Journey To Mars –
Evolvable Mars Campaign
Overview

NASA Alumni League
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Scott Vangen (NASA/KSC)
Douglas Craig (NASA/HQ)
Pat Troutman (NASA/LaRC)
“Fifty years after the creation of NASA, our goal is no longer just a destination to reach. Our goal is the capacity for people to work and learn and operate and live safely beyond the Earth for extended periods of time, ultimately in ways that are more sustainable and even indefinite. And in fulfilling this task, we will not only extend humanity’s reach in space -- we will strengthen America’s leadership here on Earth.” (April 2010)
NASA Strategic Plan Objective 1.1

Expand human presence into the solar system and to the surface of Mars to advance exploration, science, innovation, benefits to humanity, and international collaboration.

Every decision made is made with this purpose in mind.

It requires sustainable exploration.

To us, that means affordable and continuous.
A Brief History of Human Exploration Beyond LEO
A trail of point solutions…pointing to the need for a resilient architecture
Evolvable Mars Campaign – Study Activity

Body of Previous Architectures, Design Reference Missions, Emerging Studies and New Discoveries

- Internal NASA and other Government
- International Partners
- Commercial and Industrial
- Academic
- Technology developments
- Science discoveries

2010 Authorization Act, National Space Policy, NASA Strategic Plan

- Establish capacity for people to live and work in space indefinitely
- Expand human presence into the solar system and to the surface of Mars

Evolvable Mars Campaign

- An ongoing series of architectural trade analyses, guided by Strategic Principles, to define the capabilities and elements needed for a sustainable human presence on Mars
- Builds off of previous studies and ongoing assessments
- Provides clear linkage of current investments (SLS, Orion, etc.) to future capability needs
Evolvable Mars Campaign

EMC Goal: Define a pioneering strategy and operational capabilities that can extend and sustain human presence in the solar system including a human journey to explore the Mars system starting in the mid-2030s.

• Identify a plan that:
  – Expands human presence into the solar system to advance exploration, science, innovation, benefits to humanity, and international collaboration.
  – Provides different future scenario options for a range of capability needs to be used as guidelines for near term activities and investments
    • In accordance with key strategic principles
    • Takes advantage of capability advancements
    • Leverages new scientific findings
    • Flexible to policy changes
  – Identifies linkages to and leverage current investments in ISS, SLS, Orion, ARM, short-duration habitation, technology development investments, science activities
  – Emphasizes prepositioning and reuse/repurposing of systems when it makes sense
    • Use location(s) in cislunar space for aggregation and refurbishment of systems

Internal analysis team members:
– ARC, GRC, GSFC, HQ, JPL, JSC, KSC, LaRC and MSFC
– HEOMD, SMD, STMD, OCS and OCT

External inputs from:
International partners, industry, academia, SKG analysis groups
Strategic Principles for Sustainable Exploration

- Implementable in the *near-term with the buying power of current budgets* and in the longer term with budgets commensurate with economic growth;

- *Exploration enables science* and science enables exploration, leveraging robotic expertise for human exploration of the solar system;

- Application of *high Technology Readiness Level* (TRL) technologies for near term missions, while focusing sustained investments on technologies and capabilities to address challenges of future missions;

- *Near-term mission opportunities* with a defined cadence of compelling and integrated human and robotic missions providing for an incremental buildup of capabilities for more complex missions over time;

- Opportunities for *U.S. commercial business* to further enhance the experience and business base;

- *Resilient architecture featuring multi-use, evolvable space infrastructure*, minimizing unique major developments, with each mission leaving something behind to support subsequent missions; and

- Substantial *new international and commercial partnerships*, leveraging the current International Space Station partnership while building new cooperative ventures.
Implementable in the *near-term with the buying power of current budgets*

- Early transportation development (SLS/Orion) prior to development of additional elements required for Mars vicinity missions
- Continuity of human space flight during transition from ISS human exploration to Beyond Low Earth Orbit human exploration missions
- Reuse of infrastructure for multiple missions / limited one time use of elements
- Commonality of systems (habitation, transportation)
- Reusability of systems
Near-term mission opportunities with a defined cadence of compelling missions

- Cadence of missions that establish human spaceflight capabilities beyond LEO and maintain critical mass for ground processing and flight operations.

- SLS Launch Rate from 2021-2028 is 1 per year, past 2028 is maximum 2 per year (1 crew and 1 cargo) with surge capacity of 3 per year (not in consecutive years).
Resilient Architecture Featuring Multi-Use, Evolvable Space Infrastructure, Minimizing Unique Major Developments

- Use ISS to the Maximum Extent Possible
- Use Evolution of ARV SEP for Human Transportation
- Reuse of Infrastructure for Multiple Missions
Substantial New International and Commercial Partnerships

- Four Crew Members and robots on each Mars Vicinity Mission – potentially 8 crew in space for periods of time during Mars Missions (4 crew in cislunar)

- Missions will have ample opportunity for commercial and international participation
Reference Campaign
High Level Ground Rules and Assumptions

- Utilize ISS to greatest extent possible for capability development
- Use test and validation missions as pre-deployment missions
  - Emphasis on reducing the number of unique system developments
  - Maintain cadence of at least one crewed mission per year
  - Utilize SLS Block 1B co-manifested cargo capability to the greatest extent possible
  - 1 SLS crew flight per year in the Proving Ground
  - SLS Block 2B for Mars era missions
- ARM / ARV SEP derived vehicle used for missions to Mars vicinity
  - ACRM mission occurs in 2025
- Initial cis-lunar habitat is comprised of capabilities whose design can be leveraged for future missions to Mars vicinity and Mars surface
- Crew of 4 for Mars missions
- First crew mission to Mars vicinity in 2030s - mission lays the foundation for later crew Mars surface missions
  - Accommodate Mars Mission opportunities throughout the 2030s
- Use Lunar DRO as aggregation point for missions to Mars vicinity and Mars surface
  - Use of Proving Ground foundational capabilities for Mars vehicle build-up and checkout
  - Use Lunar DRO for potential refurbishment and resupply location
EMC Expansion of Capabilities
Informed by NASA Technology Roadmaps, System Maturation Teams, Partners and External Experts

**EARTH RELIANT: ISS**

International Space Station: Can humans live & operate independently for ~1000 days in micro-G?
- Long-duration, Zero-g human factors research platform
- Highly reliable life support, advanced logistics, low maintenance systems
- Environmental monitoring
- Supportability & maintenance concepts

**EARTH INDEPENDENT: PHOBOS/DEIMOS/MARS ORBIT**

Can humans travel to Mars orbit and safely return to Earth?
- Deep Space Proving Ground plus:
  - High power SEP
  - ~1000 day deep space habitat(s)
  - Deep space countermeasures
  - Mars vicinity propulsion

**MARS SURFACE**

Can humans break the supply train with Earth to enable long-term presence?
- Phobos/Deimos plus:
  - Mars entry & landing systems
  - Partial-gravity countermeasures
  - Long duration surface Systems (ISRU, fission power)

**PROVING GROUND: cis lunar & DEEP SPACE**

Bridging from ISS, can human class systems operate in a deep space environment in a crew tended mode for long durations?
- Distant Retrograde Orbit:
- Heavy lift launch (SLS), Orion
- High-power In-Space Propulsion
- Initial beyond-Earth orbit habitation- Crew support for increasing duration
- Advanced EVA (Suit, Portable Life Support System)
- Deep space long duration systems and operations testing
- Aggregation of Mars Mission Vehicles

Continued Leveraging of Commercial & International Partnerships
## Major Elements Required for Journey to Mars

<table>
<thead>
<tr>
<th>LEO</th>
<th>cislunar Proving Ground</th>
<th>Mars</th>
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<tbody>
<tr>
<td>2010s</td>
<td>2020s</td>
<td>2030s and Beyond</td>
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### Phase 0
ISS and Commercial LEO

#### Mars Orbit w/Mars Moons Mission Elements
- Mars Taxi (and Ascent Vehicle)

#### Mars Surface Mission Elements
- Short Stay – EDL/ Lander/Ascent Vehicle
- Long Stay – Habitat, Rover, Power

### Proving Ground Phase 1
Initial Proving Ground Elements
- Initial cislunar Habitat
- Asteroid Redirect Vehicle
- ISS
- International and Commercial Crew & Cargo

### Proving Ground Phase 2
Shakedown Cruise with Mars Class Habitat and In-Space Transportation
- Hybrid Transhab
- SLS 1B
- SLS 2B

### LEO Proving Ground Phase 0
- SLS
- In-Orbit
- Earth-Robotic Elements

Illustrations of spacecraft and elements are shown throughout the diagram.
INTERNATIONAL SPACE STATION
EARTH RELIANT
NEAR-TERM OBJECTIVES

DEVELOP AND VALIDATE EXPLORATION CAPABILITIES IN AN IN-SPACE ENVIRONMENT

• Long duration, deep space habitation systems
• Next generation space suit
• Autonomous operations
• Communications with increased delay
• Human and robotic mission operations
• Operations with reduced logistics capability
• Integrated exploration hardware testing

LONG-DURATION HUMAN HEALTH EVALUATION

• Evaluate mitigation techniques for crew health and performance in micro-g space environment
• Acclimation from zero-g to low-g

COMMERCIAL CREW TRANSPORTATION

• Acquire routine U.S. crew transportation to LEO
ISS – Earth Reliant – Phase 0

• ISS will play a critical role in advancing the capabilities that will be required for human Mars missions
  – Only platform available to conduct crewed, long-term, in-space evaluation of critical capabilities and technologies
    • Available resources include: crew time, power, thermal, communications, and Earth return
  – Only platform to conduct long-duration human spaceflight test and validation activities related to human physiological and physiological responses to extended periods in space

• A series of analog activities, progressively increasing in duration and scope, will be conducted by ISS crewmembers
PROVING GROUND
Cislunar Aggregation of Systems and Proving Ground Testing

LOCATION

• Only ~3 to 5 days away from Earth yet farther than Apollo went
• Ideal mission aggregation location
  – Lunar Surface, Mars and Asteroids all accessible for less than 2.5 km/sec
  – Cryogenic oxygen & hydrogen used to inject to cislunar without requiring ZBO
• The next “high ground” beyond GEO
  – L2 – Lunar far-side science
  – L1 – Earth observations
  – All cislunar – low latency teleoperations of lunar assets
• Access to local resources (ISRU)
  – Lunar gravity assists
  – Lunar surface volatiles
  – Asteroidal material
• Accessible by NASA, commercial, and international launch systems

ENVIRONMENT

• True deep space radiation environment
  – Similar to Mars system & transit there
  – No van Allen belts
• Benign orbital debris environment
• Minimal station keeping requirements
• Some stable orbits
• Orbital phasing and transfer for minimal energy
• Infrequent/avoidable eclipse periods
• Thermal environment compatible with cryogenic oxygen and methane
<table>
<thead>
<tr>
<th>Category</th>
<th>Title</th>
<th>Objective</th>
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</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>Crew Transportation</td>
<td>Provide ability to transport at least four crew to cislunar space</td>
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<tr>
<td>Transportation</td>
<td>Heavy Launch Capability</td>
<td>Provide beyond low-Earth orbit launch capabilities to include crew, co-manifested payloads, and large cargo</td>
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<tr>
<td>Transportation</td>
<td>In-Space Propulsion</td>
<td>Provide in-space propulsion capabilities to send crew and cargo on Mars-class mission durations and distances</td>
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<tr>
<td>Transportation</td>
<td>Deep Space Navigation and Communication</td>
<td>Provide and validate cislunar and Mars system navigation and communication</td>
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<tr>
<td>Working in Space</td>
<td>Science</td>
<td>Enable science community objectives</td>
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<tr>
<td>Working in Space</td>
<td>Deep Space Operations</td>
<td>Provide deep-space operations capabilities</td>
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<td>• EVA</td>
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<td>• Staging</td>
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<td>• Logistics</td>
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<td>• Human-robotic integration</td>
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<tr>
<td></td>
<td></td>
<td>• Autonomous operations</td>
</tr>
<tr>
<td>Working in space</td>
<td>In-situ Resource Utilization</td>
<td>Understand the nature and distribution of volatiles and extraction techniques and decide on their potential use in human exploration architecture.</td>
</tr>
<tr>
<td>Staying Healthy</td>
<td>Deep Space Habitation</td>
<td>Provide beyond low-Earth orbit habitation systems, sufficient to support at least four crew on Mars-class mission durations and dormancy</td>
</tr>
<tr>
<td>Staying Healthy</td>
<td>Crew Health</td>
<td>Validate crew health, performance and mitigation protocols for Mars-class missions</td>
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Proving Ground

- The Proving Ground will include two phases:
  - Phase 1
    - Begins with EM-1 and ends with the crew visit (ARCM) to the ARV and its captured boulder
    - Focus of Phase 1 is concept and testing in preparation of Mars systems deployment
    - Elements include Orion and SLS, ARM, initial cislunar habitat facility
  - Phase 2
    - Begins after ARCM and ends with all systems ready for the first crewed Mars mission
    - Focus of Phase 2 is validation of shakedown of Mars transportation and exploration systems
    - Elements include long duration deep space habitat, transportation stages, and excursion vehicles/taxi
- The initial cislunar habitat will serve to augment the capabilities of Orion in cislunar space, providing additional capabilities for crew habitation, utilization, and stowage
  - Designed to allow a crew of four to remain in cislunar space for durations of up to 30 days, in conjunction with Orion
  - Has a dedicated airlock capability to enable the crew to conduct EVAs utilizing full EVA suits and without having to depressurize the Orion capsule
  - Includes docking capabilities to allow multiple elements to be co-located in cislunar space to extend the initial cislunar habitation capability
  - Orion will augment primary crew habitation capabilities
- In conjunction with Proving Ground activities, robotic precursor missions and capability demonstrations may occur in the Mars system
Asteroid Redirect Mission: Three Main Segments

IDENTIFY
Ground and space based assets detect and characterize potential target asteroids

REDIRECT
The Asteroid Redirect Robotic Mission (ARRM) uses solar electric propulsion (SEP) based system to redirect asteroid to cis-lunar space.

EXPLORE
Crew launches aboard SLS rocket, travels to redirected asteroid in Orion spacecraft to rendezvous with redirected asteroid, studies and returns samples to Earth
NextSTEP BAA: Habitation Awards

NASA awarded seven habitation projects. Four will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS).

**Lockheed Martin**
Denver, CO

Habitat to augment Orion’s capabilities. Design will draw strongly on LM and partner Thales Alenia’s heritage designs in habitation and propulsion.

**Bigelow Aerospace LLC**
Las Vegas, NV

The B330 for deep-space habitation will support operations/missions in LEO, DRO, and beyond cis-lunar space.
NextSTEP BAA: Habitation Awards

NASA awarded seven habitation projects. Four will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS).

**Orbital ATK**
Dulles, VA

Habitat that employs a modular, building block approach that leverages the Cygnus spacecraft to expand cis-lunar and long duration deep space transit habitation capabilities and technologies.

**Boeing**
Houston, TX

Developing a simple, low cost habitat that is affordable early on, allowing various technologies to be tested over time, and that is capable of evolving into a long-duration crew support system for cis-lunar and Mars exploration.
Objective - Proving Ground Satisfaction Criteria

• When can we push the big green button and fly a Mars vicinity mission?
  – For this study Mars vicinity is described as transit, orbital and Mars moons missions

• Proving Ground satisfaction criteria definition
  – How do we know the exploration systems and subsystems are ready to transition beyond the Proving Ground to Mars vicinity?
  – What development, testing and integration are needed in the Proving Ground to have confidence that the exploration mission architecture is ready for a Mars vicinity mission?
Proving Ground Satisfaction Criteria = Planning for a trip with a brand new car

• To Do
  – Test drive
  – Engine break in
  – Get comfortable with operating it
  – Understand how to service it
    • Check tire pressure
    • Change oil
    • Fill gas tank
  – Print map
  – Clean car
  – Feed cat
  – Get snacks
  – Pack

• To Do
  – SEP validation
  – ECLSS run time
  – Propellant transfer
  – Trajectory planning and selection
  – Shake down habitat
  – Ground operations
  – Crew health and performance
  – Logistics

What did we forget?
Transportation Architecture
Split Mission Concept

Using SEP for pre-emplacement of cargo and destination systems enables sustainable Mars campaign

- Minimizes the cargo needed to be transported with the crew on future launches
- Enables a more sustainable launch cadence
- Pre-positions assets for crew missions, allowing for system checkout in the Mars vicinity prior to committing to crew portion of mission
DRO as an aggregation point for Mars habitation systems

- Provides a stable environment and ease of access for testing Proving Ground capabilities
- Allows for Mars transit vehicle build-up and checkout in the deep-space environment prior to crew departure
- Able to transfer Mars Transit Vehicle from DRO to High Earth Orbit with small amount of propellant to rendezvous with crew in Orion – HEO is more efficient location to leave Earth-moon system for Mars vicinity
Split Mission Concept

- Returning from Mars, the crew will return to Earth in Orion and the Mars Transit Habitat will return to the staging point in cis-lunar space for refurbishment in support of future missions.
Space Launch System
“Evolving the Nation’s Deep Space Rocket”

Cargo Configurations
Co-manifested, 5m, 8.4m and 10m

Exploration Upper Stage
Core Stage
Solid Rocket Boosters
RS-25

Upper Stage
Exploration Upper Stage
Core Stage
RS-25

Advanced Booster
Solid or Liquid

Block 1
70 mT

Block 1B
105 mT

Block 2
130 mT

As documented in “Pioneering Next Steps in Space Exploration”
Mission concepts with Universal Stage Adaptor Co-Manifested/Dual Payload

Orion with EAM
total mission volume = ~ 400m³

Orion with ARV
total mission volume = ~ 400m³

5m fairing w/R robotic Lunar Lander & EAM
total mission volume = ~ 650m³

8m fairing with telescope
total mission volume = ~ 1200m³

10m fairing w/notional Mars payload
total mission volume = ~ 1800m³

Comparative: STS Total mission Volume: ~304m³
Delta IV 5m Med PLF: ~256m³
SEP Module Extensibility for Mars

Asteroid Redirect Mission
- 50-kW Solar Array
- 40-kW EP System
- 10-t Xenon Capacity with refueling capability

SEP/Chemical
- 190-kW Solar Array
- 150-kW EP System
- 16-t Xenon Capacity

Hybrid
- 250 to 400-kW Solar Array
- 150 to 300-kW EP System
- 24-t Xenon capacity with Xe refueling capability
EMC Reusable In-Space Transportation (Hybrid SEP/Chem)

1. Deploy spacecraft to Cislunar Space
2. Refueling and Logistics Resupply in Cislunar Space
3. Outbound and Inbound Crew Rendezvous in LDHEO
4. Lunar Gravity Assist Departure
5. SEP Thrust to Mars
6. Chemical Mars Mars Orbit Insertion
7. High Mars Orbit Dwell
8. Chemical Trans Earth Injection
9. SEP Thrust to Earth
10. Lunar Gravity Assist Arrival
11. Resupply, refuel, and recertified in cislunar space between crew missions
MARS VICINITY
The Moons of Mars as a Human Destination

**Unexplored and Intriguing**
- Rich science
- A link to Mars past and its future
- Incredible views

**A More Achievable Step**
- Common crew transportation system to Mars orbit
- Low gravity environment for access and exploration
- Less investment than Mars surface required

**An Enabler for Mars Surface Exploration**
- Alternate mission modes opened up
- Low latency tele-operations of Mars surface assets
- ISRU potential for sustainable pioneering of Mars
Maximum Vertical Jump –
650 lb. Suited Crew (crew + suit + jetpack)

Weight on Phobos | lbf |
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Crewmember in a Suit</td>
<td>0.3</td>
</tr>
<tr>
<td>SEV (6,000 kg)</td>
<td>7.7</td>
</tr>
<tr>
<td>Habitat (15,000 kg)</td>
<td>19.2</td>
</tr>
<tr>
<td>Lander (50,000 kg)</td>
<td>63.9</td>
</tr>
</tbody>
</table>

Apollo 16 – John Young’s Jump Salute

<table>
<thead>
<tr>
<th></th>
<th>Time of Flight</th>
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<tbody>
<tr>
<td>Moon</td>
<td>2.5 sec.</td>
</tr>
<tr>
<td>Phobos</td>
<td>11.7 min.</td>
</tr>
<tr>
<td>Deimos</td>
<td>22.2 min.</td>
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</table>
Mars Surface
Mission to Mars Surface: Learn to Live Independent from Earth

• Initial Human Mission Include Testing and Validation for:
  – ISRU (Water, other resources extracted from regolith)
  – Building infrastructure
  – Manufacturing systems in-situ
  – Growing food
  – Human/Social “Engineering”
  – Humans Perform Mars Science
  – Humans return and reuse infrastructure at a single Mars site.
Example Exploration Zone with Mars Surface Field Station and Surrounding Regions of Interest (ROI’s)

A collection of Regions of Interest (ROIs) within about 100 km of a landing site and a habitation site. ROIs are areas of interest for science and capability development, and may contain resources to support human explorers,
Mission to Mars Surface: First Crew to the Surface

3 Precursor Cargo Landers + 1 Crew Lander

- Lander 1: Power
- Lander 2: Mars Ascent Vehicle (MAV)
- Lander 3: Logistics
- Lander 4: Habitation Crew Arrival

1 km radius plume ejecta hazard zone (typ)

100 m dia designated landing site
A two-major-milestone, three-step surface architecture approach is used to achieve the Ultimate Goal (i.e., Earth Independence), and would include a “Mars Surface Testing and Validation” during Step 2.
Capability Needs
Transportation of Crew and Cargo To/From Deep Space

**Challenges**

- Deliver crew and cargo to deep space
- Return crew from deep space

**Orion**

- Support crew during trip to/from cislunar space
- 4 crew for 21 days
- Contingency EVA in a Launch, Entry, and Abort (LEA) suit using umbilical life support
- Ability to rendezvous and dock with other in-space elements
- Earth to cislunar navigation
- Earth entry from cislunar space: 11 km/s

**Space Launch System**

- Transport crew and cargo to cislunar space
  - Initial launch vehicle that can launch 36 t to TLI
  - Upgraded launch vehicle that can launch 43 t to TLI
  - Option for 5, 8.4, or 10 m diameter shroud
  - 1/year launch rate with surge to 2/year for cislunar missions
  - 2/year launch rate with surge to 3/year for Mars missions

**Commercial Launch**

- Use commercial launch vehicles to deliver logistics and small cargo to cislunar space
  - Small cargo vehicle to deliver up to 11 t to TLI
  - Shroud = 5 m diameter
Common Capabilities

4 crew for short durations (up to 60 days)
Support autonomous mission operations with time delay

Autonomous rendezvous, prox ops, and docking
Ability to be teleoperated with <0.5 s latency
Communications to/from Earth and between elements

Common, lightweight pressure vessel and common hatch
15 year lifetime with long dormancy periods
Design for maintainability

Initial Cislunar Habitation

Support crew each year for short duration stays in cislunar space
- 4 crew for up to 60 days
- EVA pressure garment and PLSS <200 kg with dual-band radio avionics and radiation hardened bio-med sensors
- High frequency EVA (15 min. ingress-egress time)
- Lightweight exercise equipment under 25 kg
- 1 year dormant before use
- Up to 300 days dormant between uses

Excursion Vehicle

Protect and support crew in deep space for up to 60 days
Uncrewed operations during deployment and between uses
Earth-independent operations

Common, partially closed ECLSS under approx. 800 kg
(3 years MTBF and 2 crew per torr of CO₂ removal)

Autonomous rendezvous, prox ops, and docking
Ability to be teleoperated with <0.5 s latency
Communications to/from Earth and between elements

Common, lightweight pressure vessel and common hatch
15 year lifetime with long dormancy periods
Design for maintainability

Logistics Module

- Launched on either SLS and ELV launch vehicles
- Carries up to 5-10 t of pressurized logistics
- 10-15 t total mass
- 4 crew for up to 2 weeks, contingency 4 crew for 1 week
- EVA pressure garment and PLSS <200 kg with dual-band radio avionics and radiation hardened bio-med sensors
- High frequency EVA (15 min. ingress-egress time)
- 4 years dormant before first use and between uses
- Design for reuse for 3 missions
- Lightweight exercise equipment under 25 kg

Return crew to Mars orbit
- 4 crew for up to 3 days flight duration
- Open loop ECLSS under approx. 400 kg
- 5 years dormant before use
- 4 crew for up to 2.5 day crewed duration
- 560 days operational (uncrewed) at Mars
- 2 years dormant before use
- Up to 1.5 years dormant between uses

Mars Taxi

Transport crew between Mars orbit and Mars Moons
- 4 crew for up to 2.5 day crewed duration
- 560 days operational (uncrewed) at Mars
- 2 years dormant before use
- Up to 1.5 years dormant between uses

Mars Ascent Vehicle

Explore kilometers away from the destination habitat
- 2 crew for up to 2 weeks, contingency 4 crew for 1 week
- EVA pressure garment and PLSS <200 kg with dual-band radio avionics and radiation hardened bio-med sensors
- High frequency EVA (15 min. ingress-egress time)
- 4 years dormant before first use and between uses
- Design for reuse for 3 missions
- Lightweight exercise equipment under 25 kg

Logistics Module to cislunar space

Launches to the Mars taxi, transports crew to Mars surface
- Carries up to 5-10 t of pressurized logistics
- 10-15 t total mass
- 2 crew for up to 2 weeks, contingency 4 crew for 1 week
- EVA pressure garment and PLSS <200 kg with dual-band radio avionics and radiation hardened bio-med sensors
- High frequency EVA (15 min. ingress-egress time)
- 4 years dormant before first use and between uses
- Design for reuse for 3 missions
- Lightweight exercise equipment under 25 kg
LIVING IN SPACE: LONG DURATION HABITATION

**Common Capabilities**

- 4 Crew for 500-1100 days
- Common pressure vessel
- 15 year lifetime with long dormancy periods
- Design for reusability across multiple missions
- 100 m³ habitable volume and dry mass < 22 t
- Autonomous vehicle health monitoring and repair
- Advanced Exploration ECLSS with >85% H₂O recovery and 50% O₂ recovery from reduced CO₂
- ECLSS System (w/o spares): <5 t mass, <9 m³ volume, <4 kW power
- Environmental monitoring with >80% detection rate without sample return
- 14-kW peak operational power and thermal management required
- Autonomous mission operations with up to 24 minute one-way time delay
- Autonomous medical care, behavioral health countermeasures, and other physiological countermeasures to counteract long duration missions without crew abort
- Exercise equipment under 500 kg
- Provide 20-40 g/cm² of radiation protection
- EVA pressure garment and PLSS <200 kg
- Contingency EVA operations with 1 x 2-person EVA per month
- Communications to/from Earth and between elements

**Mars Surface Habitat**

- Live and operate on the Mars surface in 1/3 g
  - 4 crew for up to approx. 500 days
  - 48 m³ volume for logistics and spares
  - Logistics Mass: 10.7 t
  - 4 years dormant before use
  - 3-4 years dormant between uses
  - EVA system with surface mobility, dust mitigation, and atmospheric compatibility

**Transit Habitat**

- Live and operate in microgravity during trip to/from Mars
  - 4 crew for up to 1,100 days
  - 93 m³ volume for logistics and spares
  - Logistics Mass: 21 t
  - 4 years dormant before use and between uses

**Challenges**

- Protect and support crew in deep space for up to 1100 days
- Uncrewed operations during deployment and between uses
- Reduced logistics and spares
- Earth - independent operations

**Phobos Habitat**

- Live and operate in microgravity at Phobos
  - 4 crew for up to approx. 500 days
  - 48 m³ volume for logistics and spares
  - Logistics Mass: 10.7 t
  - EVA system with Phobos mobility and dust mitigation
  - 4-5 years dormant before use
  - 3 years dormant between uses
Mars EDL

**Challenges**
- Transport crew and cargo to/from Mars vicinity
- Provide transportation within the Mars system
- Provide access to Mars surface
- Uncrewed operations during deployment and between uses

**Possible aerocapture at 6.3 km/s if not propulsively delivered to orbit**
- Entry velocity of 3.8 – 4.7 km/s
- 100 m precision landing with hazard avoidance
- Supersonic retropropulsion with LOX/CH₄ engine
- Deployable/Inflatable (16-23 m) entry systems
- Surface access at +2 km MOLA
- 20-30 t payload to the surface, 40-60 t arrival at Mars

**Electric Propulsion**
Deliver approx. 40-60 t to Mars orbit
- 200-kW class solar array system (BOL at 1 AU)
- using 30% efficient GaAs, triple junction solar cells
- 300 V array system converted to 800 V for EP and 28 V for spacecraft

**Common Capabilities**

**Chemical Propulsion**

**Common LOX/CH₄ Pump-Fed Engine:**
- Thrust: 25 klbf
- Isp: 355-360 s
- Up to 15 year lifetime
- 150-500 s burn time
- 5:1 throttling
- Near-ZBO storage with 90 K cryocooler

**LOX/CH₄ Pressure-Fed RCS:**
- Thrust: 100-1000 lbf; Isp: 320 s

**SEP - Chemical**

**SEP delivers cargo to Mars vicinity, and LOX/CH₄ propulsion delivers crew to/from Mars vicinity**
- 1 x 200-kW class solar array
- >8 kW thermal rejection
- Flight times to Mars approx. 1,400 days
- 4-6 years dormant before use

**SEP - Hybrid**

**Combined SEP and hypergolic propulsion system delivers crew and cargo to Mars vicinity**
- 2 x 200-kW class arrays
- 1,100 days total trip mission time, 300 days at Mars
- >16 kW thermal rejection
- Ability to refuel 24 t of Xe on orbit
- 15 year lifetime, 3 uses, 3 refuelings

**Mars Ascent**

**Return crew and cargo from Mars surface**
- 4 crew and 250 kg payload from ≥30 deg latitude, 0 km MOLA to Mars parking orbit
- 26 t prop (20 t O₂, 6 t CH₄), 35 t total liftoff mass, 8 t Earth launch dry mass
- Up to 3 days flight duration
- 5 years dormant before use
- Use of ISRU-produced oxygen

**Mars Taxi**

**Transport crew and cargo within the Mars system**
- 4 crew for up to 2.5 days
- 7 t inert mass, 14 t wet mass
- 8 kW EOL at Mars solar power
- Reusable and refuelable

**Mars EDL**

**Delivery crew and cargo to Mars surface**
- Possible aerocapture at 6.3 km/s if not propulsively delivered to orbit
- Entry velocity of 3.8 – 4.7 km/s
- 100 m precision landing with hazard avoidance
- Supersonic retropropulsion with LOX/CH₄ engine
- Deployable/Inflatable (16-23 m) entry systems
- Surface access at +2 km MOLA
- 20-30 t payload to the surface, 40-60 t arrival at Mars
**Destination Systems**

**Phobos / Deimos**
- Mobility power generation of 1-3 kW BOL and 120 kW-hr eclipse storage
- Mobility systems for crew (2 nominal, 4 contingency) and cargo (up to 3 t) with approx. 40 km range
- RCS mobility sled for excursion vehicle
- Dormant for 6 years at Phobos/Deimos before use
- Dormant for 3 years between uses
- All elements have 15 year lifetime
- Low-g body docking and interaction

**Mars Surface**
- Uncrewed operations during deployment and between uses
- Extracting and processing local resources
- Operations in harsh environments
- 40 kW stationary Mars surface power
- 1-5 kW deployable/mobile Mars power
- Mars surface rover for crew (2 nominal, 4 contingency) and cargo (up to 3 t) with a range of 90 km per charge and max speed of 10 km/hr
- Mars surface ISRU plant capable of processing >2.2 kg/hr of atmosphere CO₂ into O₂ with a process efficiency of 36%, power of 20-22 kWe, and is less than 1 t
- Liquification and cryogenic fluid storage in Mars atmosphere
- All systems dormant for 4-5 years before first use and between uses
- All elements have 15 year lifetime
- Offloading and transport systems capable of up to 10 t

**Cis - Lunar/Asteroid**
- Acquisition and processing of 0.08 – 1.6 kg/day of water, oxygen, carbon, nitrogen (e.g. water, oxygen, carbon, nitrogen) to achieve Earth-independence
- Ability to be teleoperated from other destination elements
- Support autonomous mission operations with time delay
- Communications to/from Earth and between elements
- Robotic support for setup, operations, and maintenance
- Sample acquisition
- Dust mitigation

**Moon**
- Robotic rover with acquisition and processing of icy regolith
Summary
Major Results to Date

- Regardless of Mars vicinity destination, common capability developments are required
  - Mars vicinity missions selection not required before 2020
- ISS provides critical Mars mission capability development platform
- Lunar DRO is efficient for aggregation and potential refurbishment due to stable environment
  - Use of gravity assist trajectories enable use of DRO
- Orion provides key capability for Mars architectures with reusable habitats
- SLS co-manifested cargo capability increases value of crewed missions and improves cadence
- Deep-space habitation serves as initial starting point regardless of implementation or destination
- ARV derived SEP vehicle can serve as an effective tool for human Mars missions
  - Reusability can enable follow-on use in cislunar space
  - Refuelability under study to enable Mars system follow-on use
  - Current SEP evolvability enables Mars system human missions
- Either Mars Orbit / Phobos / Deimos as an initial Mars vicinity mission spread out development costs and meets policy objectives of Mars vicinity in 2030’s
  - Common crew transportation between Mars Phobos / Deimos and Mars Surface staging
  - Phobos provides 35% reduction of radiation exposure compared to other Mars orbit missions
  - Provides ability to address both exploration and science objectives
  - ARM returned asteroid at Lunar DRO serves as good location for testing Mars moon’s operations
Summary

• The Journey to Mars requires a resilient architecture that can embrace new technologies, new international / commercial partners, and identify agency investment choices to be made in the near, mid and long term.

• The Evolvable Mars Campaign:
  – Informs the agency choices by providing technical information from a cross agency, end-to-end integrated analysis
  – Needs to continue to develop linkages to the agency decision making and capability investment processes

• Regardless of which path is ultimately selected, there are a set of common capabilities required to be developed by NASA and its partners over the next 5 to 10 years
THE JOURNEY TO MARS HAS ALREADY BEGUN.
Read All About It

http://go.nasa.gov/1VHDXxg
Backup Slides
Proving Ground Phase Activities Underway

- Space Launch System
  - Engines
  - Stages (including EUS)
  - Boosters
- Orion Crew Vehicle
- Ground System Development and Operations
- Asteroid Redirect Mission
  - Capture mechanism
  - Solar electric propulsion
  - Spacecraft bus and solar arrays
- Habitation Systems
- cislunar Habitat
- EVA systems
Beginning human exploration beyond LEO as soon as practicable helps secure our future in space.
Orion Accomplishments

The European Service Module Structural Test Article at the Space Power Facility at NASA Glenn Research Center's Plum Brook Station

A manufacturing development unit of Orion's heat shield is being built at Lockheed Martin's facility in Denver

Successful completion of 17th and final Orion parachute engineering development test series, January, Yuma, Arizona

Completed barrel segment of Orion's EM-1 crew module pressure vessel at MAF, New Orleans, Louisiana

Completed cone segment of Orion's EM-1 crew module pressure vessel at MAF, New Orleans, Louisiana
Space Launch System Accomplishments

Launch Vehicle Stage Adapter Test Article fabrication

Booster Test Article in progress for second qualification firing

RS-25 flight engine 2059 installed for testing at Stennis Space Center

Steel towers rising for new SLS test stands at Marshall Space Flight Ctr.

SLS Core Stage test article progress, Michoud Assembly Facility

Interim Cryogenic Propulsion Stage Test Article complete
Ground Systems Development & Operations Accomplishments

- First Work Platform for Space Launch System Installed in VAB
- Conducted the Critical Design Review
- Completed Phase A Testing of the Orion Service Module Umbilical
- Started Construction of Flame Trench at Launch Pad B
- Completed Command and Control Software Release 3.2
- Received First Shipment of Booster Pathfinder Hardware for V&V Testing at RPSF