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Mars Surface Tunnel Element Concept

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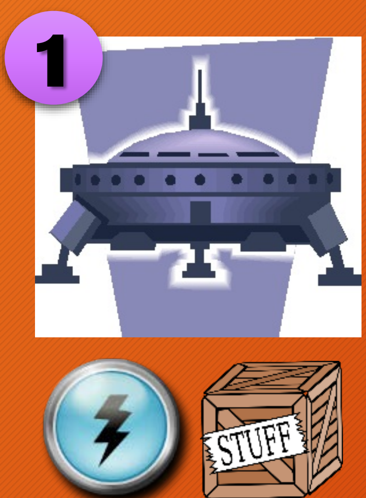
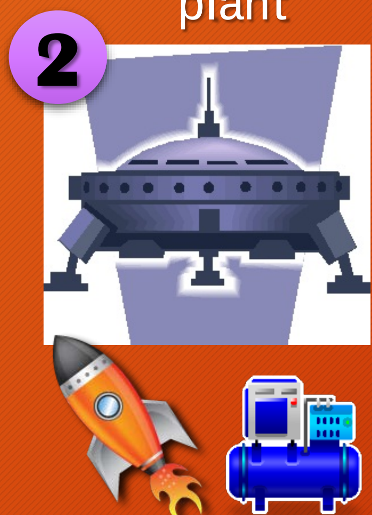
Background
Evolvable Mars Campaign

FIRST we send a power supply and cargo



Power System + Cargo

THEN a Mars Ascent Vehicle (MAV) and propellant production plant

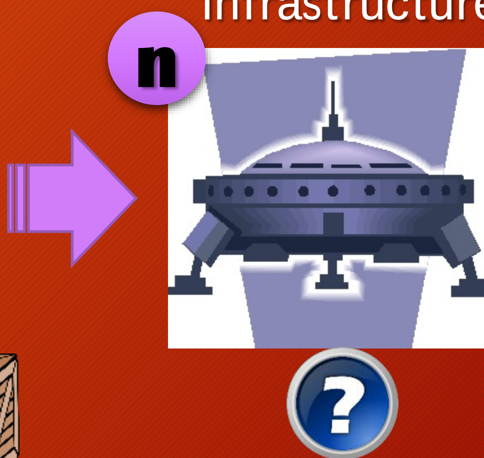


Ascent Vehicle + Propellant Production System

WHEN MAV tanks are full, crew lands

Habitat + Crew + Logistics

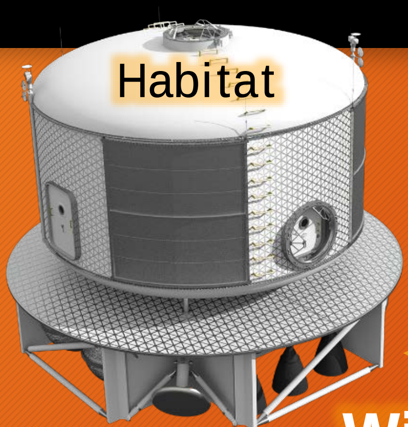
SUBSEQUENT crews land at the same site and use infrastructure



Additional Crew + Ascent Vehicles + Cargo

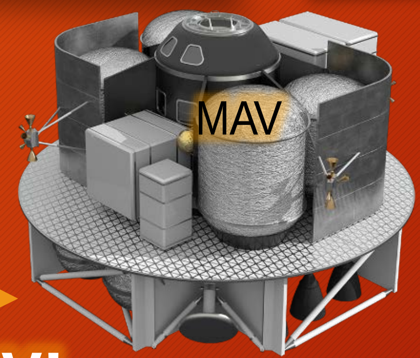
When it's time to leave Mars, the crew must transfer from their habitat to the MAV…
but they have to leave Mars dust behind to meet planetary protection protocols!

Issue: Keep Dust out of MAV



Crews have to get from here

To here



~1 km

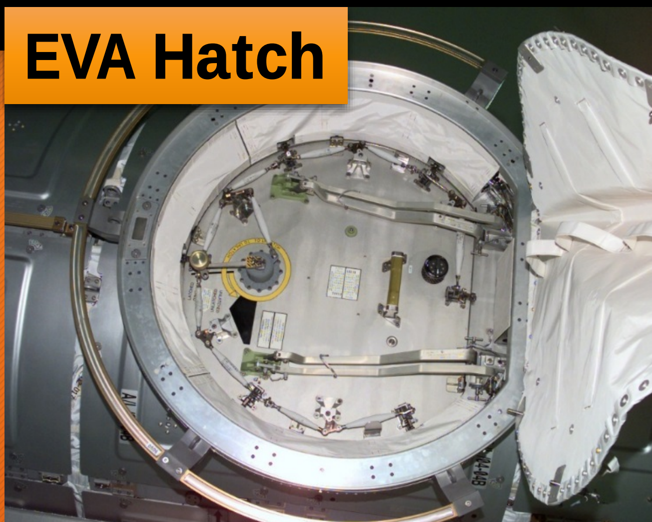
Without bringing dust into MAV!

or they need to change clothes, dispose of their dirty surface suits, and clean the MAV before docking with their Earth return vehicle

Complication: MAV is the largest "gear ratio" element of crewed Mars exploration architecture

- Up to 15 kg propellant needed to boost 1 kg of ascent vehicle to orbit (we assume a minimum of 7:1 ratio)
- MAV ingress method can't add a lot of mass to the MAV!

MAV Access Options



MAV Access Option Comparison

Tunnel is an attractive option

Option	Low Mass	Controls Dust	Notes
EVA Hatch	✓	✗	Opens cabin to dusty surface and requires MAV to be large enough for crew to don/doff EVA suits inside
Airlock	✗	✗	Better dust control than hatch, but higher mass
Suitport	✗	✓	High ascended mass to carry EVA suits, may not support incapacitated crew ingress
Suitport-Airlock	✗	✓	Highest overall mass impact
Tunnel	✓	✓	If there's another element available to tunnel from (i.e. pressurized rover), tunnel may provide best dust control with low MAV mass impact

Tunnel Definition Approach

1 Identify a minimum set of tunnel functional requirements

- "One job, one time:" get crew into the MAV without going outside
  - ➢ Don't worry about re-use, alternate use, etc. for the time being
- This would presumably give us the simplest, lowest mass design

2 Use this Minimum Functional Tunnel as a baseline to trade alternative concepts against

- Is a tunnel really the lowest mass option?

3 Starting from the Minimum Functional Tunnel, assess mass penalties as functionality is increased

- Example: What's the mass penalty to make the tunnel reusable?

So...How Would A Tunnel Work?
Notional Concept of Operation

- Surface tunnel is attached at MAV's ingress/egress hatch on Earth
  - Remains attached through Earth launch, transit, Mars entry, descent, and landing
  - Tunnel is unused until the crew prepare for departure
- Before crew depart Mars, 2-person MAV check-out crew transfers from their surface habitat to the pressurized rover, and drives to the MAV
- Check-out crew deploys tunnel and attaches it to the rover's hatch
  - Crew verifies tunnel is environmentally sealed from surface dust
- Wearing clean IVA clothes, check-out crew translate from rover to the MAV via tunnel to stow return cargo, perform pre-flight inspections
- After MAV prep, check-out crew retreats through the tunnel to rover, closing the tunnel hatch before detaching and driving back to the habitat
- On departure day, 4 crew transfer from their surface habitat to the pressurized rover, drive to the MAV, and re-dock with the tunnel
- After translating from the pressurized rover to the MAV in clean IVA suits, crew detaches the tunnel from the MAV and departs Mars

Minimum Functional Tunnel Requirements

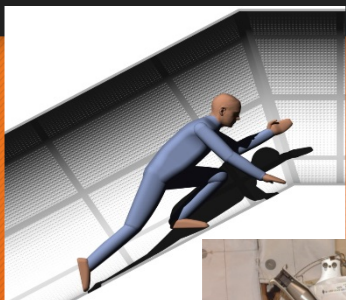
- **R1** Provide a controlled environment between the MAV and pressurized rover, isolated from the Martian environment
- **R2** Provide an environmental seal around ingress-egress hatches on both the MAV and pressurized rover
- **R3** Provide sufficient internal volume for passage of up to four crew members (not necessarily all at the same time) wearing IVA suits
- **R4** Provide sufficient crew interface devices (such as handrails) to facilitate crew translation
- **R5** Provide a means of aligning with the rover hatch
- **R6** Provide a means for detaching from the MAV
- **R7** Accommodate relative elevation difference between the MAV and rover

Functional Requirement Options

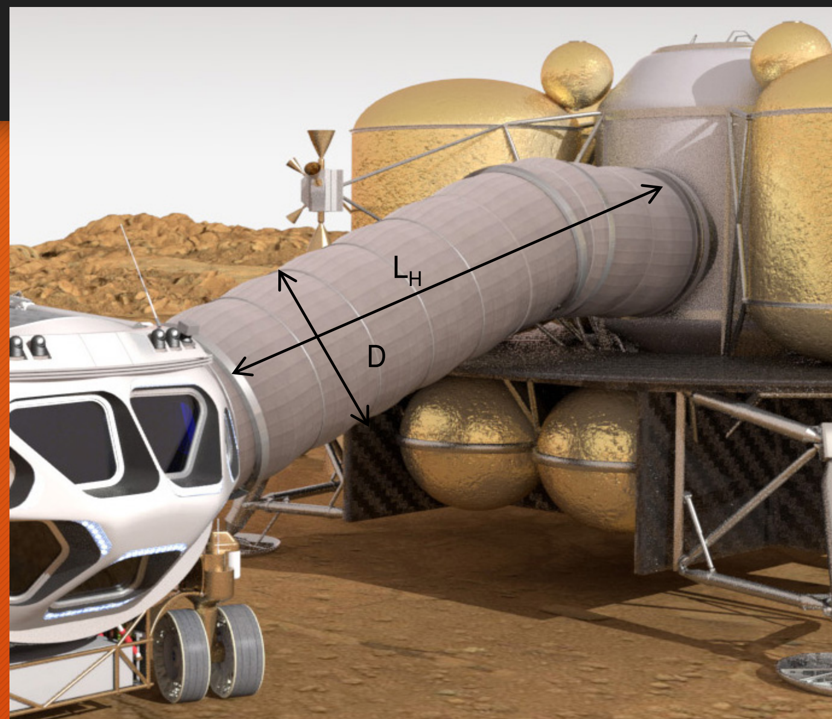
- **R1** Controlled Environment
  - Pressure
    - 56.5 kPa
    - 70.3 kPa
    - 101 kPa
    - 0 kPa
  - Source
    - Rover
    - MAV
    - Lander
    - Tunnel
    - Combo
- **R2** Hatches
  - Dust Cover
  - Pressure Hatch
  - Open
- **R3** Internal Volume
  - Slide
  - Crawl
  - Walk
- **R4** Crew Interfaces
  - Winch
  - Hand-rails
  - Slide rails
  - Ladder
- **R5** Hatch Alignment
  - Tunnel DOF
  - Rover DOF
  - Robotic Arm(s)
  - Rover Ramp
  - Rover Berm
- **R6** Dock/ Undock
  - Pyro
  - Manual Latches
  - Active Mating
  - Passive Mating
- **R7** Relative Position
  - Modify Deck
  - Shallow Angle
  - Raise Rover
  - Segment Tunnel

Selected Study Option

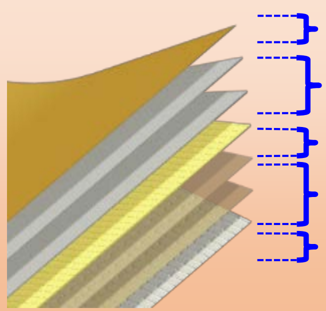
Minimum Functional Tunnel Concept




Crawl + Cargo Winch



Design Constraints/Parameters	
Internal Dia. (D)	1.4 m
Length (L_H)	7.11 m
Stowed volume	TBD m^3
Internal Pressure	56.5 kPa
Service Life	1 week
Shelf Life	4+ years
Power Consumption	TBD W



Component	Mass (kg)
MAV-Side Disconnect	17.3
MAV-Side End Frame	28.3
MAV-Side Winch	9.5
Winch Motor	10.0
Tunnel Body	52.1
Tunnel Straps	2.7
Grappling Fixture	9.1
Rover-Side Hatch Frame	28.3
Ground Support Structure	30.0
Rover-Side Pressure Hatch	30.0
Rover Mating Mechanism	13.0
Handrails (2 ea. X 30.5 cm)	1.4
Maintenance Kit	5.0
Total Mass	**236.7**

Fits within EMC cargo mass allocation

More Detailed Operational Concept
Minimum Functional Tunnel

1. Tunnel is pre-attached to MAV hatch prior to Earth launch
2. Inflation system on lander descent stage is pre-integrated on Earth
3. Crew remotely actuate inflation system to partially inflate tunnel
4. As tunnel unfurls, ground support structure at the rover-end self-deploys
   - Similar to the way ambulance stretcher legs deploy
5. Crew use rover arm to grapple end of tunnel and align with rover hatch
   - Then hard dock to rover and fully inflate tunnel
6. Prep crew crawl up tunnel to MAV: prep MAV, retrieve winch hook, stow cargo
7. Prep crew slide back down to rover, close tunnel pressure hatch, undock from tunnel and return to Hab to retrieve remaining crew
8. Departure day: crew don IVA suits and rover to MAV, docking with tunnel
9. Crew crawl (or are winched) aboard MAV, closing rover/tunnel hatch
10. Close MAV hatch and manually disconnect tunnel from MAV
11. Rover pulls tunnel away from MAV then disconnects and drives to safe distance

Comparison with Alternatives

❑ Suitport

- Can't support incapacitated crew
  - ➢ Have to open EVA hatch, which will bring dust inside
- Requires substantial MAV cabin area
  - ➢ Will need 2 suitports to meet "buddy system" requirement
- Saves landed mass, but heavier ascended mass
  - ➢ Preliminary analysis: a single suitport saves ~73 kg *landed* mass versus minimum functional tunnel
  - ➢ But 119 kg of suitport mass also has to be *launched* with the MAV, requiring at least 800 kg more MAV propellant

❑ Forward Work

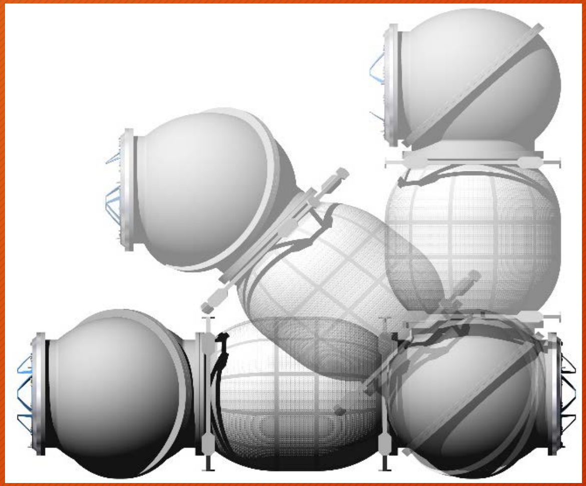
- EVA Hatch, Airlock, Suitport-Airlock Analysis

Alternate Uses for A Tunnel

If We Have It…What Else Can We Do With It?

Forward Work: Assess mass penalty to enhance functionality for other applications

- Habitat-to-Rover Transfer
- Habitat-to-Habitat Transfer
- Habitat-to-Logistics Module
- Rover-to-Rover Transfer
- Extra Storage
- Habitat-to-Lab Module
- Rover-to-Lab Module



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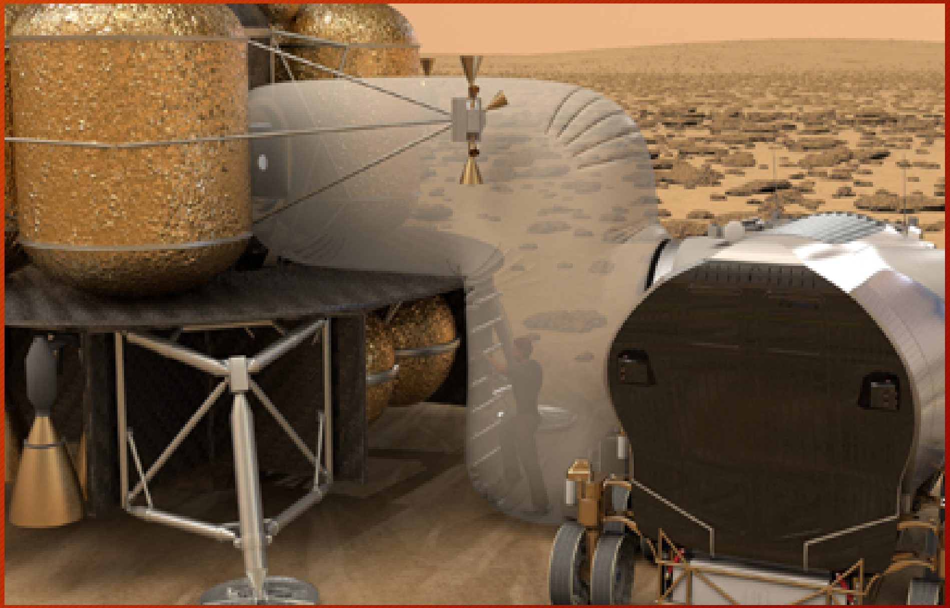

Conclusions

- Given a mobile pressurized element—such as a rover—a tunnel is an attractive MAV ingress option
  - Good dust control with relatively low mass penalty
    - ✓ Keeps dirty EVA suits out of MAV, and eliminates need to open MAV cabin directly to the surface
- *Minimum Functional* Tunnel is ~237 kg
  - Fabric tunnel, with a pressure hatch and cargo winch
  - Sized for current conceptual Lander and MAV concepts
    - Fits within current EMC lander mass allocation
- Minimum Functional Tunnel approach provides a baseline against which to compare tunnel alternatives and mass penalties of additional functionality
- Forward work
  - Trade tunnel against alternate ingress options
  - Assess mass penalty to enhance functionality

Questions?

National Aeronautics and Space Administration
Human Spaceflight Architecture Team
Evolvable Mars Campaign