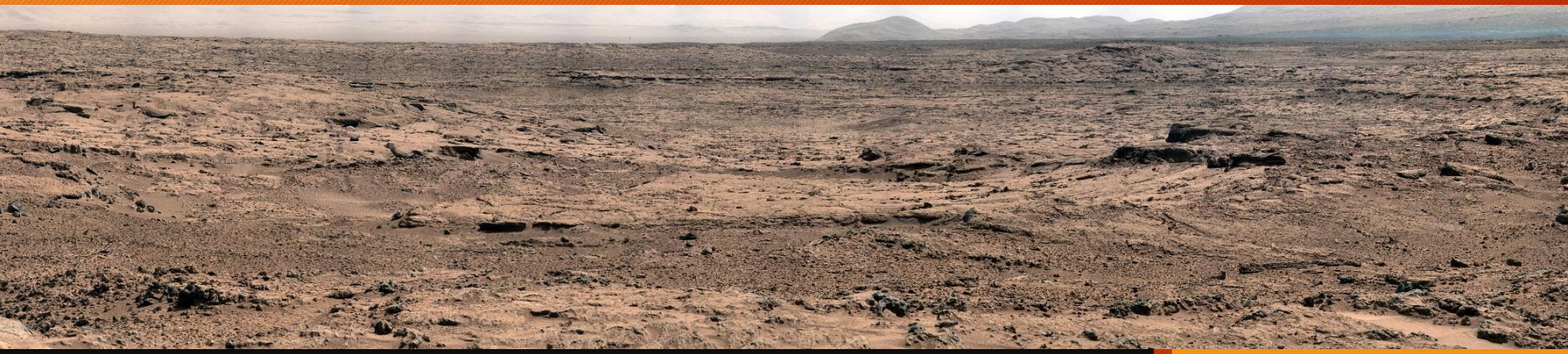

Mars Ascent Vehicle Design Considerations

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Background

- **Mars Ascent Vehicle (MAV) will lift crew from the surface of Mars and rendezvous with an orbiting habitat that will take them home**
- **Two broad categories of MAV crew cabin design:**
  1. Small, short-duration cabin used only for a brief ascent
  2. Large, longer-duration cabin
     - Could be used as both a surface habitat and for longer ascents
- **MAV is the largest "gear ratio" element of a crewed Mars exploration architecture**
  - Propellant needed to boost 1 kg of ascent vehicle to a 1-sol orbit ranges from 3.5 kg (for an *ideal* rocket) to as much as 15 kg (for 0.73 stage mass fraction)
  - We used an optimistic 7:1 gear ratio to assess impacts

Bigger Is Not Always Better!

- The bigger the MAV crew cabin is, the bigger the structure will be, and that means longer cable runs and more surface area to insulate
  - All that adds cabin mass → need more propellant to leave Mars
- More propellant means bigger propellant tanks
  - And that means more structure and insulation
  - If the tanks get too big, it starts to cause problems with hatches and visibility

Goal: Minimize Crew Cabin Size!

4 Key Factors Drive MAV Cabin Size

1. Number of Crew
   - 1, 2, 3, 4, 5, or 6
2. Which Suit Is Worn During Ascent
   - IVA (Launch/Entry Type) vs. EVA Surface Suits
3. How Much Time Crew Spends in MAV
   - Less than 12 - 24 Hours and it can be a "Taxi" ride
   - More than 24 Hours and it becomes a Habitat
     - *Crew is the limiting factor: hygiene, sleep, etc.*
4. How Crew Gets In/Out of MAV
   - EVA Hatch vs. Tunnel vs. Suit Port

1. Number of Crew

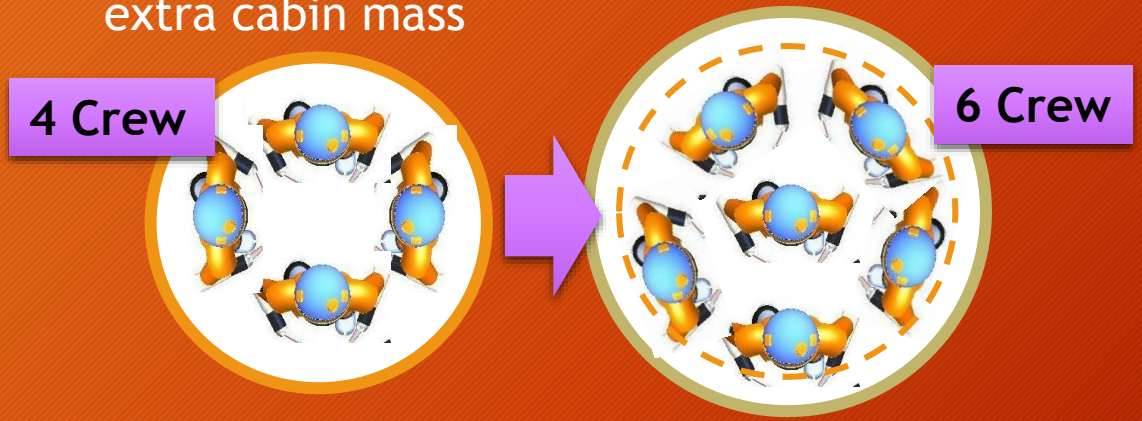
5

Number of Crew Directly Drives Propellant Load

- **At ~82 kg each (for 50th percentile crew), the difference between 2 and 6 crew is 328 kg**
  - 394 kg assuming 95th percentile male crew
  - Doesn't sound like much until you apply the Mars gear ratio
- **7:1 Gear Ratio means more crew require up to 2,758 kg more ascent propellant to leave Mars**
- **More propellant means more mass launched from Earth**
  - Either have to launch that propellant from Earth, then burn more descent propellant to land it on Mars, or
  - Must launch more surface power mass from Earth, then burn descent propellant to land it on Mars, so we can make propellant from Martian resources
    - If In Situ Resource Utilization (ISRU) is an option

More Crew Need More Volume

- You need a bigger cabin to contain more crew members
  - Bigger cabin = more structural mass = more propellant
    - Not just for ascent…you need more descent propellant to *land* that extra cabin mass

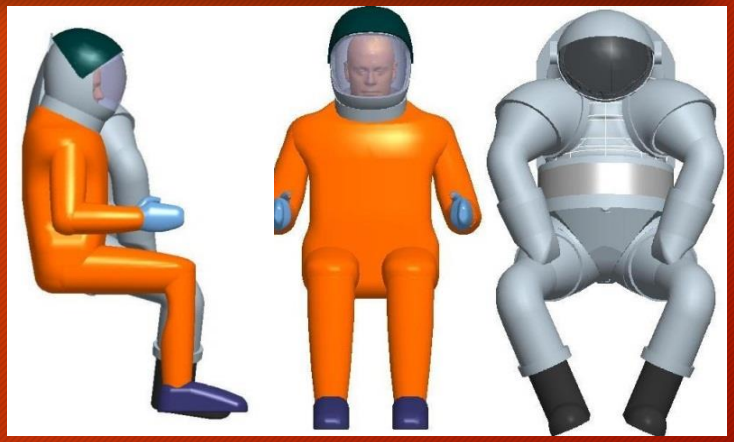


- **More crew need more stuff: umbilicals, food, water, wet wipes, etc.**
  - More stuff means an even bigger cabin for stowage
  - This is how much stuff 6 crew needs for a week
    - Unless you add more mass/volume for spacewalks, your stuff can't be stowed outside

Extravehicular Activity (EVA)
→ *Outside* the Spaceship

Intravehicular Activity (IVA)
→ *Inside* the spaceship

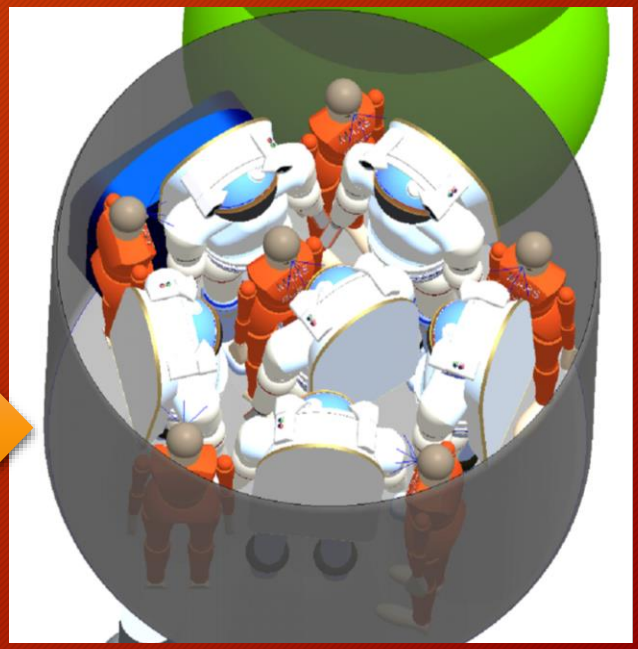
2. IVA vs. EVA Suit



IVA Suit EVA Suit

3. Suits Drive Cabin Diameter

- **EVA Suits are Physically Larger Than IVA Suits**
- **EVA Suits are less flexible than IVA suits**
  - Drives cabin design, especially piloting operations
  - Mockup testing: PLSS plates prevented crew from standing close together
    - Drives pilot controls and windows further apart
- **If crew has to remove suits, it gets worse!**
  - Must remove suits after about 12 hours
    - Maximum Absorbency Garment (MAG) is rated for ~8 hours, but work is ongoing to extend limit
  - An empty EVA suit takes up about as much volume as a person
  - So a 6-crew MAV would effectively have to be sized for 12 people if their EVA suits have to come off during a long ascent



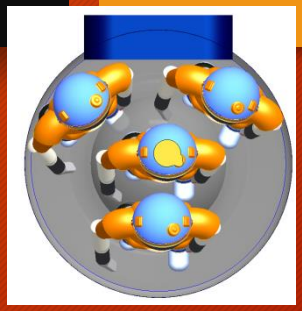
EVA Suits Are Heavy and Dusty

- **Added cabin volume aside, EVA suits will likely be much heavier than the IVA suits**
  - Current estimate is ~75 kg difference between an IVA and EVA suit
  - For 6 crew, that's an extra ~450 kg
    - With 7:1 gear ratio, that's another 3,150 kg ascent propellant
    - Plus bigger tanks and more descent propellant to land it all
- **If crew ascend in EVA suits, it also becomes more difficult to keep Martian dust from migrating back to the return architecture**
  - Returning in IVA suits that have never been outside helps mitigate Planetary Protection concerns

Dusty EVA suit & Astronaut Cernan (Apollo 17)

3. Crewed Duration

Crewed Duration Drives Cabin Diameter



- **Duration crew is inside MAV depends on…**
  - Destination orbit (which affects ascent duration)
  - Whether MAV is used only for ascent, or also for surface habitation
- **4 Crew only need ~1.8 m diameter cabin if they ascend standing up**
  - As long as it's a relatively short ride
  - And they don't have to change suits
- **But if they sleep in the MAV on the surface, the cabin has to be as wide as the tallest crewmember**
  - Depends on cabin curvature and crew stature, but probably >2 m
  - Bigger cabin = heavier structure = more propellant to land and ascend

Crewed Duration Drives Cabin Diameter

- **If crew remain in MAV more than 12-24 hours, they likely have to remove their suits**
  - Regardless of whether they ascend in IVA or EVA suits
- **NASA *Human Integration Design Handbook* recommends 6.35 m3 for suit don/doff**
  - Mockup testing found suit don/doff was one of the biggest cabin volume drivers
  - Rear entry suits require extra ceiling height to pull up/out of suit

2.20 m H x 1.45 m L x 1.99 m W

- **Once the suits are off, crew will need someplace to stow them**
  - Plus volume for waste/hygiene

4. How Crew Get In/Out of MAV

Ingress/Egress Considerations

- **Up to 5 MAV Ingress/Egress Operations**
  1. Into MAV from transit vehicle in Mars orbit (micro-gravity)
  2. From MAV to surface asset if used as a descent cabin (Mars gravity)
  3. In/out of MAV retrieve logistics or stow return cargo (Mars gravity)
  4. Into MAV to ascend to Mars orbit (Mars gravity)
  5. From MAV to orbiting asset for return (micro-gravity)
- **3 Factors Drive MAV Ingress/Egress Design**
  1. ***Which suits is the crew wearing?***
     - IVA suit can pass through docking hatch, pressurized EVA suit can't
  2. ***Where will the crew change from EVA to IVA suits?*** (if they change suits)
     - If crew change inside the MAV, then an EVA hatch will work
     - If crew change elsewhere, they must get to MAV without going outside
  3. ***How much dust can we tolerate?***
     - Mars dust may contain toxic chemicals
     - Once in the MAV, it's more difficult to keep dust from migrating

EVA Hatch

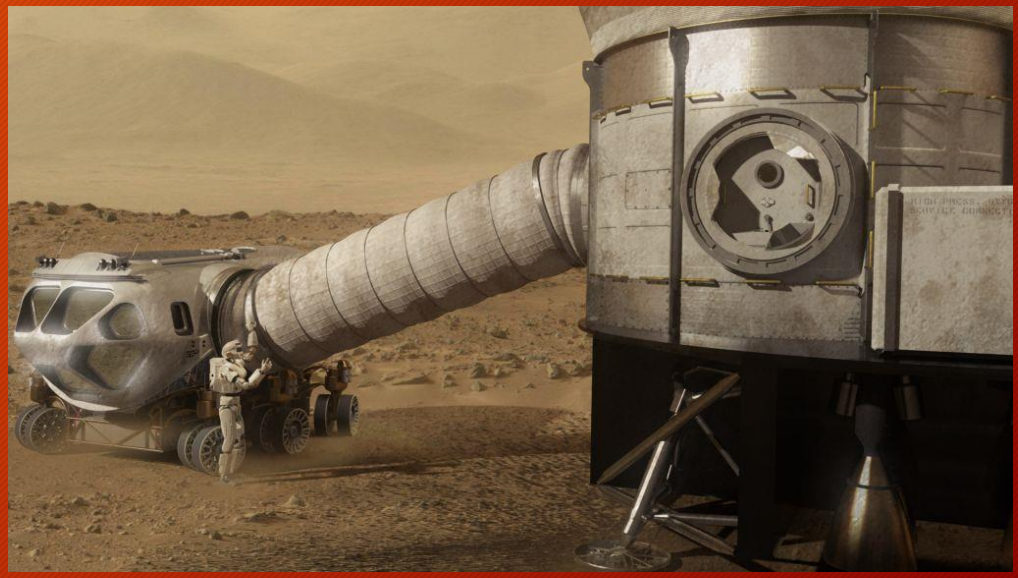
- Relatively low mass, high Technology Readiness Level
- But requires cabin depressurization → wastes consumables
- Mockup testing found that even 3 EVA suited crew could stand together in a small 1.8 m diameter cabin
- Rear-mounted life support system design drives cabin dia.
  - EVA hatch doesn't provide any dust mitigation

Suit Ports

- **Suit Ports promise dust mitigation but…**
  - Current protocol requires an EVA hatch to take the suits out the first EVA, and back in the last
  - So cabin is still exposed to dust
- **Suit ports add ~100 kg each to MAV mass**
- **Suit ports need cabin wall real estate**
  - Need at least 2 ports for redundancy, but more than that drives cabin size
    - ➢ On the other hand, only two suit ports complicates getting everyone in and out quickly
    - ➢ Two crew go out, undock their suits, then place 2 externally stowed suits on the Suit Ports so the next 2 crew can come out
    - ➢ Reverse the process to come back in – slow in an emergency
  - Externally stowed suits require thermal conditioning, which adds mass

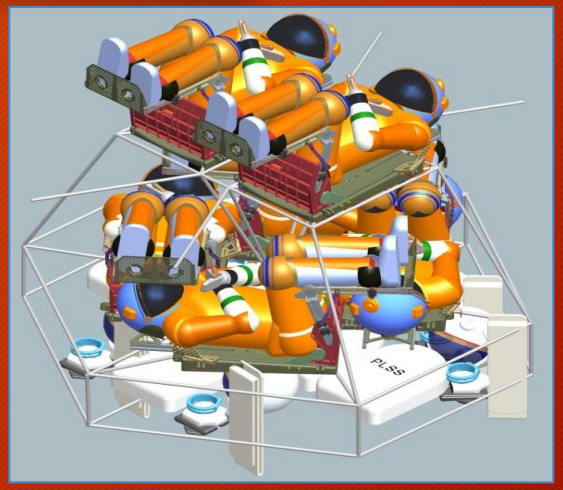
Tunnel

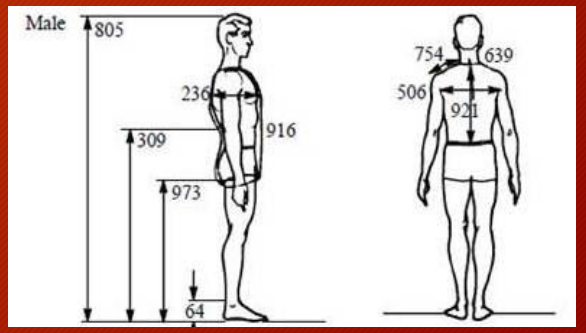
- **If paired with a habitable surface element, retractable tunnel is an attractive option**
  - Works with a pressurized rover or surface habitat
- Minimizes MAV cabin mass by pushing suit don/doff and EVA operations to an element that remains on the surface
- **Downside is that tunnel adds mass**
  - ➢ But it's landed—not ascended—mass
  - ➢ Could also be used to reconfigure other surface assets



Additional Considerations

1. **Whether or not crew require recumbent seating**
   - Recumbent seats are ~25 kg each and take up a lot of volume
2. **Crew physical stature**
   - Sleep bunk length drives cabin diameter for surface use (for vertical cylinder configuration)
     - 50th percentile male crew stature & mass = 179.9 cm x 82.2 kg
     - 95th percentile male crew stature & mass = 190.1 cm x 98.5 kg
   - 10 cm on the shell diameter and 16 kg per crew, with the 7:1 gear ratio could be significant

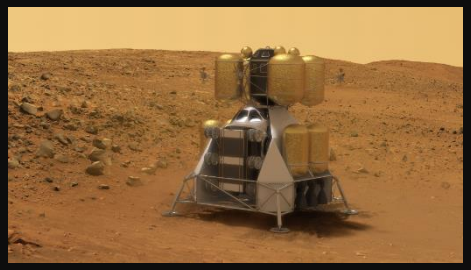




Additional Considerations

3. **Whether crew is actively piloting**
   - –Windows add mass
     - Penetrations in pressure shell require reinforcement + glass is heavy
   - –Synthetic vision (via camera) is possible, but costly to certify
     - Historically, crew pushes back on no windows
     - If crew is recumbent, we may have no choice
4. **Return Cargo**
   - –Current goal is 250 kg of return cargo per ascent

Conclusions



- **MAV crew cabin mass profoundly impacts end-to-end mission architecture**
- **To minimize MAV crew cabin mass:**
  1. Limit MAV usage to 24 consecutive hours or less
  2. Abandon EVA suits in a surface asset and ascend in the MAV wearing IVA suits
  3. Limit MAV functionality to ascent only, rather than dual-use ascent/habitat functions
  4. Ingress/egress MAV via a retractable tunnel to another pressurized surface asset

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Questions?