# Making Mars Affordable

## Integrating Architecture, Programmatic, and Affordability Viewpoints

Robert Shishko
Jet Propulsion Laboratory
California Institute of Technology

Humans to Mars Summit

May 9, 2018

© 2018 California Institute of Technology

# Determining Affordability

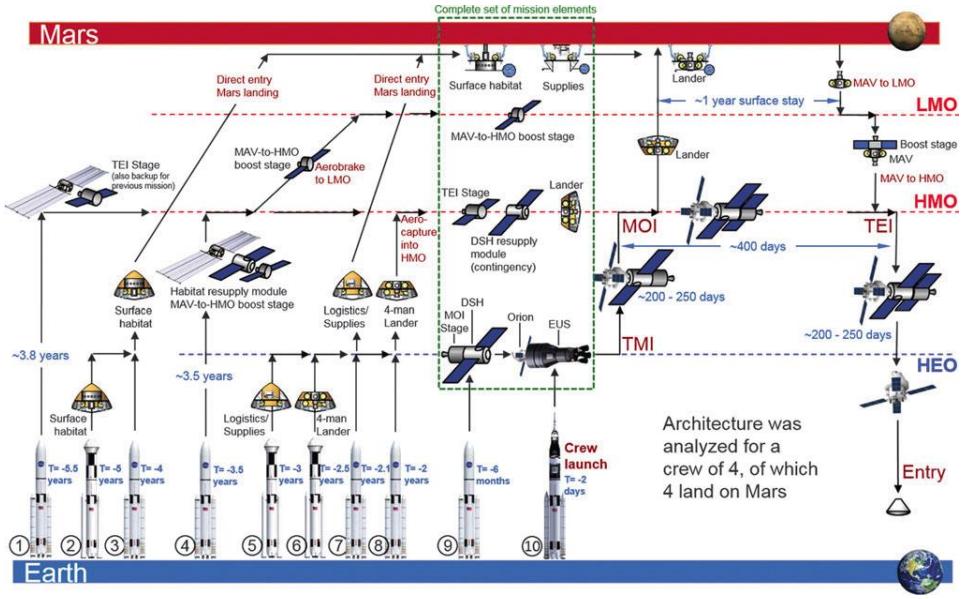


- Different views as what that means
- NRC 2014 Report, "*Pathways to Exploration: Rationales and Approaches For a U.S. Program of Human Space Exploration*," used a "sand chart" approach
  - Could a human mission be done within NASA's current human spaceflight budget?
  - Could it be done within NASA's current human spaceflight budget that grows to maintain current purchasing power?
- NRC 2014 Report sand charts were based on a methodology and cost data developed by the Aerospace Corporation
  - Methodology has three cost "flavors"
  - Cost estimates from public sources only
  - Needs a multi-faceted description of the architecture

# Building the Sand Chart—Defining an Architecture

*Humans to Mars*

| Vehicles | # Vehicles per Mission |
|---|---|
| Orion | 1 |
| SLS | 6 |
| SEP Tug | 2 |
| Deep Space Habitat | 1 |
| In-Space Chemical Propulsion Stages | 3 |
| Mars Lander | 1 |



# Defining an Architecture—Dance Card View (2021-2033)

## Revised Minimal Mars (As Of 16 July 2016)

| SLS Launches | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flight Name<br>Orion | EM-2 (3 wks) | | EM-3 (8 wks) | | ARCM/MarsSim1 (6 months) | | MarsSim2 (1yr) | | MarsSim3 (1.5yr) | | | Mars lander test crew at moon | Phobos crew |
| Co-manifested NASA | | | Small hab w/bus | | Logistics resupply | | Logistics resupply | | Logistics resupply | | | | |
| Co-manifested IP | | | | | | | | | | | | | |
| Flight Name<br>NASA Cargo | | | | | | Mars DSH protoflight unit | | Uncrewed ½-scale Mars lander | Phobos SEP #1 | Phobos SEP #2 | Mars lander test at moon | Phobos DSH | |
| Flight Name<br>NASA Cargo | | | | | | | | | | | | | |
| Flight Name<br>IP Cargo | | | | | | | | | | | | | |
| Planetary Missions | | Europa Clipper on SLS Blk-1b | | Europa Lander on SLS Blk-1b | | | | | | | | | |
| Comments | SEP (ARM) on Delta IV | | | | | | | Half-scale test at Mars | | | Full scale test at the moon | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Third Mars landing mission | | First Mars landing mission | | Phobos mission | | SLS-Orion mission |
| | Fourth Mars landing mission | | Second Mars landing mission | | Mars lander test | | SLS cargo mission |

# Defining an Architecture—Dance Card View (2034-2046)

## Revised Minimal Mars (As Of 16 July 2016)

| SLS Launches | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flight Name<br>Orion | | | | Mars-1 crew | | | | Mars-2 crew | | | | Mars-3 crew | |
| Co-manifested NASA | | | | | | | | | | | | | |
| Co-manifested IP | | | | | | | | | | | | | |
| Flight Name<br>NASA Cargo | Mars SEP #1 | Mars Lander #1 | Mars SEP #3 | Mars DSH #1 | Mars SEP #4 | Mars Surface Habitat #1 | Mars SEP #5 | Mars DSH #2 | Mars SEP #6 | Mars Surface Habitat #2 | Mars SEP #7 | Mars DSH #3 | Mars SEP #8 |
| Flight Name<br>NASA Cargo | Mars SEP #2 | EUS #1<br>Mars Lander #1 | Mars Surface Cargo #1 | EUS #2<br>Mars Surface Cargo | Mars Lander #2 | EUS #3<br>Mars Surface Habitat | Mars Surface Cargo #2 | EUS #5<br>Mars Surface Cargo | Mars Lander #3 | EUS #6<br>Mars Surface Habitat | Mars Surface Cargo #3 | EUS #3<br>Mars Surface Cargo | Mars Lander #4 |
| Flight Name<br>NASA Cargo | | | | | | EUS #4<br>Mars Lander #2 | | | | EUS#7<br>Mars Lander #3 | | | |
| Planetary Missions | | | | | | | | | | | | | |
| Comments | DSH-based logistics module on SEP #2 | | | Mars-1 is an opposition class (surface stay ~24 days) mission | | | | Mars-2 is a conjunction class (surface stay >1 year) mission | | | | Mars-3 is a conjunction class (surface stay >1 year) mission | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Third Mars landing mission | | First Mars landing mission | | Phobos mission | | SLS-Orion mission |
| | Fourth Mars landing mission | | Second Mars landing mission | | Mars lander test | | SLS cargo mission |

# HSF Architectures Can Be Complex



- A well-defined architecture framework is useful in abstracting essential information from the underlying complexity
- DoDAF-inspired Human Spaceflight Architecture Model (HSFAM)* artifacts:

| Name | Description of Architectural Content | Classes, Types, and Subtypes |
|---|---|---|
| **Operational Nodes** | Spatial locations in the solar system; locus of an operational function or activity | Surface locations (terrestrial and planetary); orbits; Lagrange points |
| **Systems** | Notional objects that fulfill a function; a hardware and/or software build | Based on broad system purposes, e.g., surface mobility, habitation |
| **Operational Functions** | Activities that transform inputs (resources) into outputs (other resources or end products), or change their state | Based on broad functional areas, e.g., mission operations, etc. |
| **Milestones** | Time-stamped identification of significant changes; milestones are four-dimensional as the spatial location (operational node) is also included | Based on capability achieved, e.g., initial operational capability (IOC) |
| **Measures** | Measurable (quantifiable) properties or attributes of interest | Mass, cost, quantity, etc. |
| **Standards** | Applicable technical, operational or business standards and rules | ISO, ANSI, Community of Practice (CoP), government-unique, etc. |
| **Flight Types** | Arcs (or edges) between operational nodes that form a feasible network along which systems can move | |
| **Flights** | Time-stamped assignment of flight types | |

*Available at http://hdl.handle.net/2014/45707

# Use of a Formal Architecture Framework—Flights Datatable (Partial)



## Flights Table

| Flight ID | Flight Name | Flight Type ID | Flight Type Name | Mission Group Name | Destination Node | Nominal Flight Start Date (FY) |
|---|---|---|---|---|---|---|
| 1 | EM-1 | 1 | Uncrewed Exploration Mission | Uncrewed | Lunar DRO | 2018 |
| 2 | SEP Demo-1 | 2 | SEP Demo | Uncrewed | Lunar DRO | 2021 |
| 3 | Mars Sim-2 | 5 | Exploration Mission+Small Log | Lunar Proving Ground | Lunar NRO | 2027 |
| 4 | SEP Cargo-1 | 7 | SEP100+ChemProp (TEI+MOT) | Mars System | HMO/Phobos | 2029 |
| 5 | SEP Cargo-2 | 8 | SEP100+PhoHab | Mars System | Phobos | 2030 |
| 6 | Phobos DSH | 9 | DSH+ChemProp (MOI) | Mars System | HMO | 2032 |
| 7 | MS-1 | 10 | Orion+Crew | Mars System | Phobos | 2033 |
| 8 | SEP Cargo-3 | 14 | SEP100+Storables (TEI+MOT) | First Mars Lander | HMO | 2034 |
| 9 | SEP Cargo-4 | 11 | SEP100+Log | First Mars Lander | HMO | 2034 |
| 10 | ML-1 | 12 | Mars Lander | First Mars Lander | Mars Surface | 2035 |
| 11 | ML-1P | 13 | EUS for TMI | First Mars Lander | | 2035 |
| 12 | Mars DSH-1 | 9 | DSH+ChemProp (MOI) | First Mars Lander | HMO | 2037 |
| 13 | Mars-1 | 10 | Orion+Crew | First Mars Lander | Mars Surface | 2037 |
| 14 | SEP Cargo-5 | 14 | SEP100+Storables (TEI+MOT) | Second Mars Lander | HMO | 2036 |
| 15 | ML-2P | 13 | EUS for TMI | Second Mars Lander | | 2037 |
| 16 | ML-2 | 15 | Long Stay Mars Habitation | Second Mars Lander | Mars Surface | 2039 |
| 17 | SEP Cargo-6 | 11 | SEP100+Log | Second Mars Lander | HMO | 2038 |
| 18 | ML-3 | 16 | Mars Surface Log | Second Mars Lander | Mars Surface | 2036 |
| 19 | ML-4 | 12 | Mars Lander | Second Mars Lander | Mars Surface | 2038 |
| 20 | ML-3P | 13 | EUS for TMI | Second Mars Lander | Mars Surface | 2039 |
| 21 | ML-4P | 13 | EUS for TMI | Second Mars Lander | Mars Surface | 2039 |
| 22 | Mars DSH-2 | 9 | DSH+ChemProp (MOI) | Second Mars Lander | Mars Surface | 2041 |
| 23 | Mars-2 | 10 | Orion+Crew | Second Mars Lander | Mars Surface | 2041 |
| 24 | EM-2 | 3 | Exploration Mission | Lunar Proving Ground | Lunar NRO | 2021 |
| 30 | DSH Protoflight | 4 | L2 TransHab Test | Lunar Proving Ground | Lunar NRO | 2026 |
| 31 | EDL-1/2 | 23 | Half-Scale Mars EDL Test | Lunar Proving Ground | Mars Surface | 2028 |
| 32 | Mars Sim-3 | 22 | Exploration Mission+Small Log+ | Lunar Proving Ground | Lunar NRO | 2029 |
| 38 | Lunar-1a | 12 | Mars Lander | Lunar Proving Ground | Lunar Surface | 2031 |
| 39 | Lunar-2a | 10 | Orion+Crew | Lunar Proving Ground | Lunar Surface | 2032 |
| 41 | EM-3 | 18 | Exploration Mission+Small Hab | Lunar Proving Ground | Lunar NRO | 2023 |
| 62 | Mars Sim-1 | 5 | Exploration Mission+Small Log | Lunar Proving Ground | Lunar NRO | 2025 |

Pre-decisional. For discussion purposes only.

# Use of a Formal Architecture Framework—Building the Sand Chart

**Systems Table**

System development, production, and sustaining cost estimates, and durations, with anticipated cost sharing arrangements

**Systems Table**

**Flight Types Table**

Flight Type definition

**Flights Table**

Schedule of flights by Flight Type

**Life Cycle Cost Model**

Actual budget costs by year for existing systems

**Actual Cost Table**



Pre-decisional. For discussion purposes only.

# Building the Sand Chart—The Life Cycle Cost Model

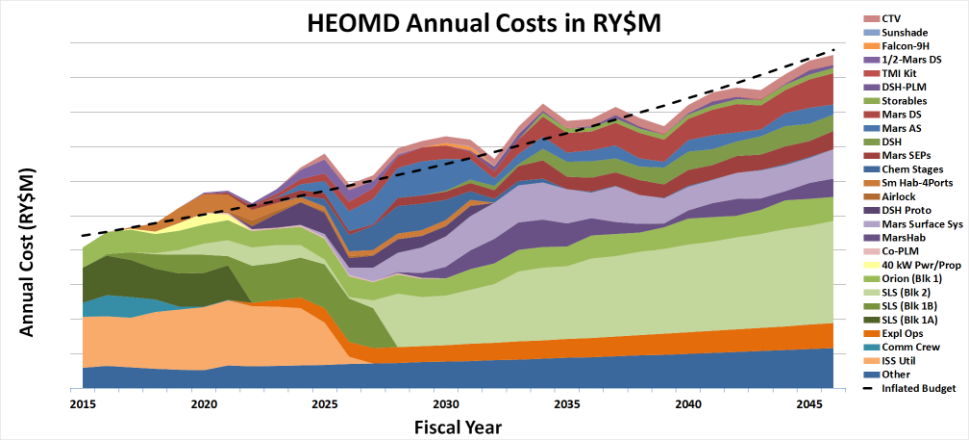
**Conceptual Architecture**

**Life Cycle Cost Model**

**Design, Development, Test and Evaluation (DDT&E) Cost Model**

**Production Cost Model**

**Operations and Support (O&S) Cost Model**








Pre-decisional. For discussion purposes only.

# Key Messages



- The capability to integrate system-of-systems architecting, programmatics, and affordability assessments could significantly benefit HEOMD architecture teams and NASA/ OCFO strategic planning.

- With a modest investment, the affordability tool can be substantially improved and integrated with other data bases (e.g., technology roadmaps), mission analysis, and MBSE tools.

- With personnel trained in its use, the affordability assessment capability can be embedded within HEOMD and the NASA/ OCFO as needed.