National Aeronautics and Space Administration

Exploring Mars: An Overview

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A Presentation to the Senior Aerospace Design Course

University of California Los Angeles

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Agenda

- History of Mars Exploration
  - Why Explore Mars?
  - An Overview of the Mars System
  - Overview of Missions to Mars
- Challenges of Mars Exploration
  - Getting there – To Orbit and to the Surface
  - Delta-V: Ballistic, Aeroassist, SEP
  - EDL – Controlled landing
  - Flight Systems – Rover example
- Potential Mars Sample Return
  - Architecture and Challenges
- Potential Phobos Sample Return - Challenges

Brief Introduction to Mars Exploration

Why Explore Mars?

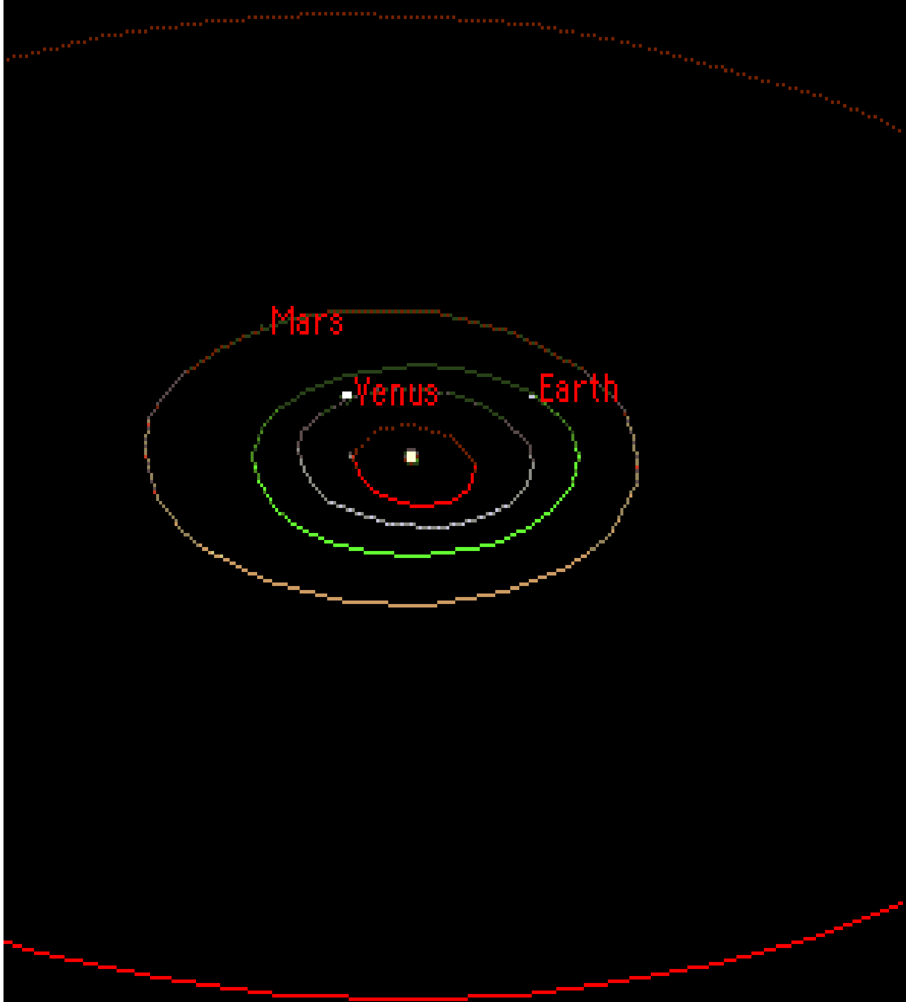
"Mars is unique among the planets in having experienced processes comparable to those on Earth during its formation and evolution. Crucially, the martian surface preserves a record of earliest solar system history, on a planet with conditions that may have been similar to those on Earth when life emerged."

"Discoveries on the surface of Mars point to an early warm wet climate, and perhaps conditions under which life could have emerged."

- **"Vision and Voyages for Planetary Science in the Decade 2013-2022",** Committee on the Planetary Science Decadal Survey, Space Studies Board, Division on Engineering and Physical Sciences, National Research Council, 2011

- http://www.nap.edu

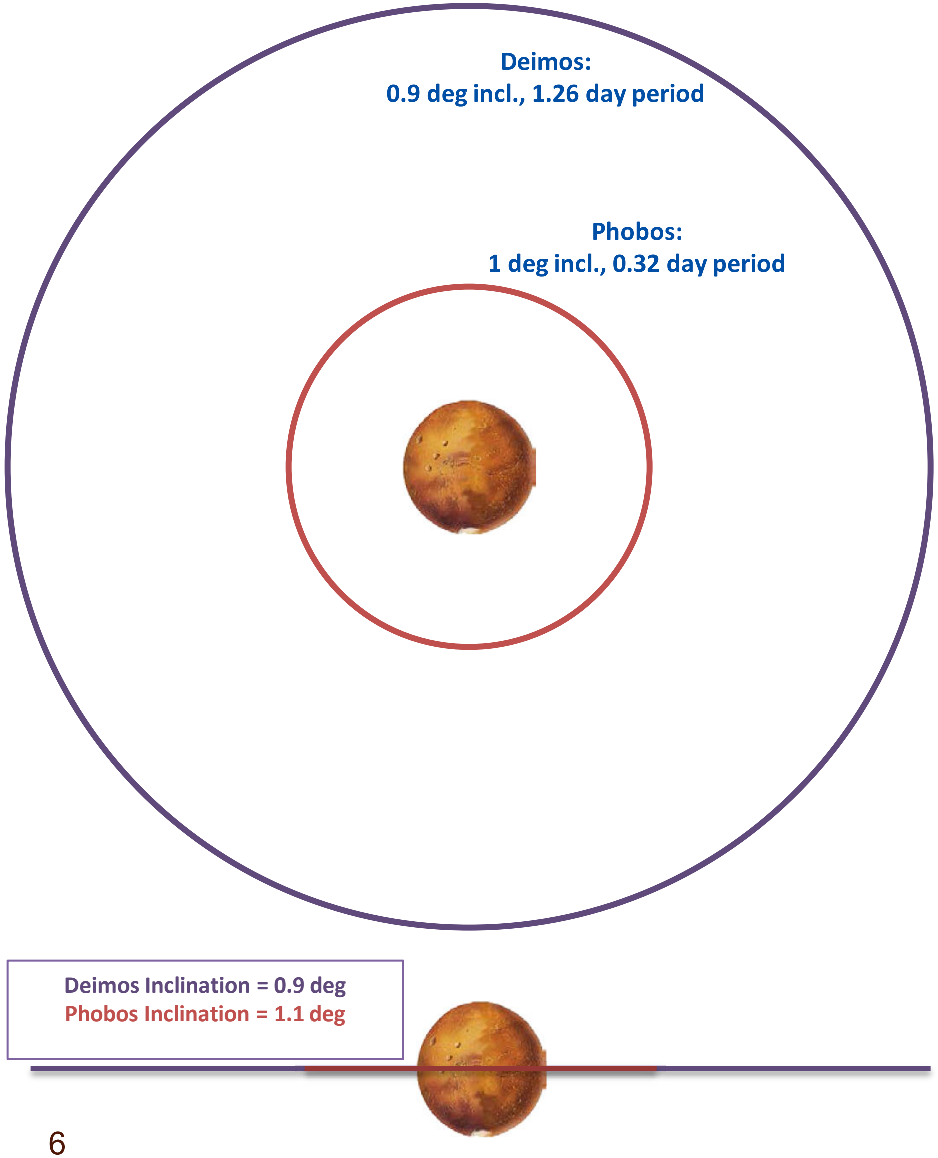
An Overview of the Mars System



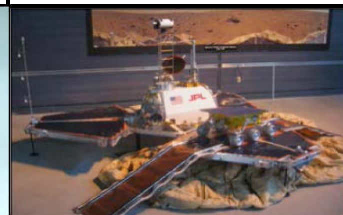
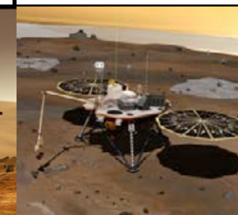
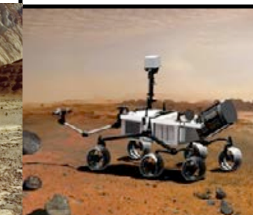
- Mars:
  - 1.67 AU (0.093 eccentricity)
  - 686.97 day orbital period
    - 779.9 day synodic period
  - Mass: 6.4 x10^{23} kg (~1/10 Earth)
  - 1.85 deg inclined orbit relative to the ecliptic plane
  - Radius: 3,396.2 km
  - Rotation period: 24.622 hours

An Overview of the Mars System

- Phobos:
  - 9235 km x 9518 km orbit
  - 0.319 day orbital period (7h 32 min)
  - Mass: 1.07 x10^{16} kg
  - 1.1 deg inclined orbit relative to Mars Equator
- Deimos:
  - 23,460 km orbit
  - 1.26 days (30h 18 min)
  - Mass: 1.48 x10^{15} kg
  - 0.93 deg inclined orbit relative to Mars Equator



Historical Surface Mission Summary

	Deep Space 2	Mars Pathfinder	Mars Exploration Rovers A/B	Phoenix	Viking 1/2	Mars Science Laboratory
						
Launch mass - wet	NA	891	1059	673	3527 (w/ orbiter) 1199 (w/o orbiter)	4050
Entry mass - wet	3.6	587	831	578	1168	3460
Aeroshell diameter (m)	0.35	2.65	2.65	2.65	3.54	4.5
Landing Ellipse - 3 sigma, Major x Minor axis (km)	180 x 20	200 x 100	80 x 12	110 x 20	280 x 100	25 x 20
Surface system mass - dry	2.4	Total: 372* Lander: 361* Rover: 11	Total: 540* Lander: 363* Rover: 177	349	590	Total: 1612 Descent Stage: 712 Rover: 900
Payload	Total: 0.7 Instruments: 0.7 PL Support: 0	Total: 13.7 Instruments: 10 (Lander), 0.7 (Rover) PL Support: 3 (Lander)	Total: 22 Instruments: 5 PL Support: 17	Total: 59 Instruments: 46 PL Support: 13	Total: 102 Instruments: 91 PL Support: 11	Total: 224 Instruments: 74 PL Support: 150
Design lifetime (sols)	1	Lander: 30, Rover: 7	90	90	90	668
Power / Thermal	Primary battery	Lander: Solar only Rover: Solar + RHU's	Solar + RHU's	Solar only	Nuclear	Nuclear

All masses in kg

* includes airbags

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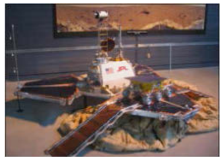
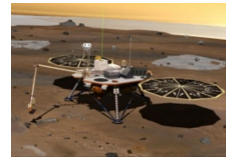
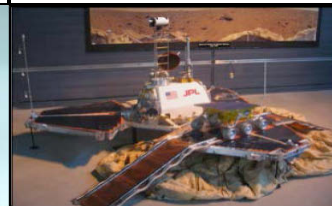
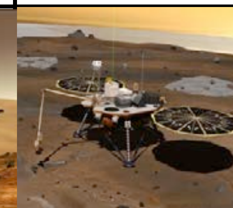
Historical Missions Payload Overview

	Deep Space 2	Mars Pathfinder	MER	Phoenix	Viking	MSL
Landed Mass	 **2.4 kg**	 **Lander: 361 kg, Rover: 10.6 kg**	 **177 kg**	 **349 kg**	 **590 kg**	 **900 kg**
Instruments [kg]	**0.7 kg**	**Lander: 5.6 kg, Rover: 0.7 kg**	**3.9 kg**	**30.0 kg**	**91 kg**	**72.0 kg**
	Evolved Water Experiment Soil Conductivity Experiment Atmospheric Descent Accelerometer Impact Accelerometer	**Lander:** IMP, 4.3 ASI/MET, 1.3 Magnetic Properties, 0.14 Wind Sock Investigation, 0.04 Radio Science **Rover:** APXS, 0.6 Rover Imaging Cameras, 0.1 Materials Adherence Experiment Wheel Abrasion Experiment	Mini-TES, 2.5 Pancam, 0.6 APXS, 0.3 MI, 0.2 Mossbauer, 0.2 Magnet Arrays, 0.1	TEGA, 11.5 MECA, 8.1 MET, 5.7 SSI, 3.8 MARDI, 0.5 RAC, 0.4	GC/MS, 19.0 Biology, 15.0 Lander Imaging, 7.5 NMS, 6.2 XRFS, 2.0 Atmospheric Structure Lander Radio Science Magnetic Properties Meteorology Physical Properties RPA Seismology	SAM, 37.7 ChemCam, 11.5 CheMin, 10.3 DAN, 4.8 RAD, 1.9 APXS, 1.7 Mastcam, 1.6 REMS, 1.3 MARDI, 0.6 MAHLI, 0.6
Payload Support [kg]	**N/A**	**7.1 kg**	**18.2 kg**	**28.2 kg**	**11.3 kg**	**152.2 kg**
	N/A	**Lander:** Payload Electronics, 3.6 Rover Mounting Hardware, 3.4 Calibration Targets, 0.1 Mast (Included in IMP mass)	Mast, 12.1 Arm, 4.4 RAT, 0.7 Payload Electronics, 0.7 Calibration Targets, 0.3	Payload Electronics, 15.3 Robotic Arm (RA), 12.1 Mast, 0.7 Calibration Targets, 0.1	Subsurface Sample Acquisition Assembly, 11.3 Meteorology Boom (Included in Instruments)	Robotic Arm & Turret, 72.9 Mast, 32.7 Other Sampling Hardware, 17.8 Drill, 16.6 CHIMRA, 8.6 Payload Electronics, 2.1 DRT, 1.4 kg Calibration Targets, 0.1

Surface System EDL Characteristics – Details

	Deep Space 2	Mars Pathfinder	Mars Exploration Rovers A/B	Phoenix	Viking 1/2	Mars Science Laboratory
						
Entry type	ballistic, direct	ballistic, direct	ballistic, direct	ballistic, direct	lifting, unguided, from orbit	lifting, guided, direct
TPS material	SIRCA-SPLIT	SLA-561	SLA-561	SLA-561	SLA-561	PICA
Aeroshell diameter (m)	0.35	2.65	2.65	2.65	3.54	4.5
Parachute diameter (m)	NA	12.5	14	11.5	16	21.5
Landing System Description	hard lander	small solid rockets, airbags, rover egress from lander	small solid rockets, airbags, rover egress from lander	soft-lander, pulsed engines, 3 crushable legs	throttled engines, 3 crushable legs	skycrane, throttled engines, mobility touchdown
Landing Ellipse - 3 sigma, Major x Minor axis (km)	180 x 20	200 x 100	80 x 12	110 x 20	280 x 100	25 x 20
Landing elevation - actual vs. max design (MOLA km)	? / +2.4	0 / -2.5	-1.3 / -1.4, -1.9	-4.1 / -2.5	? / -4.2, -2.7	-1.5 / +1
Landing latitude range - design vs actual (deg)	? / 72 S	10 N to 20 N / 19 N	15 S to 10 N / 15 S, 2 S	65 N to 72 N / 68 N	? / 48 N, 22N	30 S to 30 N / 4 S *

*The MSL mission may have been able to land in higher or lower latitudes but 30 degrees N or S was the working design value.

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Surface System Characteristics / Performance – Details

	DS2	PF – Rover	PF – Lander	MER A/B	PHX	Viking 1/2	MSL
Power / Thermal	Primary battery	Solar + RHU's	Solar only	Solar + RHU's	Solar only	Nuclear	Nuclear
Telecom	UHF	UHF to Lander	DTE X-band	UHF, DTE X-band	UHF	UHF, DTE S-band	UHF, DTE X-band
Payload Support	NA	NA	2 Masts	Mast + Arm	Mast + Arm	Mast + Arm + MET boom	Mast + Arm
Design traverse distance (m)	NA	100	NA	500	NA	NA	20,000
Actual odometery (m)	NA	100	NA	34,361+	NA	NA	?
Redundancy	Single	Single	Single	Single	Dual		Dual
Design lifetime (sols)	1	7	30	90	90	90	668
Actual lifetime (sols)	0	83	83	2,886+	155	~2,000	?

Surface System Mass	2.4	11	361	177 (rover only)	349	590	900
Instruments	0.7	0.7	10	5	46	91	74
Payload Support	0	0	3	17	13	11	150
Other Systems	1.7	10.3	348	155	290	488	676

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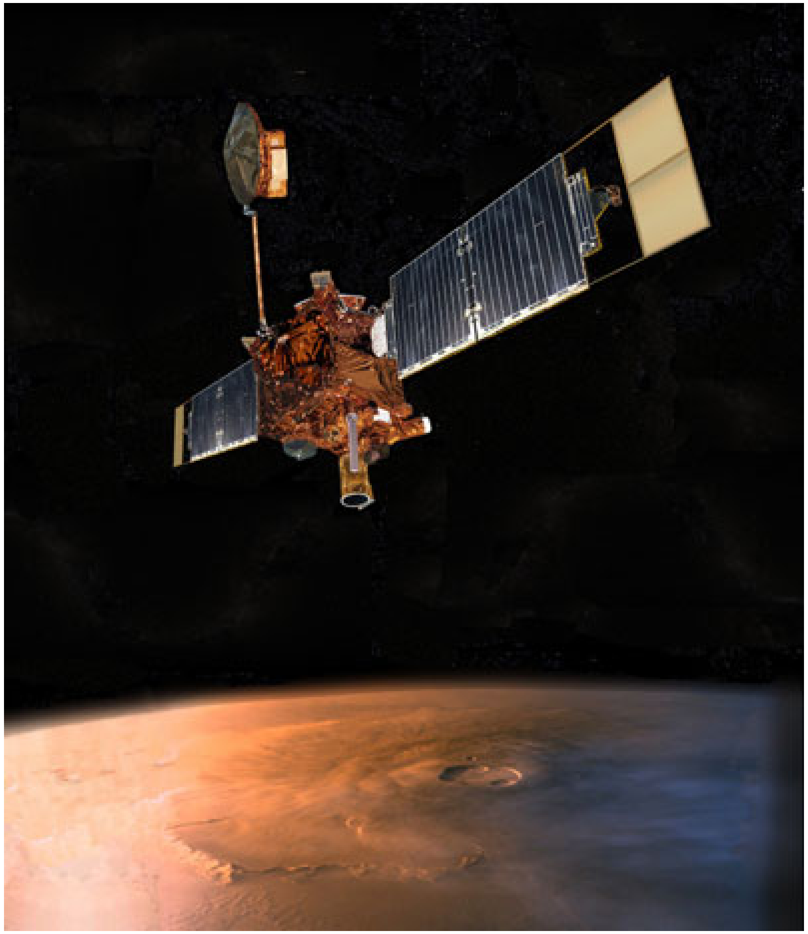
Mars Observer

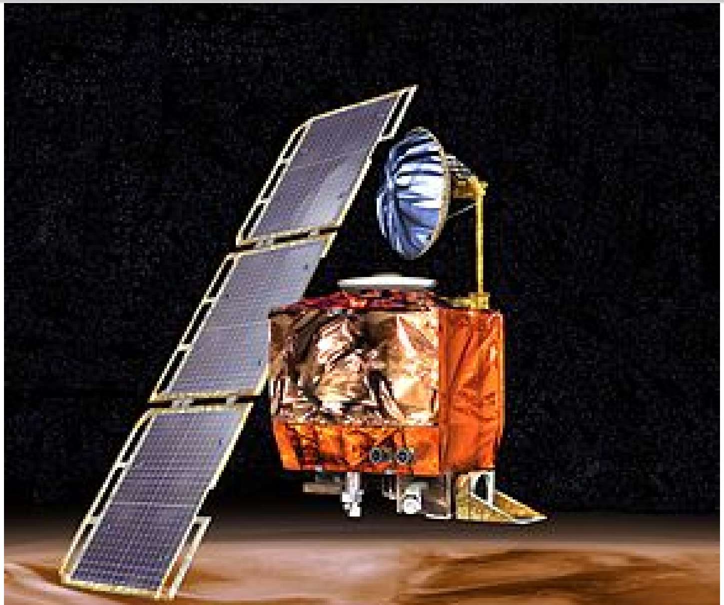
Mission Name	Mars Observer
Launch Date	25-Sep-92
Launch Vehicle	Titan III
Launch Mass (kg) (dry)	1018
Launch Mass (kg) (wet)	2455
Launch C_3	could not find
Instrument 1	MOLA
Instrument 2	TES
Instrument 3	PMIRR
Instrument 4	GRS
Instrument 5	MOC
Instrument 6	MAG/ER
Instrument 7	Radio Science
Instrument 8	MBR
Instrument 9	
Instrument 10	
Payload Mass (kg)	could not find
Development Cost (A thru D) (Then Year $M)	496.9 excl LV
Total Cost (Then Years $M)	535.8 excl LV
Development Duration (beginning of Phase A to Launch) (yrs)	≈11

MGS



Mission Name	MGS
Launch Date	7-Nov-96
Launch Vehicle	Delta II 7925A
Launch Mass (kg) (dry)	658.1
Launch Mass (kg) (wet)	1035.1
Launch C_3	could not find
Instrument 1	MOLA
Instrument 2	MR
Instrument 3	TES
Instrument 4	MOC
Instrument 5	(USO (RS))
Instrument 6	MAG/ER
Instrument 7	
Instrument 8	
Instrument 9	
Instrument 10	
Payload Mass (kg)	76.3
Development Cost (A thru D) (Then Year $M)	199.0
Total Cost (Then Years $M)	324.2
Development Duration (beginning of Phase A to Launch) (yrs)	4.3

Mars 98: MCO and MPL



Mission Name	Mars 98	MCO	MPL
Launch Date	--	11-Dec-98	3-Jan-99
Launch Vehicle	--	Delta II 7425	Delta II 7425
Launch Mass (kg) (dry)	--	338	512
Launch Mass (kg) (wet)		629	576
Launch C_3		could not find	could not find
Instrument 1	--	MARCI	MVACS
Instrument 2	--	PMIRR	MARDI
Instrument 3	--		Lidar
Instrument 4	--		DS 2 μprobes
Instrument 5			
Instrument 6			
Instrument 7			
Instrument 8			
Instrument 9			
Instrument 10			
Payload Mass (kg)		could not find	could not find
Development Cost (A thru D) (Then Year $M)	196.7 excl LV		
Total Cost (Then Years $M)	277.3 excl LV		
Development Duration (beginning of Phase A to Launch) (yrs)		4.3	4.3

Developed during Faster, Better, cheaper era

Odyssey

Mission Name	Mars Odyssey
Launch Date	7-Apr-01
Launch Vehicle	Delta II 7925-9.5
Launch Mass (kg) (dry)	380.9
Launch Mass (kg) (wet)	757.4
Launch C_3	could not find
Instrument 1	GRS
Instrument 2	THEMIS
Instrument 3	MARIE
Instrument 4	
Instrument 5	
Instrument 6	
Instrument 7	
Instrument 8	
Instrument 9	
Instrument 10	
Payload Mass (kg)	45.5
Development Cost (A thru D) (Then Year $M)	313.9
Total Cost (Then Years $M)	410.9
Development Duration (beginning of Phase A to Launch) (yrs)	4

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Mars Reconnaissance Orbiter

OBJECTIVES

Imaging & Mineralogy Science
Characterize the present climate of Mars
Determine the nature of complex layered terrain on Mars and identify water-related landforms
Search for evidence of aqueous or hydrothermal activity

Preparation for Human Exploration
Landing Site Certification for Future Missions

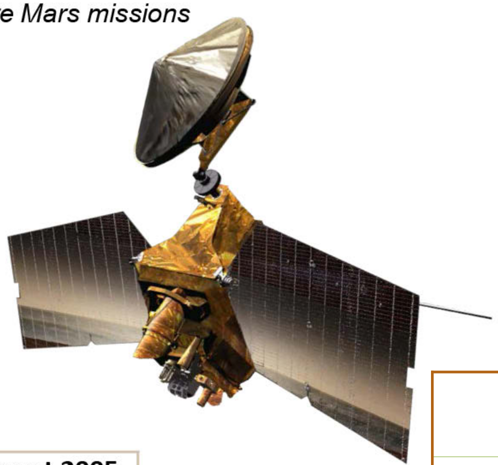
Infrastructure for future missions
Telecommunications support
Sub-m imaging for landing safety
Identify and characterize sites with the highest potential for landed science and sample return by future Mars missions

FLIGHT SYSTEM

10-year X/UHF telecom 25-200 Gbit/day
(near continuous DSN tracking)
Data storage 160 Gbit
EOL power 2000 W
Nadir-pointing capability
Mono-propellant propulsion

PAYLOAD

Instruments
Imager (Sub-m-Class: HiRISE)
Mineralogy (CRISM)
Sub-Surface Sounder (SHARAD)
Context Camera (CTX)
Wide Angle Camera (MARCI)
Climate Sounder (MCS)



MASS SUMMARY

Spacecraft Bus Dry Mass	850 kg
Orbital Science Payload	130 kg
Propellant	1200kg
Total Wet Mass	**2180 kg**

MISSION DESIGN

Launch Date	**August 2005**
Launch C_3	**20 km^2/sec^2**
Mars Approach $V_{infinity}$	**2.9 km/sec**
MOI Date	**March 2006**
MOI Capture Orbit	**35 hour period**
Aerobraking Duration	**~6 months**
Science Emphasis	**~2 years, ~320 km**
Relay Emphasis	**~4.5 years, ~320 km**

COST SUMMARY

Cost History (RY$M)
(through launch, including reserves)

Element	Cost -RY		
Flight System	$235M		
Payload	$135M		
SE/MA/Mgt/I&T /GDS/Other	$100M		
Total	**$470M**		
Launch	$80M		

Challenges of Mars Exploration – Mission Design

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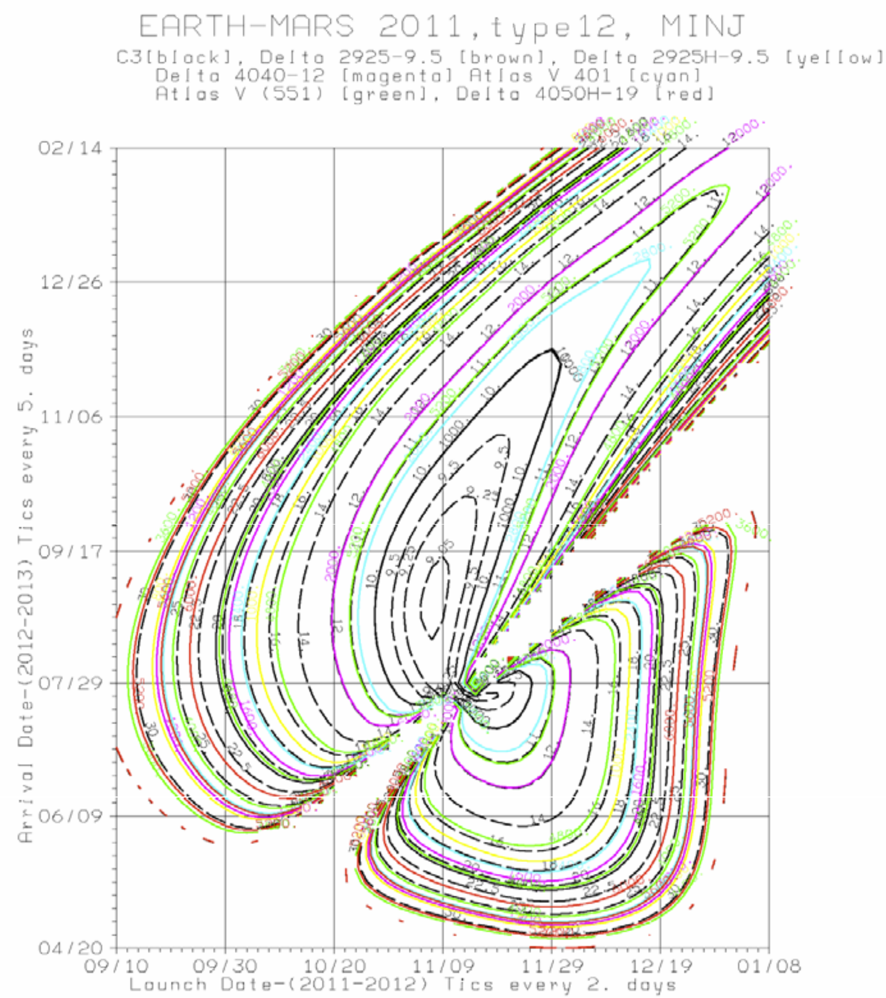
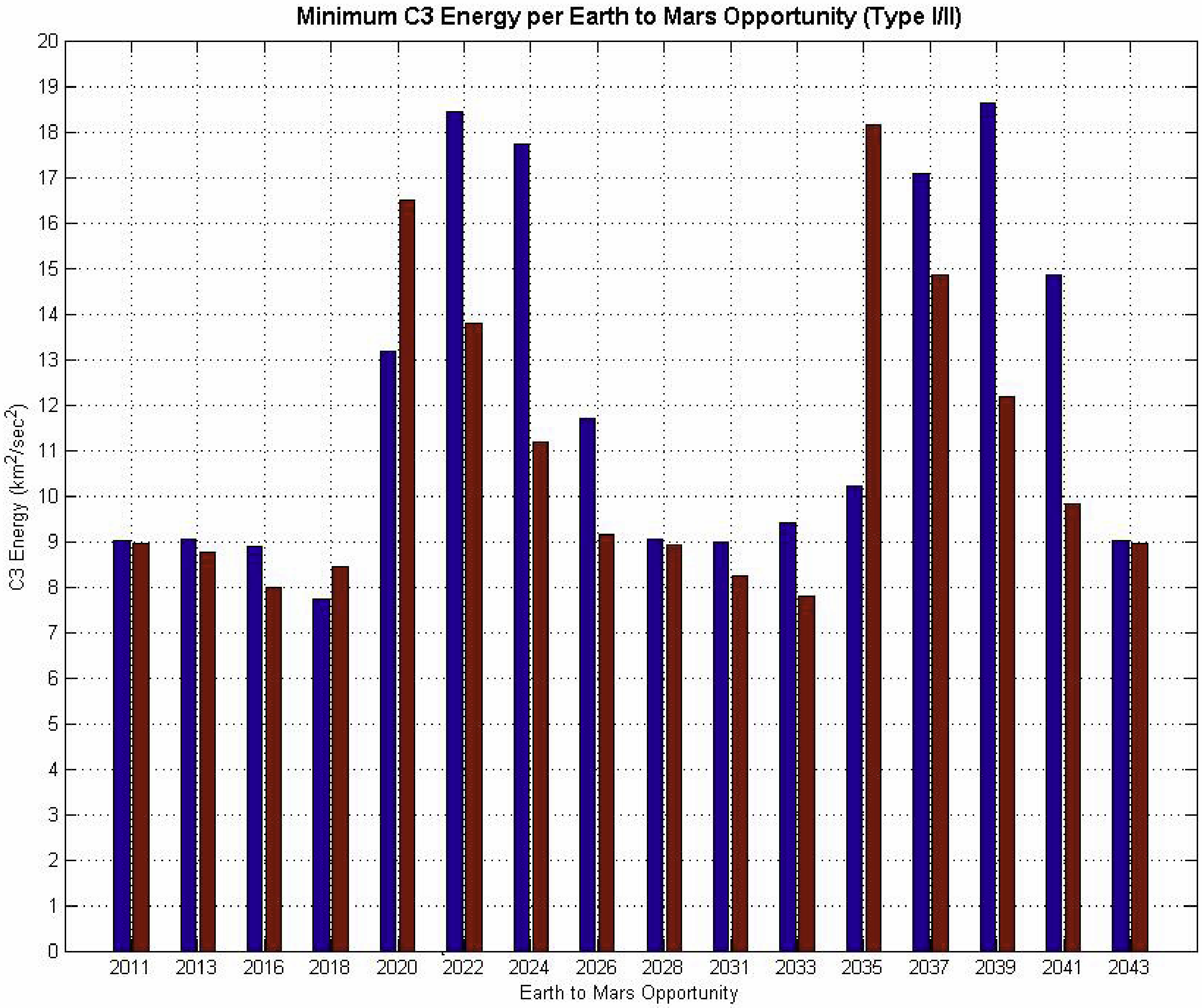
Getting There

- Launch on an ELV
  - Delta IV or Atlas V
    - Launch C3 between ~8 and ~20 km^2/sec^2
- Typically ballistic trajectory to Mars
  - Type 1 or Type 2 trajectory
  - Ballistic capture at Mars
    - Can also do Aerocapture
  - Circularization via Aerobraking or ballistic
- Solar electric Propulsion can also be used for transfer

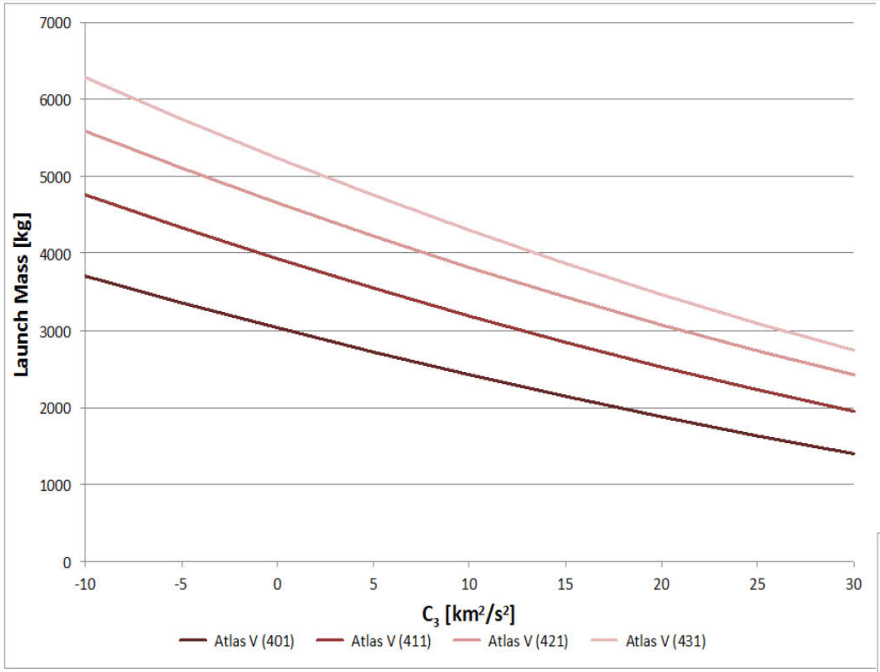


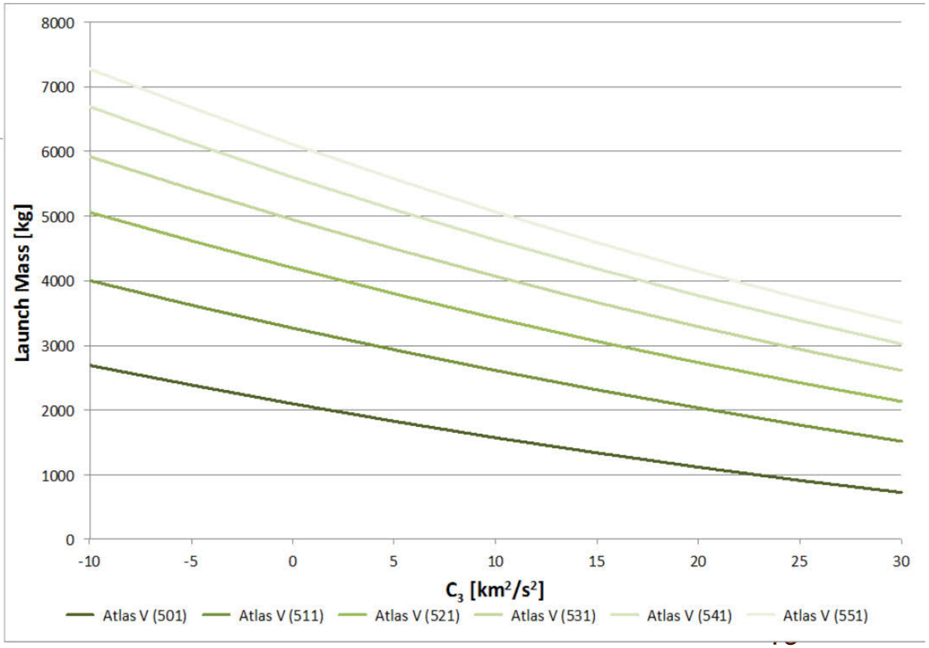
Earth to Mars 2011, Type I/II - Maximum Injected Mass

Minimum C3 Transfer



Launch Vehicle Capability





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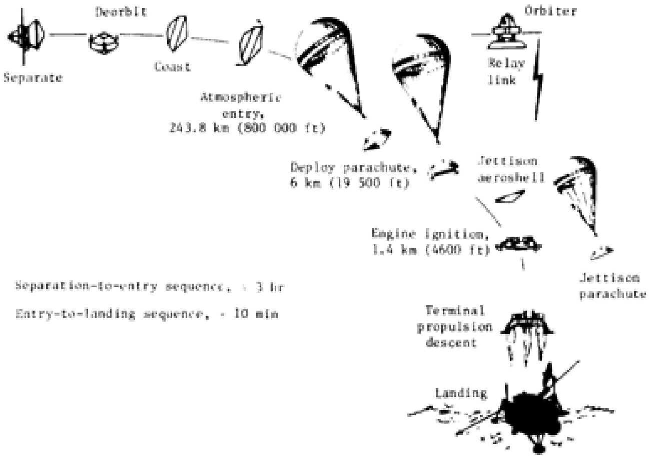
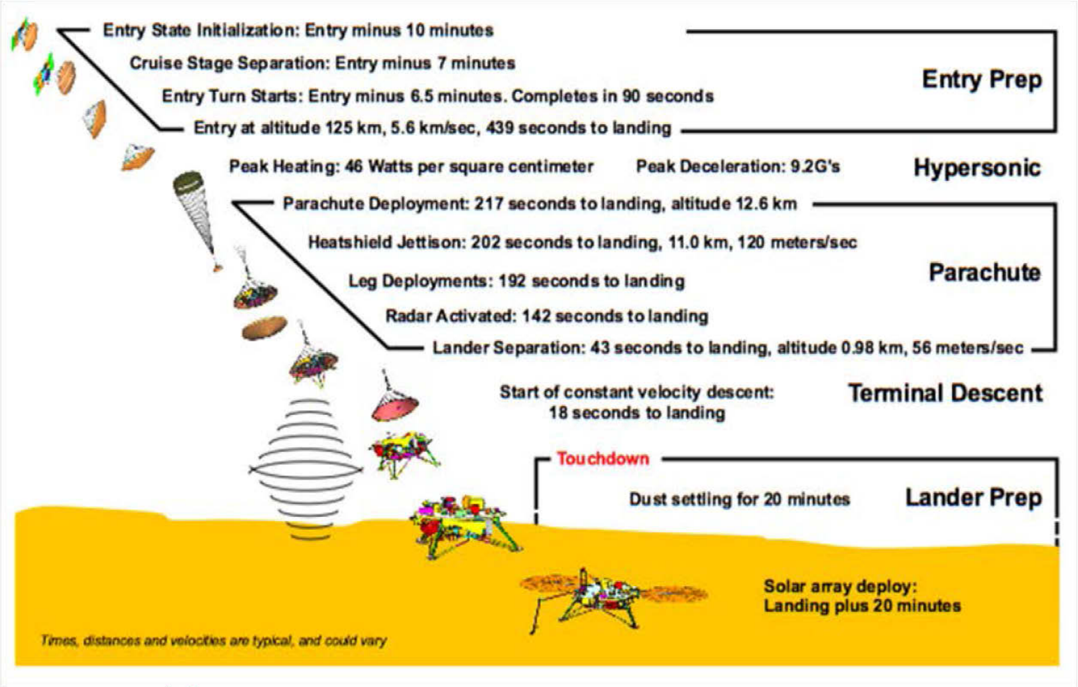
Entry, Descent and Landing – Fixed Landers

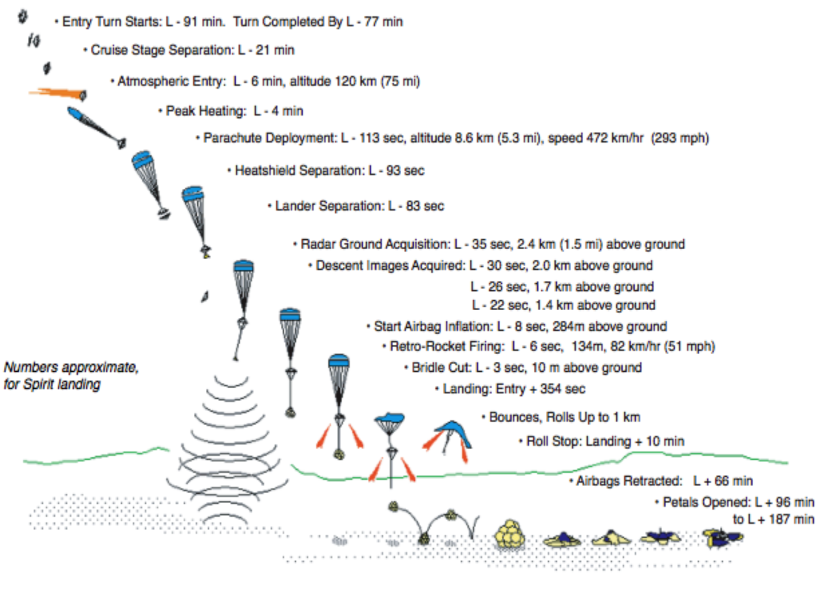


Viking Lander EDL Sequence Diagram

Mars Phoenix Lander EDL Sequence Diagram

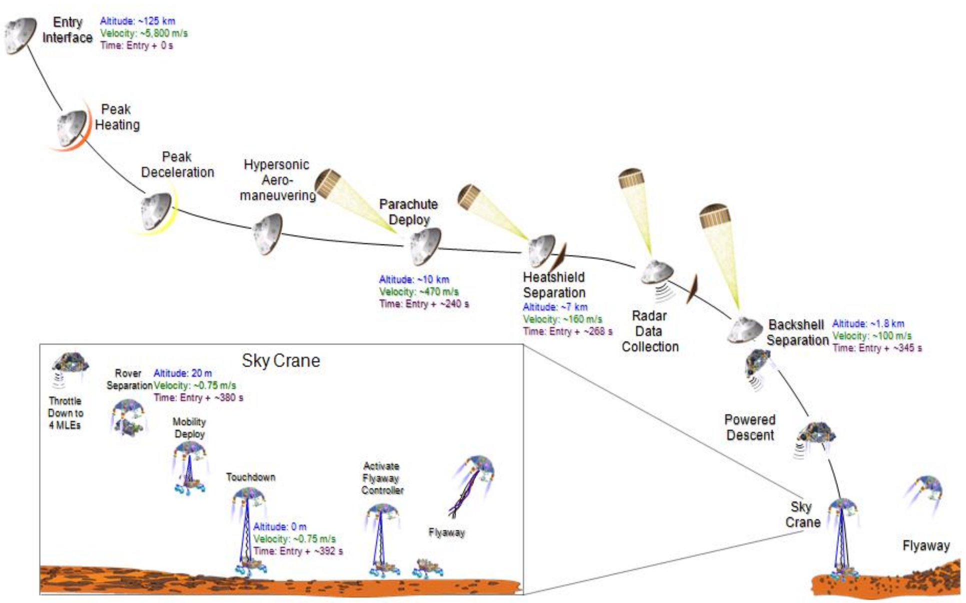


Entry, Descent and Landing - Rovers



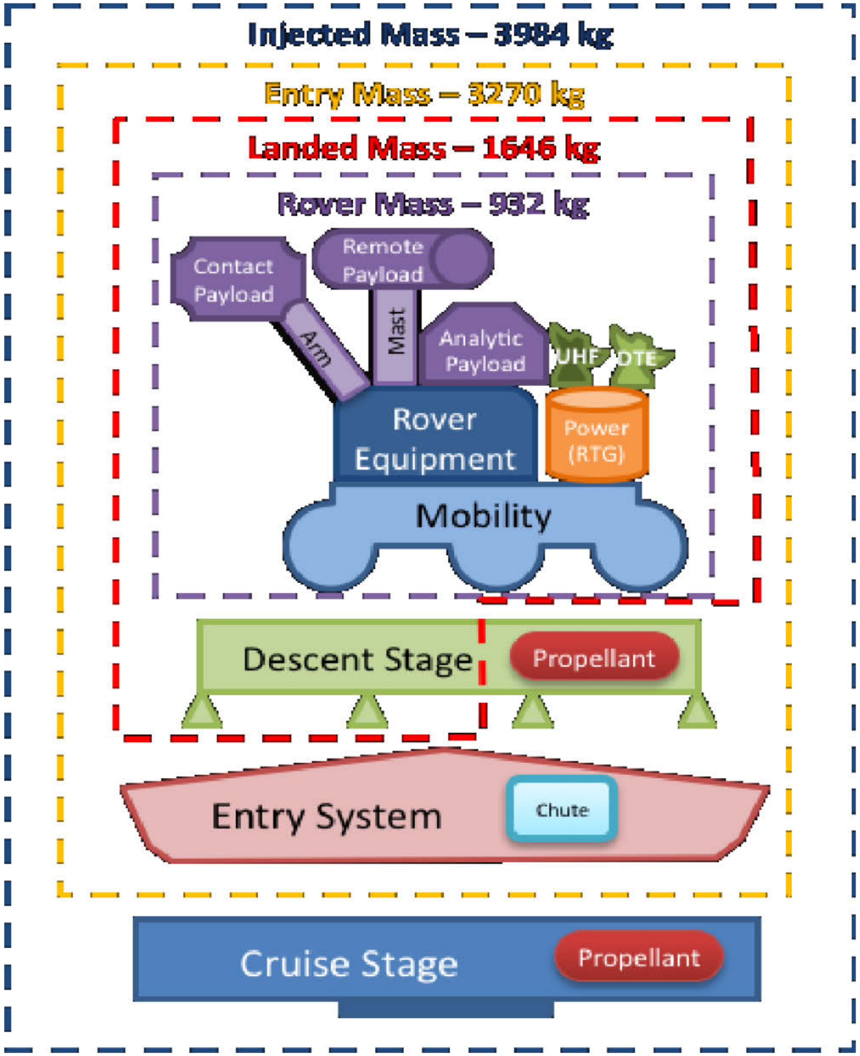
Entry, descent and landing

MER EDL Sequence Diagram

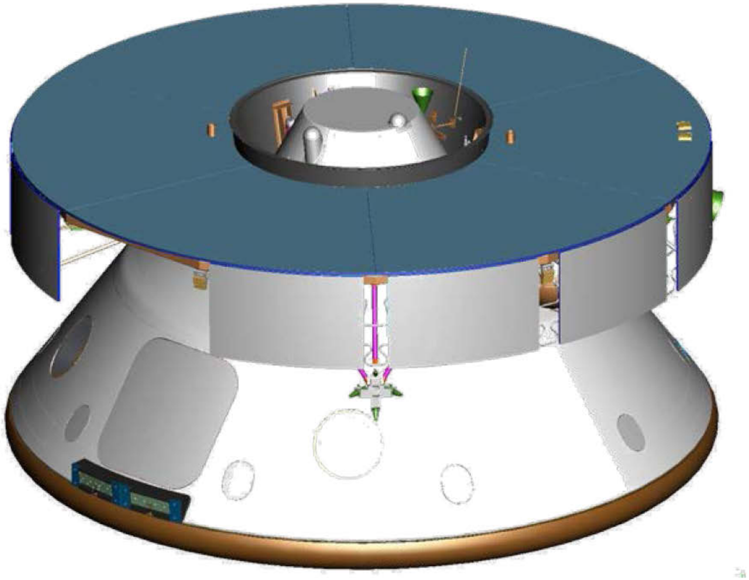


MSL EDL Sequence Diagram

Flight Systems - Rover



Mars Science Laboratory Architecture Diagram



Mars Sample Return

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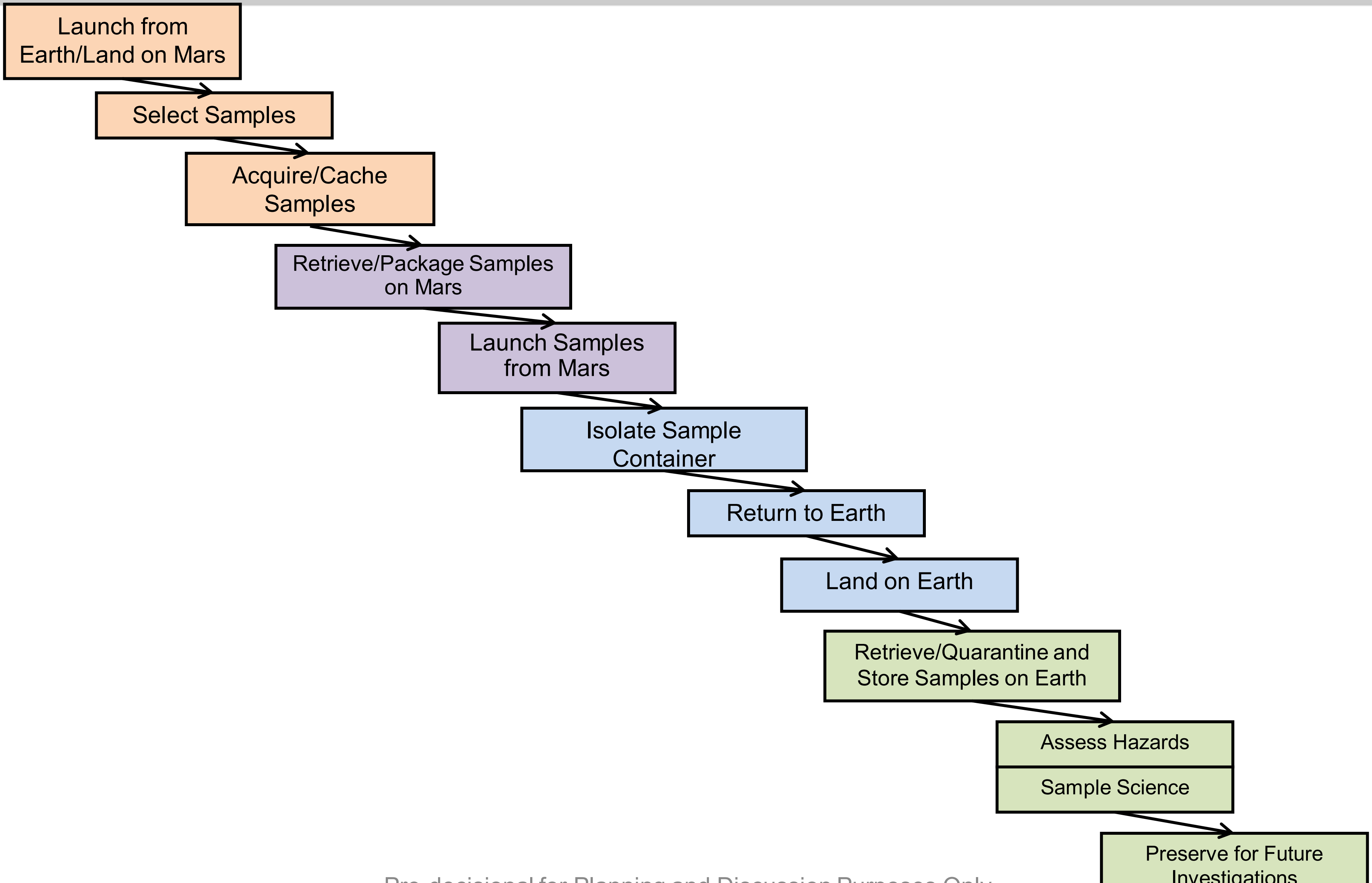
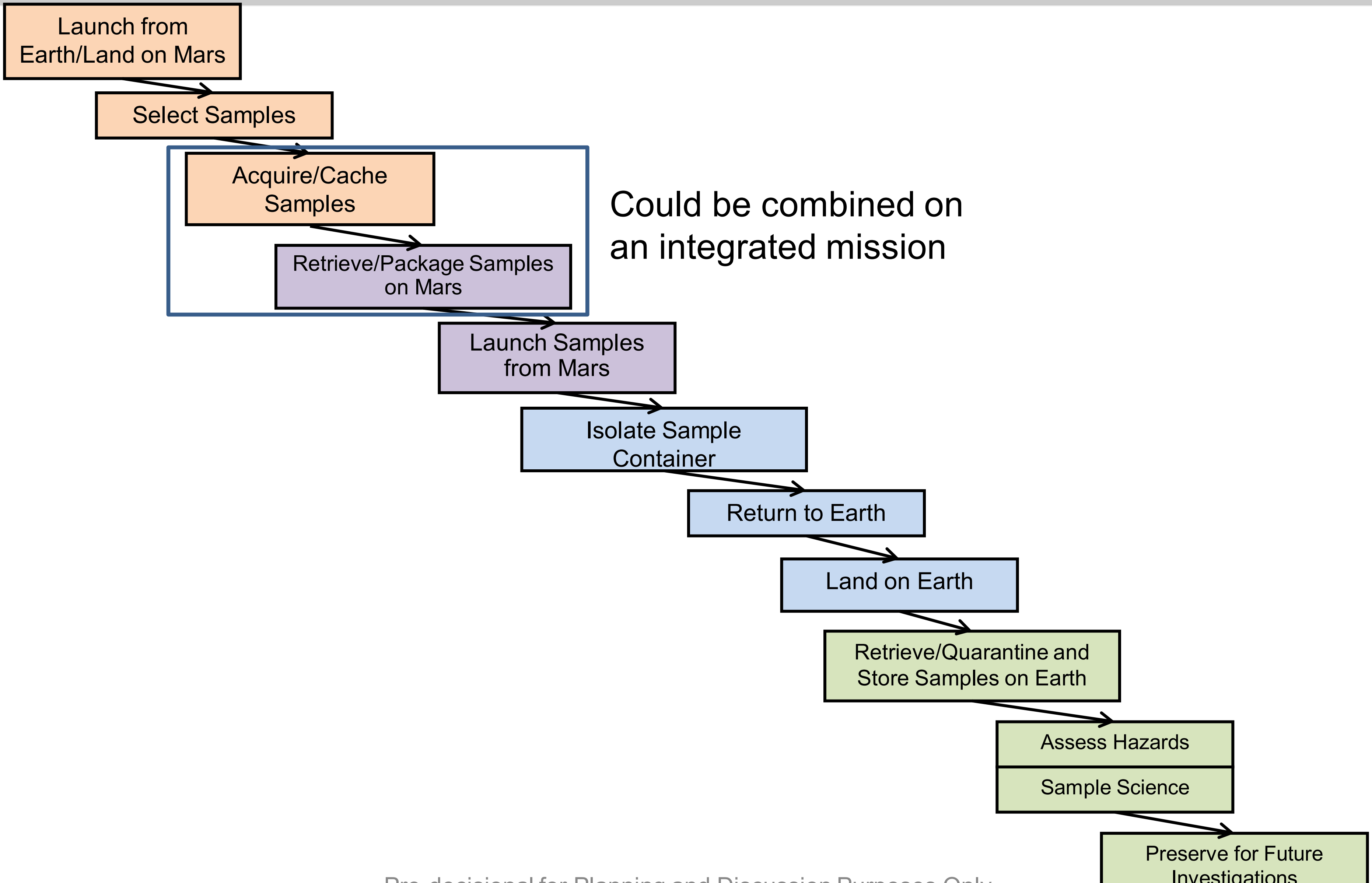
MSR Key Elements



MSR Key Elements



Creating An Architecture from the Elements

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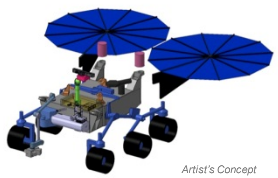
Potential MSR 4 "Element" Architecture

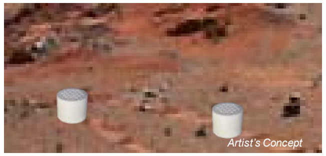
Implementation Elements

Stable Sample State



Sample Caching Rover

Launch from Earth/Land on Mars → Select Samples → Acquire/Cache Samples



Sample Canisters On Mars Surface

Sample Retrieval and Launch

→ Retrieve/Package Samples on Mars → Launch Samples to Mars Orbit

Orbiting Sample (OS) in Mars Orbit

Sample Return Orbiter

→ Capture and Isolate Sample Container → Return to Earth → Land on Earth

Orbiting Sample (OS) On Earth

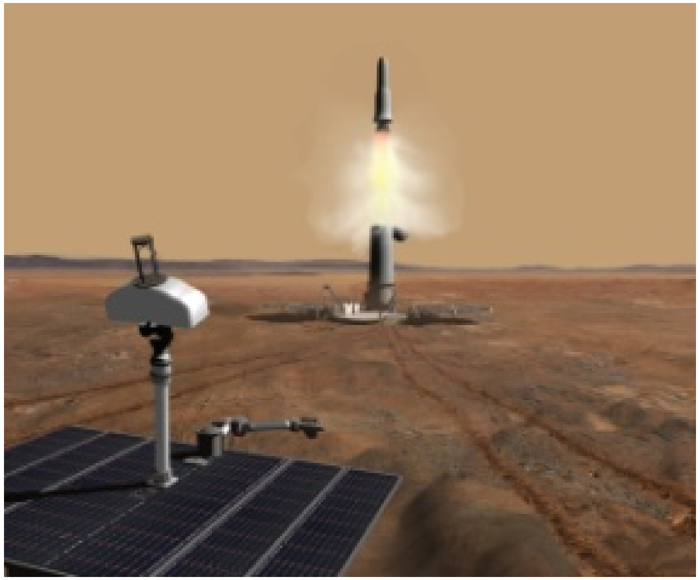
Mars Returned Sample Handling

→ Retrieve/Quarantine and Preserve Samples on Earth → Assess Hazards → Sample Science

**Note: Launch sequence of MSR-L/MSR-O can be switched: launching MSR-O first can provide telecom relay support for EDL/surface operation/MAV launch

Potential Mars Ascent Vehicle (MAV) Overview

- MSR would require a low mass, highly reliable MAV to move samples from the surface of Mars to low Mars orbit
- Key MAV requirements would likely include:
  - Deliver Orbiting Sample (OS) to target ~ 500 km circular Mars orbit
  - Single point failure tolerant
  - Transmit both real-time and recorded engineering data to relay orbiter with enough fidelity to allow determination of root cause of off-nominal performance or failure
  - Meet MSL EDL system physical envelope and environmental requirements
- FY11 funding through In Space Propulsion Technology Program supported system level concept studies



- All MAV concepts selected were two stage rockets, but different architectures (solid 1st and 2nd stages, solid 1st stage / liquid 2nd stage, liquid 1st and 2nd stages)
- Technology investments needed to retire key risks for each concept:
  - Solid: Validate solid rocket motor assembly can meet environmental requirements (driven by MSL EDL system requirements, and long duration cold storage on martian surface)
  - Liquid: Integrated propulsion tank assembly mass uncertainty, multiple new thrusters, new propellant
  - All concepts require further refinement of interfaces to host flight system (lander or rover) and the MAV support systems (thermal enclosure and erector system)

Potential Phobos Sample Return

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Challenges of Phobos Sample Return

- Phobos is small
  - Getting to Phobos will be more like a rendezvous problem, rather than an orbital problem (no stable orbits)
  - 'landing' on Phobos will be difficult (again, a rendezvous)
  - Anchoring (surface gravity 0.006 m/s^2)
    - What are you anchoring in?
  - Sampling
    - What are you sampling? What are you looking for?
      - Expelled Mars rocks? Native soil?
    - What is your instrument package?
      - How can you tell what you have
    - How are you sampling?
      - 'Grab' sample? Scoops and cups
      - 'adhesive' sample
    - Planetary protection
      - How do you protect Phobos from Earth contamination
      - How do you protect Earth from possible return contamination?