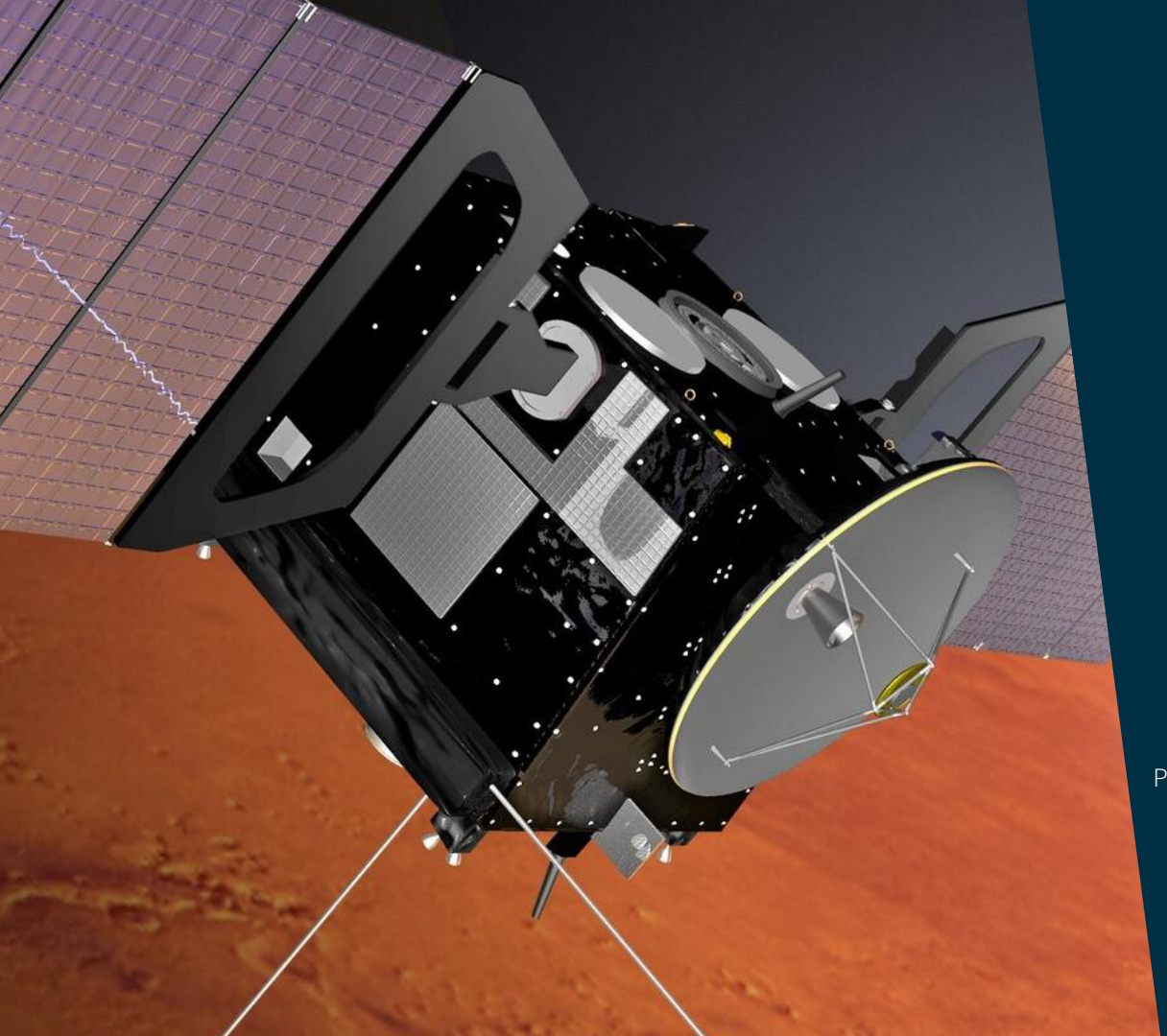

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MBSE-aided reverse engineering of an Interplanetary Space Mission

Arioli Andrea | Bellicoso Davide | Pecchini Luca
Prosperi Alessio | Rambaldi Riccardo | Tomassi Emanuele

SWISSED

esa
mars express

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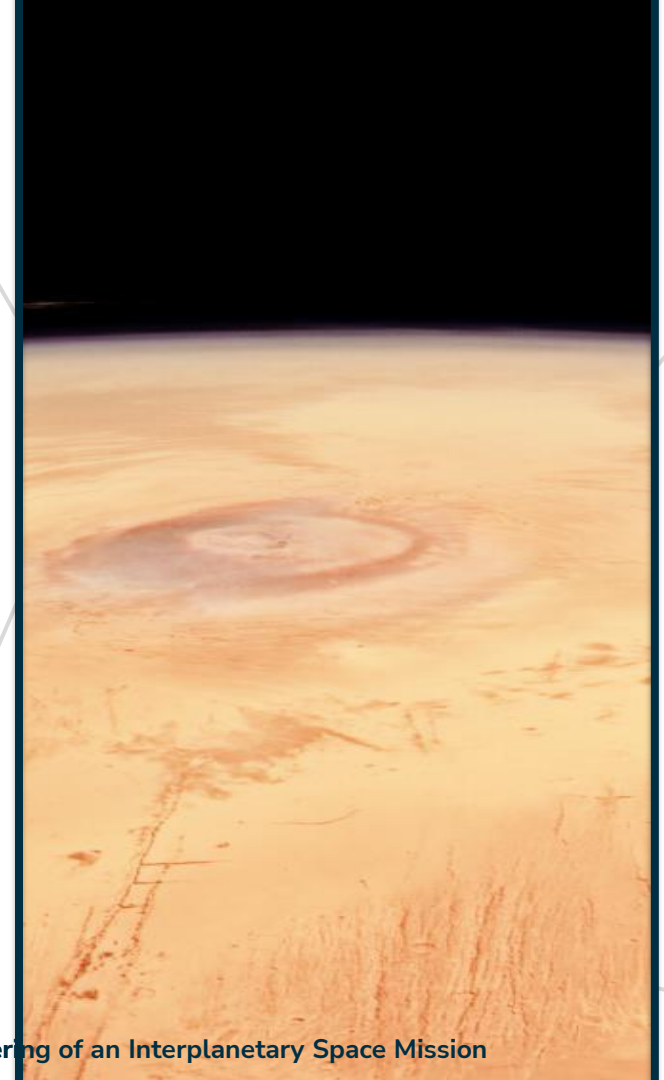
INTRODUCTION

Mission Statement

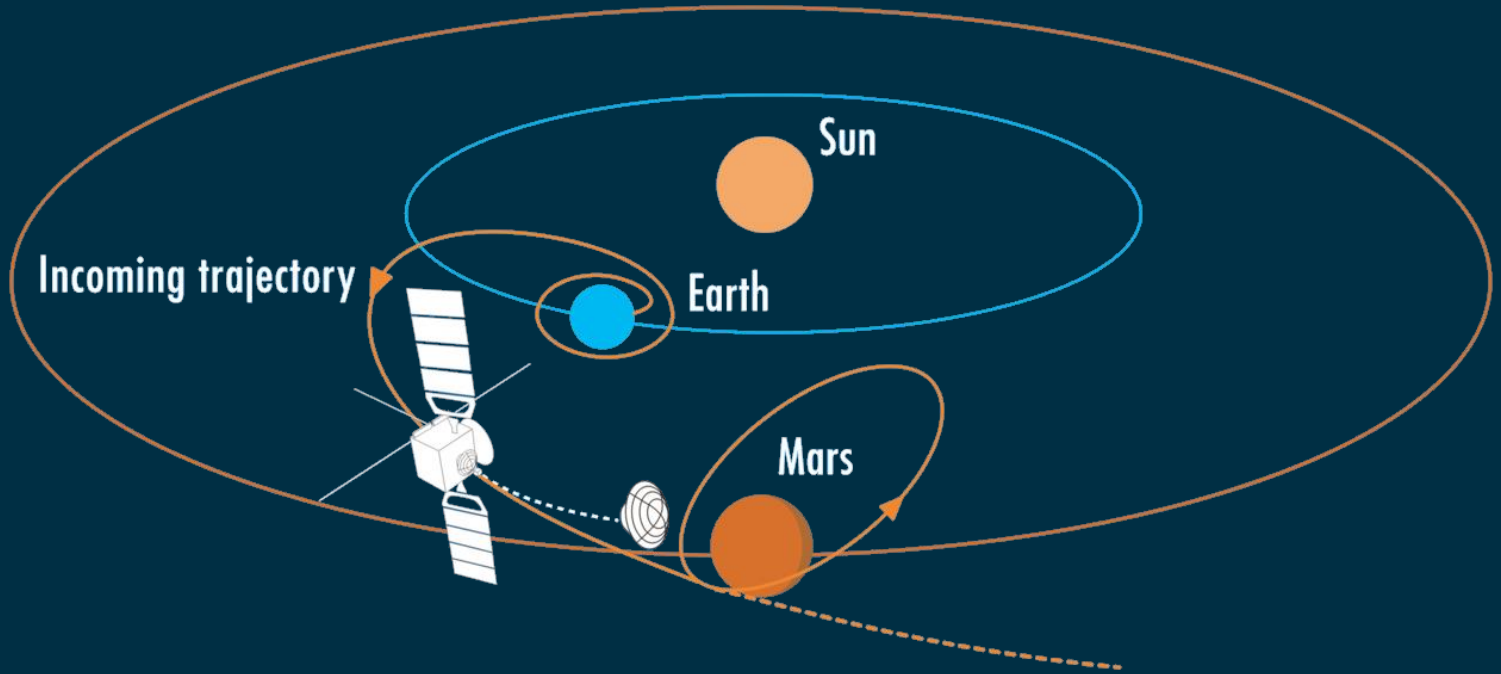
"The Mars Express mission has the objective to monitor all aspects of the martian environment, including the subsurface, surface and atmosphere of the planet, and to take pictures of the Martian moons Phobos and Deimos, in order to search for evidence of extinct or extant life"



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

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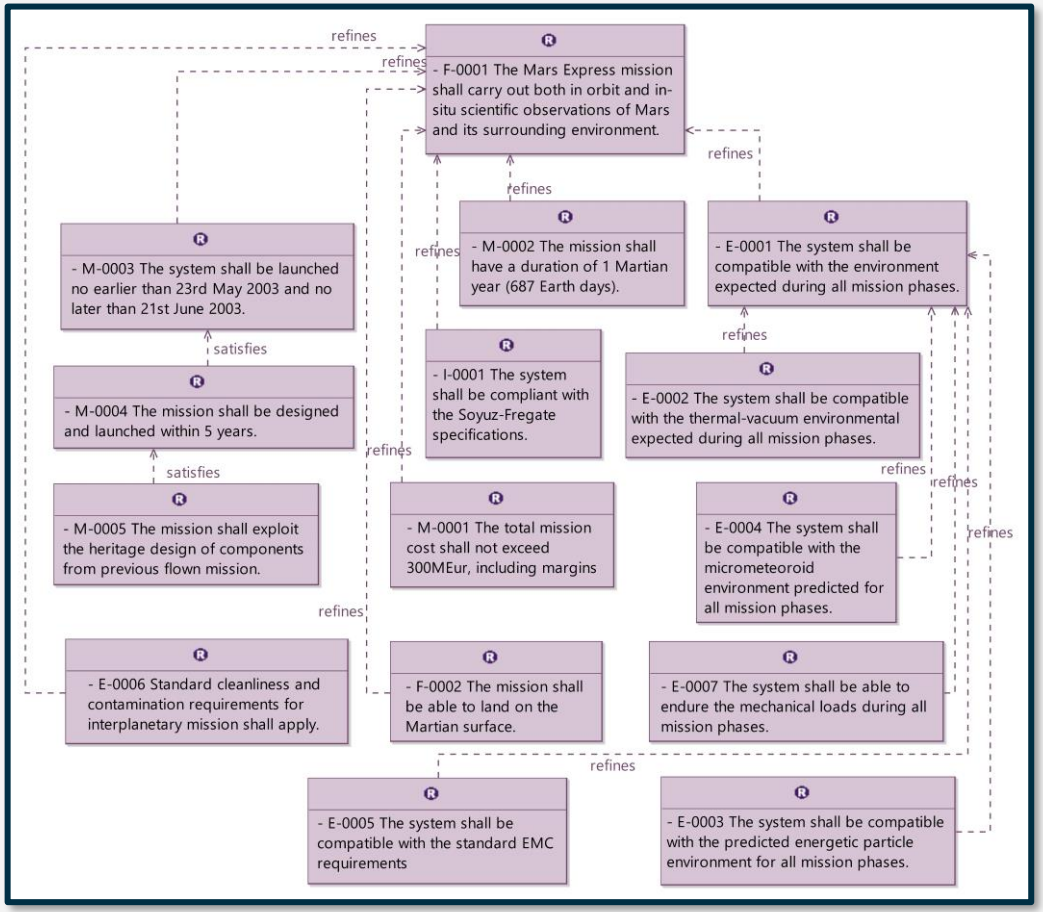
MISSION REQUIREMENTS



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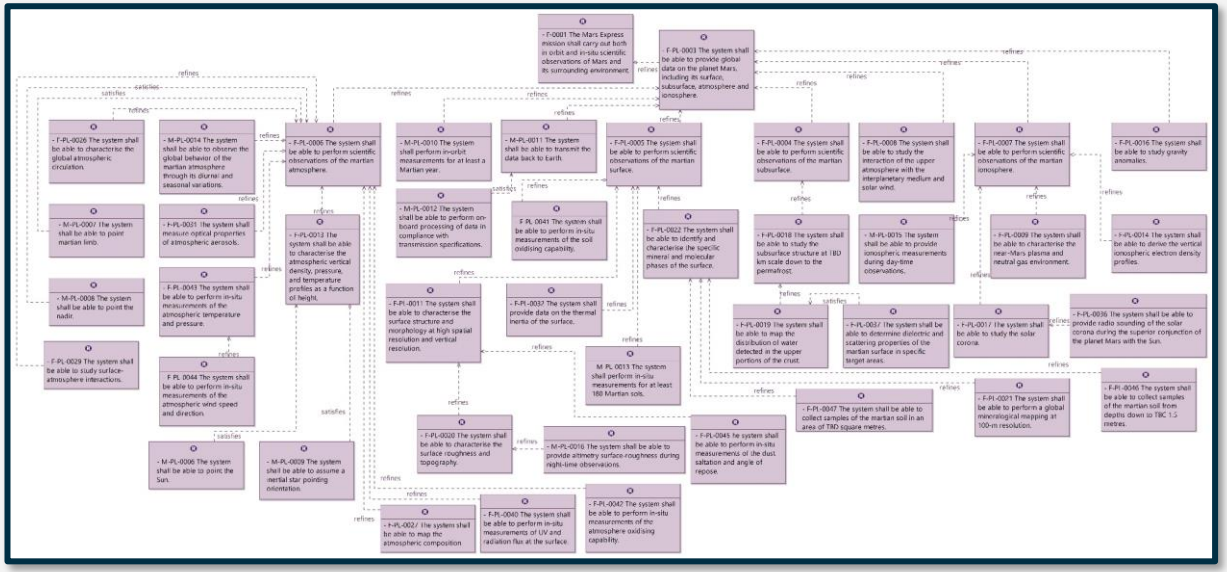
PAYLOAD REQUIREMENTS



8 PAYLOADS FOR THE ORBITER
MULTIPLE (~10) PAYLOADS FOR THE LANDER

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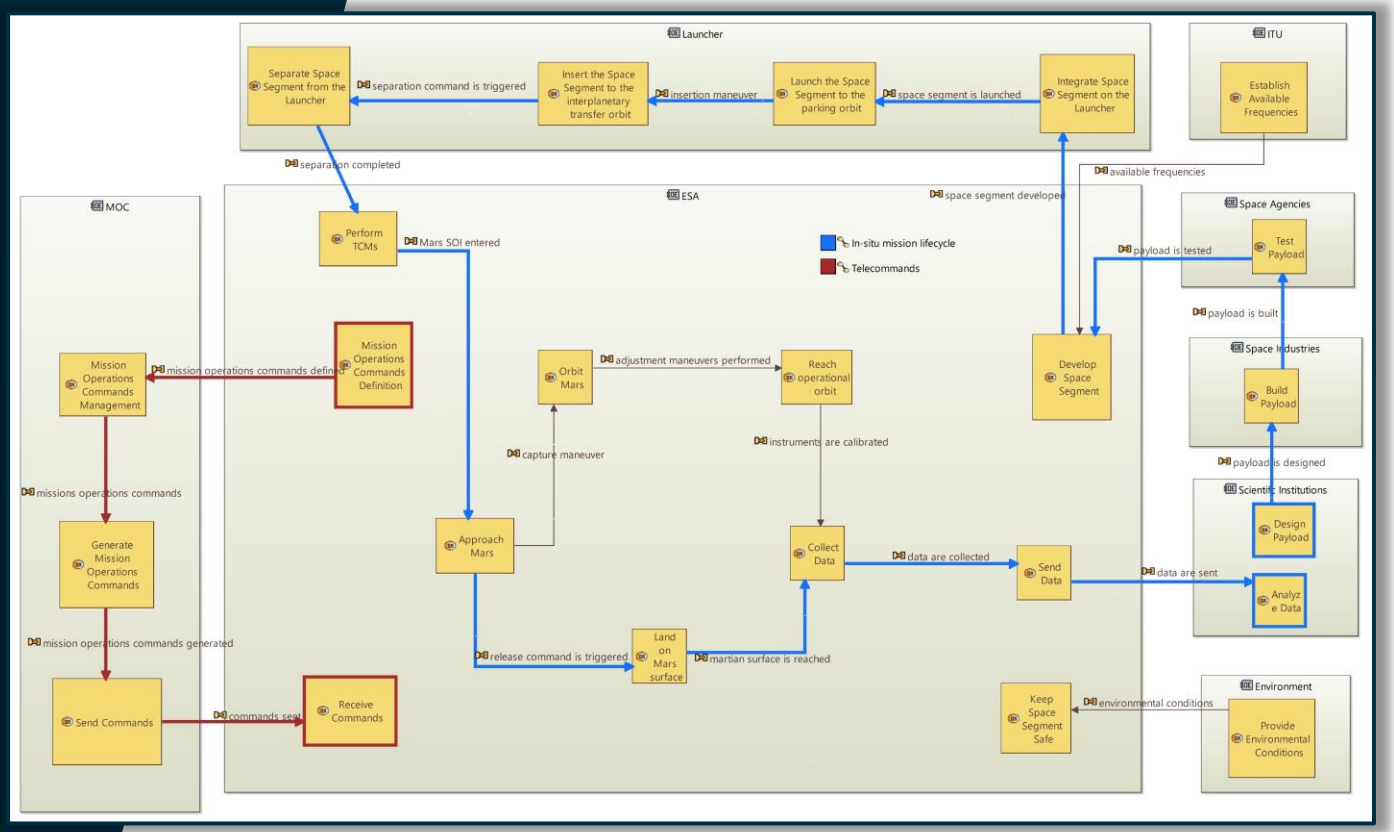
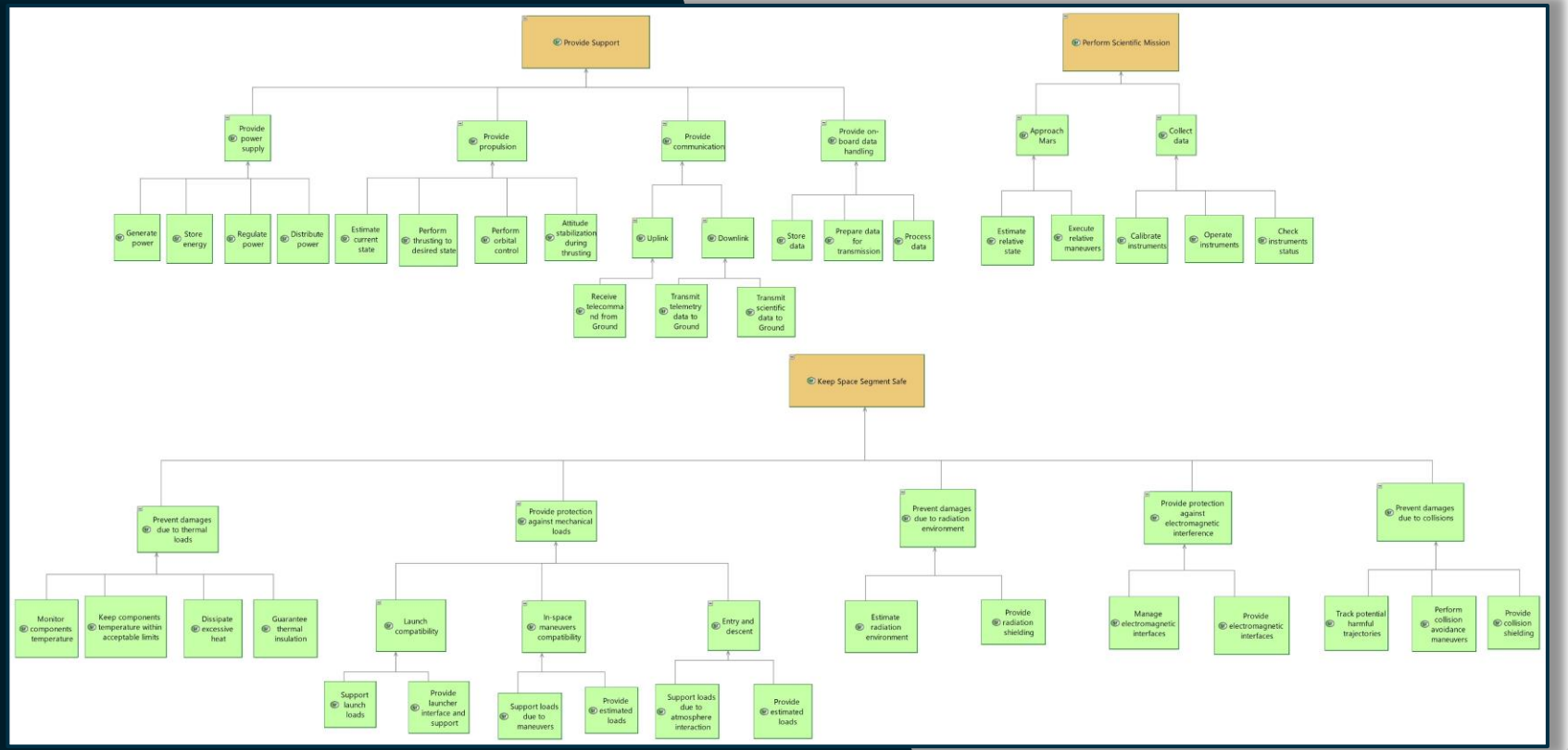
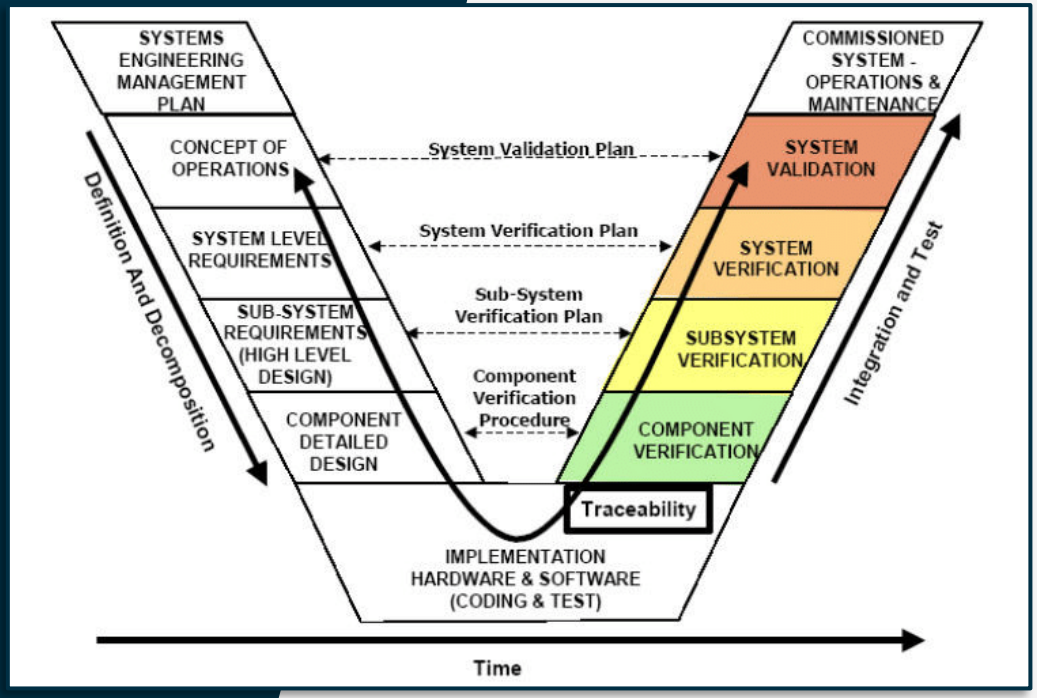
OPERATIONAL ARCHITECTURE



FUNCTIONAL ANALYSIS



V-DIAGRAM



Reversed approach:

- define requirements from the final design choices and mission real lifetime
- start from data listed in literature to go through the calculations that led to the ultimate design

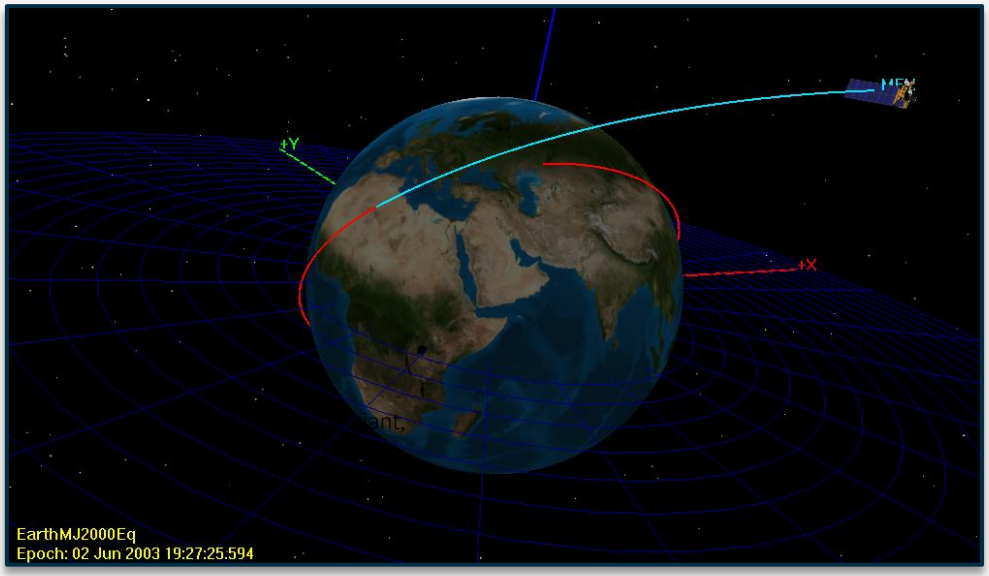
MISSION ANALYSIS
REVERSE ENGINEERING

Find data from literature:

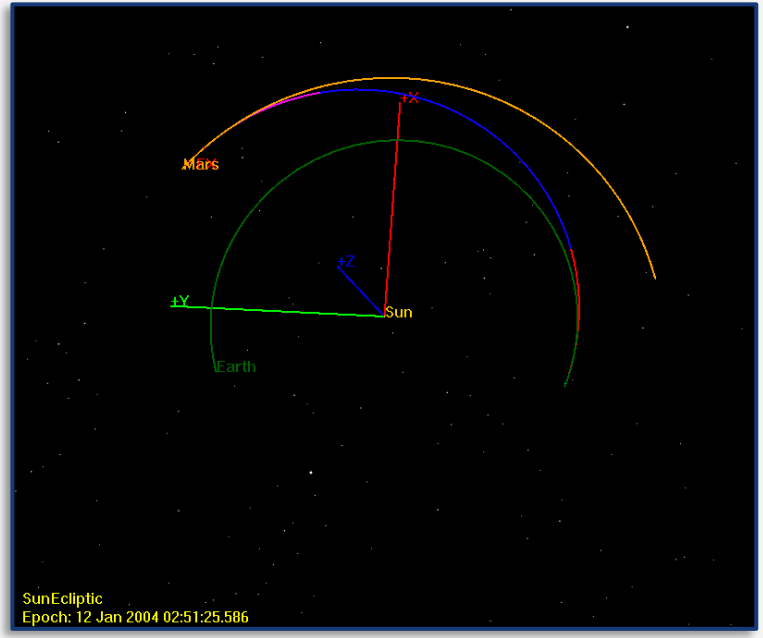
- Departure date
- Launch site
- Launcher user manual

Retrieve initial parking orbit and escape manoeuvre

SMA [km]	6571
ECC	0
INC [deg]	52.11
RAAN [deg]	167.98
AoP [deg]	0
TA [deg]	76.9



MISSION ANALYSIS
REVERSE ENGINEERING



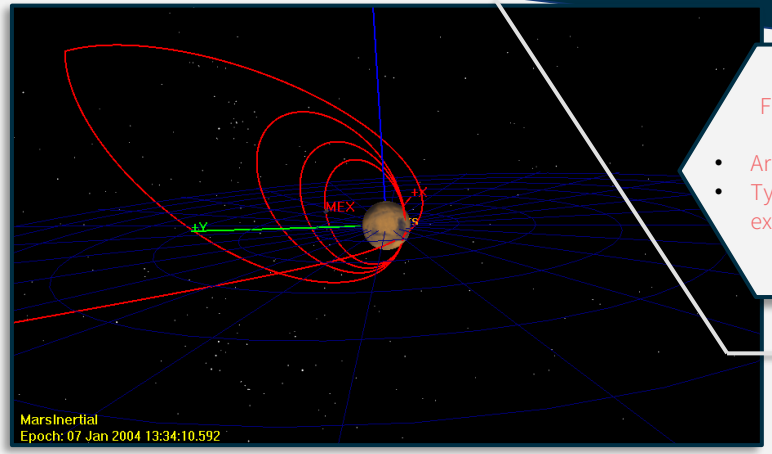
Find data from literature:

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

Compute the Trajectory Correction Manoeuvres

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

MISSION ANALYSIS
REVERSE ENGINEERING

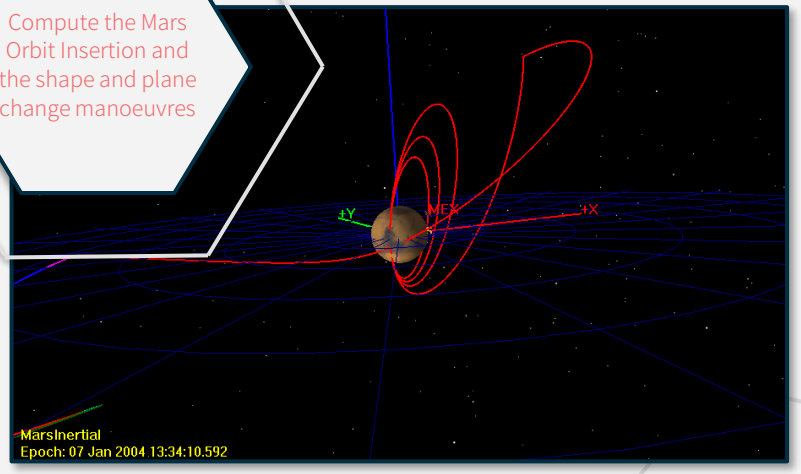


Find data from literature:

- Arrival date
- Type of manoeuvres executed

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

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



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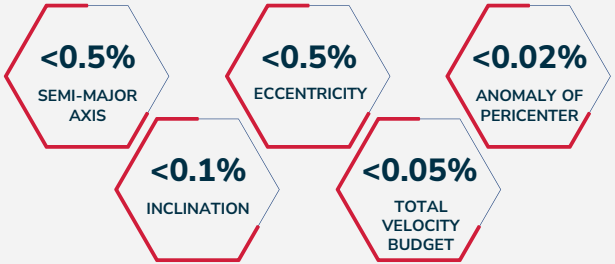
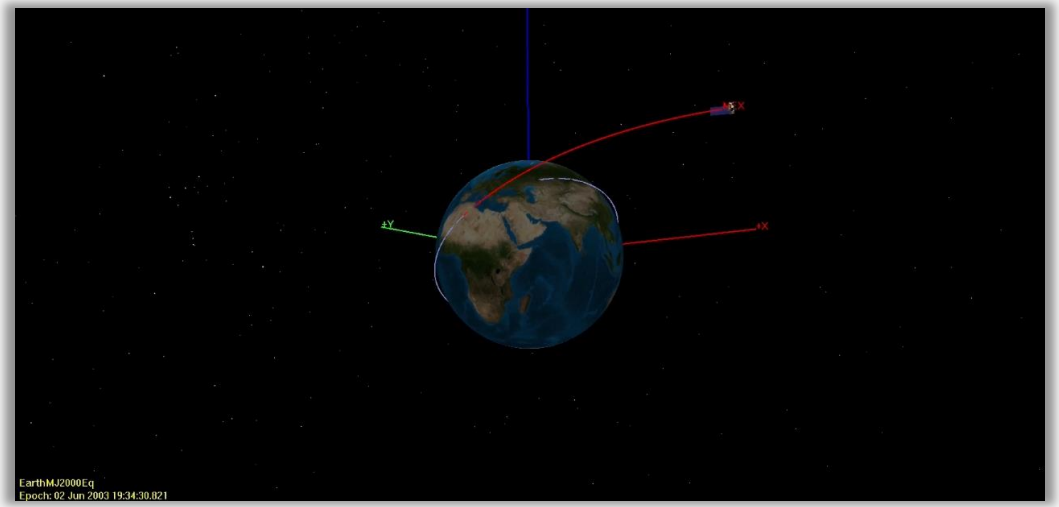
MISSION ANALYSIS REVERSE ENGINEERING

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





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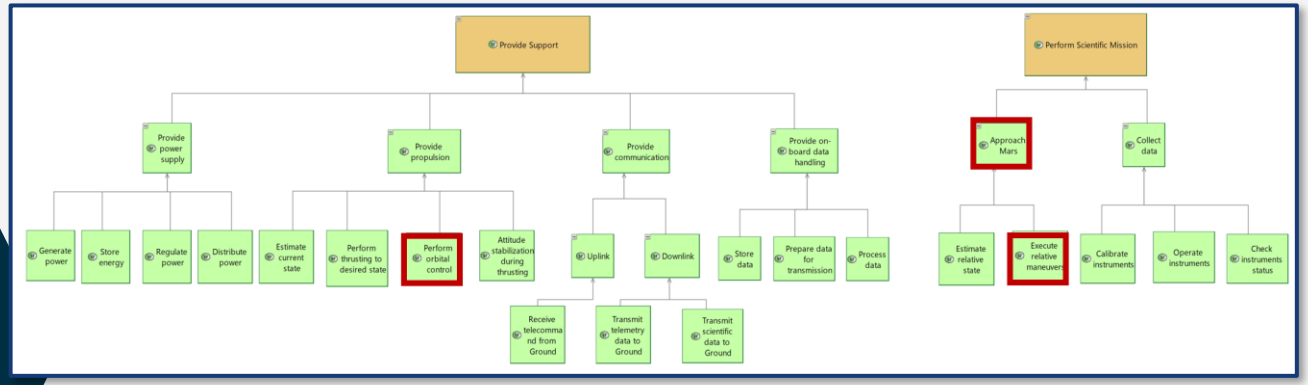
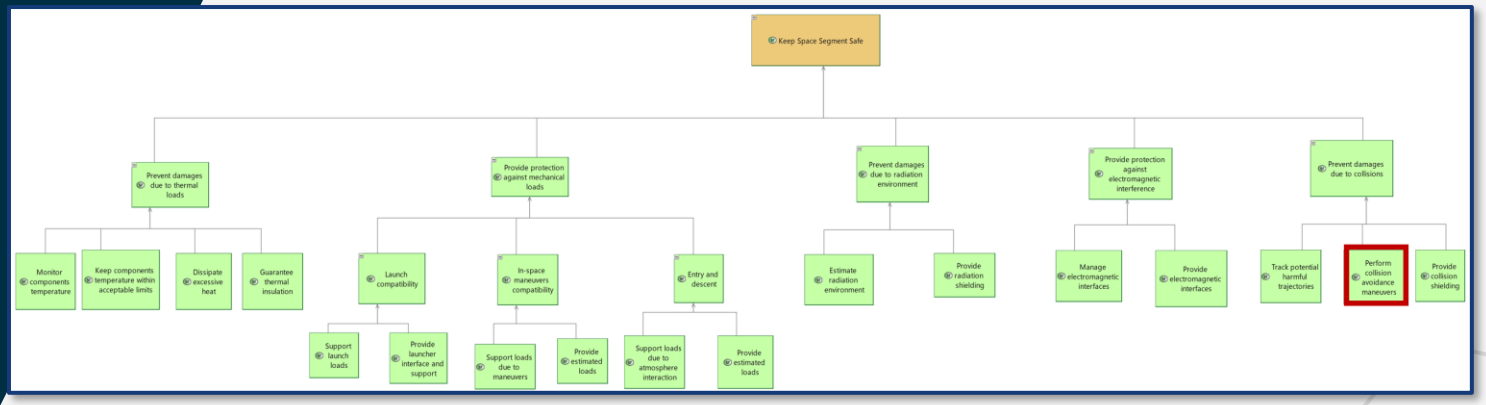
MISSION ANALYSIS JUSTIFICATION

From Functionalities





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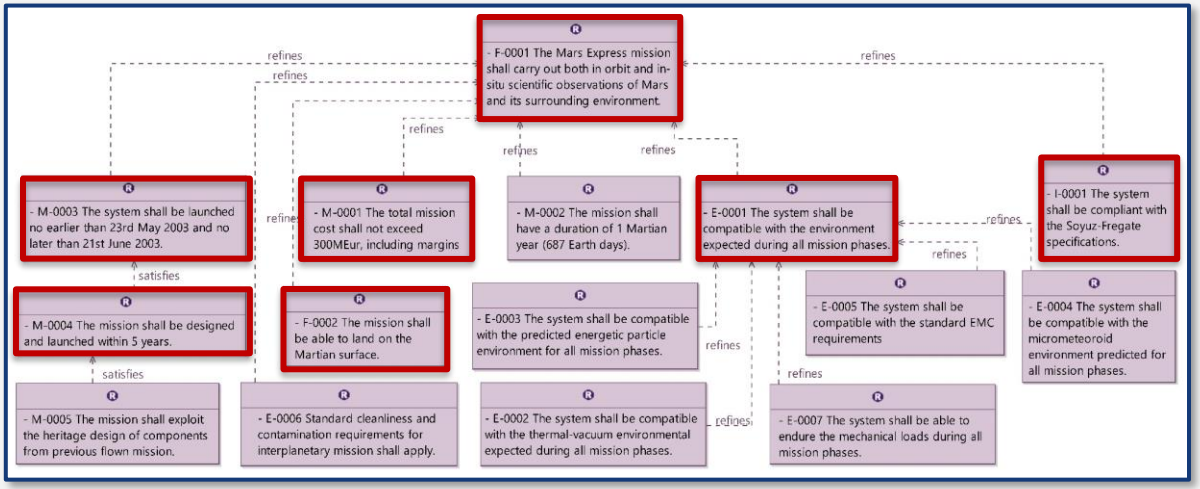
MISSION ANALYSIS JUSTIFICATION

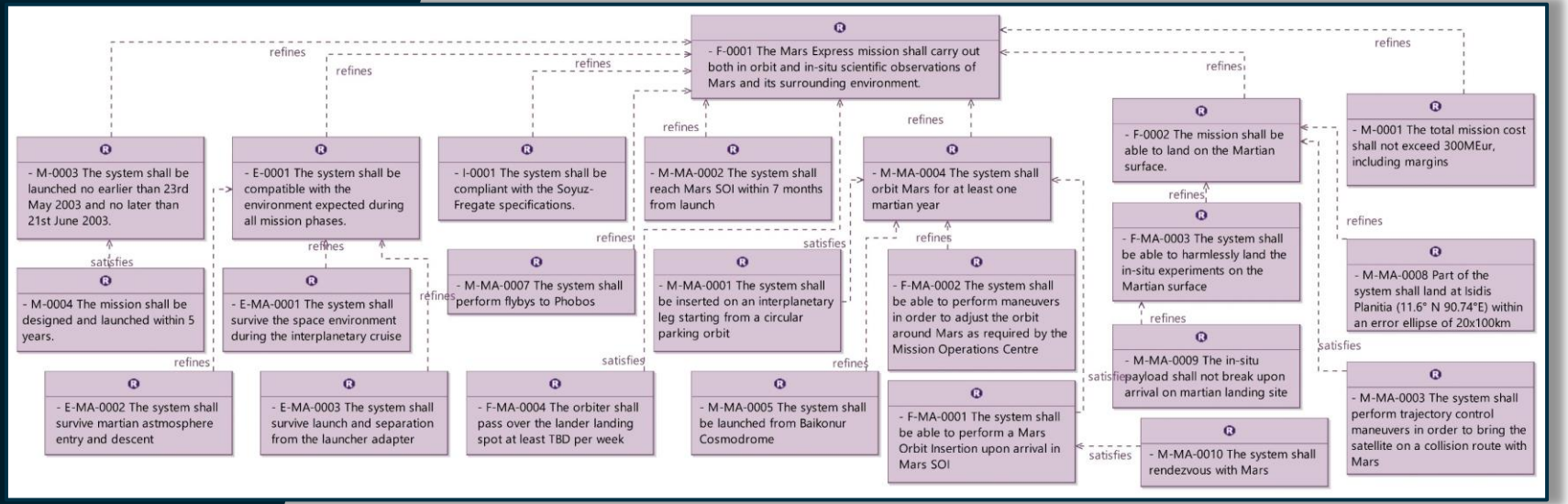
From Mission Requirements



From Mission Objectives

POLAR ORBIT	PLANET OBSERVATION
HIGH ECCENTRICITY	COMMUNICATION WITH GROUND STATION
HIGH SEMIMAJOR AXIS	STUDY SOLAR WIND AND ATMOSPHERE
LANDER	IN-SITU INVESTIGATION

MISSION ANALYSIS REQUIREMENTS



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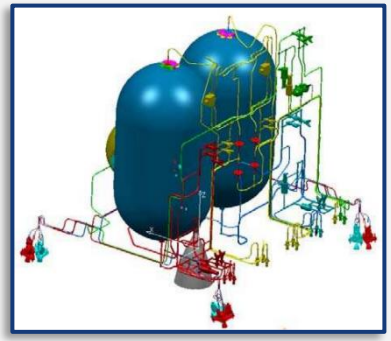
ELECTRIC POWER SUBSYSTEM

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/m^2
Inherent degradation factor	0.77	-
Peak Power Tracking (PPT)	-	-
Degradation factor Si- cell	2	%/year

RESULTS		
Total Solar Array Area	11.89	m^2
Total Solar Array Mass (+hinges)	~50	kg

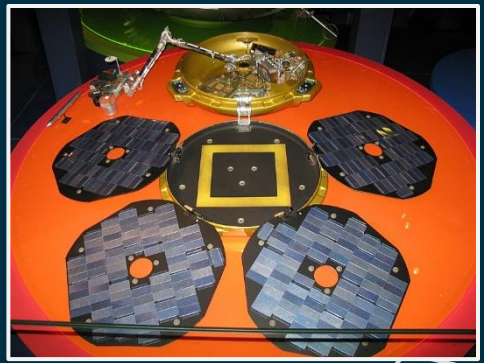


	MARGINS	ESTIMATED VALUE	REAL VALUE
Dry mass	0 %	555 kg	555 kg
Thruster	10%	From MA	-
Main engine	5%	From MA	-
Propellant mass	Inherited	433 kg	427 kg
Max volume tanks	10% (3% on masses)	213 L	267 L
Pressure Ox tank	Inherited	13.72 Bar	-
Pressure Fuel tank	Inherited	13.44 Bar	-
Low pressure Gas side	Inherited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

PROPULSION SUBSYSTEM

THERMAL CONTROL SUBSYSTEM

COMPONENT	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 platform	Teflon gold-backing	Unfolded	0,24	0,43



A fully deployed Beagle 2 replica

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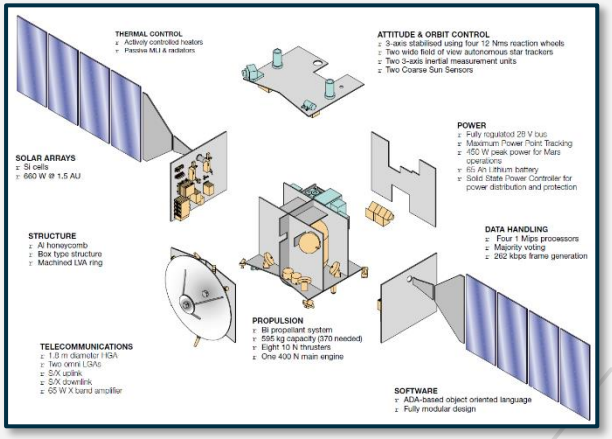
COMPONENT	RELEVANT FEATURES	QTY	MASS	POWER
HGA	a)1,65 m diameter b)X-band and S-band c)Cassegrain system d)Centered paraboloid main reflector e)hyperboloid dichroic sub-reflector f) circular polarisation	1	~25 kg	20 W in X-band, 5 W in S-band
LGA	a) quasi-omni-directional b) S-band c) 40cm long	2	~1.2 kg each	10 W each
Amplifier	output power 48.4 dBm=69 Watts	2	7kg each	65 W each
Transponder	a) X-band transmitting at 8420 MHz b) S-band transmitting at 2296 MHz (output power 37dBm)	2	5kg each	14 W
WIU		1	\\	\\
RFDU		1	\\	\\
3dB Hybrid Module		1	~75g	passive
TOTAL			51.4 kg (8% of total mass budget)	~ 184 W (36% of total power budget)

TRACKING, TELEMETRY & TELECOMMUNICATION SUBSYSTEM

ATTITUDE DETERMINATION AND CONTROL SUBSYSTEM

PHYSICAL PROPERTY	T_{ext_mean} | DEG/S	RESULT	REAL VALUE	MARGIN	CONSTRAINT MET
$Torque_{max\_RW}$	180 deg /360 s	< 0.0914 Nm	0.075 Nm	Null because worst case perturbation are assumed)	✓
H_{RW}	1.5357e-04 Nm	> 12.29 Nms	12 Nms	100%	Needs slightly less than 3 orbits in worst case scenario



Credit: ESA bulletin 98 – June 1999

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DESIGN EFFECTS

TCS

- **EPS:** Provide 400 W
- **OBDH:** Analyze the s/s temperatures and give commands
- **Instruments:** Functioning influenced by TCS
- **ADCS:** Different coatings cause a change in SRP and active TCs change inertia

PS

- **TCS:** Dissipation of heat from the ME
- **STR:** Support structure for propellant tanks
- **MA:** Constraints on maneuvering windows due to engine characteristics

ADCS

- **Disposal:** Passivation of batteries
- **Configuration:** Solar Arrays unfolding
- **TCS:** Dissipation of heat due to electric power
- **STR:** Loads on Solar Arrays

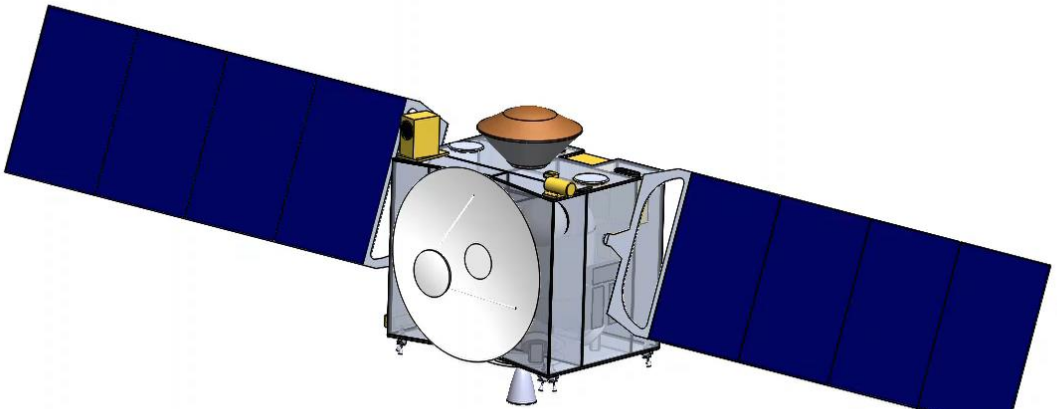
TTMTC

- **OBDH:** Manage and compress collected data
- **ADCS:** Fine attitude for HGA
- **Configuration:** Antenna shall not put shadow on SAs and must stay on the cold side far from exhaust gases

ADCS

- **EPS:** Provide 111 W or 391 W in worst case
- **OBDH:** Estimate the attitude and provide control in short time
- **STR:** Real principal axes of inertia oriented as desired
- **PS:** 4.113 kg of propellant for RWs desaturation

FINAL DESIGN



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***Project realized during the academic course: «Space Systems Engineering and Operations», Prof. M. Lavagna, Politecnico di Milano**