A Scenario for a Human Mission to Mars Orbit in the 2030s

Thoughts Toward an Executable Program

Fitting Together Puzzle Pieces & Building Blocks

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Introduction

- The content of this talk is the result of a study which is an input to NASA for framing the Agency’s Human Exploration Planning
Why Yet Another Architecture?

NRC Pathway(s)
Evolvable Mars Campaign
Inspiration Mars
Modular Mars Architecture
Mars Society
Space-X Red Dragon
Mars Cycler
DRA-5
Explore Mars
H2M Minimal Architecture
The Art and the Science of Long Range Program Planning

Program System Engineering

Bring into Alignment:
- Technical
- Fiscal
- Engagement
- Programmatic
- Political

Solutions.
Competing Constraints Butting Heads

Limit on HSF Annual Budget

Delivering on a Time Horizon That Anyone Cares About
NRC Schedule Driven Pathway:
First Mars Landing by 2033

First Mars Landing
2033

Based on DRA 5

Current Programs

ISS to 2028

Support

ISS crew
Cis-Lunar Crew
Phobos Crew
Mars Long Stay Crew

HSF Annual Cost

2015 2020 2025 2030 2035 2040 2045

Inflation
Flat Budget

AEROSPACE
How Do You Stay Affordable?

• How do you stay below an annual affordability constraint and yet deliver engaging missions within the interest horizon of stakeholders?

1. **Staggered mission campaigns.**
   - Each campaign builds on the heritage left behind from previous campaign and leaves a legacy for those coming after

1. **Minimal architecture**
   - Relying on limited set of elements already built or planned by NASA and avoid complicated developments (such as nuclear thermal propulsion)
Breaking up the challenges of crewed travel to the Mars surface and back into **two** separate campaigns spreads the risks and cost (cash flow).
Building Blocks of a Minimal Architecture

Launch

SLS

100KW SEP Tugs

In-Space Propulsion

Orion

Crew Quarters

EUS

In-space Chemical Stages

Habitat

Mars Surface Elements

20t Mars Lander

20t Landed Infrast. Module
Mission to Mars Orbit and Phobos
Phobos Landing Concept
Attributes of the Mission

- Precursor to Mars landing mission
- Proves out method for getting to Mars orbit and back
- Uses 4 SLS launches
- Pre-position assets in Mars system with SEP tugs prior to crew arrival
- Round trip crew mission ~2 ½ years; ~300 days at Phobos
Overall Architecture Concept

Architecture was analyzed for a crew of 4
First Launch

- SLS Block 2 injects 100 kWe SEP Tug and its payload to Earth escape
- SEP Tug transfers its payload to High Mars Orbit (HMO). Trip time ~3.8 years
- The SEP Payload: Two in-space chemical stages
  - Phobos Transfer Stage to get crewed Orion from HMO to Phobos and then back to HMO later
  - Trans-Earth Injection (TEI) for returning crew to Earth
Second Launch

- Similar to the first except …
- The SEP payload is the **Phobos Habitat**
- The SEP tug pre-positions the habitat on Phobos
- The SEP tug remains with the habitat to provide power and the possibility of relocation
- The habitat is a common design with the Deep Space Habitat (DSH) that transfers the crew to Mars and back
Getting Cargo to HMO and Phobos

100 kWe SEP Tug

SEP Payload: TEI Stage + Phobos Transfer Stage (PTS)

~3.5 years

SEP Payload: Phobos Habitat

~3.8 years

Pre-placement

Mars

Phobos

HMO

HEO

Earth
Getting Crew to HMO

Deep Space Hab (DSH) + MOI Stage

Orion

EUS

TMI

MOI

~200 - 250 days

Crew launch

Earth

Mars

Phobos

HEO

HMO
Third Launch

- SLS Block 2
- Payload
  - Deep Space Habitat (DSH)
  - Mars Orbit Insertion (MOI) stage
- Launch to High Earth Orbit (HEO)
- Wait for the crew
Fourth Launch

- SLS Block 2
- Payload: **Orion + crew of 4**
- Launch to HEO to dock with DSH and MOI stage
- EUS has sufficient propellant remaining to perform Trans Mars Injection (TMI)
- The Transit Takes ~200-250 days
- MOI stage injects the DSH + Orion + crew into HMO
Getting Crew from HMO to Phobos and Back to HMO

Mars

Phobos Base

~300 days

Deimos

Deep Space Hab + TEI Stage

HMO

HEO

Earth
Getting Crew from HMO to Phobos and Back to HMO

- DSH and pre-positioned TEI stage dock and stay in HMO waiting for the return trip
- Orion docks with pre-positioned Phobos Transfer Stage (PTS) which takes crew to Phobos and the pre-positioned Phobos habitat
- The PTS would be docked at Phobos habitat. It would be used later to take Orion back to HMO
- Orion docks to Phobos habitat
- The crew spends ~300 days at Phobos base
Phobos Base Concept

- Supports a crew of 4
- Could be relocated to different sites
- Could be re-used by future crews
Coming Back to Earth

Mars

Phobos

Phobos Base

Orion+ PTS

Deep Space Hab + TEI Stage

~200 - 250 days

HMO

TEI

HEO

Entry

Earth
Solar Electric Propulsion (SEP) Tug

ARM or TDM SEP Tug, Block 1
50 kWe, 8 t Xenon
4-Hall Thrusters

SEP Tug, Block 1a,
100 kWe, 16 t Xenon
8-Hall Thrusters
Deep Space Habitat Concept

- Supports a crew of 4 for 500 days (transit to Mars and back)
- Mass is approximately 30 t
- Requires solar arrays and batteries for power
- Attitude control is provided by the attached propulsion stage or by Orion
In-Space Chemical Propulsion Stages

- Need 3 units one each for
  - Mars Orbit Insertion (MOI)
  - Phobos Transfer Stage (PTS) and
  - Trans-Earth Injection (TEI)

- Hydrazine/NTO biprop stage with ~500 kN thrust pump-fed engine; similar in size to the Titan II second stage or Proton 3\textsuperscript{rd} stage and Dnepr 2\textsuperscript{nd} stage
Mars Short-Stay Surface Mission
Short-stay Mars Lander Concept

Attributes of the Mission

- 23 t useful-landed-mass lander
  - Crew of 2 to the surface, 24-day stay
  - (Could support crew of 4 for 6 days)

- Architecture re-uses the Phobos approach for getting crew to HMO and back to Earth (already tested in 2033)

- The lander requires 2 additional SLS launches relative to Phobos mission, bringing total SLS launches to 6

- Lander sent to Mars with 2-SLS launch scenario and aero-captures into HMO to await crew arrival

- Lift off from Mars surface is achieved through a two-step ascent to High Mars Orbit (HMO)
  - MAV: Surface to Low Mars Orbit (LMO), then boosted to HMO
  - Minimizes the MAV propellant load to enable 23 t lander
Short-stay Surface Mission Concept

24-Day Surface Stay; Crew of 2; 6 SLS Launches

Architecture was analyzed for a crew of 4, of which 2 land on Mars.
Descent/Ascent Vehicle (DAV)

Can support crew of 2 for 28 days, or crew of 4 for 6 days
EDL Concept for Blunt Body Mars Lander

Entry

Peak Heating

Hypersonic Aeromaneuvering

Supersonic Retropropulsion

Peak Deceleration: 6.4 g

Powered Descent: Const. V Phase

Ground Acquisition

Touchdown

Vrel < 5 m/s

Note: There are no deployable decelerators or parachutes. We will be examining options to utilize an LDSD-type SIAD to increase performance.
Supersonic Retro-Propulsion (SRP)

- Mars landers to date have used subsonic retro-propulsion
- Analyses have indicated the need for SRP for landing large payloads on Mars
- CFD analysis and wind tunnel tests have been performed, and now SRP data utilizing actual flight data has become available from Space X Falcon 9 stage recovery flights
  - 7 flights have been conducted with a portion of the flight regime being analogous to Mars atmospheric conditions
Landed Configuration
MAV Separation and Ascent

Mars Ascent Vehicle (MAV)

Contoured aerodynamic fairing

Descent Stage

H2M
Minimal Architecture
### Vehicles to Enable Crewed Missions to Mars Surface (Short Stay)

<table>
<thead>
<tr>
<th>Vehicles</th>
<th># Vehicles per Mission</th>
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<tbody>
<tr>
<td>Orion</td>
<td>1</td>
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<td>SLS</td>
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<td>SEP Tug</td>
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<td>Deep Space Habitat</td>
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<td>In-Space Chemical Propulsion Stages</td>
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<td>Mars Lander</td>
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</table>
Toward a Permanent Presence

- Follow-on missions would have 1 year surface stays supported by a habitat and other supplies
  - Same descent stage design as crewed lander
  - Would support a landed crew of 4
  - Infrastructure would be built up on Mars to provide power, ISRU, food production, and increasing habitable volume

- The Mars program would evolve a reusable transportation architecture between Earth and Mars with an increased flight rate

- With an in-situ water source on Mars, a permanent presence with an Antarctica-type population could be achieved
The Integrated Program
Fitting Together the Pieces
Notional Timeline

- Orion First Crewed Flight
- Orion Second Crewed Flight
- SLS Initial Test
- Mars Sim 1
- Mars Sim 2
- Crew to Phobos
- Crew to Mars (1 year)
- Crew to Mars (Short stay)
- Build Up Infrastruc.
- Earth
- Cislunar
- Mars

Timeline:
- 2015: ISS Extension End
- 2016: Orion First Crewed Flight
- 2017: Orion Second Crewed Flight
- 2018: Crew to Mars (1 year)
- 2019: Crew to Mars (Short stay)
- 2020: SEP Demo
- 2021: Robotic EDL Test
- 2022: Mars Lander Test@Moon
## Notional SLS Flight Sequence

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<tr>
<td>Uncrewed Missions</td>
<td>EM-1</td>
<td>SEP DEMO</td>
<td>Un-crewed Mars EDL test</td>
<td>Crewed test of Mars Lander at the Moon</td>
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<td>Lunar Proving Ground</td>
<td>EM-2 Test Flight</td>
<td>EM-3 Test Flight</td>
<td>Mars Sim#2</td>
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<tr>
<td>First Mars System Mission</td>
<td>EM-4/EAM/Mars Sim1</td>
<td>SEP Cargo 1&amp;2</td>
<td>DSH</td>
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- **EM-1**: Uncrewed flight test
- **SEP DEMO**: SEP Demo Mission
- **EM-2 Test Flight**: Uncrewed flight test
- **EM-3 Test Flight**: Uncrewed flight test
- **Mars Sim#2**: Mars Simulation test
- **SEP Cargo 1&2**: SEP Cargo 1 & 2
- **DSH**: Directly Shaped Habitat
- **ISS LEO**: International Space Station Low Earth Orbit
- **Mars Surface**: Mars Surface Exploration

### Time Lines
- **2017**: Initial SLS Flight
- **2019**: SEP Demo Flight
- **2020**: EM-1 Flight
- **2021**: EM-2 Flight
- **2022**: EM-3 Flight
- **2023**: Uncrewed Mars EDL test
- **2024**: Crewed test of Mars Lander at the Moon
- **2025**: SEP Cargo 1 & 2
- **2026**: DSH
- **2027**: Orion
- **2028**: Mars Lander
- **2029**: Orion
- **2030**: Mars Lander
- **2031**: Orion
- **2032**: Mars Lander
- **2033**: Orion
- **2034**: Orion
- **2035**: Orion
- **2036**: Orion
- **2037**: Orion
- **2038**: Orion
- **2039**: Orion
- **2040**: Orion

### Stage Masses
- **105 t SLS**
- **130 t SLS**
Cost “Sanity Check”

- Since affordability was one of the objectives of the study, to do a cost sanity check, we asked Aerospace Corporation, which had done the cost estimating for the NRC study, to do a first-look cost assessment.

- The cost estimating done by Aerospace is based on models and analogy which is common at this stage of project formulation. As technical concepts mature, grassroots rather than model-based cost assessments should be performed for budget commitment.

- Aerospace’s assessment suggests that meeting the Study Team’s self-imposed cost constraint is plausible.
NRC Schedule Driven Pathway:
First Mars Landing by 2033

First Mars Landing
2033

Based on DRA 5

Current Programs
ISS to 2028

ISS crew
Cis-Lunar Crew
Phobos Crew
Mars Long Stay Crew

HSF Annual Cost
2015 2020 2025 2030 2035 2040 2045

Inflation
Flat Budget
Support
NRC Budget Driven Pathway
Constrained by Current NASA Human Space Flight Budget Adjusted for Inflation

Based on DRA 5

ISS crew
Cis-Lunar Crew
Phobos Crew
Mars Long Stay Crew

ISS to 2028
Current Programs
Support

2015  2020  2025  2030  2035  2040  2045

Phobos Lander 2038
Mars Lander 2046

HSF Annual Cost
Inflation
Flat Budget

40
The High TRL Pathway
Presented Today

Higher TRL elements would present less cost and schedule risk
High TRL Pathway with ISS to 2024

Current Programs

ISS to 2024

Support

Inflation

Flat Budget

Phobos Lander 2033

Mars Lander Short Stay 2039

Mars Lander Long Stay 2043

ISS crew

Cis-Lunar Crew

Phobos Crew

Lunar Sortie Crew

Mars Short Stay Crew

Mars Long Stay Crew
Takeaways

- This work was aimed at showing an example (an existence proof) that journeys to Mars could be doable using technologies that NASA is currently pursuing and on a time horizon of interest to stakeholders -- without large spikes in NASA budget.

- Program system engineering is key in balancing several competing constraints
In Conclusion

Mars is Possible

...and in a time horizon of interest