An Introduction to the Concept of a Deep Space Science Vessel

2019 IEEE Aerospace Conference

Contents

Introduction

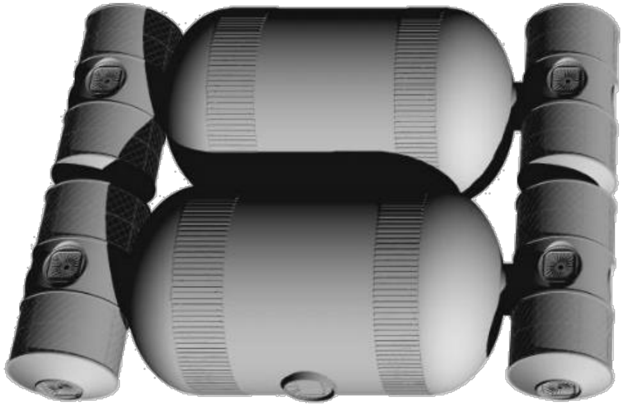
- **Why are we in space?**
  - Knowledge for all
  - Economic growth
  - Real estate
  - Protect and preserve human rights
- **Where should we go in space?**
  - Mars called "the ultimate goal for US human spaceflight"
  - What happens after 1st Mars landing? After we've "already been there"
  - The first is not (should not be) the end
    - Magellan, First Transcontinental Railroad, Charles Lindbergh, John Glenn
  - The first is the herald of new era of activity, not a one-time deal
  - More than "we've never been there" or value is only bragging rights
  - Expansion wave of human presence into the inner solar system

Introduction

- **Rationale for a Deep Space Science Vessel**
  - The journey is as important as the destination
    - Value is lost when focus only on the destination
  - Apollo 8 Earthrise photo
    - Goal of Apollo was lunar surface
    - Photo taken of Earth, from lunar orbit
    - Photo credited with starting the environmental movement
  - Deep Space Transport 1100-day mission
    - Contingency scenario
    - Psychological requirement for meaningful work
    - Mars missions actually an 1100-day science cruise with option to substitute up to 500 days for surface excursion; transit is the mission
  - Just as science vessels traverse the ocean, so can they traverse space
    - Limitless source of science in the ocean
    - Limitless source of science in the inner solar system and asteroid belt

Deep Space Science Vessel

- **Possible next step after human missions to Mars**
  - Dedicated deep space science spacecraft
  - Science exploration and discovery throughout inner solar system
    - Operating region: 0.39 AU (Mercury) to 2.8 AU (Ceres)
    - Independent operations or rendezvous with predeployed assets
      - Both in-space and surface excursions via attached / predeployed vehicles
    - Ongoing life science, physical science, and engineering technology research with 48-person crew
    - Extensive onboard fabrication, maintenance, and repair capability
- **Pressurized Volume**
  - Local vertical consistent (down is to aft)
  - Hab and Lab Modules (one each)
    - 10 m diameter, 12.5 m barrel length, 5 m dome
  - Node Modules (four total)
    - 4.2m diameter, 7m total length



Deep Space Science Vessel

- **Power-Thermal-Propulsion Module (PTP)**
  - Notional in this study
  - Deployable and body mounted radiators
  - Swappable propellant tanks
  - Hybrid chemical and nuclear electric propulsion/power
- **External Science**
  - Deep space observatories
  - Remote sensing platforms
  - Additional mission-specific and space environment exposure payloads
- **DPMA (DSSV Pressurized Mating Adapter)**
  - Family of docking systems derived from MMSEV AAMA
  - Enables docking with dissimilar docking systems
    - IDSS, CBM, Probe and Drogue, etc.
    - Includes electrical, optical, and fluid connectivity across elements

DSSV Internal Configuration

- **Habitat Module**
  - 2 domes, 5 decks
  - Upper Dome
    - Galley & Wardroom
    - Ship Theater (IMAX-style viewing)
    - RISD low fidelity mockup – one slice of dome
      - Notional feasibility demonstration
      - Accommodates entire 48-person crew for group meals
      - Includes subdivisions to facilitate group meals for subsets of crew
  - Deck 3
    - Waste, hygiene, and exercise deck
      - 8 toilets, 8 hand wash stations
      - 16 full body hygiene units
      - 4 aerobic, 4 resistive exercise devices
    - Connection point to Laboratory Module and docked MMSEV spacecraft

DSSV Internal Configuration

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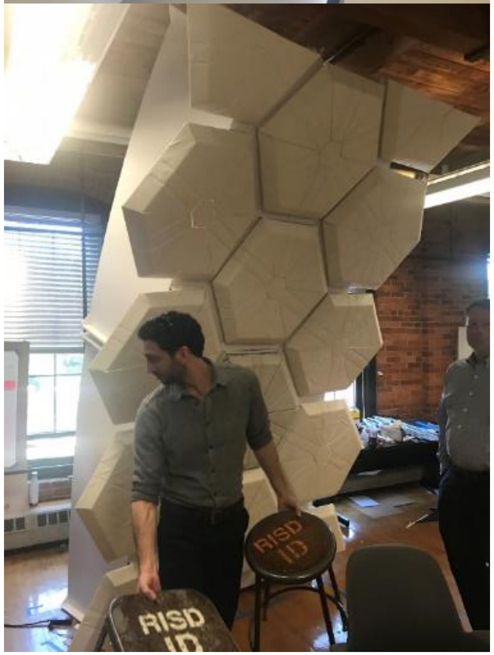
- **Habitat Module**
  - Deck 1, 2, 4, 5
    - All identical Crew Quarters decks
    - 12 private quarters per deck (enabled by 10m diameter)
    - RISD low fidelity mockup of single crew quarters
      - Demonstrates preliminary viability
      - Additional design refinement and human-in-the-loop testing needed to increase confidence in solution
  - Lower Dome
    - Crew recreation level
    - Large, open volume, reconfigurable “play” facility
    - Padded stowage lockers



DSSV Attached and Visiting Vehicles

- **Logistics Module**
  - Up to six nominally docked
    - DPMA enables dissimilar suppliers, dissimilar docking systems
  - Stowage for supplies and waste
    - Point of use stowage within DSSV; restock stowage in Logistics Modules
    - Includes at least 8 crew 30-day supplies in each module
- **External Airlock**
  - Nominally at least one airlock; additional on mission-specific basis
    - Dissimilar airlock types possible
  - If utilities connections can receive services via DSSV DPMA
- **Single Person Spacecraft**
  - Currently conceptual EVA alternative
  - Rigid, non-articulated small spacecraft volume
  - Usage on mission-specific basis; dock to any DPMA port

DSSV Attached and Visiting Vehicles

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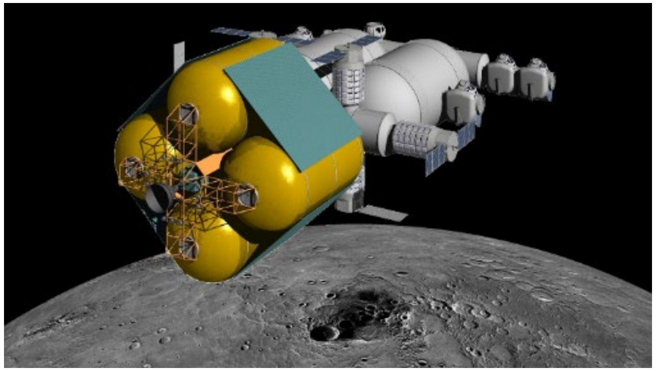
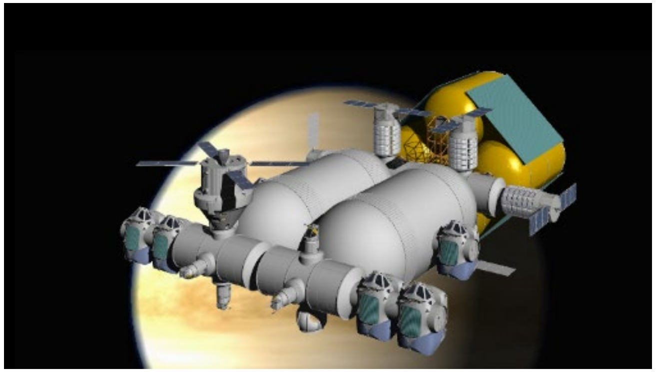
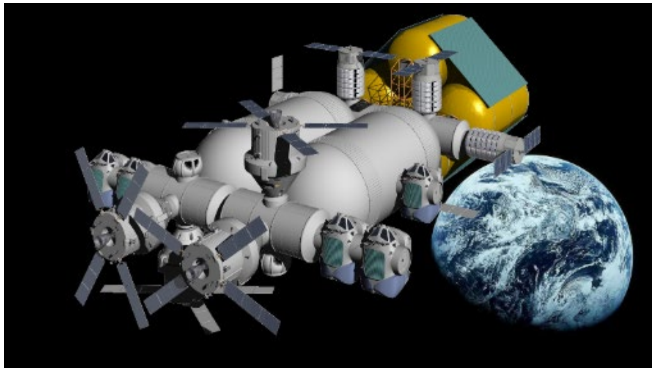
- **Multi-Mission Space Exploration Vehicle**
  - Scout craft developed under Constellation, initially as surface rover
  - Cabin can be used with thrusters module as free-flyer
  - 30-day lifeboat mode (with Logistics Modules) for up to 8 crew in event of DSSV contingency
- **Human Landers**
  - Prepositioned landers can dock with DSSV at a destination orbit
- **Earth Entry Capsules**
  - Transport crew between DSSV and Earth
- **Space Stations and Deep Space Vehicles**
  - Gateway, another DSSV, other space station in orbit of a particular moon or planet

DSSV Mission Concepts

- **Mercury**
  - Temperate regions near permanently shadowed craters at poles
  - Human or robotic landers
- **Venus**
  - Most Earth-like planet at 50 km altitude
  - Meteorological science
  - Spacecraft testing beyond Earth-Moon system
- **Cislunar Space**
  - Home port:
    - Repair, servicing, upgrades, crew transfers
  - Microgravity research, esp. coordinated with Gateway

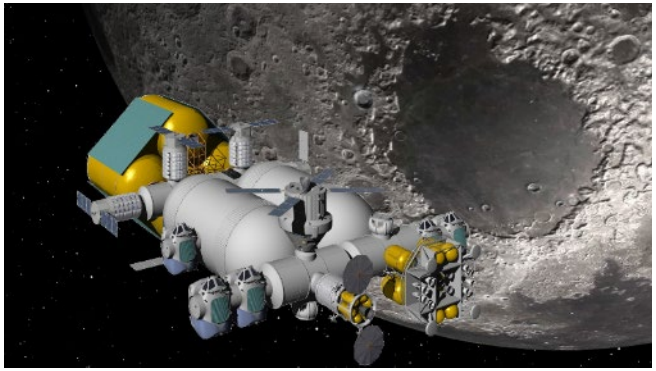


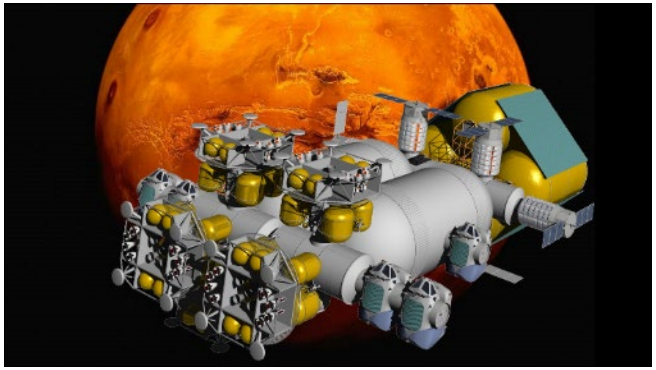


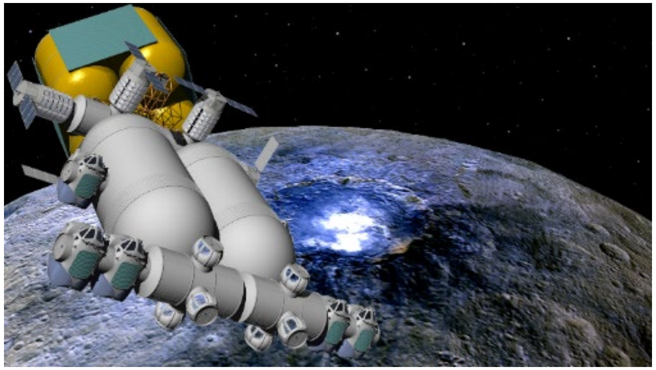


DSSV Mission Concepts

- **Moon (always one DSSV present)**
  - Lunar surface crew transfers; access node to surface
  - Orbital study of the Moon
- **Mars (always one DSSV present)**
  - Access node to surface, Phobos, Deimos
- **Ceres**
  - 1/3 mass of asteroid belt; water suspected
  - Extended surface exploration
- **Standing missions at all locations**
  - Great Observatory
    - Vantage points throughout inner solar system
  - Microgravity laboratory (all sciences)







Sample Crew

- **Generally organized within five departments**
  - Executive Department
    - Leads of technical or operational capabilities
  - Engineering Department
    - Engineering research; in-flight maintenance, repair, fabrication, and testing
  - Medical Department
    - Physiological and psychological health care
  - Life Science Department
    - Biological research inclusive of life in distant destinations as well as extending life from Earth to those destinations
  - Physical Science Department
    - Research of the physical nature of the universe, both at the DSSV current position and the universe as observed from the DSSV's position
- **Significant number of crew cross-trained as pilots to operate MMSEVs and other mission-specific piloted craft**

Sample Crew

- **Generic, multi-mission example crew allocation**
  – Specific crew allocations likely to vary on mission-specific basis

Executive Department
Mission Commander / Pilot
Executive Officer / Public Affairs Director
Excursion Commander / Pilot
Sortie Commander / Pilot
Sortie Commander / Pilot
Chief Engineer / Pilot
Deputy Chief Engineer
Chief Medical Officer
Deputy Chief Medical Officer
Chief Scientist / Pilot
Deputy Chief Scientist

Medical Department
Psychologist / Public Liaison
Medical Doctor / Pilot
Psychologist / Medical Doctor

Engineering Department
Electrical & Mechanical Engineer
Mechanical Engineer
Software Engineer
Engineer / Pilot
Engineer / Pilot
Mechanic / Public Liaison
Mechanic / Pilot
Mechanic / Pilot
Mechanic

Life Science Department
Animal Scientist
Botanist
Botanist
Life Scientist / Pilot
Life Scientist / Pilot / Public Liaison
Life Scientist / Nutritionist
Life Scientist
Life Scientist / Pilot
Life Scientist
Life Scientist

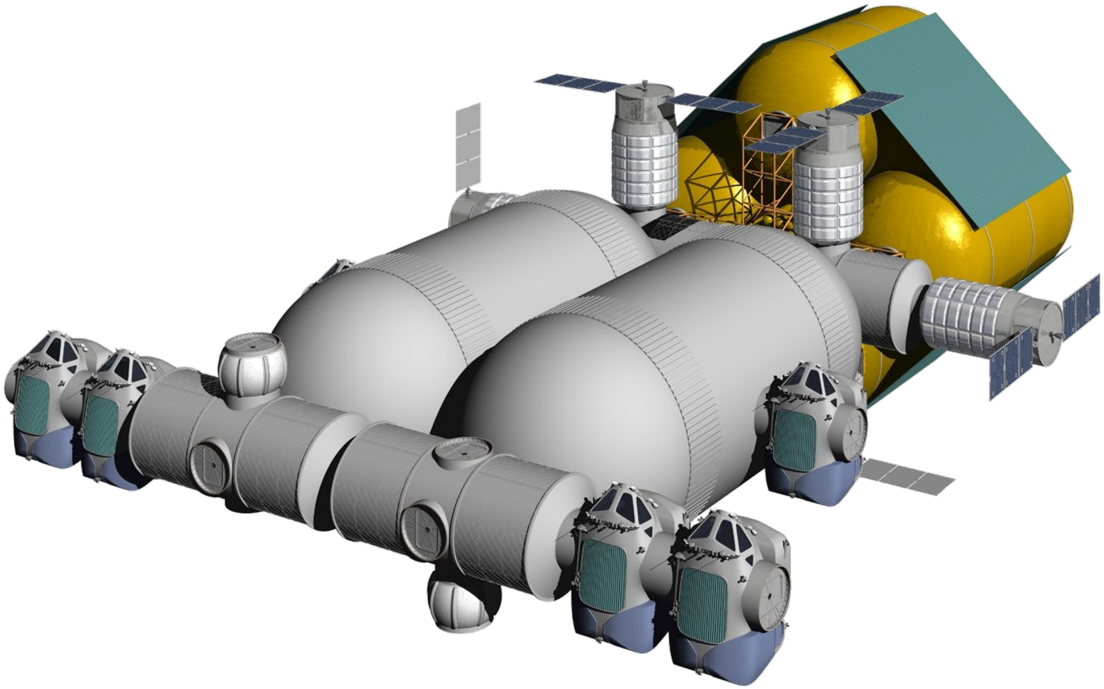
Physical Science Department
Astronomer / Public Liaison
Astronomer / Pilot
Geologist
Geologist / Paramedic
Geologist / Public Liaison
Geologist
Meteorologist
Materials Scientist / Paramedic
Materials Scientist
Metallurgist
Metallurgist
Physicist
Civil Engineer
Civil Engineer / Public Liaison
Civil Engineer

Enablers from Initial Mars Missions

- **Mars likely to be first human activity beyond Earth-Moon system**
- **Key role in developing capabilities needed for DSSV**
  - Spacecraft technology developments
  - Maintenance, fabrication, and repair capability
  - Multi-spacecraft flight operations
  - ISRU capabilities
  - Autonomous operations
- **Conjunction class missions valuable**
  - Approximately equal time between transit and surface ops
    - Lessons learned opportunities in both domains
- **Long duration surface facilities valuable**
  - Develop surface infrastructures for future use
  - Build expertise in distributed crew operations (rover excursions)

Recommendations and Conclusions

- **Extensive work needed to determine feasibility**
- **Currently unfunded; leveraging university partnering**
- **Key areas of forward work**
  - Propulsion and Trajectory
  - Nuclear Reactor and Shielding
  - Radiation Monitoring
  - Secondary Power
  - Power Management and Distribution
  - Deployable Radiators
  - Communications
  - Data Systems
  - Data Networks
  - Guidance, Navigation & Control
  - Environmental Control and Life Support
  - Utilities Distribution
  - Mechanisms, Docking Ports, and Mating Adapters
  - Pressure Vessels
  - Truss Structures
  - External Science Payloads
  - Habitat Module Internal Architecture
  - Lab Module Internal Architecture
  - Node Modules Internal Architectures
  - Logistics Module
  - Inflatable Airlocks and EVA Support
  - MMSEV Cabins
  - MMSEV External Modules
  - Single Person Spacecraft
  - Plant Growth Facilities
  - Food Systems
  - Aggressive Cost Reduction
  - Global Program Management
  - Mission Concept Visualizations
  - Logos and Graphics



Questions?

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EXPLORE MOON to MARS

Opportunities and Challenges of a Common Habitat for Transit and Surface Operations

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Contents

Introduction

- **Space Policy Directive 1**
  - *"the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."*
  - Specifies long duration lunar surface presence
- **Presently three long duration mission cases beyond LEO**
  - Lunar surface
  - Deep space transport (e.g. Earth to Mars)
  - Mars surface
- **Key drivers for long duration habitats**
  - Psychosocial tolerance
  - Meaningful work
  - Exercise and medical
  - No evacuation (medical), no return to Earth surface (maintenance)

Introduction

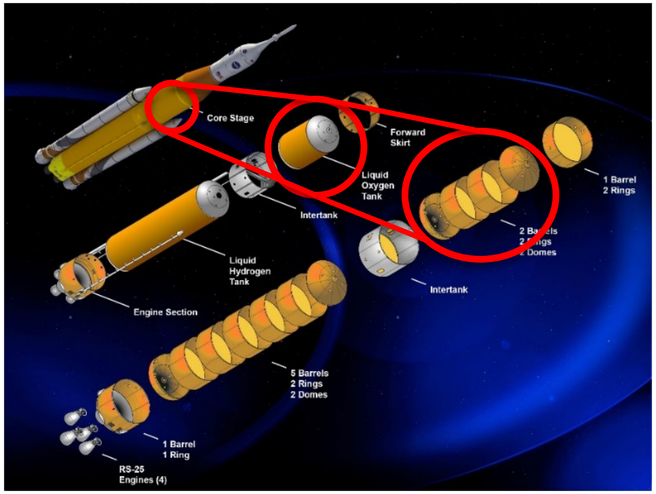
- **Temporal challenge**
  - Three habitats by the 2030s
    - Lunar Surface Habitat: primary habitation in lunar outpost
    - Mars Transit Hab: habitable element of Deep Space Transport
    - Mars Surface Hab: primary habitation in Mars outpost
  - Traditional development path is serial, separate programs
    - Example: Skylab, Shuttle, ISS development
      - Skylab: 1965-1973
      - Shuttle: 1968-1981
      - ISS: 1984-1988 (Unity) or 2011 (Leonardo and AMS)
      - Total development time 33-46 years depending on how ISS development counted
    - Similar pace for long duration habitats (if begin 2020) puts first Mars crew on surface in 2053-2066 timeframe
      - Serial development takes far too long
      - Possible solution: common habitat; single development and parallel exploration

Introduction

- **Requirement to be a true "Common Hab"**
  - Must be equally acceptable in design for lunar, Mars, and transit missions
  - One production line: serial number 001 is a lunar surface hab, 002 is a transit hab, 003 is a Mars surface hab
  - Ideal goal: negligible changes between production units (in theory could swap on pad)
- **Common Habitat study being implemented using the Skylab II concept for the pressure vessel**
  - Skylab II concept originated at Marshall Space Flight Center
  - Based on original Skylab "dry hab" concept
  - Various versions used SLS, Shuttle ET, Saturn, Delta, or Centaur propellant tanks

Skylab II Concept

- **Variant for this paper is a truncated SLS Core Stage LOX Tank**
  - 8.4m diameter
  - 2.65m dome height
  - One 5.15m tall barrel segment
    - LOX tank has two segments
  - Manufactured at Michoud Assembly Facility
    - New Orleans, LA

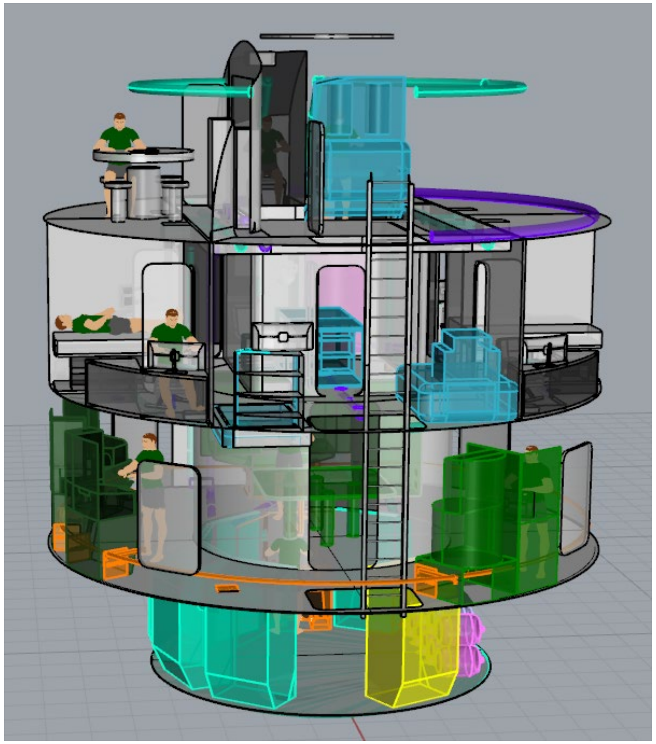


Skylab II Concept

- **Minimum number of hatches/docking ports: four axial**
  - All hatches 60” x 40” with passive flanges – AAMA compatible
  - Some concepts also include two radial hatches
  - Some concepts include additional docking ports with no hatches
- **Unclear whether horizontal or vertical internal configuration is superior**
- **Living and Working Functions**
  - Living Functions
    - Private habitation, hygiene, waste collection, meal preparation, meal consumption, group socialization and recreation, exercise, and medical operations
  - Working Functions
    - Scientific research, robotics / teleoperations, EVA operations, spacecraft monitoring and commanding, mission planning, maintenance, and logistics operations

Preliminary Work Completed

- **Leveraged NASA civil servant and intern work to conduct preliminary feasibility**
  - No CAD models or images reflect final configurations
- **Initial design parameters**
  - 4 crew, up to 1100 day mission
  - Both vertical and horizontal configurations considered
  - Human operations priority driver for internal layout
  - Not true monolithic habitat
    - Stowage permitted to require attached logistics modules
    - External airlock



Notional layout demonstrates accommodation of living and working functions in four-deck vertical orientation

Preliminary Work Completed

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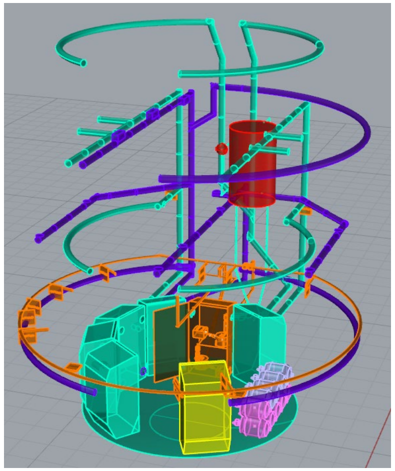
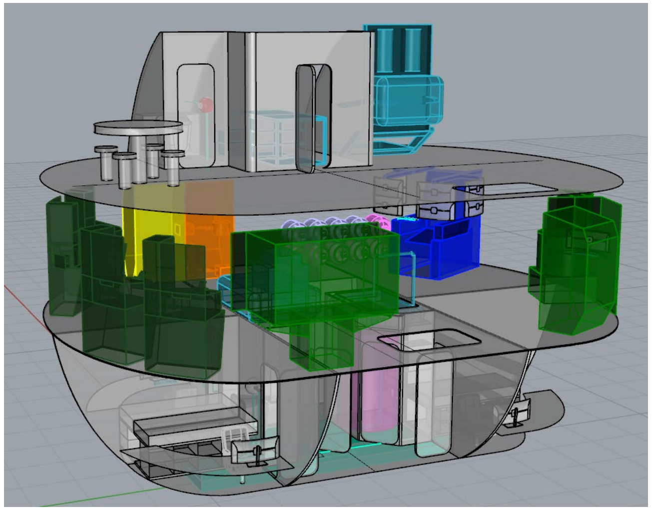
- **Vertical Configuration**
  - Initial layout completed
  - Utilities duct work completed
  - Design philosophy by deck
    - Subsystems on lowest deck (dome)
    - Hatches, science, maintenance on deck 2
    - Crew quarters, aerobic exercise, medical on deck 3
    - Galley, wardroom, resistive exercise, recreation on deck 4 (dome)
- **Horizontal Configuration**
  - Design philosophy by deck
    - Private functions on lowest deck
    - Working functions on mid deck
    - Group functions on upper deck

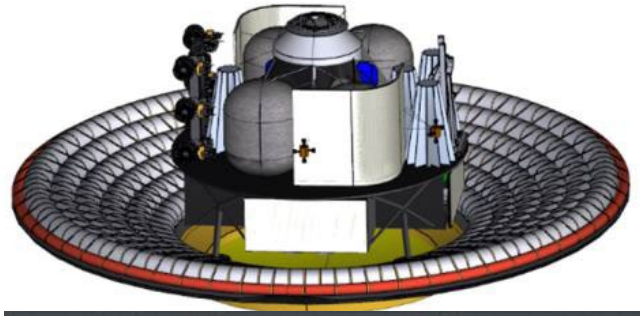


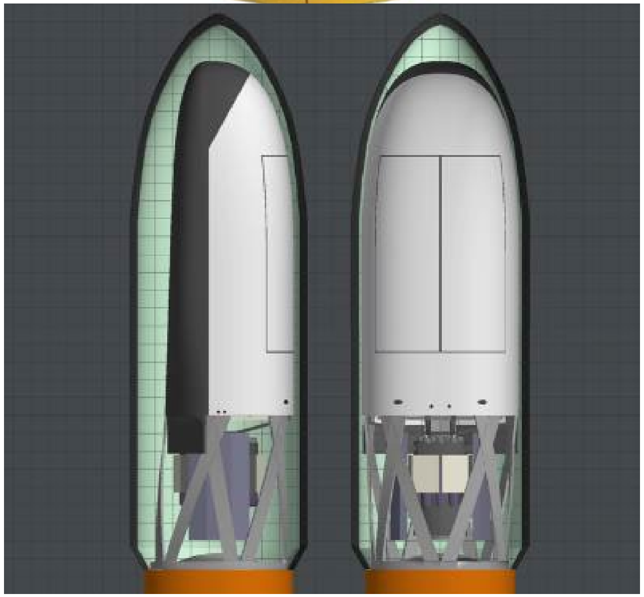


Notional layout demonstrates accommodation of living and working functions in three-deck horizontal orientation

Lander Integration

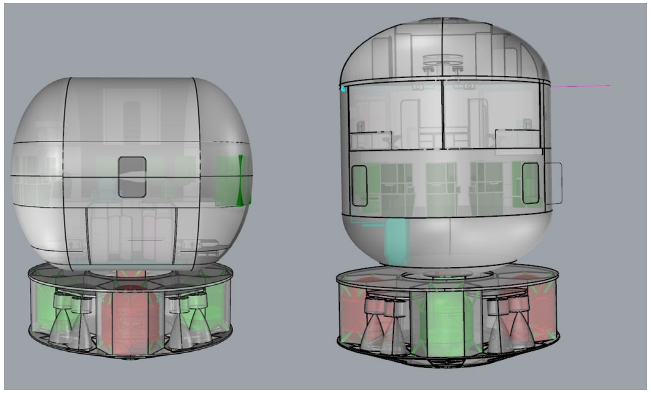
- **NASA conceptual studies exist for two Mars landers**
  - HIAD (Hypersonic Inflatable Aerodynamic Decelerator)
    - Inflatable aeroshell reduces entry heating
    - Flat deck lander
    - Additional payload bay in core
  - Mid L/D
    - Higher lift to drag than capsules
    - Less than winged vehicles
    - Large payload bay
  - Neither lander intended for Skylab II class payloads
    - Both mass and volume accommodation expected to be problematic

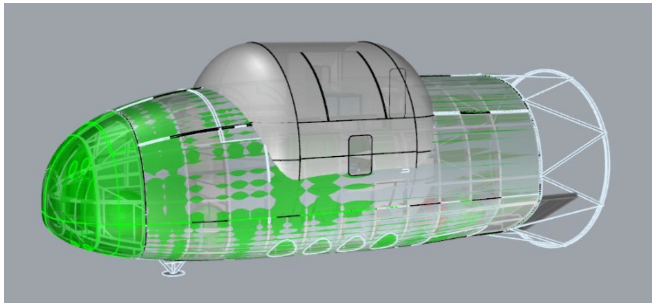


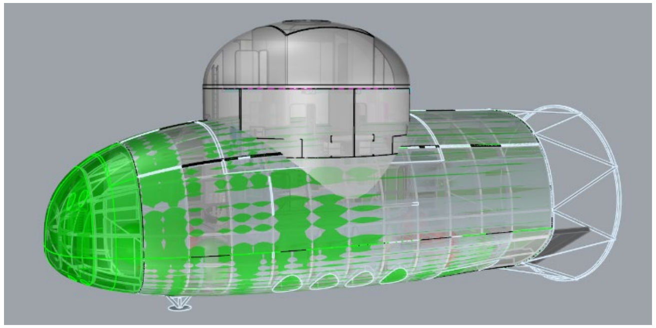


Lander Integration

- **CAD Sizing Exercise**
  - HIAD Lander
    - Both hab orientations require further study
    - Airflow likely to impinge on upper sections of hab unless inflatable aeroshell resized
    - Could be evolved into a lunar lander (additional propellant)
  - Mid L/D Lander
    - Horizontal Hab does not presently package
      - Common Hab 8.41m diameter
      - Payload Bay 7.3m tall by 8.8m wide
    - Vertical Hab is not feasible with Mid L/D
- **Lunar**
  - Constellation Altair lander may have accommodated Skylab II
  - Current studies all smaller landers

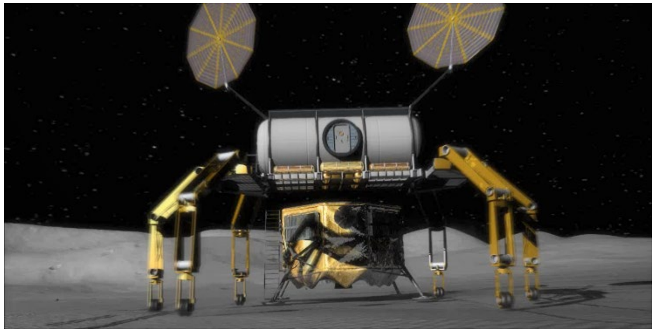






Surface Integration

- **Common Habitat must be removed from lander**
  - Transport hab from landing site to outpost location; potentially 0.5 km or greater
  - Pressurized rover and logistics module docking access
  - EVA access to surface
  - Landed habitat mass could be 20-50 ton range, depending on outfitting plan
- **NASA JPL Tri-ATHLETE**
  - (All-Terrain Hex-Legged ExtraTerrestrial Explorer)
  - Half-scale unit field tested during Constellation
  - Two pairs (12 legs) can offload Hab on Mars



Surface Integration

- **Hatches significant height from surface once offloaded**
  - Vertical hab: ~2.7m above surface
  - Horizontal hab: ~3-3.5m above surface
  - Both cases assume bottom of hab touches surface
- **Options to build ramps and platforms for docking access**
  - Reuse structural elements from landers
    - Landing gear, truss segments
    - Closeout panels, deck plates
    - Payload attach fittings
    - Propellant tanks
  - Use Earthmoving attachments on rovers
    - Both pressurized rover and Tri-ATHLETE demonstrated ability in field testing

Crew Size Sensitivity

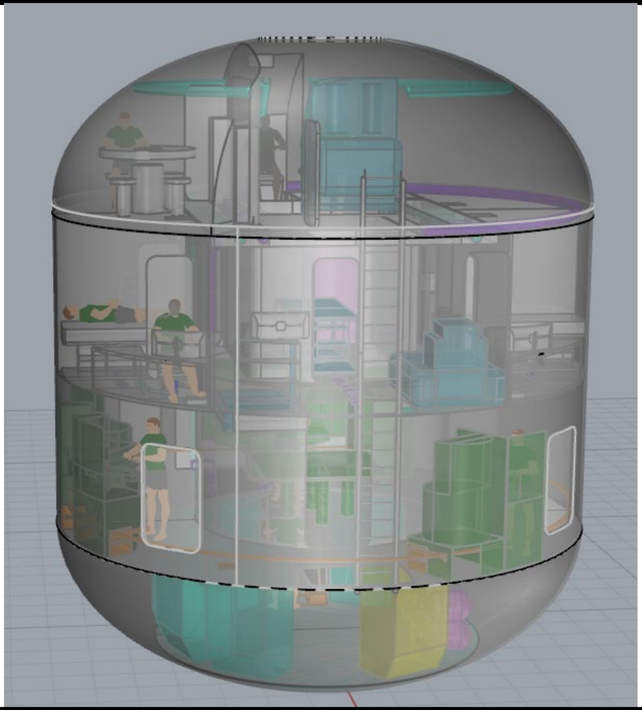
- **Most modern NASA exploration studies assume 4-person crew**
  - Based in part on Orion's 4-crew capacity
  - Departs from pre-Orion 6-crew Mars studies
- **Potential limitations of 4 crew**
  - ISS Lessons Learned (from 3-crew buildup period)
    - Struggle to conduct science due to vehicle maintenance workload
  - Pressurized Rover Lessons Learned (from field testing)
    - Safety and effectiveness call for two 2-crew rovers working together
    - Draws all 4 crew away from Hab during rover excursions
  - NASA Langley study predicts as low as 5% of outpost crew hours available for science / utilization

Crew Size Sensitivity

- **Possible 8-crew mitigation**
  - Uses two Orion flights to deploy crew
  - Enables 4-person crew in Hab during rover excursions
  - Surges to 8-person crew when rovers docked
  - Schedule outpost maintenance when full crew available
  - Changes both habitat design and logistics

Forward Work

- **Only initial feasibility explored; numerous studies remain**
  - Validate living and working functions
  - VR walk-through assessments
  - Crew timeline analyses
  - 4 vs. 8 crew
  - Vertical vs. horizontal orientation
  - Vehicle mass and c.g.
  - Site selection, lander integration and offloading
  - Radiation exposure
  - Transit propulsion
  - Window placement
  - Launch and delivery ConOps
  - Outfitting studies
  - Etc.



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