Mars Ascent Vehicle Design Considerations

Michelle A. Rucker
National Aeronautics and Space Administration
August, 2015
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

Michelle.a.rucker@nasa.gov/AIAA Space 2015
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 \(\rightarrow\) 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

Michelle.a.rucker@nasa.gov/AIAA Space 2015
1. Number of Crew
At ~82 kg each (for 50\(^{th}\) percentile crew), the difference between 2 and 6 crew is 328 kg
- 394 kg assuming 95\(^{th}\) 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
• 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

Michelle.a.rucker@nasa.gov/AIAA Space 2015
2. IVA vs. EVA Suit

Extravehicular Activity (EVA) → *Outside* the Spaceship

Intravehicular Activity (IVA) → *Inside* the spaceship
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
• 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
3. Crewed Duration
• 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
• 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

Michelle.a.rucker@nasa.gov/AIAA Space 2015
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

Michelle.a.rucker@nasa.gov/AIAA Space 2015
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
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
Questions?

Michelle.a.rucker@nasa.gov/AIAA Space 2015

NASA Johnson Space Center
XM/Michelle Rucker
Michelle.a.rucker@nasa.gov

Acknowledgements

Graphics courtesy of John Teter, Victor Dang, Tim Collins, Dan Miller, and David Paddock. EVA information courtesy of Natalie Mary. Gear ratio estimates courtesy of Walter Stephens and Ryan Whitley.