Advantages of a Modular Mars Surface Habitat Approach

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Mars Surface Habitat Evolution

1969
- Von Braun
- 9.1 m dia, 3 Crew, 30-60 days

1985
- ISS-Derived
- 4.27 m dia, 4 Crew

1997
- DRA-1
- 7.5 m dia, 6 Crew, 600 days

2016
- EMC
- 7.2 m dia, 4 Crew, 550 days
Monolithic vs. Modular Habitats

- **Monolithic**
  - Works well for a single visit to one site (Apollo-style missions)
  - Crew has everything they need without leaving the lander
  - Size limited by Earth launch vehicle payload shroud + lander payload constraints

- **Modular**
  - Works well for repeat visits to the same site
  - Smaller → more vehicle options for Earth launch or Mars lander
  - Have to configure multiple elements on Mars
Two Important Considerations

- Post-landing crew recovery period
  - After long microgravity transit, crews *may* need physical recovery period before “Mars-walk” medical clearance
  - Strength + neurovestibular recovery

  *Whatever crew lands in may have to carry everything they need for a few days*

- Single vs. multiple visits to the same landing site
  - If first crew lands in monolithic habitat...what do subsequent crews to the same site land in?
  - Leave habitat on lander or off-load it?
  - Multi-expedition habitat must be more robust than one-time use habitat
  - Can we use empty logistics containers as habitable modules?

  *Single vs. multiple visits to a given site have different optimal architectures*
Established surface system functional requirements within the integrated mission architecture

Identified needed cargo elements
- Emphasized commonality to eliminate unique elements

Developed operational concept details
- Which pieces need to arrive on which lander?
- How do we unload and assemble everything?

Established manifesting “rules” to better compare concepts

Tried to minimize unique elements
- Similar shell for Logistics, Descent, and Airlock Modules
- Common mobility chassis, with pressurized, unpressurized or robotic rover outfitting
2018 Basis of Comparison Architecture
Mars Study Capability (MSC) Team

- Retained Evolvable Mars Campaign’s (EMC) “Field Station”
  - Multiple missions to a single landing site
- 22 t payload capacity Mars landers
  - 3-3-2 lander cadence
- Low-energy, hybrid in-space transit architecture
  - Longer in-space transit decreases surface stay to ~300 days per expedition
  - 5 sol Mars Ascent Vehicle rendezvous point
- Modular surface habitation
  - Four-hatch Airlock Module serves as the cornerstone
  - Crews land in a Logistics Module-sized Descent Module, which then becomes a habitable surface module

Requires fewer landers relative to the EMC concept, with lower landed mass over 3 expeditions than most previous schemes.
Notional Mars Surface Mission Elements

Major Elements (Dedicated Lander)
- Mars Ascent Vehicle (MAV)

Supporting Elements (Deck Mounted)
- Rover Cabin
- Descent Module
- Logistics Module
- Airlock Module

MODULAR HABITATION

Stowed Elements (In Another Element)
- Crew
- Launch/Entry Suits
- EVA Suit + Primary Life Support
- Maintenance, Logistics & Consumables

- Mobility Chassis
- Unpressurized Rover
- Pressurized Rover
- Crew Support Rover

- Kilopower Unit
- Power Management & Distribution
- Atmospheric ISRU
- Tunnel

Off-loading Hoist
General Concept of Operations
Conceptual Mission Series to a Single Exploration Site

1. **FIRST**
   - Pre-deploy cargo

2. **THEN**
   - Ascent Vehicle and ISRU

3. **WHEN**
   - tanks are full, 1st crew lands

4. **SUBSEQUENT**
   - crews add modules

**Power System + Hab Module + Cargo**

**Ascent Vehicle + Propellant Manufacturing**

**Hab Modules + Crew + Cargo**

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- Rover Cabin
- Descent Module
- **MODULAR HABITATION**
- Habitable Logistics Module
- Airlock Module
Field Station Build-up

Expedition 1

Descent Module
Logistics Module
Airlock Module
Pressurized Rover

Habitation Wing
Maintenance Wing
Descent Module
Logistics Module

Expedition 3

Habitation Wing
Maintenance Wing

Empty logistics containers: repurpose as lab space, trash
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</thead>
<tbody>
<tr>
<td>Number of Landers</td>
<td>3</td>
<td>8</td>
<td>6</td>
<td>10</td>
<td>8</td>
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<tr>
<td>Expedition 1</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>3</td>
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<tr>
<td>Expedition 2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
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<tr>
<td>Expedition 3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
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<tr>
<td>Payload Capacity per Lander (t)</td>
<td>12.68</td>
<td>65</td>
<td>40</td>
<td>20</td>
<td>22</td>
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<td>3-Expedition Cumulative Landed Mass (t)</td>
<td>38.04</td>
<td>520</td>
<td>240</td>
<td>200</td>
<td>176</td>
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</tbody>
</table>

If landed mass is the metric of choice, MSC concept looks pretty good.
Landed Payload Mass Per Crew Day
Cumulative Over 3 Expeditions

But landed mass alone is a misleading metric...

If landed mass per crew day is metric of choice, MSC compares poorly.
1. Multi-module structure is less mass-efficient
   • At current design fidelities, difficult to gauge by how much

2. Mass estimates increase as concepts/models are refined
   • Pressurized rover grew from 4.8 to >6 t from 2009 to 2018
   • Monolithic Habitat grew from 16.5 to 19.3 t

3. Maintenance models are based on number of pressurized modules, not pressurized volume
   • Baked-in disadvantage for modular architecture

4. Surface stay duration is key
   • Infrastructure—not consumables mass—is the driver
Longer Stay
Payload Landed Mass Per Crew Day (3 Expeditions)

Best value: maximize stay duration to get the most out of landed mass

MSC Variants

- Extend Exp2-3 to DRA5 duration with unallocated Exp2 mass
- Add Exp1 lander to extend match DRA 5 durations

Landed Payload Mass per Crew-Day (kg)

- 2009 DRA 5: 26.6
- 2016 EMC: 44.8
- 2018 MSC: 57.7
- MSC Full Landers: 37.8
- MSC +1 Lander: 33

Number of Crew-Days

- 9,000
- 6,000

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Advantages of a Modular Habitat Approach

1. **Smaller habitats fit on a smaller landers**
   - Eliminates a key lander size-driver $\rightarrow$ less cost/risk
   - More Earth launch system options
   - More commercial/international partner opportunities

2. **Reduced Risk**
   - A damaged module could be isolated and replaced
   - Smaller hab designed to be relocated is more tolerant of off-course landing
     - Off-course landing $\rightarrow$ loss of mission for monolithic hab

3. **Solves the “subsequent crew problem”**
   - Monolithic: either keep sending big habs, or design another element for subsequent crews to land in $\rightarrow$ costly
   - Modular: each crew lands in the same type of element, which is added to the field station as habitable volume
Advantages
of a Modular Habitat Approach

4. Improved Habitability
   • Can separate clean/quiet area from dirty/noisy work space
   • Pressurized volume increases over multiple expeditions
     ▪ Or can replace worn-out modules as new modules arrive
   • Retired modules can be dedicated for trash management
   • More accessible than climbing up/down lander to a MonoHab

5. More Flexibility
   • Can improve/add new tech to later Expedition modules
   • Smaller modules are easier to build, transport and test on Earth
     ▪ Easier for small/new providers to participate

6. Lower cumulative mass compared to previous studies
   • >30% savings vs. DRA 5.0 architecture
   • Could be optimized with longer surface stays
Disadvantages of a Modular Habitat Approach

1. **Operationally less efficient**
   - Have to offload, transport, assemble modules on Mars
   - Have to connect distributed services - similar to ISS

2. **Larger footprint on Mars**
   - May require surface preparation

3. **Higher Handling Damage Risk (on Mars)**
   - Offloading/transporting/assembling modules

4. **Potentially less commonality with transit habitat**

5. **Adds complexity to Logistics Module**
   - Off-set by improved commonality

6. **More complicated lander packaging/balancing**
Key Take-Aways
Modular vs. Monolithic Habitats

- Modular habitats work well for repeat visits to one site
  - Monolithic habitats may work better for one-time visits

- Modular habitats offer:
  - Risk reduction
  - Operational flexibility
  - Increased launch/landing system options
  - Lower cumulative landed mass

- Landed mass doesn’t tell the whole story
  - Normalized mass per crew-day doesn’t either
  - Comparing to earlier references requires updating the earlier works for current usage models and element concepts

- If landed mass is the metric of choice, best “value” is to maximize Mars surface stay
  - Regardless of habitat type
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Questions?

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