A PHOBOS-DEIMOS MISSION AS AN ELEMENT OF THE NASA MARS DESIGN REFERENCE ARCHITECTURE 5.0. S. J. Hoffman, Science Applications International Corporation, 2450 NASA Parkway, Houston, Texas 77058.

Abstract: NASA has conducted a series of mission studies over the past 25 years examining the eventual exploration of the surface of Mars by humans. The latest version of this evolutionary series of design reference missions/architectures - Design Reference Architecture 5 or DRA-5 – was completed in 2007. This paper examines the implications of including a human mission to explore the moons of Mars and teleoperate robots in various locations, but not to land the human crews on Mars, as an element of this reference architecture. Such a mission has been proposed several times during this same 25 year evolution leading up to the completion of DRA-5 primarily as a mission of testing the in-space vehicles and operations while surface vehicles and landers are under development. But such a precursor or test mission has never been explicitly included as an element of this Architecture. This paper will first summarize the key features of the DRA-5 to provide context for the remainder of the assessment. This will include a description of the in-space vehicles that would be the subject of a shake-down test during the Mars orbital mission. A decision tree will be used to illustrate the factors that will be analyzed, and the sequence in which they will be addressed, for this assessment. The factors that will be analyzed include the type of interplanetary transfer orbit (opposition class versus conjunction class), the type of parking orbit (circular versus elliptical), and the type of propulsion technology (high thrust chemical versus nuclear thermal rocket). The manner in which each of these factors impacts an individual mission will be described. In addition to the direct impact of these factors, additional considerations impacting crew health and overall programmatic outcomes will be discussed. Numerical results for each of the factors in the decision tree will be grouped with derived qualitative impacts from crew health and programmatic consideration. These quantitative and qualitative results will be summarized in a pros/cons table as a summary for this analysis.

Second International Conference on the Exploration of **Phobos and Deimos**

A PHOBOS-DEIMOS MISSION AS AN ELEMENT OF THE NASA MARS DESIGN REFERENCE ARCHITECTURE 5.0

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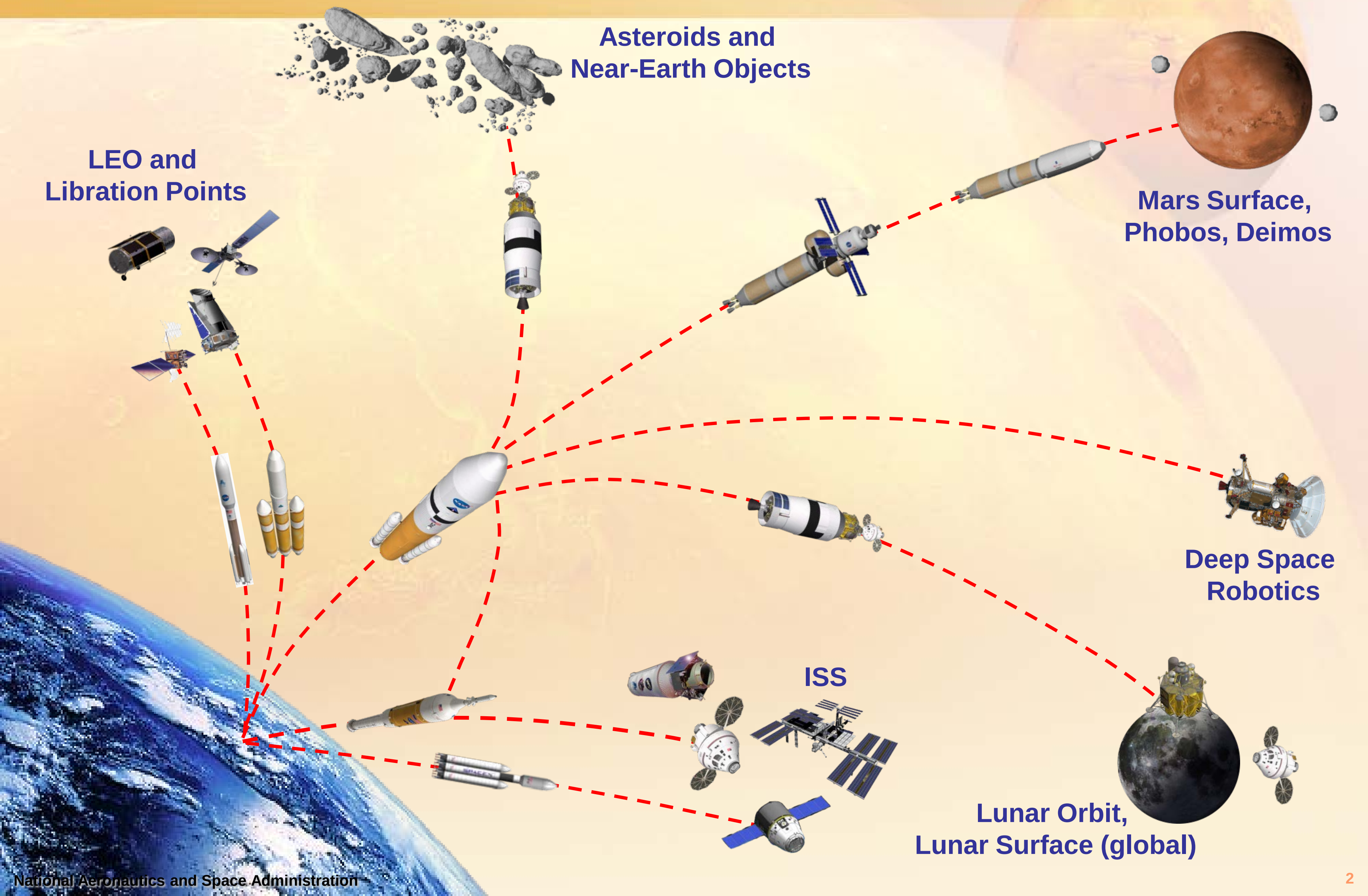
Science Applications International Corporation

March 14 - 16, 2011

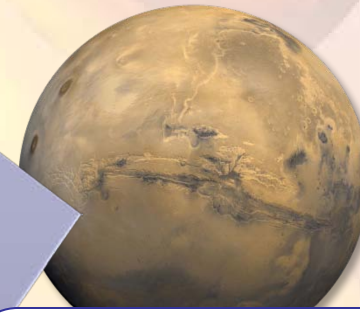
U.S. Human Spaceflight
Future Exploration Capabilities



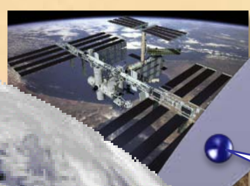
Progressive Expansion of Capabilities and Distance – Lunar First Example

3. Deep Space
- Near-Earth Space (1) plus:
  - Crew support for 360 days (habitat)
  - Radiation protection (habitat)
  - Closed-loop life support (habitat)
  - Deep space propulsion (tbd)
  - Cryogenic fluid management
  - Supportability & maintanance

2. Lunar Missions
- Near-Earth Space (1) plus :
  - Landing systems
  - Nuclear power
  - In-situ resource utilization
  - Surface habitat
  - Surface electric rover
  - Surface EVA mobility
  - Supportability & Maintenance



4. Mars Missions
- Lunar (2) & Deep Space (3) plus:
  - Mars entry & landing systems
  - Partial-gravity countermeasures



1. Near-Earth Space
- Lunar fly-by, lunar orbit, EM L-Points
  - Heavy lift launch
  - Crew support for 20 days (Orion)
  - Deep-space propulsion (Orion)
  - Radiation protection

0. Low-Earth Orbit
- International Space Station
  - Zero-g research platform
  - Closed-loop life support
  - Environmental monitoring
  - Supportability & maintenance concepts

Mars Design Reference Mission Evolution and Purpose

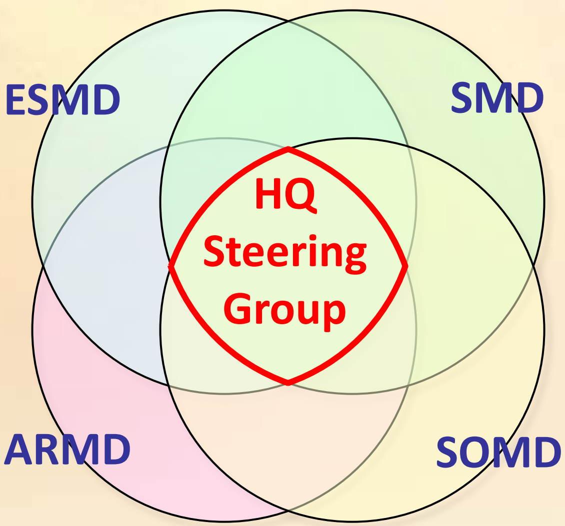
- Exploration mission planners maintain "Reference Mission" or "Reference Architecture"
- Represents current "best" strategy for human missions
- Mars Design Reference Architecture 5.0 is not a formal plan, but provides a vision and context to tie current systems and technology developments to potential future missions
- Also serves as benchmark against which alternative approaches can be measured
- Updated as we learn

DRA 5.0 available at:
http://www.nasa.gov/exploration/library/esmd_documents.html

2007 Mars Design Reference Architecture 5.0

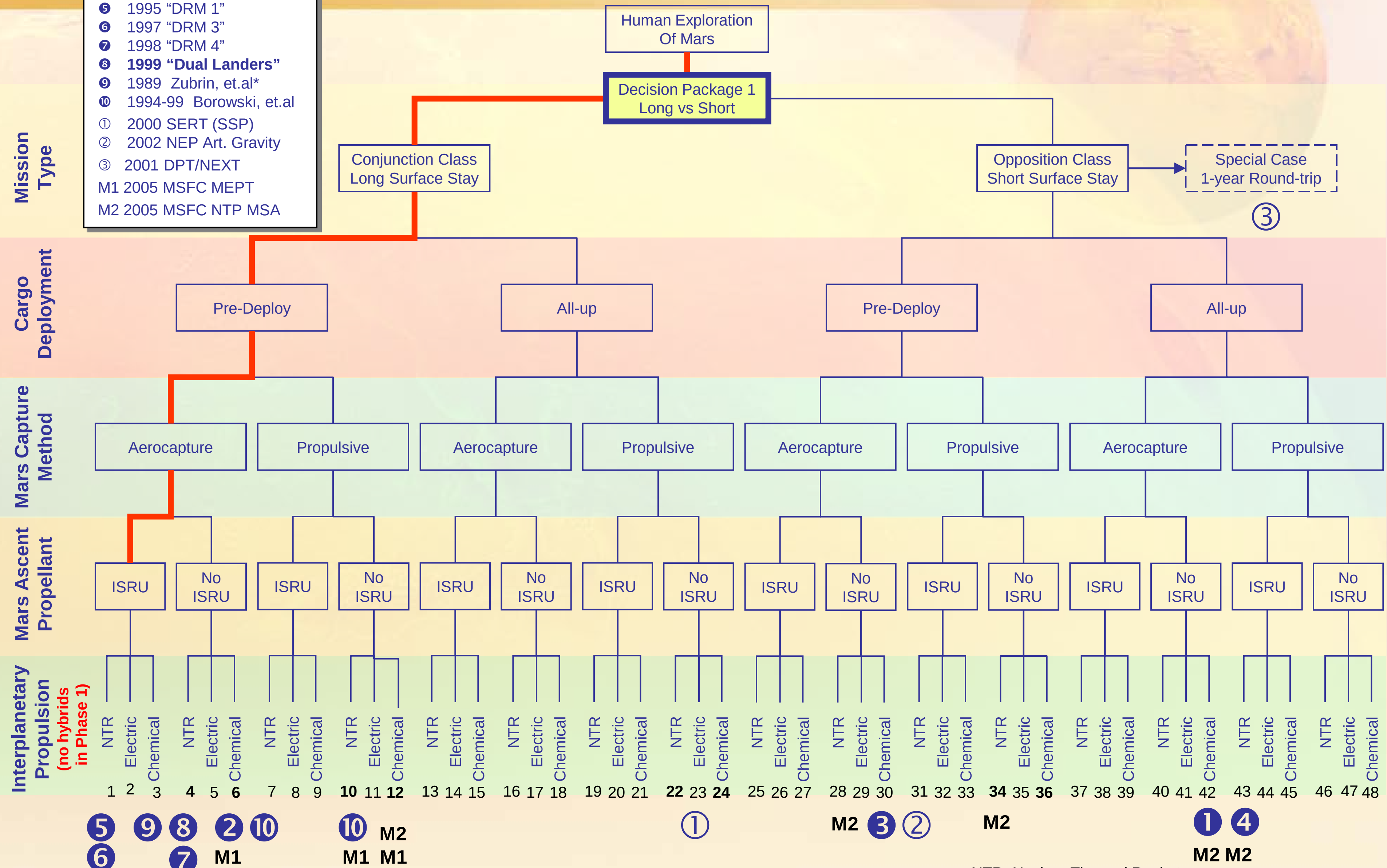
2007 Study Objectives / Products

- Update NASA's human Mars mission reference architecture, that defines:
  - Long term goals and objectives for human exploration missions
  - Flight and surface systems for human missions and supporting infrastructure
  - An operational concept for human and robotic exploration of Mars
  - Key challenges including risk and cost drivers
- Assess strategic linkages between lunar and Mars strategies
- Develop an understanding of methods for reducing the cost/risk of human Mars missions through
  - Identification of key risks
  - Investment in research, technology
  - Establishing linkages with other exploration human and robotic plans
- Agency-wide effort with key HQ Steering Group guidance and concurrence on key decision packages and recommendations



Top-level Trade Tree

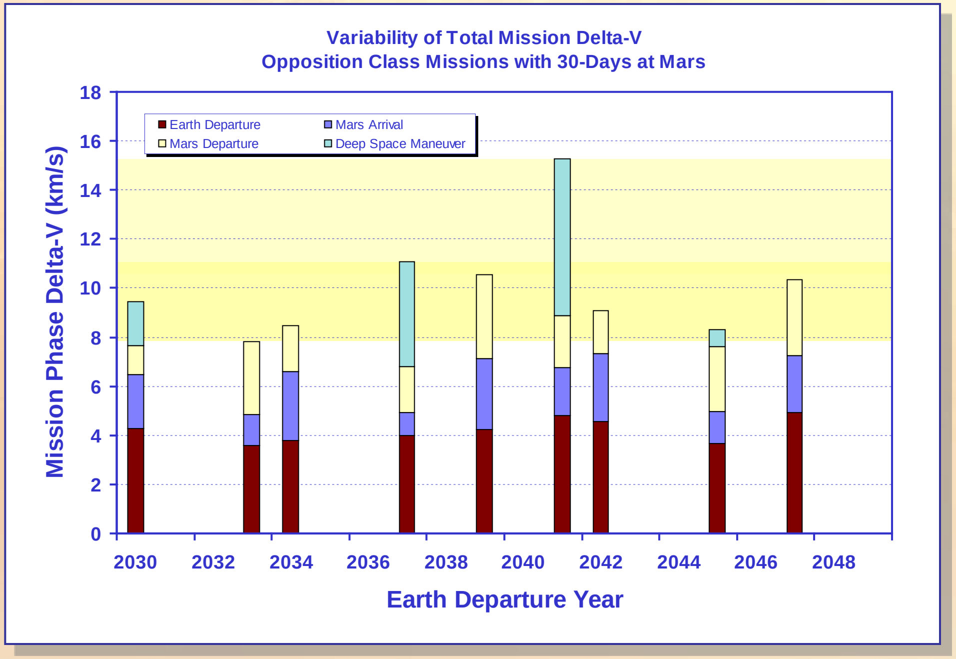
- ❶ 1988 "Mars Expedition"
- ❷ 1989 "Mars Evolution"
- ❸ 1990 "90-Day Study"
- ❹ 1991 "Synthesis Group"
- ❺ 1995 "DRM 1"
- ❻ 1997 "DRM 3"
- ❼ 1998 "DRM 4"
- **❽ 1999 "Dual Landers"**
- ❾ 1989 Zubrin, et.al*
- ❿ 1994-99 Borowski, et.al
- ① 2000 SERT (SSP)
- ② 2002 NEP Art. Gravity
- ③ 2001 DPT/NEXT
- M1 2005 MSFC MEPT
- M2 2005 MSFC NTP MSA



NTR- Nuclear Thermal Rocket
Electric= Solar or Nuclear Electric Propulsion

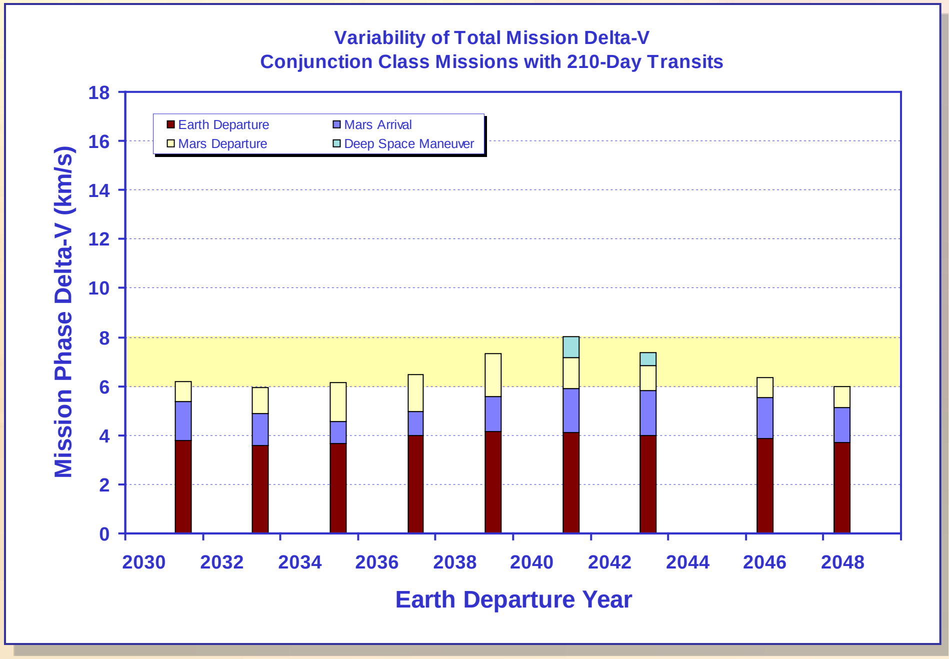
Total Interplanetary Propulsion Requirements

Opposition Class Missions (Short-Stay) Propulsive Delta-V



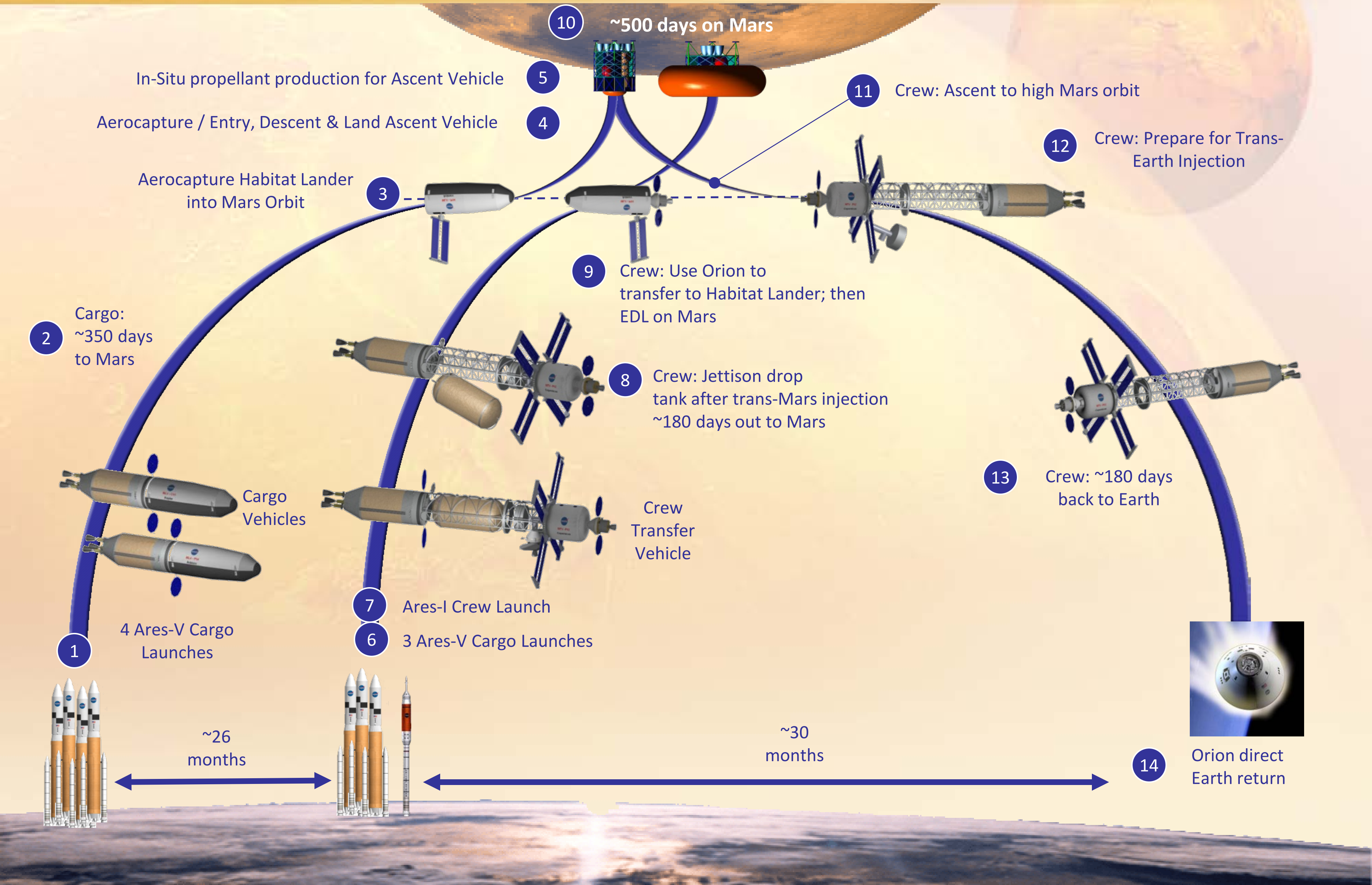
Note: Optimized trajectories assuming 407 km circular LEO departure orbit, propulsive capture at Mars into a Mars 1-Sol orbit of 250 km x 33,793 km. 30 sols stat at Mars. Direct entry at Earth with an entry speed limit of 13 km/s.

Conjunction Class Mission (Long-Stay) Propulsive Delta-V



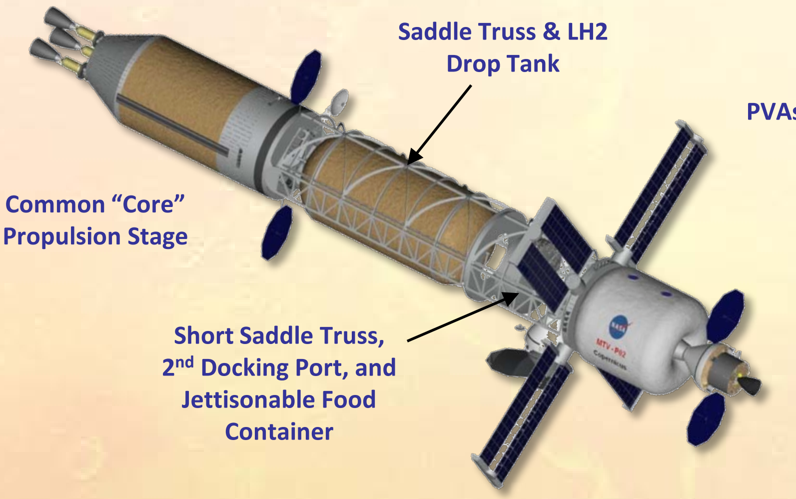
Note: Optimized trajectories assuming 407 km circular LEO departure orbit, propulsive capture at Mars into a Mars 1-Sol orbit of 250 km x 33,793 km. 210 day transits to and from Mars. Direct entry at Earth with an entry speed limit of 13 km/s.

Mars Design Reference Architecture 5.0 Mission Profile
NTR Reference Shown

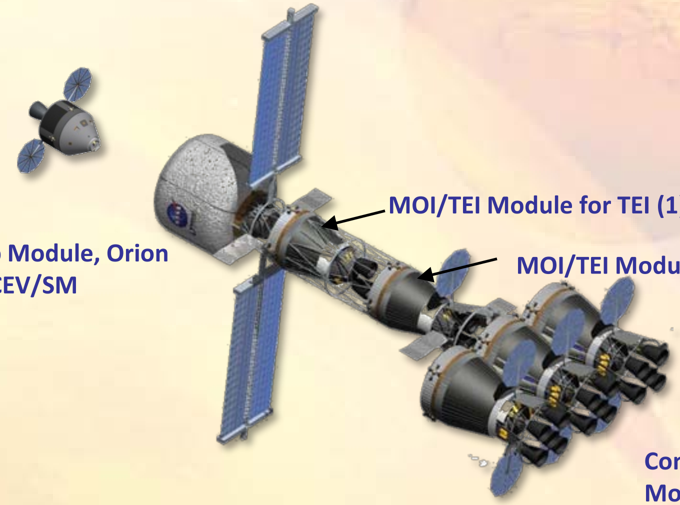


Design Reference Architecture 5.0
NTR & Chemical/Aerocapture Vehicles

NTR Crew Vehicle Elements

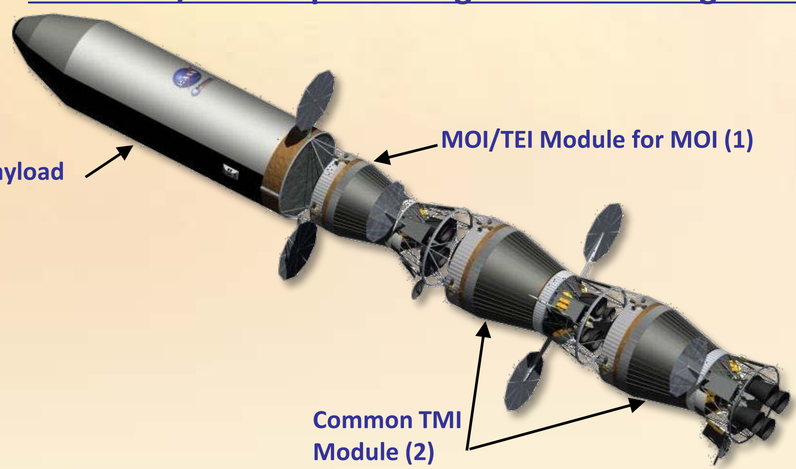


Chemical Crew Vehicle Elements



NTR Cargo Vehicle Elements

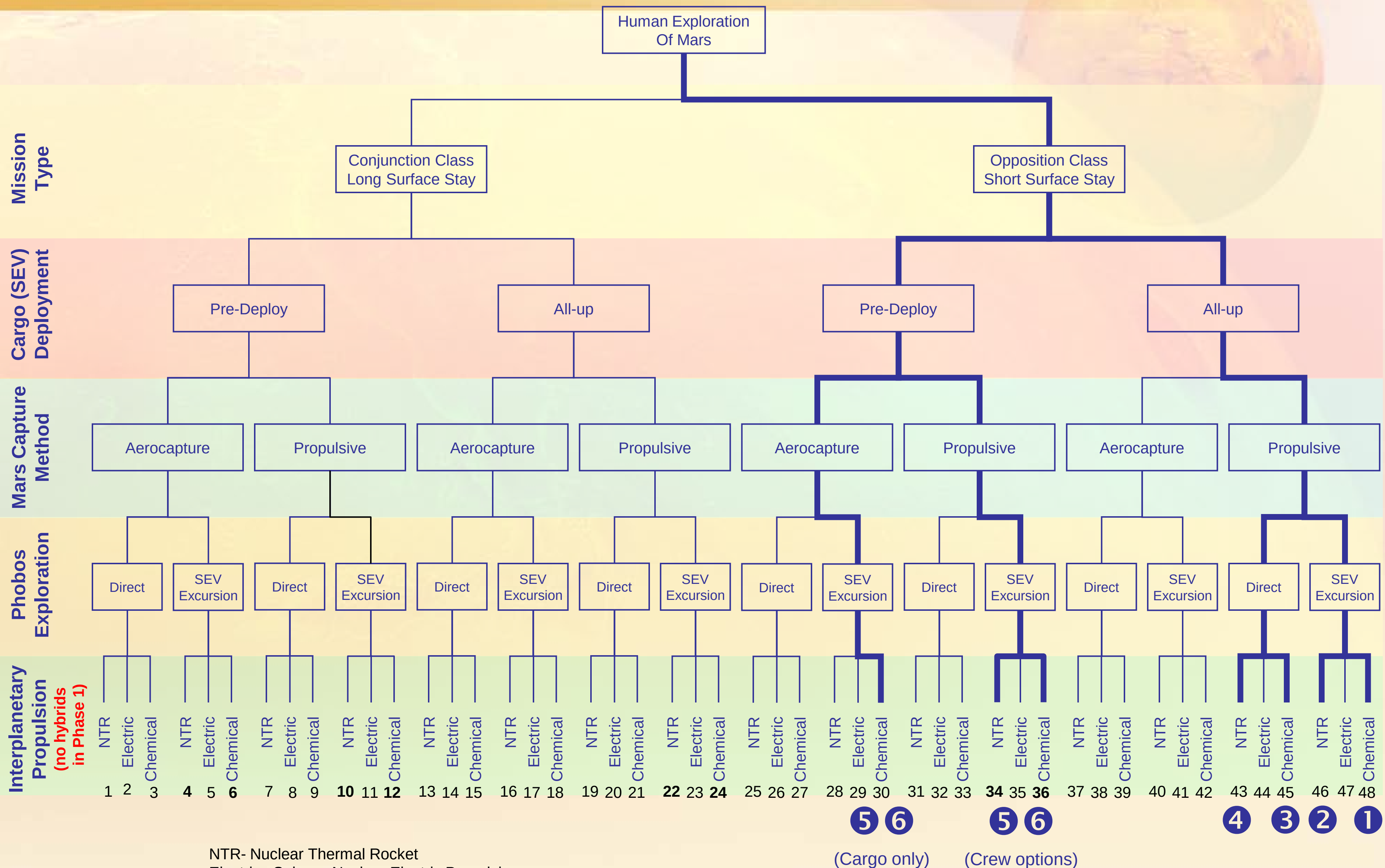
Chemical / Aerocapture Cargo Vehicle Configuration



Total NTR Mass ~ 800 t (7-9 launches)

Total Chem/AC Mass ~ 1,200 t (9-12 launches)

Phobos Mission Trade Tree



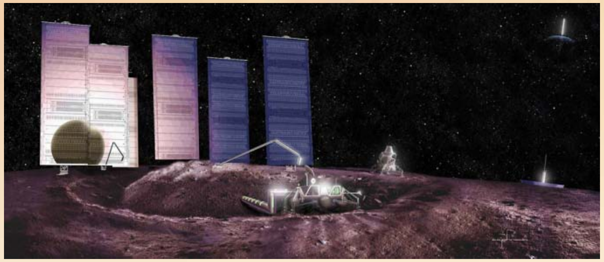
NTR- Nuclear Thermal Rocket
Electric= Solar or Nuclear Electric Propulsion

Phobos and Mars Orbit Science Activities and Benefits

Phobos field work and samples ⇨ Origin and Evolution of Phobos ⇨ Solar system formation, Earth and Mars primordial surface inventory

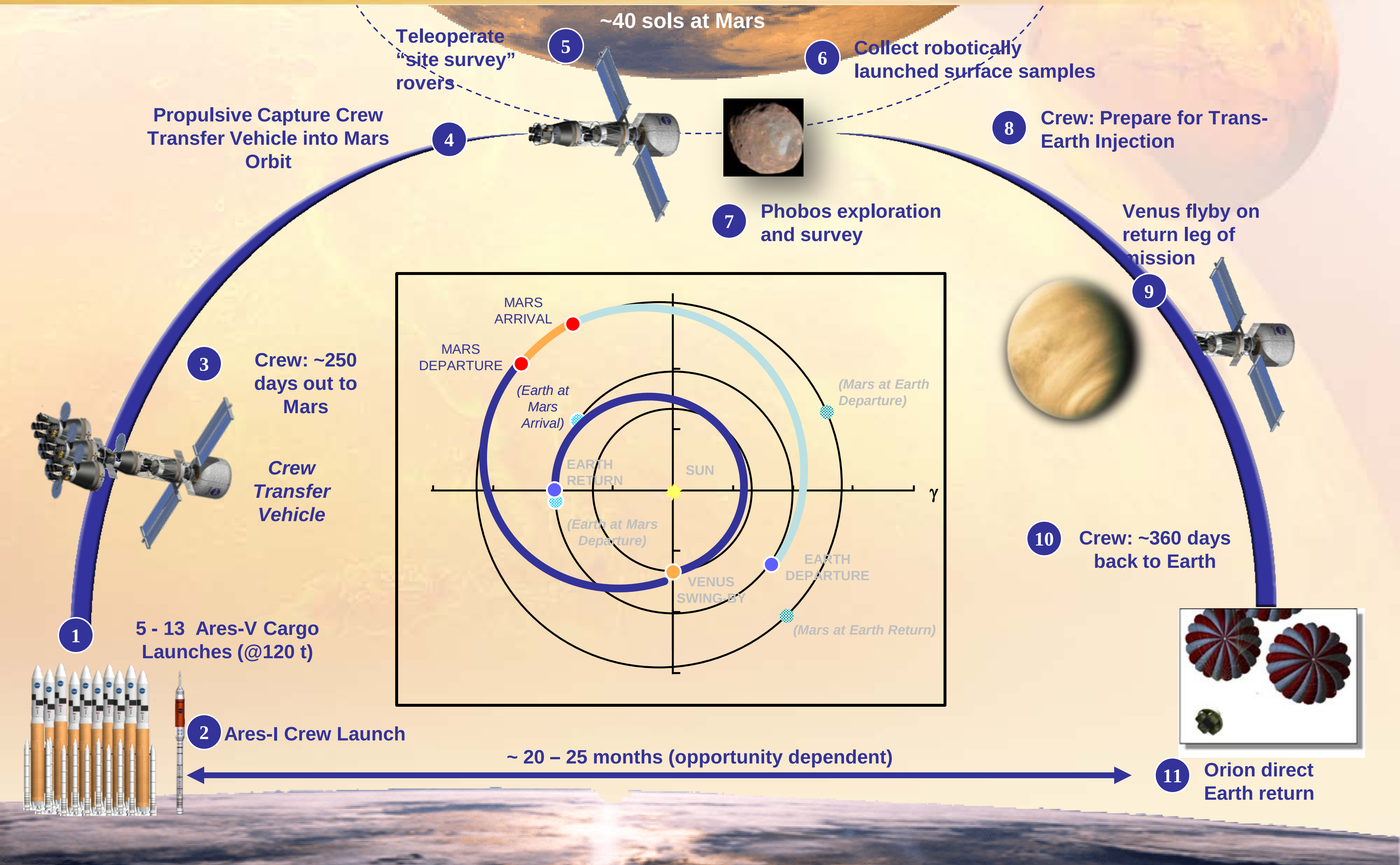
Recover Mars material deposited on Phobos ⇨ Preserved History of early Mars (that was not preserved on Mars itself)

Mars rovers tele-operation and samples ⇨ Mars biological history and human landing site certification



Search for accessible water ice ⇨ Potential for refueling in Mars orbit

Human Mars Orbit / Phobos Mission
(Chemical Propulsion Option)

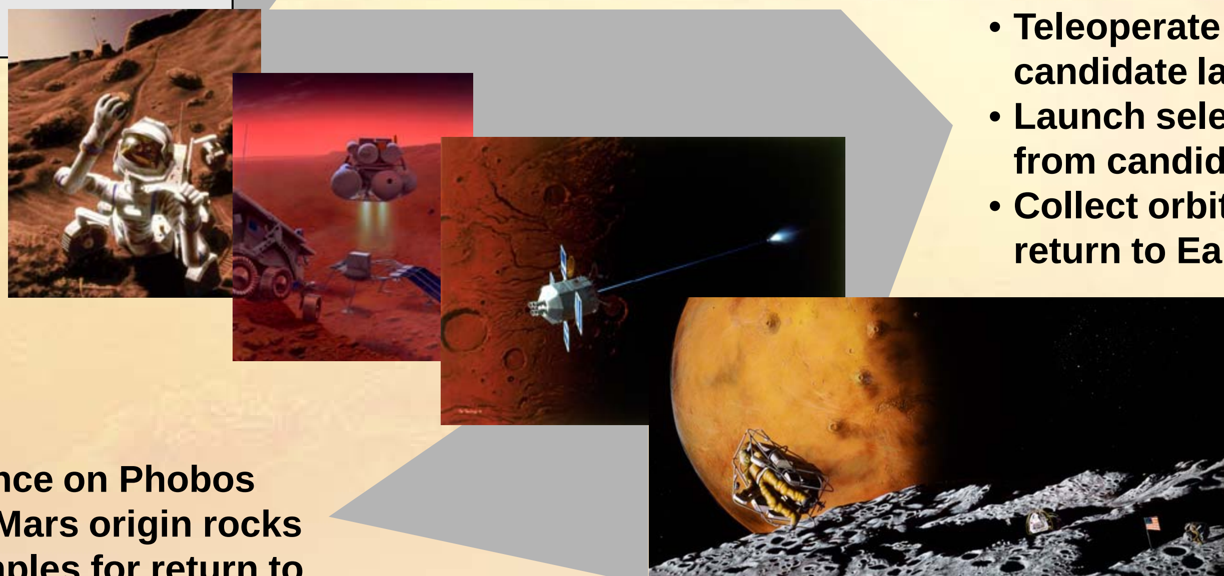


Phobos Mission Activity Flow

0 | 10 | 20 | 30

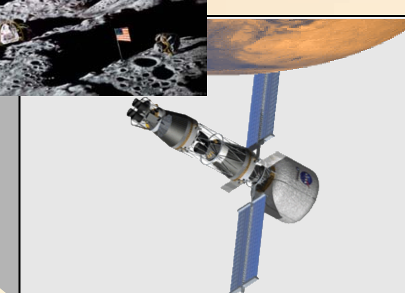
Sols in Mars Orbit

- Crew arrival at Mars
- Initial orbital operations and rendezvous with Phobos



- Teleoperate surface robots at candidate landing sites
- Launch selected samples from candidate sites
- Collect orbiting samples for return to Earth

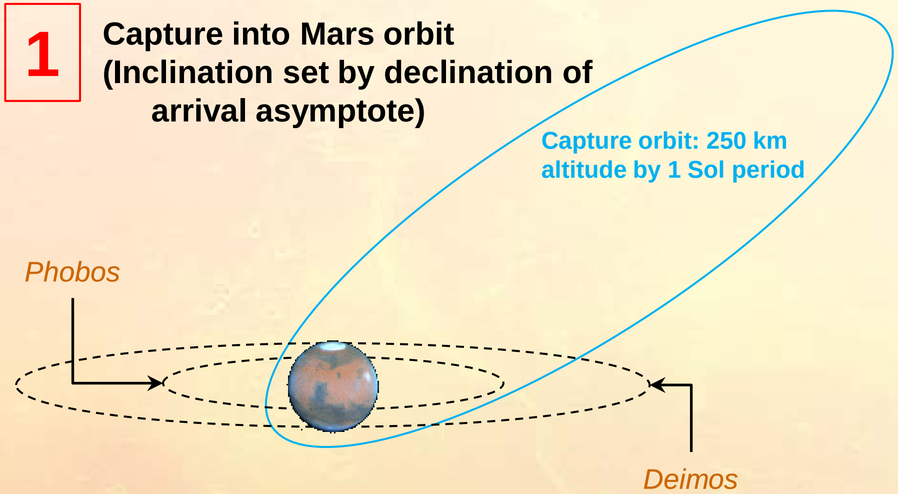
- In situ science on Phobos
- Search for Mars origin rocks
- Collect samples for return to Earth



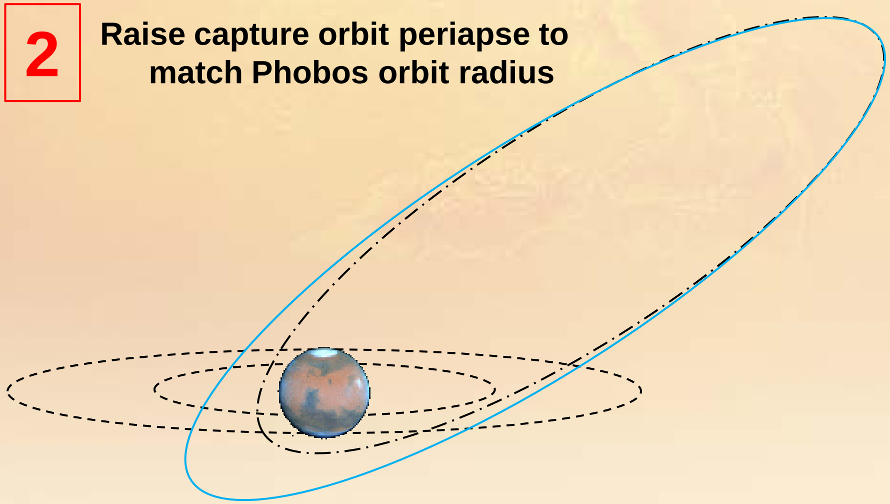
- Crew prepares for Mars departure
- Conduct preliminary analysis of gathered data and samples during return journey

Orbit Phasing to Rendezvous with Phobos

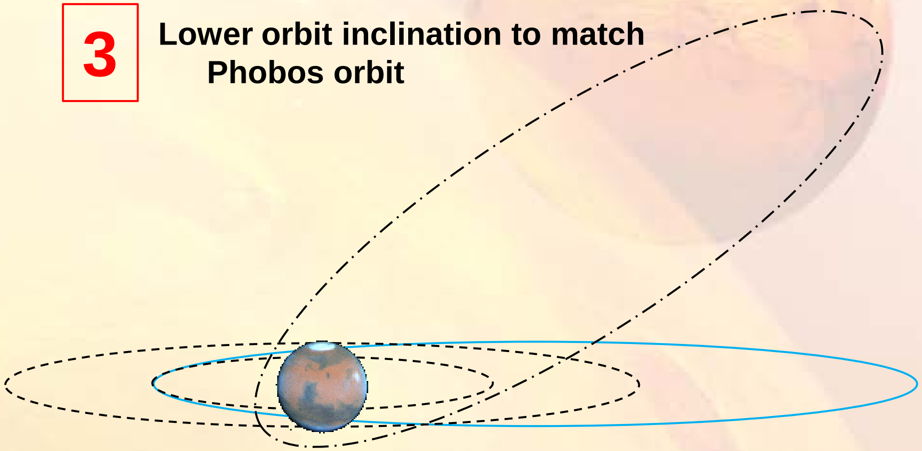
1 Capture into Mars orbit (Inclination set by declination of arrival asymptote)



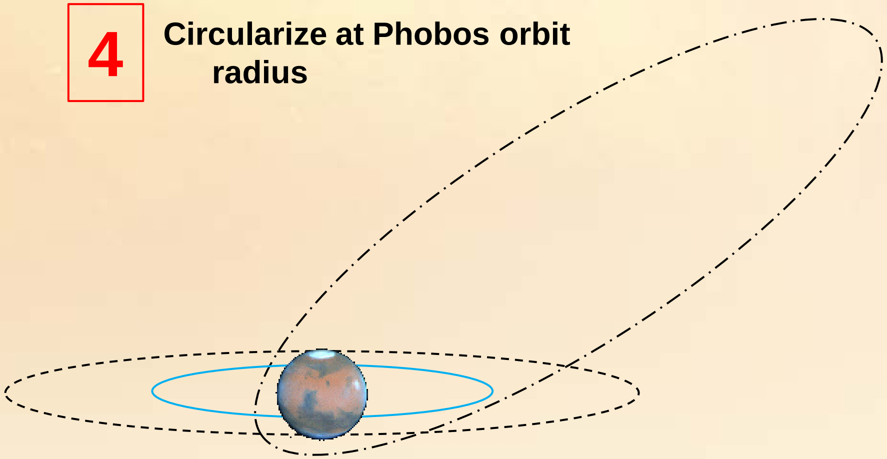
2 Raise capture orbit periapse to match Phobos orbit radius



3 Lower orbit inclination to match Phobos orbit

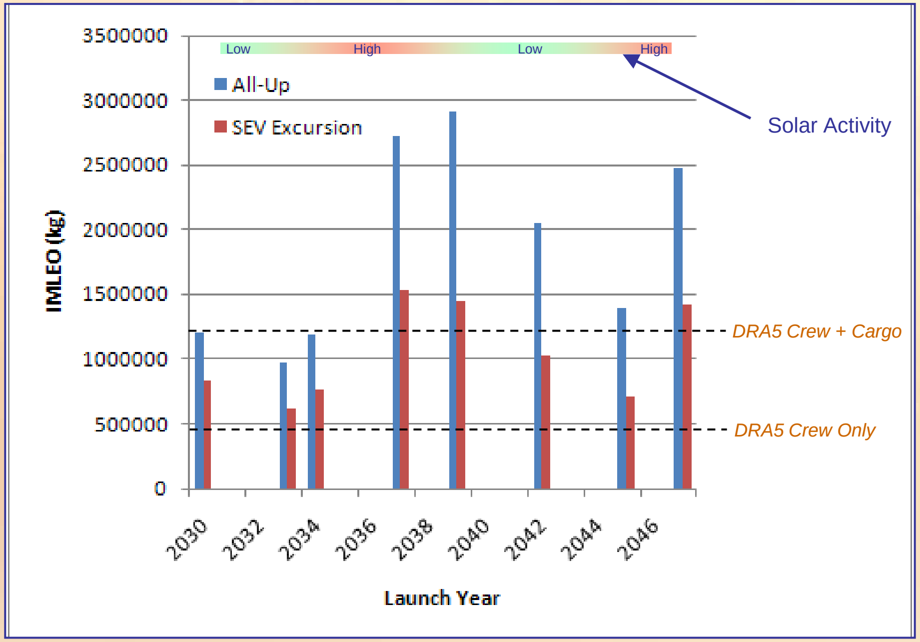


4 Circularize at Phobos orbit radius

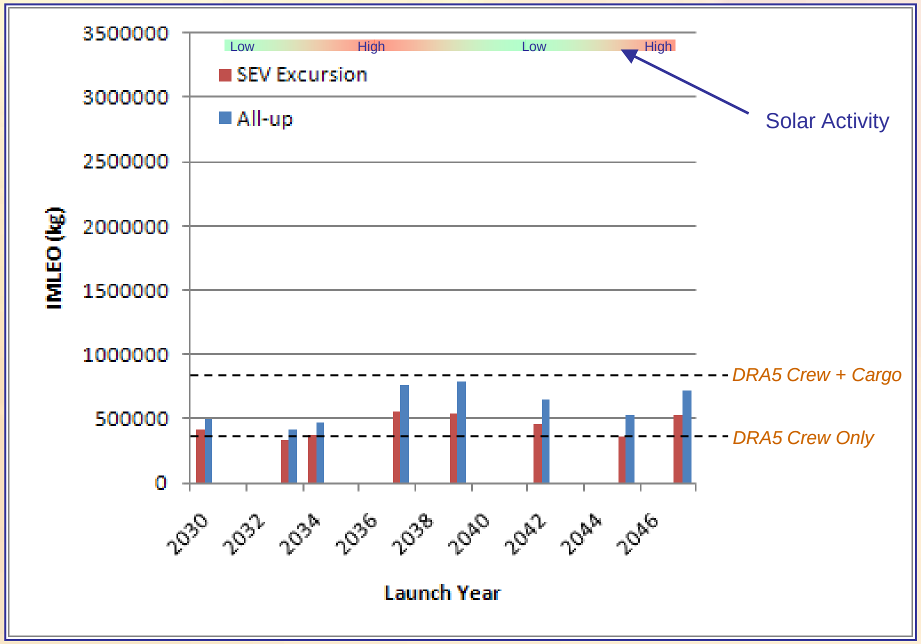


IMLEO Results for Phobos Mission

All Chemical (LOX/LH2) In-Space Propulsion

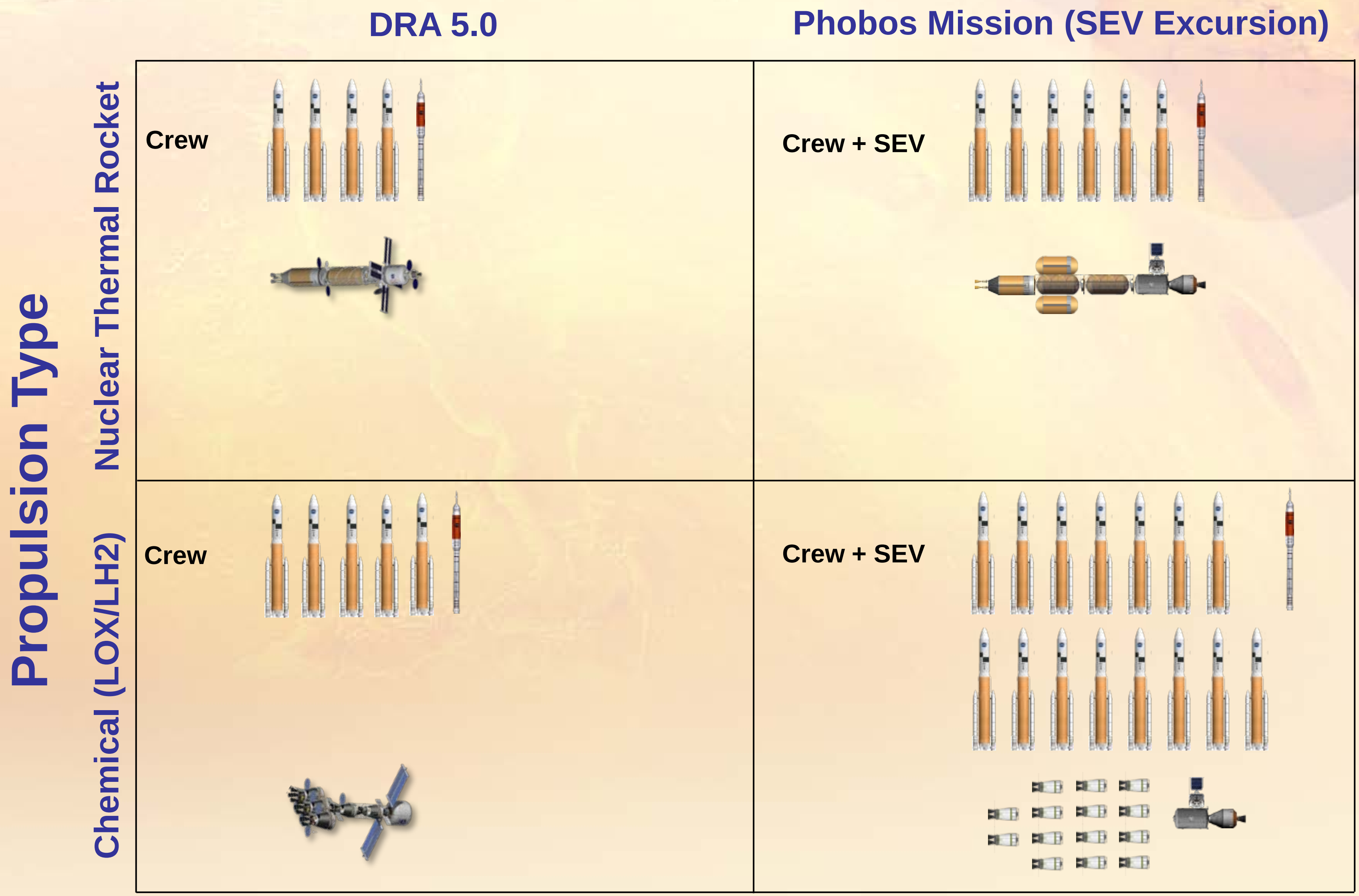


Nuclear Thermal Rocket (NTR) In-Space Propulsion



Note: Optimized trajectories assuming 407 km circular LEO departure orbit, propulsive capture at Mars into a Mars 1-Sol orbit of 250 km x 33,793 km. 30 sols stay at Mars. Direct entry at Earth with an entry speed limit of 13 km/s.

System Requirements Comparison: DRA5.0 compared to Phobos Mission



(Note: 120 MT payload for each SLS is assumed)

Phobos Mission Contribution to Retire Key Driving Requirements (KDR) & Challenges for Design Reference Architecture 5.0

Ground Ops
- ∗ 7+ launches per mission
- ● 30 day launch centers (300 day launch campaign)
- ○● Processing of nuclear systems
- ● Ares-V launch vehicle configuration
- ● Production and storage of cryogenics and helium

Ares-V
- ● 10-m dia x 30 m total length launch shroud
- ○ Dual use shroud (EDL)
- ● 125+ t to LEO
- ◖ Launch to higher inclinations
- ○ EDS evolution to long-duration (option)

Cross-cutting
- ● Automated Rendezvous & Docking (in Earth orbit)
- ● Cryogenic fluid management (H_2, O_2)
- ● Commonality & lowest level maintenance & repair
- ◖ Long-term system operation (300-1200 days)
- ● Low-Earth Orbit loiter for 300+ days
- ◖ Planetary protection
- ○ Dust mitigation

Mobility and Exploration
- ○ 100+ km roving range
- ○ 10+ m depth access
- ○ Light-weight, dexterous, maintainable EVA
- ◖ In-situ laboratory analysis capabilities

Human Health & Support
- ◖ Support humans in space for 900 days
- ∗ Radiation protection & forecasting
- ∗ Zero-g countermeasures
- ● Closed-loop life support (air & water)

In-Space Transportation
- ◖ ~50 t roundtrip (LEO to Mars orbit return)
- ∗ 110 – 125 t to Trans-Mars Injection
- ● Assembly via docking only
- ○ ISRU compatible lander propulsion (oxygen)
- ● Integrated transportation flight experience
- ◖ Advanced Inter-planetary Propulsion

Aeroassist
- ○ 40-50 t payload to the surface
- ○ Aerocapture + EDL for cargo
- ○ Abort-to-Mars surface
- ∗ 12 km/s Earth return speed

Surface Related
- ○ Auto-deployment and checkout of systems 30+ kWe continuous power
- ○ Reliable back-up power system

ISRU
- ○ Extraction, storage and use of consumables from the Martian atmosphere
- ○ Production of 24 t of oxygen for ascent
- ○ Production of life support oxygen (2 t) and water (3.5 t)

∗ Phobos mission solution exceeds DRA5 need
● Must be solved for Phobos mission
○ Not required for Phobos mission
◖ Must be partially solved for Phobos mission

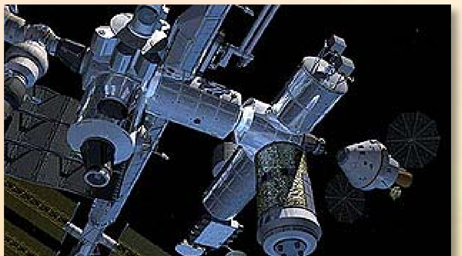
Phobos Mission: Additional Observations

- An excursion by an SEV-type vehicle is probably required to keep IMLEO in a reasonable range.
- A split mission approach (i.e., SEV and excursion stage launched separately to Mars orbit) marginally improves IMLEO; probably a programmatic decision to use this approach.
- Total flight time vary between 598 and 672 days with less than 30 days available for Phobos exploration.
- Crew health issues are problematic
  - Certification of a viable approach for almost 700 days of micro gravity
  - Enhanced SPE radiation hazard potential due to trajectory passage close to Sun (inside orbit of Venus)

Mars Design Reference Architecture 5.0
Example Evolutionary Testing Strategy

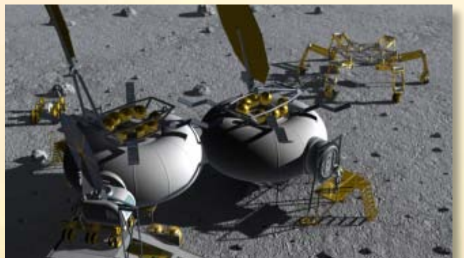
Knowledge / Experience / Confidence

Earth/ISS



- Critical long-duration performance data of both hardware and operational concepts
- Validation of gravity-sensitive phenomena & technologies
- Venue for long-duration system testing including crew interaction with hardware, software, and operational procedures
- Simulation of operational concepts
- Long-term exposure of systems to the space environment

Moon

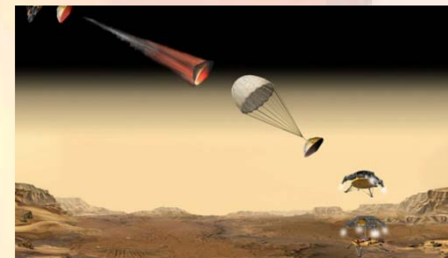


- Demonstration and use of Mars prototype systems (habitation, power, ISRU, mobility, etc.) to enhance lunar capabilities while improving confidence in future Mars systems
- Surface exploration scenarios and techniques
- Commonality and lowest level maintenance and repair concepts and technologies
- Long-term exposure of systems to the deep-space environment including radiation and dust
- Long-term “dry run” rehearsals and “what if” scenarios for future human Mars missions

Near Earth

- Demonstration of support of humans in deep-space for long durations (180+ days)
- Advanced technology demonstrations applicable to future human missions (propulsion, cryogenic fluid management, closed life support, radiation protection, etc.)
- Demonstration dry-run of humans to Mars orbit and back transportation (propulsion, habitation, crew support, Earth entry)

Mars via Robotics

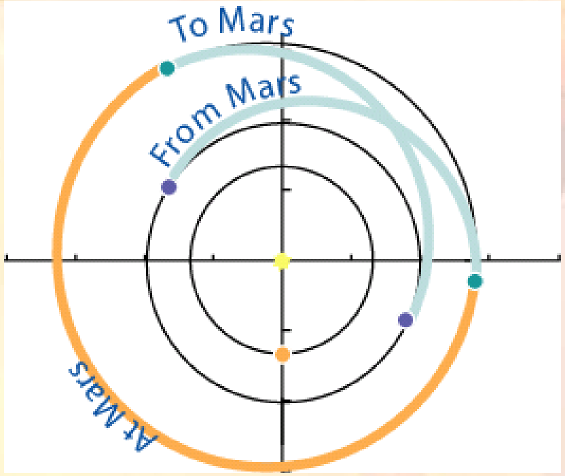


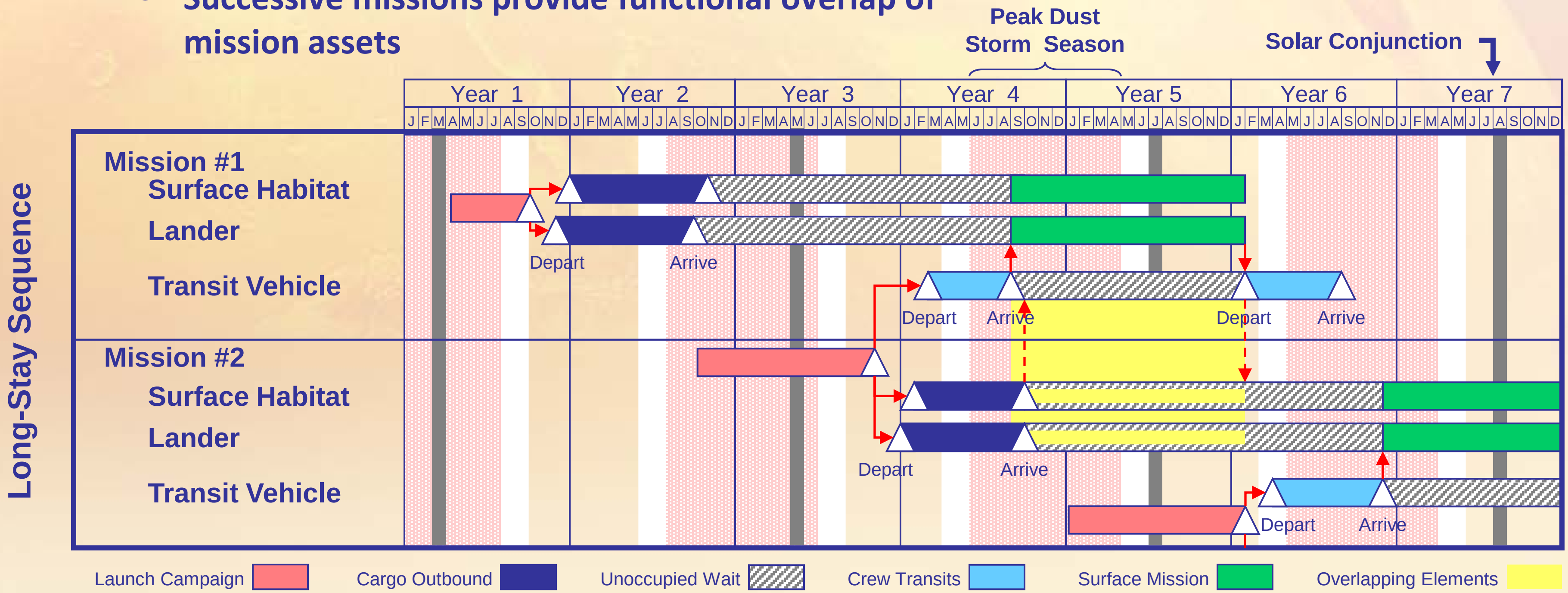
- Gathering environmental data of Mars (dust composition, thermal, radiation, terrain, hazards, etc.)
- Demonstration of landing large payloads on Mars
- Advanced technology demonstrations applicable to future human missions
- Dust mitigation techniques
- Large-scale unmanned cargo missions which land prior to the human mission can certify human landing vehicles

Backup

Mars Design Reference Architecture 5.0
Flight Sequence

- **Long-surface Stay + Forward Deployment**
  - **Mars mission elements pre-deployed to Mars prior to crew departure from Earth**
    - Surface habitat and surface exploration gear
    - Mars ascent vehicle
  - **Conjunction class missions (long-stay) with fast inter-planetary transits**
  - **Successive missions provide functional overlap of mission assets**

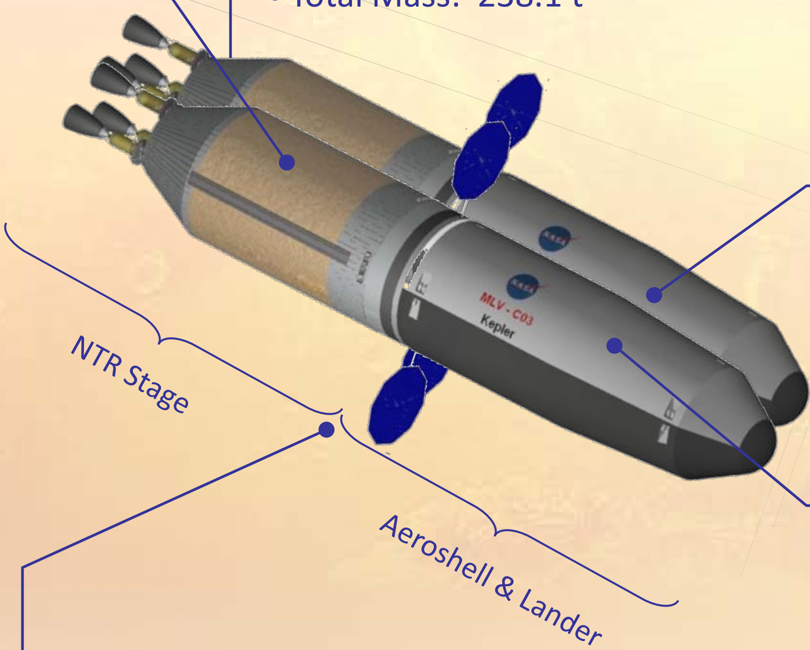




Cargo Vehicles
Surface Habitat & Descent / Ascent Vehicle

NTR Vehicle (each)

- Common "core" propulsion stage with 3 - 25 klbf NTR engines (Isp ~900 s)
- Total Mass: 238.1 t



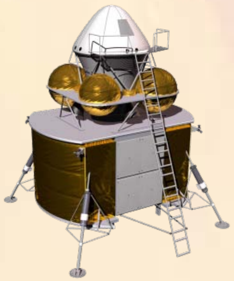
LEO Operations

- NTR stage & payload elements are delivered to LEO and assembled via autonomous rendezvous & docking

Surface Habitat (SHAB)

- Pre-deployed to Mars orbit
- Transports 6 crew from Mars orbit to surface
- Supports the crew for up to 550 days on the surface of Mars
- Ares V shroud used as Mars entry aeroshell
- Descent stage capable of landing ~40 t
- Advanced technologies assumed (composites, O2/CH4 propulsion, closed life support, etc
- Lander Mass: 64.2 t
- Lander + Aeroshell: 107.0 t

Descent Ascent Vehicle (DAV)

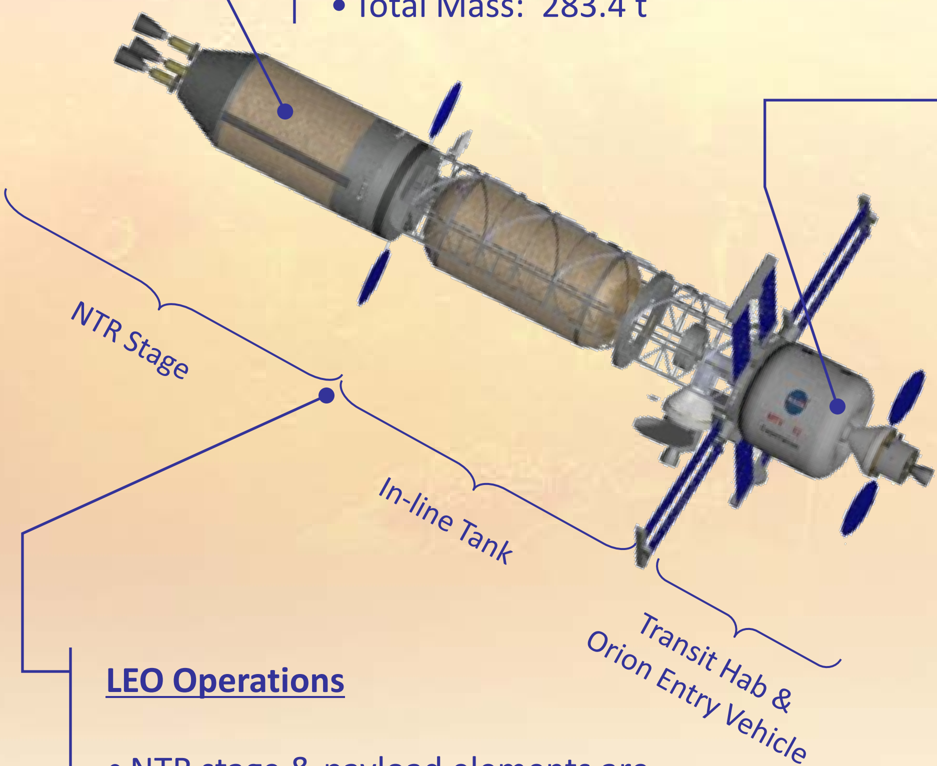


- Pre-deployed to the surface of Mars
- Utilizes locally produced propellants (oxygen) from Mars atmosphere, methane transported from Earth
- Transports 6 crew from the surface of Mars to high-Mars orbit
- Ares V shroud used as Mars entry aeroshell
- Descent stage capable of landing ~40 t
- Advanced technologies assumed (composites, O2/CH4 propulsion, etc
- Lander Mass: 63.7 t
- Lander + Aeroshell: 106.6 t

Crew Vehicle
Mars Transit Vehicle (MTV)

NTR Vehicle

- Common “core” propulsion stage with 3 - 25 klbf NTR engines (Isp ~900 s)
- Core stage propellant loading augmented with “in-line” LH2 tank for TMI maneuver
- Total Mass: 283.4 t



Transit Habitat & Orion Entry Vehicle

- Transports 6 crew round trip from LEO to high-Mars orbit and return
- Supports 6 crew for 400 days (plus 550 contingency days in Mars orbit)
- Crew direct entry in Orion at 12 km/s
- Advanced technologies assumed (composites, inflatables, closed life support, etc
- Transit Habitat Mass: 41.3 t
- Orion: 10.0 t

LEO Operations

- NTR stage & payload elements are delivered to LEO and assembled via autonomous rendezvous & docking