Advantages of a Modular Mars Surface Habitat Approach

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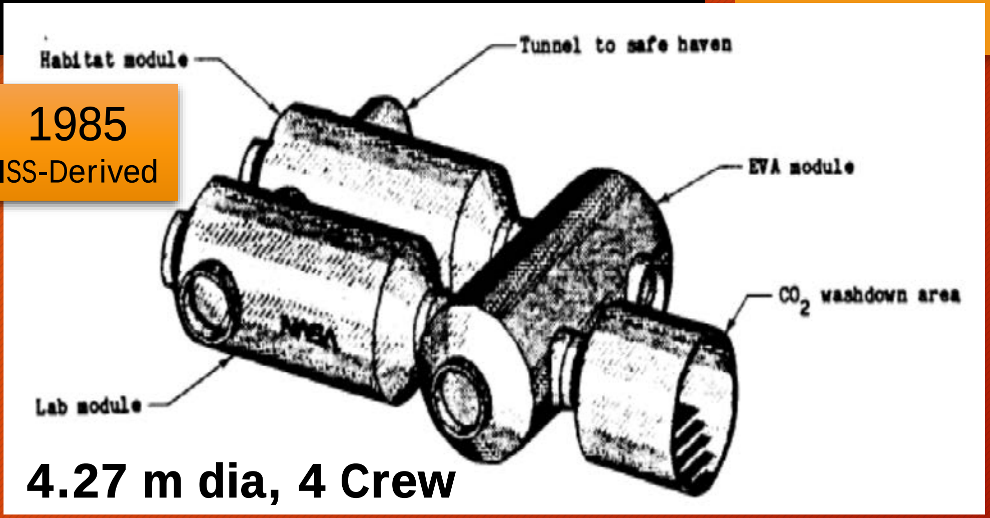
Mars Surface Habitat Evolution

1969
Von Braun

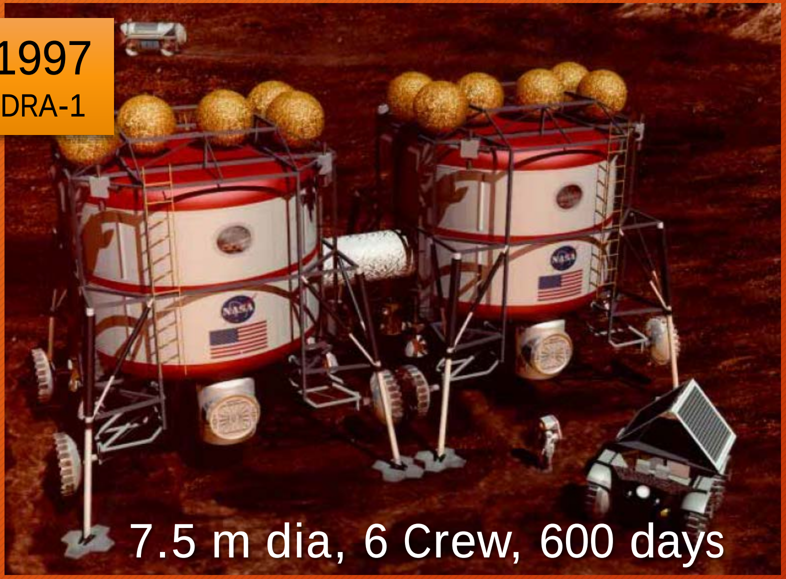
9.1 m dia, 3 Crew, 30-60 days

1985
ISS-Derived



4.27 m dia, 4 Crew

1997
DRA-1

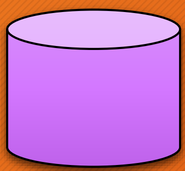


7.5 m dia, 6 Crew, 600 days

2016
EMC

7.2 m dia, 4 Crew, 550 days

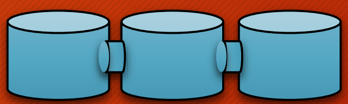
Monolithic vs. Modular Habitats



Monolithic
Single, Large Habitat

vs.

Modular
Multiple, Small 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

Surface Systems Approach
2018 Mars Study Capability (MSC) Team

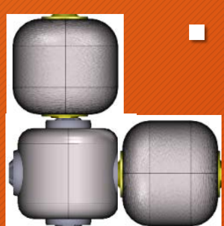
- **Established surface system functional requirements within the integrated mission architecture**
- **Identified needed cargo elements**
  - Emphasized commonality to eliminate unique elements
- **Developed operational concept details**
  - Which pieces need to arrive on which lander?
  - How do we 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

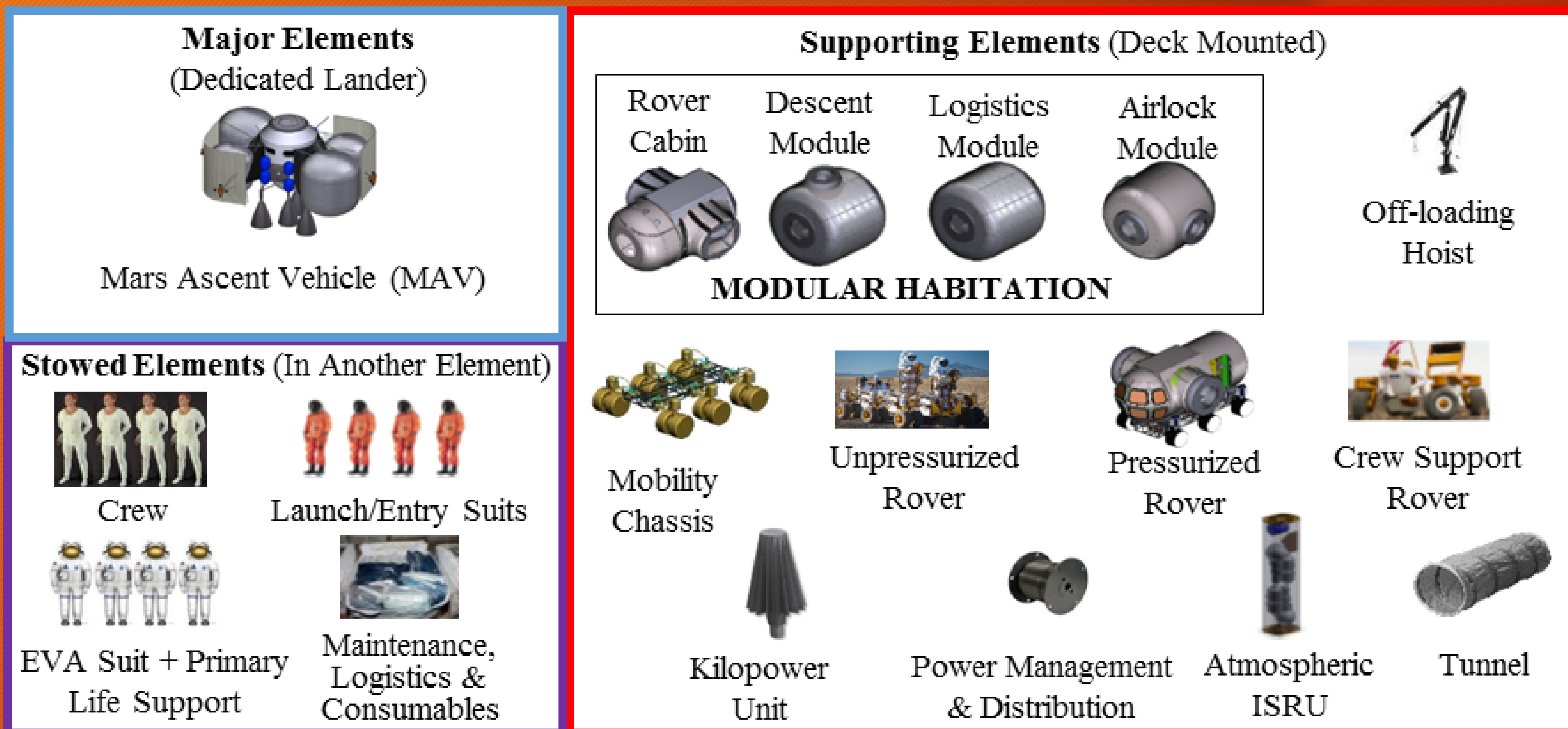
- **Low-energy, hybrid in-space transit architecture**
  - Longer in-space transit decreases surface stay to **~300 days** per expedition
  - 5 sol Mars Ascent Vehicle rendezvous point



- **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



General Concept of Operations

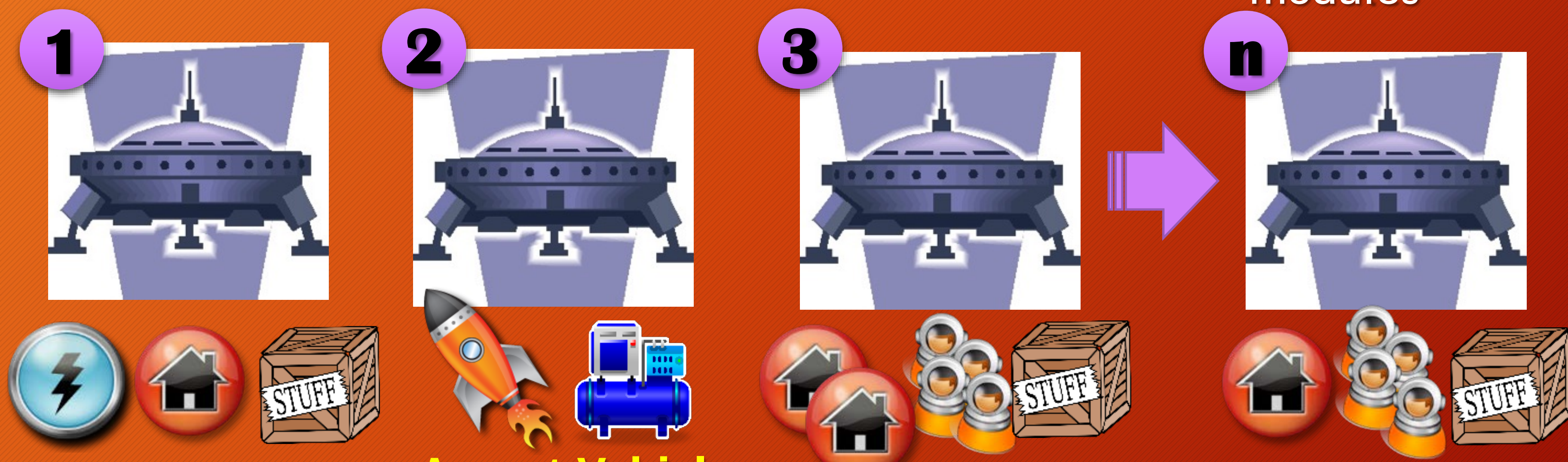
Conceptual Mission Series to a Single Exploration Site

FIRST Pre-deploy cargo

THEN Ascent Vehicle and ISRU

WHEN tanks are full, 1st crew lands

SUBSEQUENT crews add modules



Power System + Hab Module + Cargo

Ascent Vehicle + Propellant Manufacturing

Hab Modules + Crew + Cargo


Rover Cabin


Descent Module

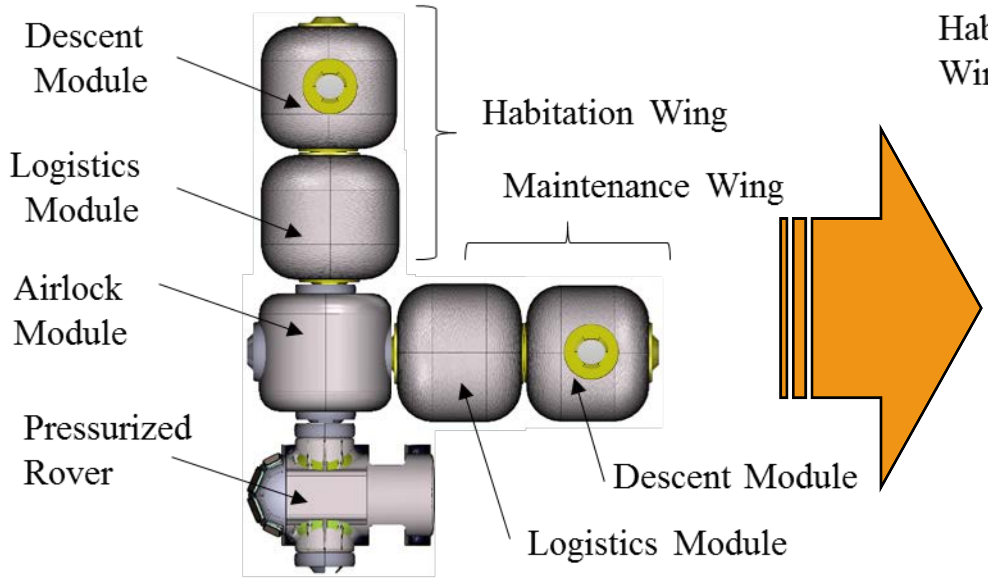
MODULAR HABITATION


Habitable Logistics Module


Airlock Module

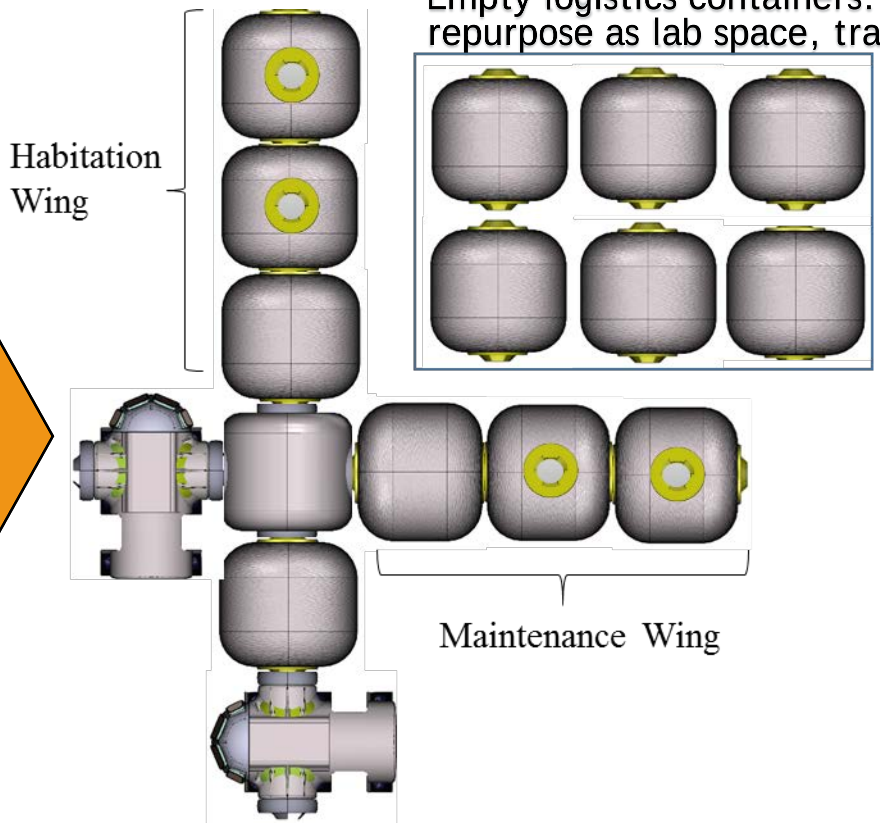
Field Station Build-up

Expedition 1



Expedition 3

Empty logistics containers: repurpose as lab space, trash



Landed Payload Mass
Cumulative Over 3 Crew Expeditions

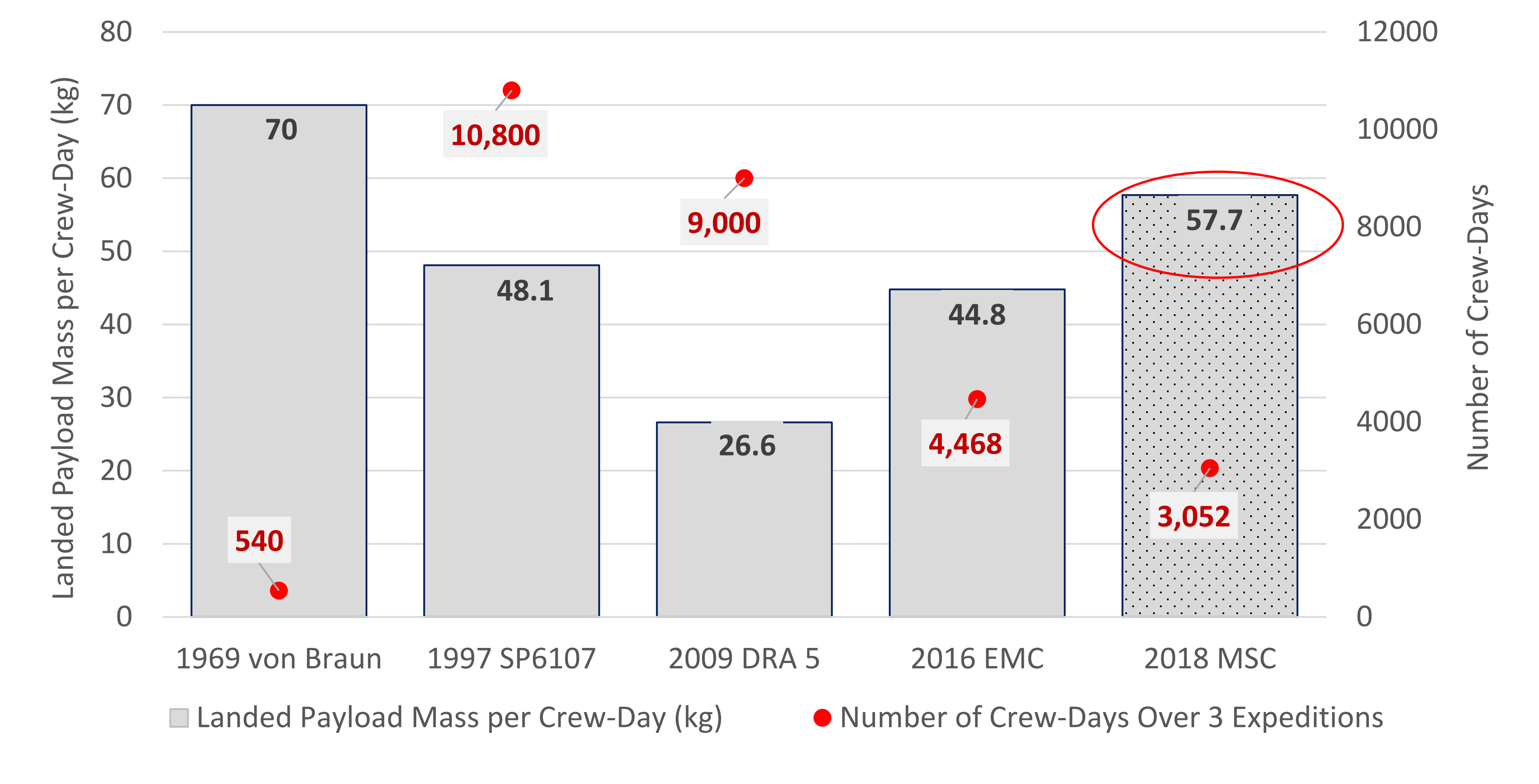
	Mission Concept				
	1969 Von Braun	**1997 SP 6107**	**2009 DRA 5**	**2016 EMC**	**2018 MSC**
Number of Landers	**3**	**8**	**6**	**10**	**8**
Expedition 1	1	4	2	4	**3**
Expedition 2	1	2	2	3	**3**
Expedition 3	1	2	2	3	**2**
Payload Capacity per Lander (t)	12.68	65	40	20	**22**
3-Expedition Cumulative Landed Mass (t) **=** (#landers) x (payload/lander)	38.04	520	240	200	**176**

If landed mass is the metric of choice, MSC concept looks pretty good

But landed mass alone is a misleading metric...

Landed Payload Mass Per Crew Day

Cumulative Over 3 Expeditions



If landed mass per crew day is metric of choice, MSC compares poorly

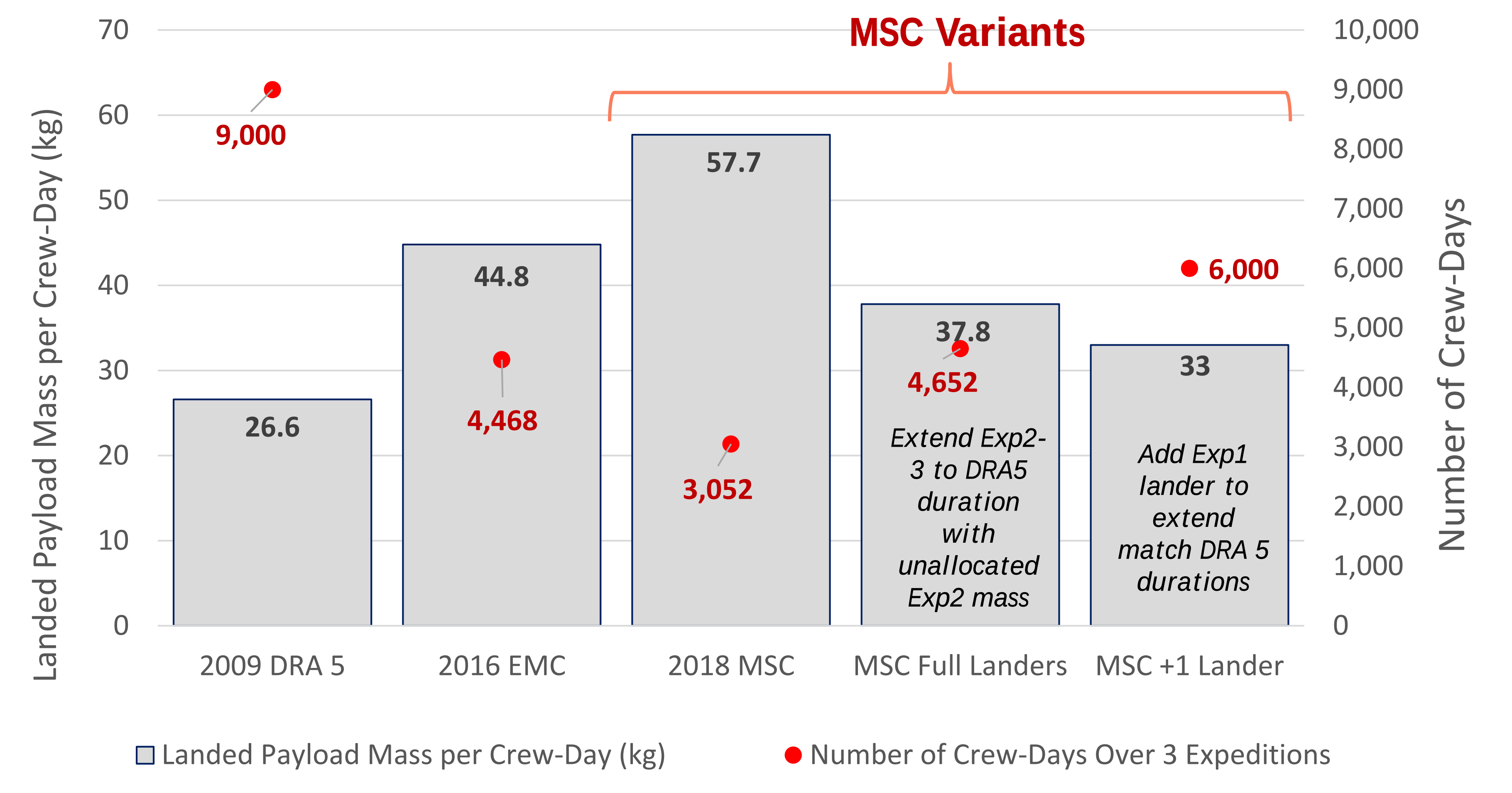
Why so much variation?

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

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

Longer Stay

Payload Landed Mass Per Crew Day (3 Expeditions)



Advantages
of a Modular Habitat Approach

1. **Smaller habitats fit on a smaller landers**
    - Eliminates a key lander size-driver → 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 → 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 → 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?