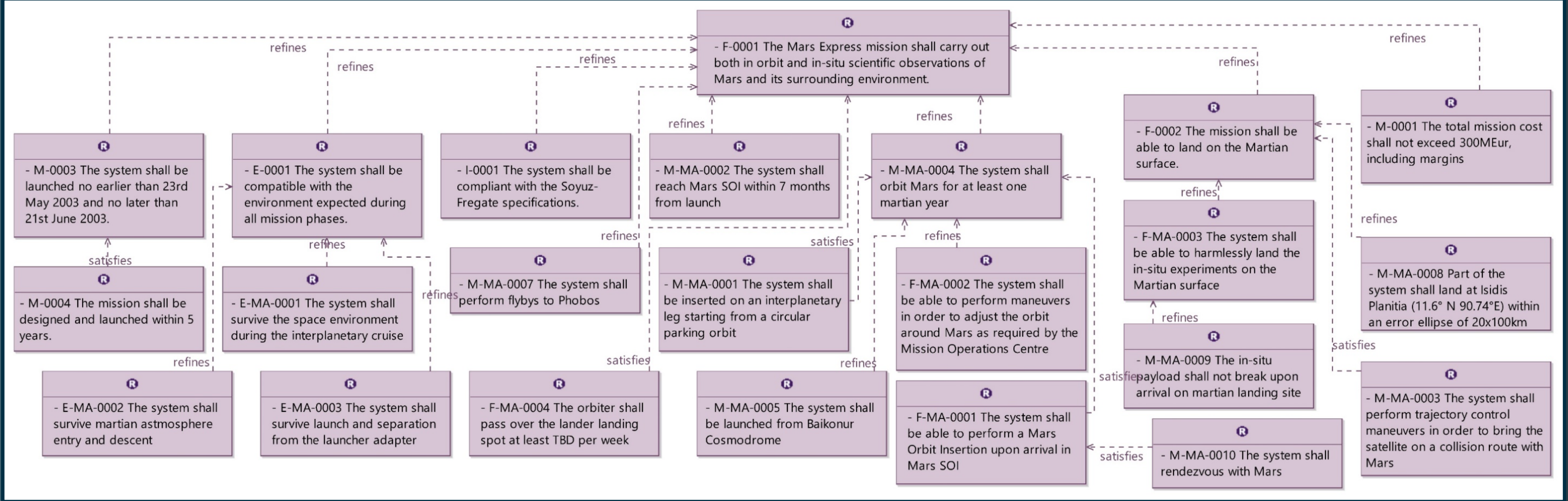
PLANET OBSERVATION

COMMUNICATION WITH GROUND STATION

STUDY SOLAR WIND AND ATMOSPHERE

IN-SITU INVESTIGATION

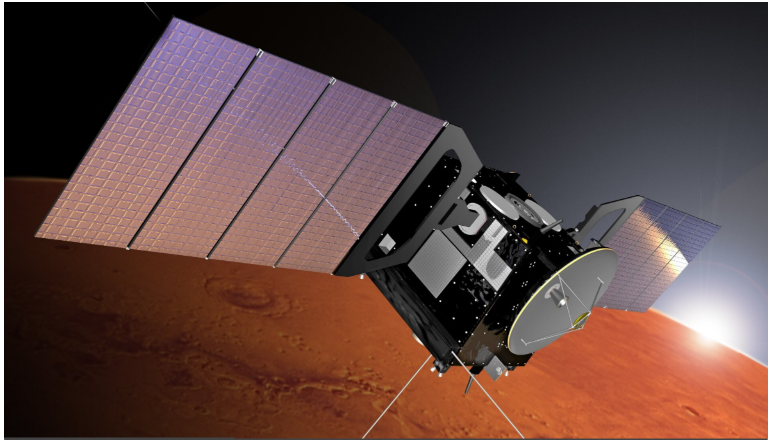
MISSION ANALYSIS REQUIREMENTS



EPS – Electric Power Subsystem – Design

INPUT DATA		
Max Eclipse time	92	min
Orbit Period	7.5	h
Max daylight power budget	500	W
Eclipse power budget	300	W
P_0 @ 1 AU of Si solar cell	202	W/m²
Inherent degradation factor	0.77	-
Peak Power Tracking (PPT)	-	-
Degradation factor Si- cell	2	%/year

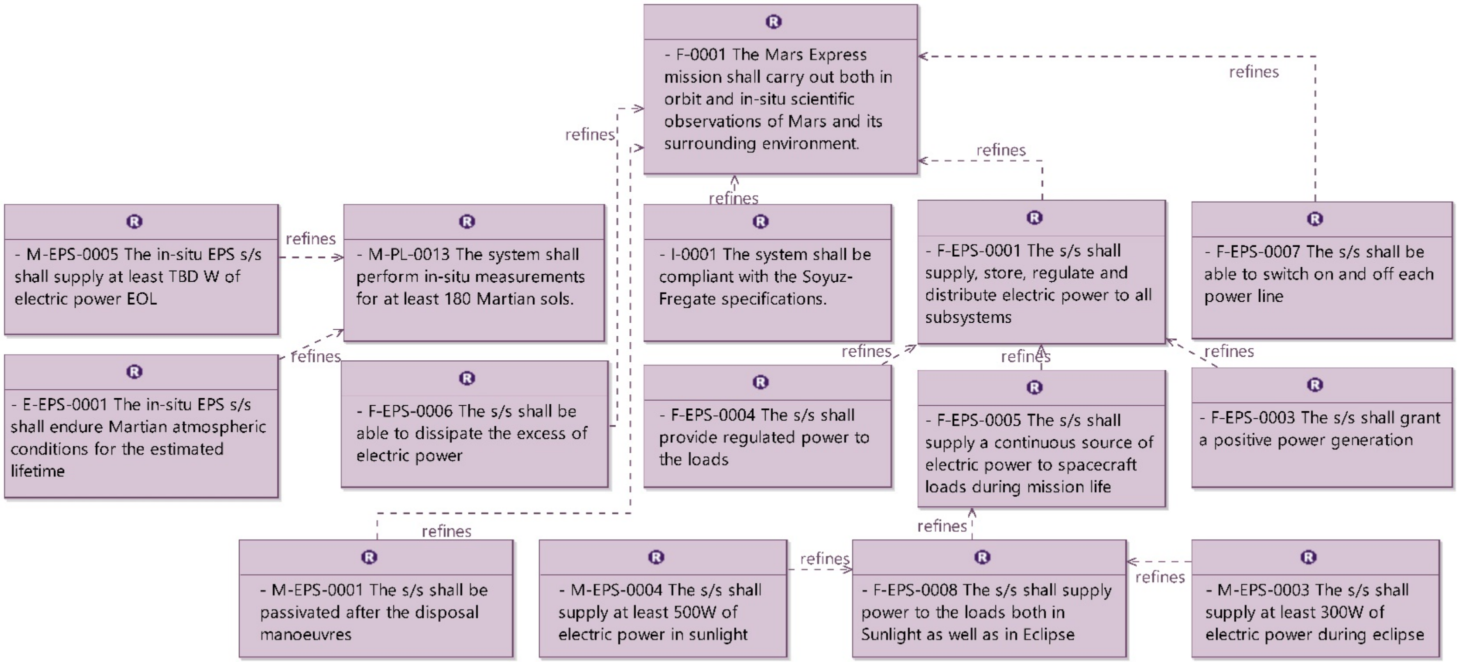
RESULTS		
Total Solar Array Area	11.89	m2
Total Solar Array Mass (+hinges)	~50	kg



Design effects

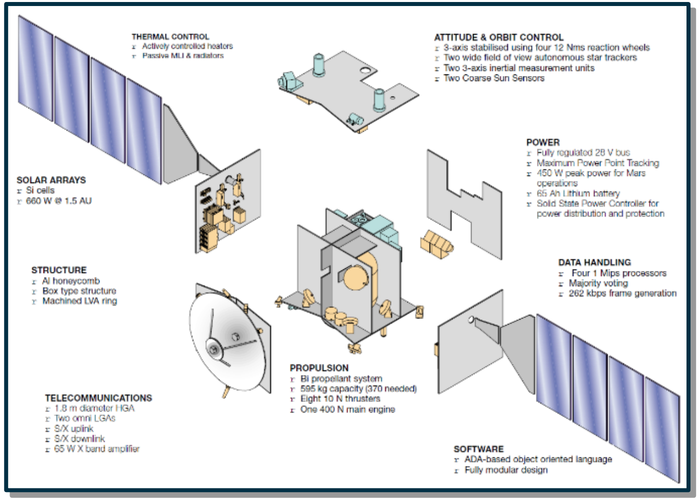
MA	The batteries shall be passivated before disposal phase, otherwise they might explode
CONFIG	Solar arrays need to be folded during launch and unfolded adterwards
STR	Solar panels are long appendages subjected to loads and vibrations
TCS	Electric power creates heat to be dissipated

ELECTRIC POWER SUBSYSTEM - REQUIREMENTS



ADCS – Attitude Determination and Control s/s – Design

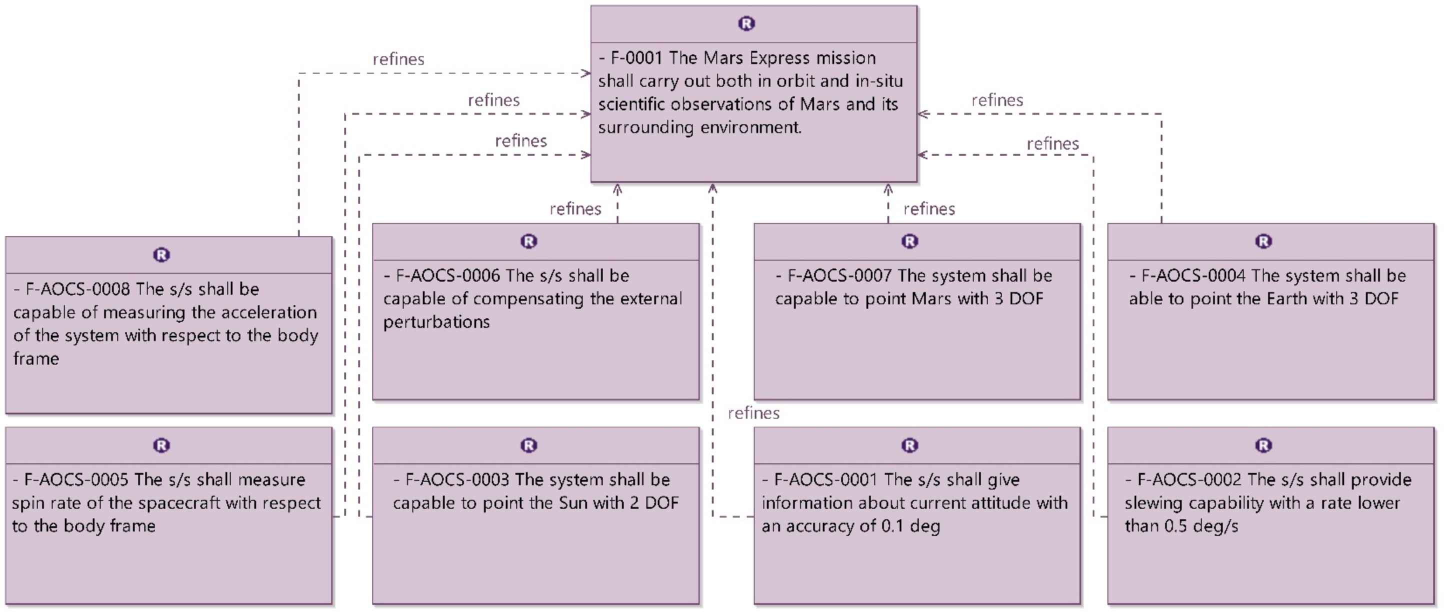
Physical property	deg/s	Result	Real value	Margin	Constraint met
	180 deg /360 s	< 0.0914 Nm	0.075 Nm	Null because worst case perturbation are assumed)	✓
	1.5357e-04 Nm	> 12.29 Nms	12 Nms	100%	Needs slightly less than 3 orbits in worst case scenario



Design effects

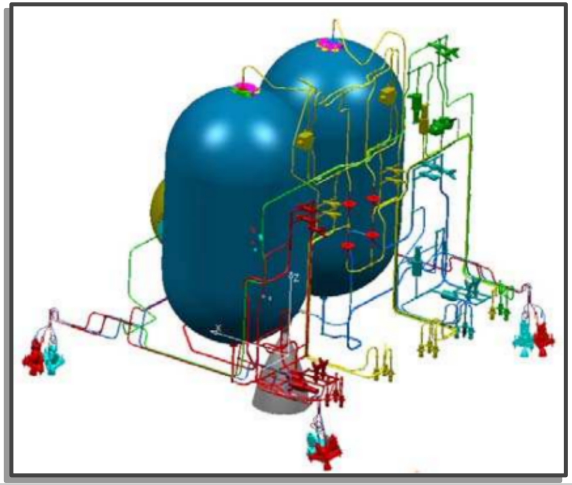
EPS	EPS shall provide 111 W during nominal operations and 391W in the worst-case scenario
OBDH	The onboard computer shall be capable of estimating the attitude and of providing control in a short enough time so that the system can be successfully controlled
STR	The structure of the satellite shall be designed so that all sensors and actuators be placed such that the principal axes of inertia shall be oriented as desired
TCS	PS shall include in the propellant mass at least 4.113kg of propellant per year for desaturation of the RW

ATTITUDE DETERMINATION AND CONTROL S/S - REQUIREMENTS



PS – Propulsion Subsystem – Design

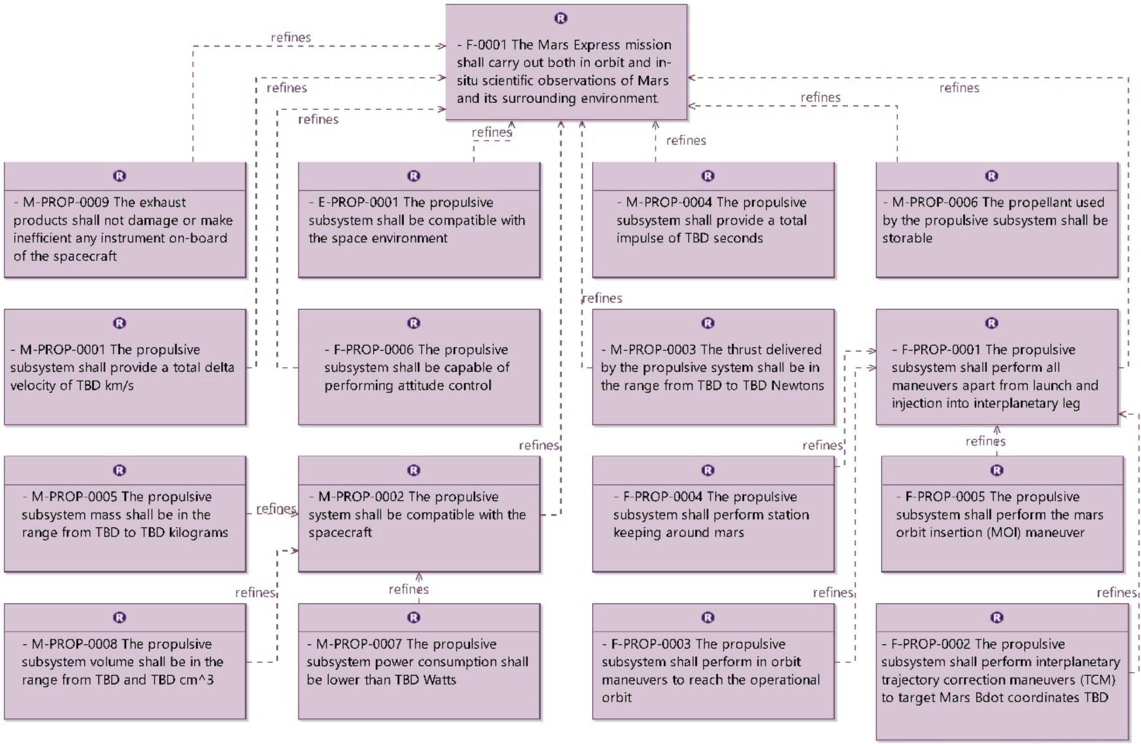
	Margins	Estimated Value	Real Value
Dry mass	0 %	555 kg	555 kg
Thruster	10%	From MA	-
Main engine	5%	From MA	-
Propellant mass	Inherited	433 kg	427 kg
Max volume tanks	10% (3% on masses)	213 L	267 L
Pressure Ox tank	Inherited	13.72 Bar	-
Pressure Fuel tank	Inherited	13.44 Bar	-
Low pressure Gas side	Inherited	13.72 Bar	20 Bar



Design effects

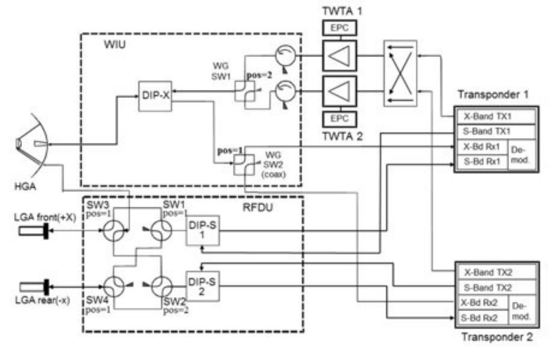
TCS	Heat generated by the main engine shall be dissipated in order not to overheat nearby components
STR	Propellant tanks need support structures which shall resist the loads during the maneuvers
MA	Maneuvreing windows are constrained by the characteristics of the engines such as thrusting range and specific impulse

PROPULSION SUBSYSTEM-REQUIREMENTS



TTMTC - Telecommunication Subsystem - Design

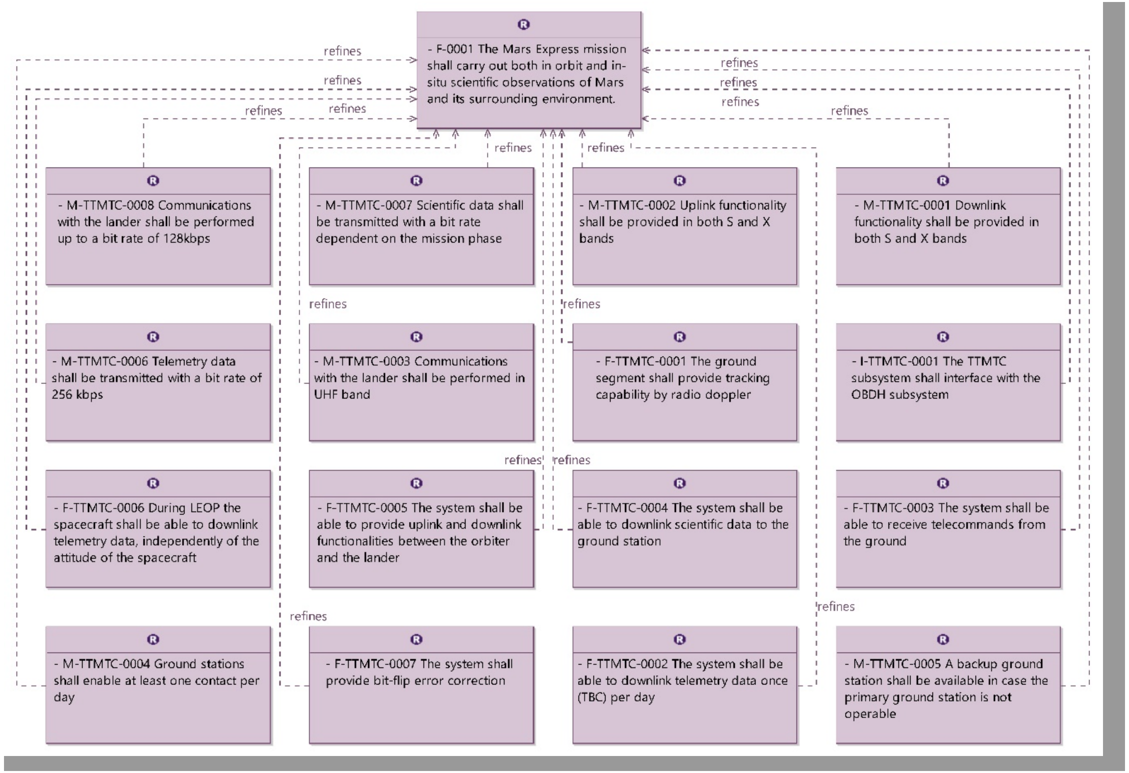
COMPONENT	RELEVANT FEATURES	#	MASS	POWER
HGA	1,65 m diameter | X-band and S-band | Cassegrain system | Centered paraboloid main reflector | hyperboloid dichroic sub-reflector | circular polarisation	1	~25 kg	20 W in X-band, 5 W in S-band
LGA	Quasi-omni-directional | S-band | 40cm long	2	~1.2 kg each	10 W each
Amplifier	output power 48.4 dBm=69 Watts	2	7kg each	65 W each
Transponder	X-band transmitting at 8420 MHz S-band transmitting at 2296 MHz (output power 37dBm)	2	5kg each	14 W
WIU		1	\\	\\
RFDU		1	\\	\\
3dB Hybrid Module		1	~75g	passive
		2		



Design effects

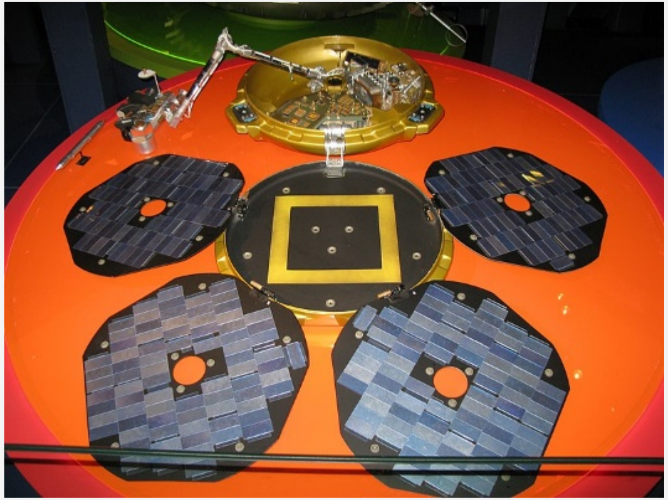
OBDH	Manage and compress collected data
ADCS	Fine attitude required for HGA
CONFIG	The solar panels shall not be overshadowed by the antenna, which shall stay on the cold side far from the exhaust gases

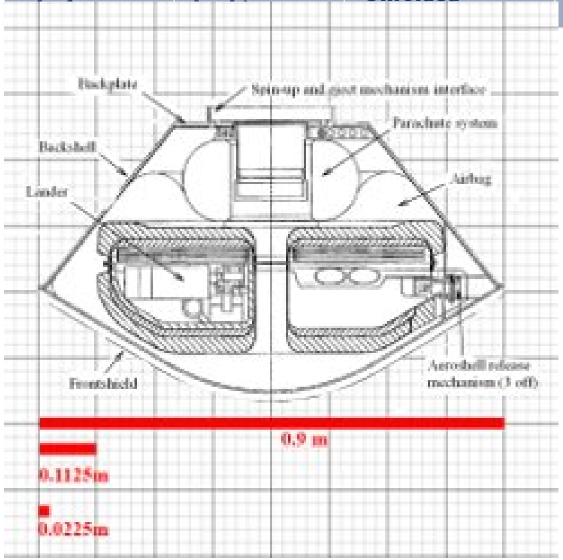
TELECOMMUNICATION SUBSYSTEM- REQUIREMENTS



TCS - Thermal Control Subsystem - Design

Componen t	Coating	Configuration	α	ε
Frontshield	Black kapton	Folded	0,52	0,8
Backshell	Vacuum deposited aluminum	Folded	0,09	0,04
Backplate	Chemglaze z306 black paint	Folded	0,92	0,89
Instrument	Teflon gold-	Unfolded	0,24	0,43

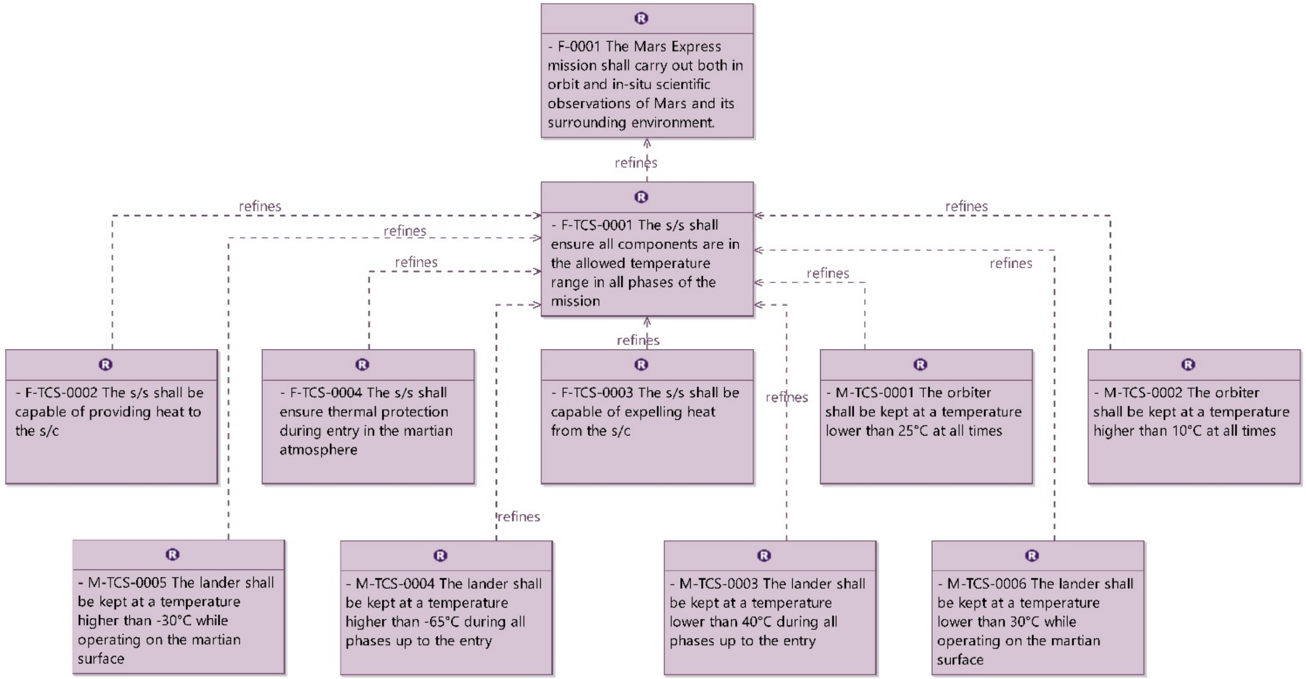




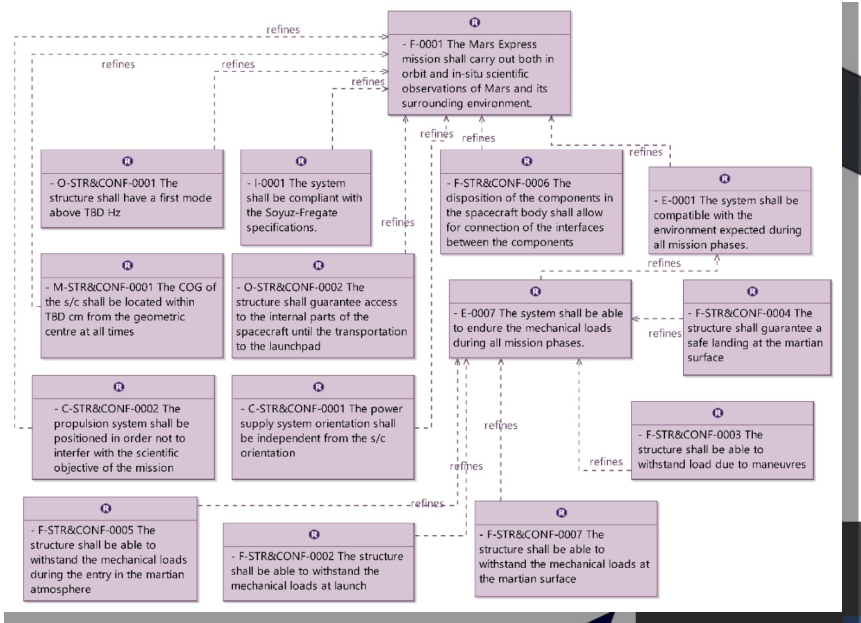
Design effects

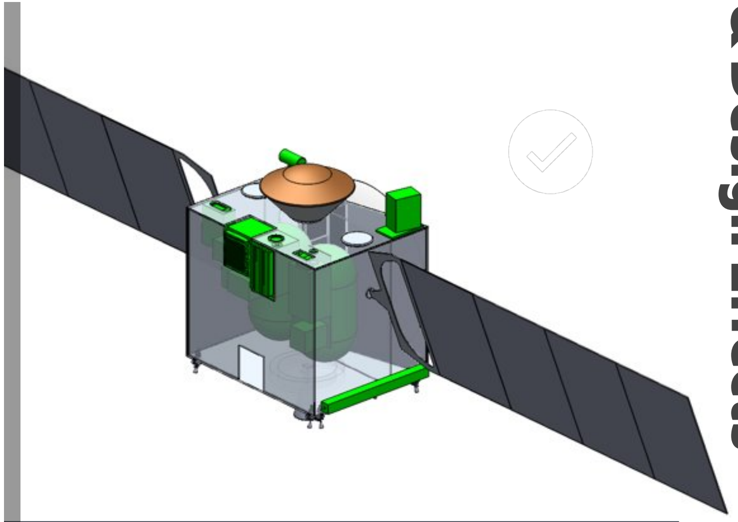
EPS	EPS shall be able of providing at least 394 W for the orbiter, and 6 W for the lander
OBDH	OBDH shall be able of analyzing the s/s temperatures and give the necessary commands
PAYLOAD	The health and correct functioning of each scientific instrument is heavily influenced by the temperature at which is kept
STR	The structure of the satellite shall be designed respecting the considerations done for the TCS
ADCS	Different coatings cause more or less SRP (solar radiation pressure) acting on the s/c. Changes in the inertia due to moving or stationary TCS components

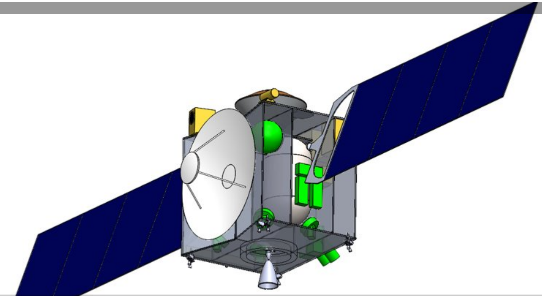
THERMAL CONTROL SUBSYSTEM- REQUIREMENTS



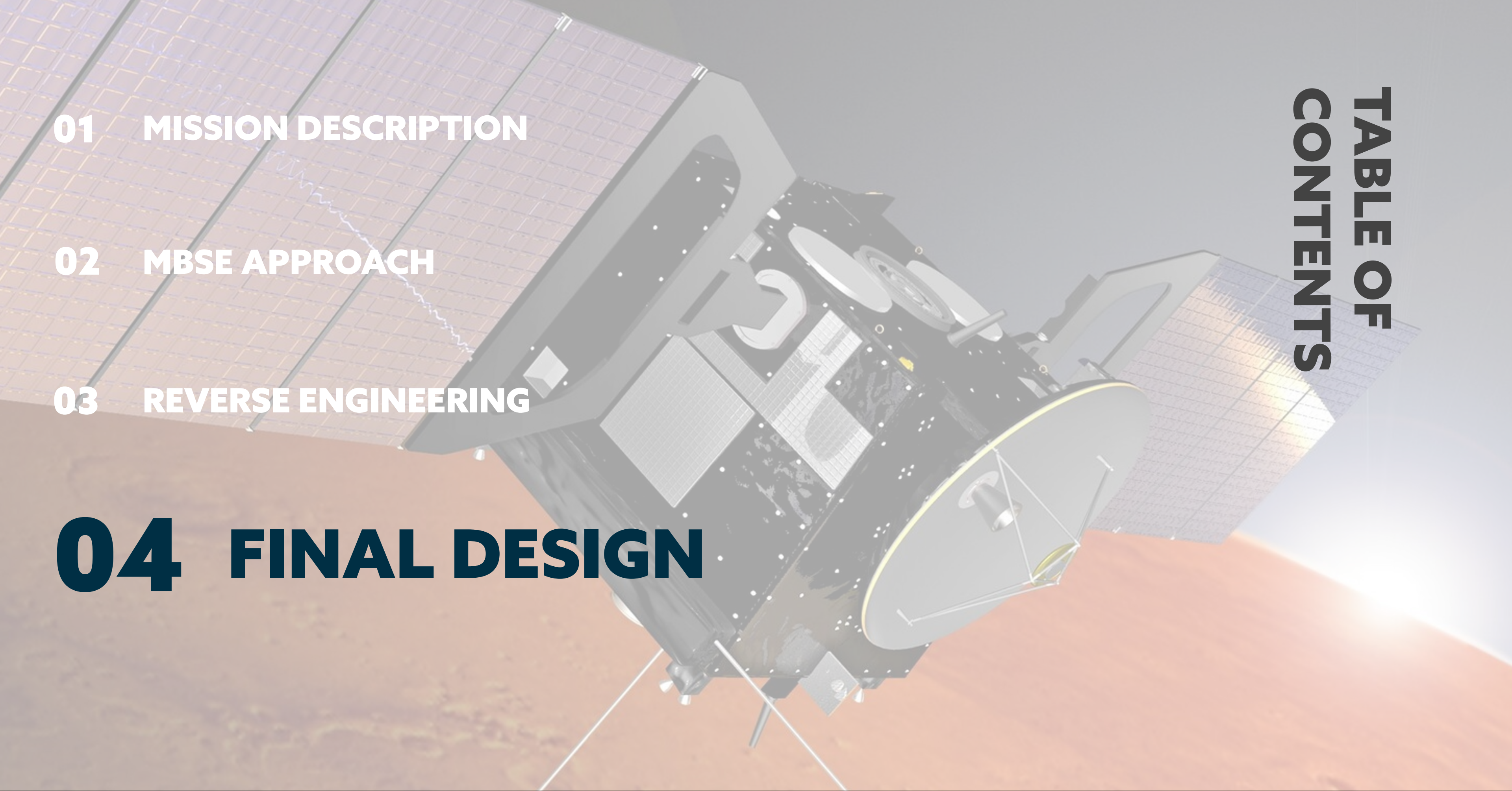
STR&CONFIG – Requirements & Design Effects







Design effects	
OBDH	Manage and compress collected data
ADCS	Fine attitude required for HGA
CONFIG	The solar panels shall not be overshadowed by the antenna, which shall stay on the cold side far from the exhaust gases



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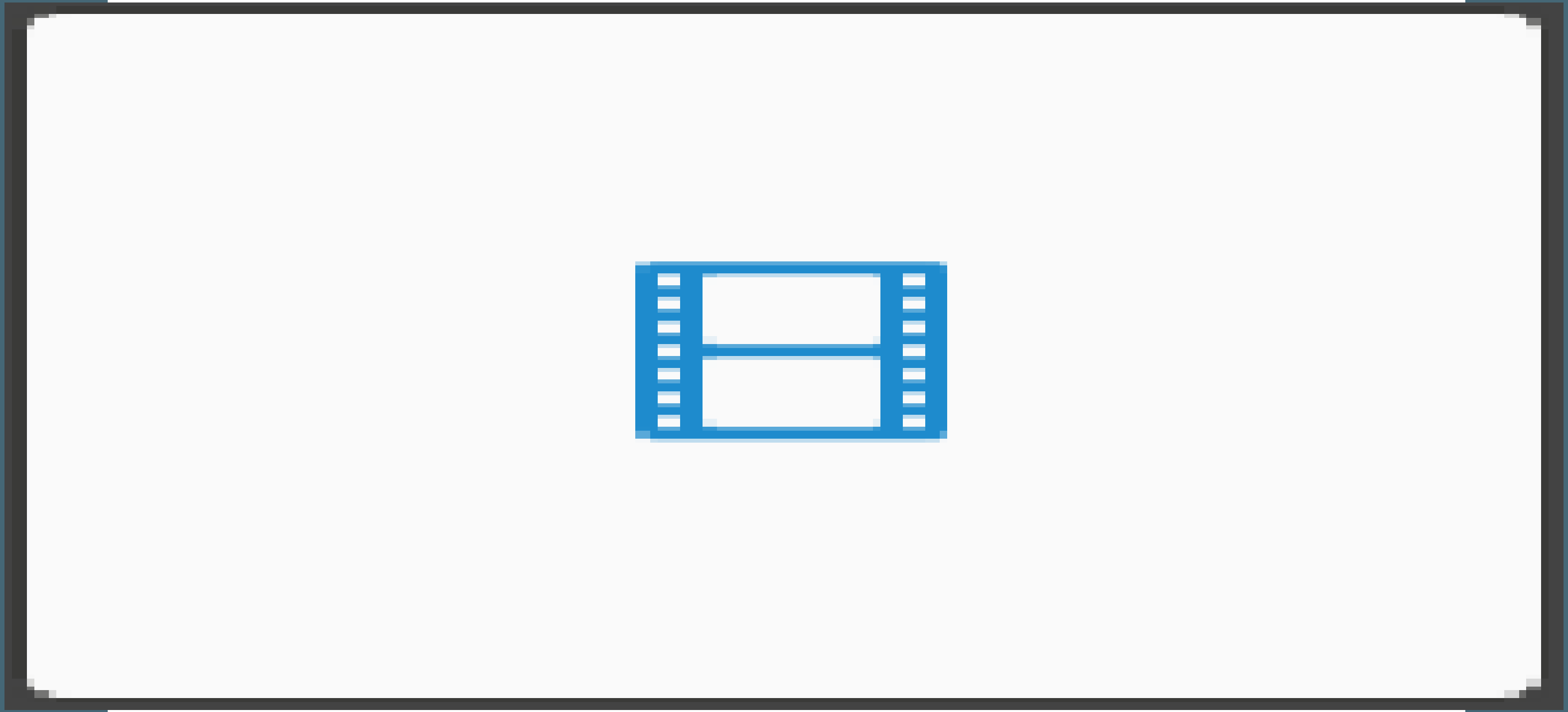
04 FINAL DESIGN

FINAL CONFIGURATION



THANKS

Do you have any questions?

Pls feel free to **contact us** for the model of the project

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***PROJECT REALIZED DURING THE ACADEMIC COURSE: «SPACE SYSTEMS ENGINEERING AND OPERATIONS», PROF. M. LAVAGNA, POLITECNICO DI MILANO**