ASCEND™

16-18 November 2020 | Online

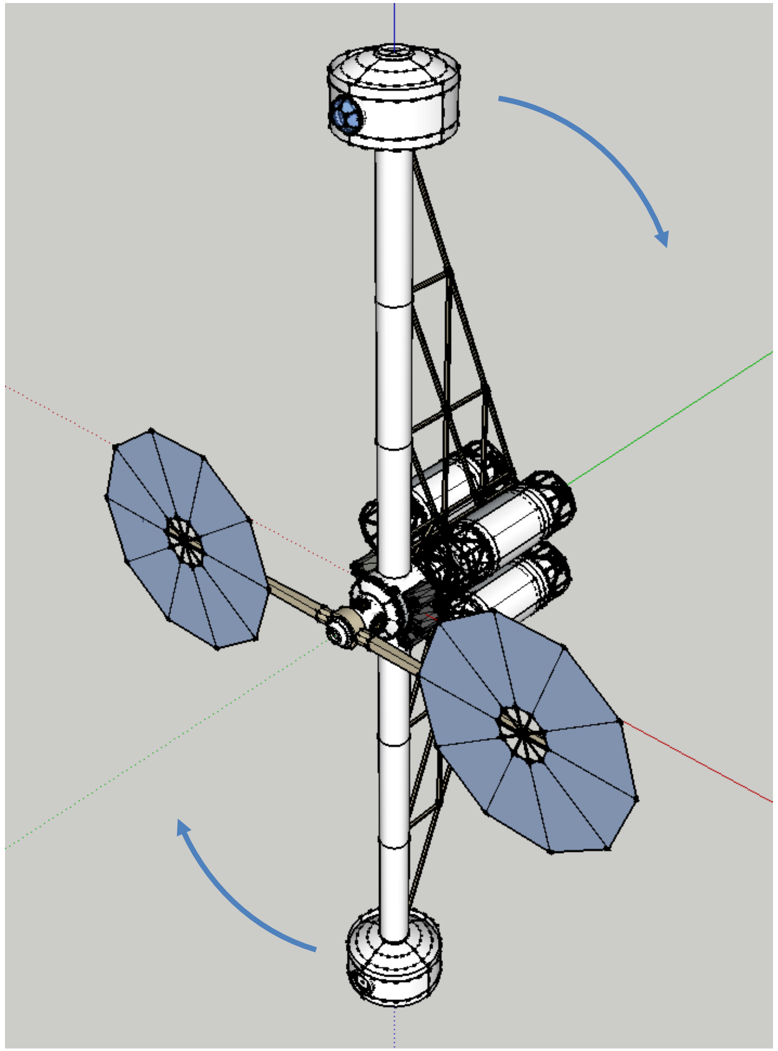
AN ARTIFICIAL GRAVITY CONCEPT FOR THE MARS TRANSIT VEHICLE

David Smitherman
Paola Gonzalez, Mandy Kiger
Advanced Concepts Office
NASA Marshall Space Flight Center

www.ascend.events

Contents

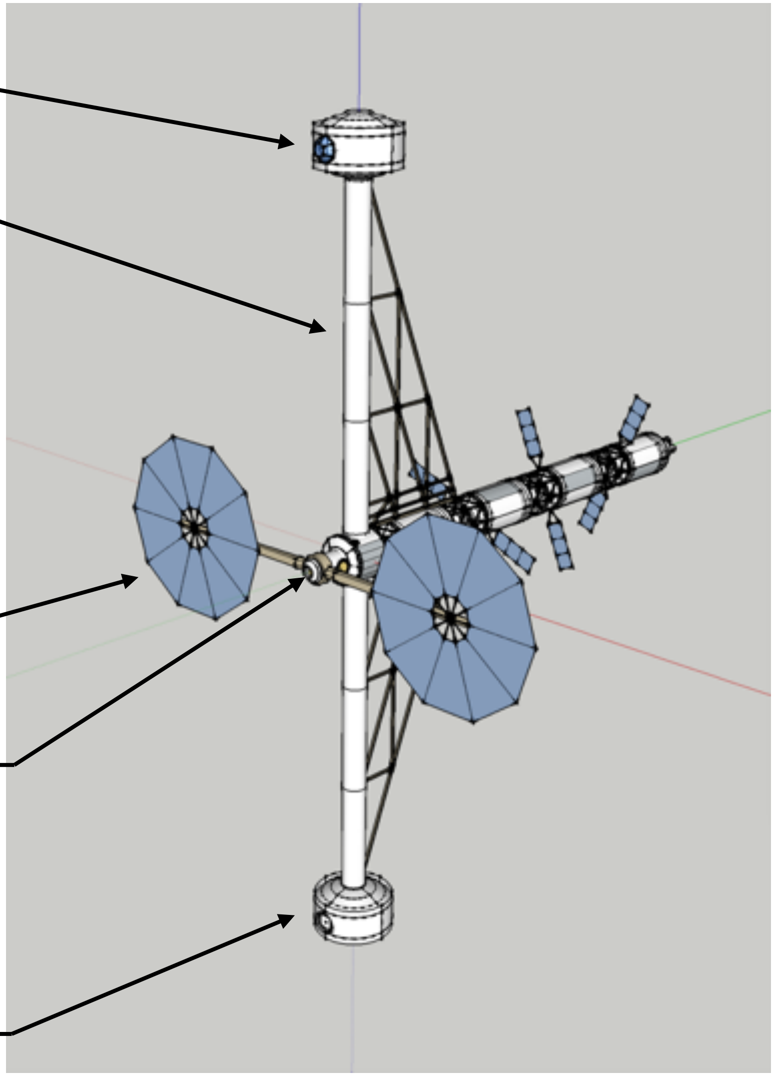
- Contents
  - Vehicle Overview
  - Assembly
  - Habitat Concept
  - Mission Operations
  - Intermediate Axis Theorem
  - Mass
  - Propulsion Options
  - Servicing
  - Rotational Docking Concepts
  - Conclusions
  - Credits & References



- Concerns addressed by this concept
  - Long term exposure to microgravity
    - Delayed operations on the surface of Mars while the crew acclimates to the gravity environment
    - Significantly delay mobility upon return to the gravity environment of Earth
    - Multiple long term and perhaps permanent physical effects that are not fully understood
  - Dual common habitat in a safe-haven configuration [1]
    - Provides redundancy of habitable volume and life support systems to protect crew from fire, life support failures, and pressure loss

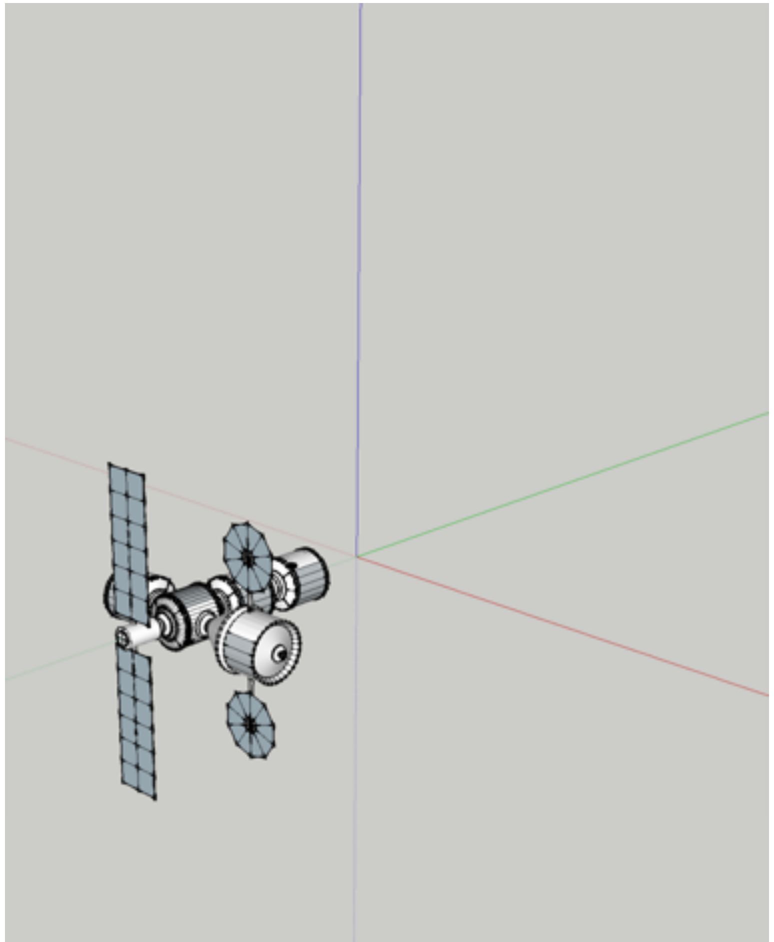
Vehicle Overview

- Habitat Module 1
  - Supports 2-4 crew
- Transfer Tunnel
  - (3) 10 m sections for crew transfer to hub airlock and second habitat module
  - Includes internal ladder and mechanical lift
- Solar Arrays
  - 15 kW system (rotates, but shown in fixed position for vehicle rotation)
- Airlock & Propulsion Stages
  - Axis of rotation
  - Removable stages
- Habitat Module 2
  - Near duplicate of 1 above



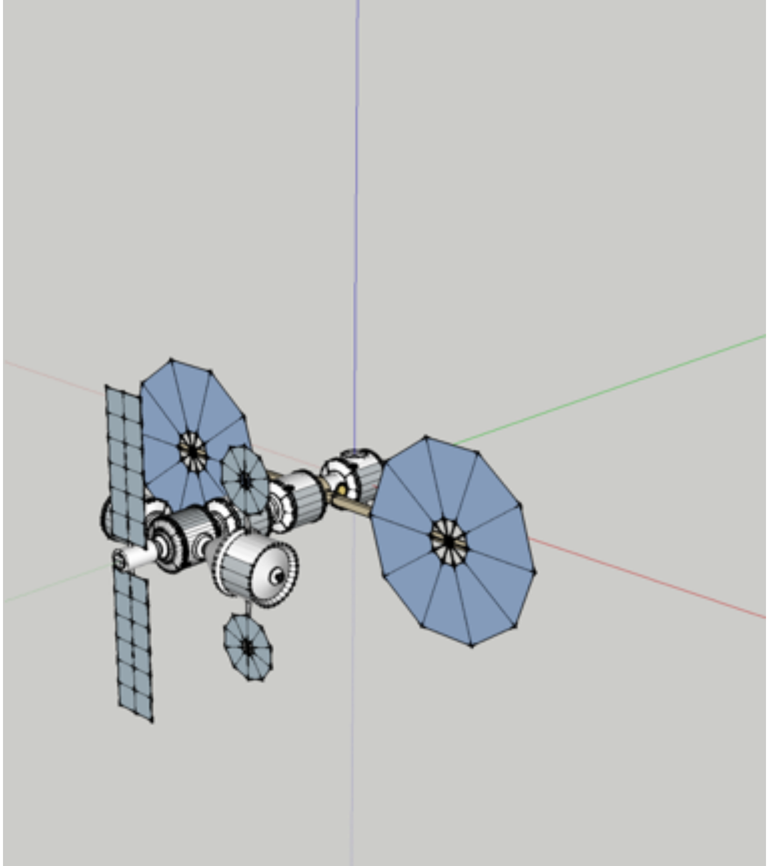
- Rotation Modes
  - No rotation, 0-g
    - Assembly, servicing and while docked to other vehicles in lunar and Mars orbit
  - 2 rpm, ~1/6-g
    - Simulates lunar surface operations
  - 3 rpm, ~1/3-g
    - Simulates Mars gravity during transit to Mars
  - 5 rpm, ~1-g
    - Maximum rate of rotation for return to Earth

Assembly



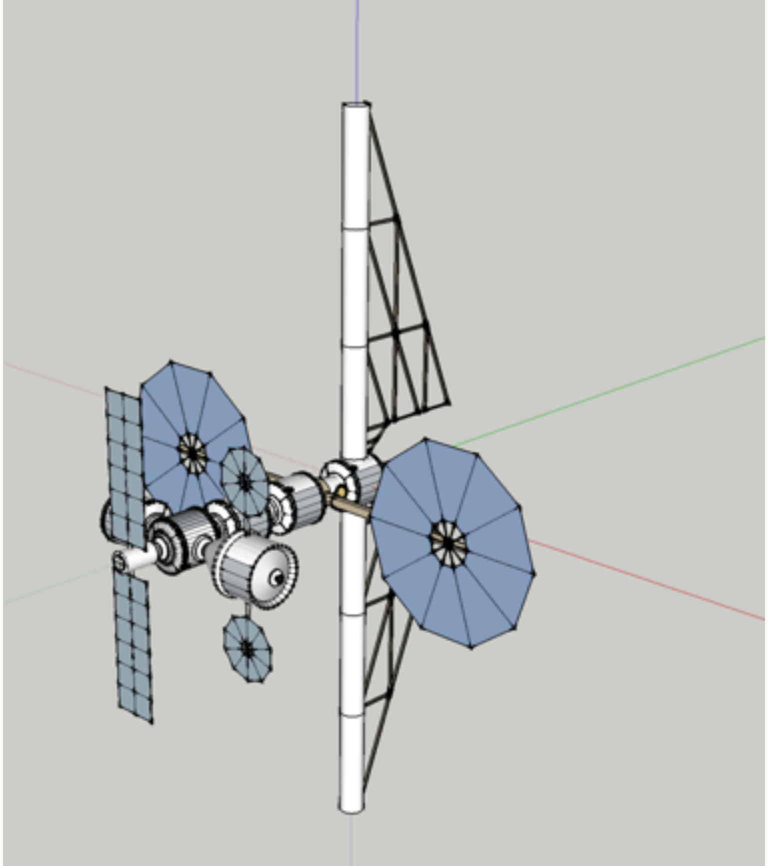
Gateway space station in lunar orbit could be used for assembly.

SLS crew or commercial launch.



1. Airlock Module with deployable solar arrays are docked to Gateway.

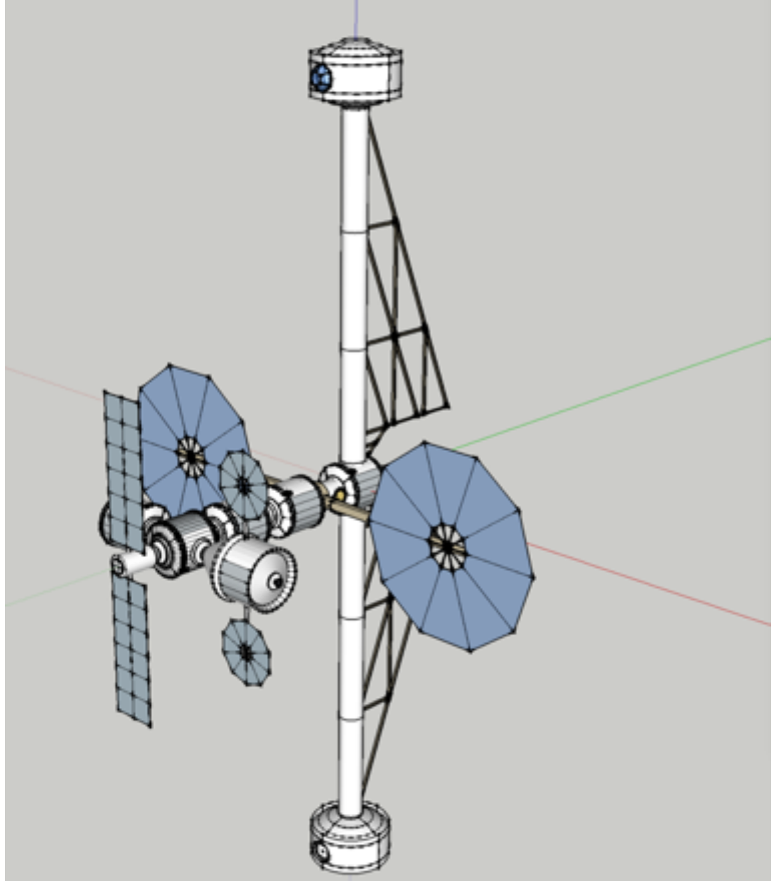
SLS payload launch.



2. Transfer Tunnels are attached to Airlock Module in 10m sections.

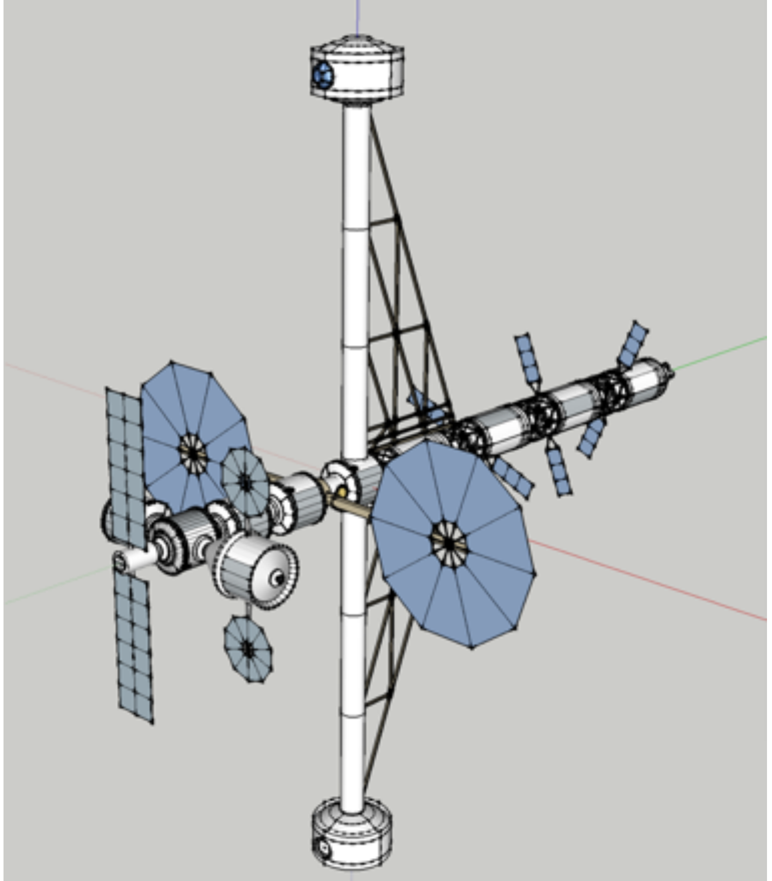
Assembly

SLS payload launch.



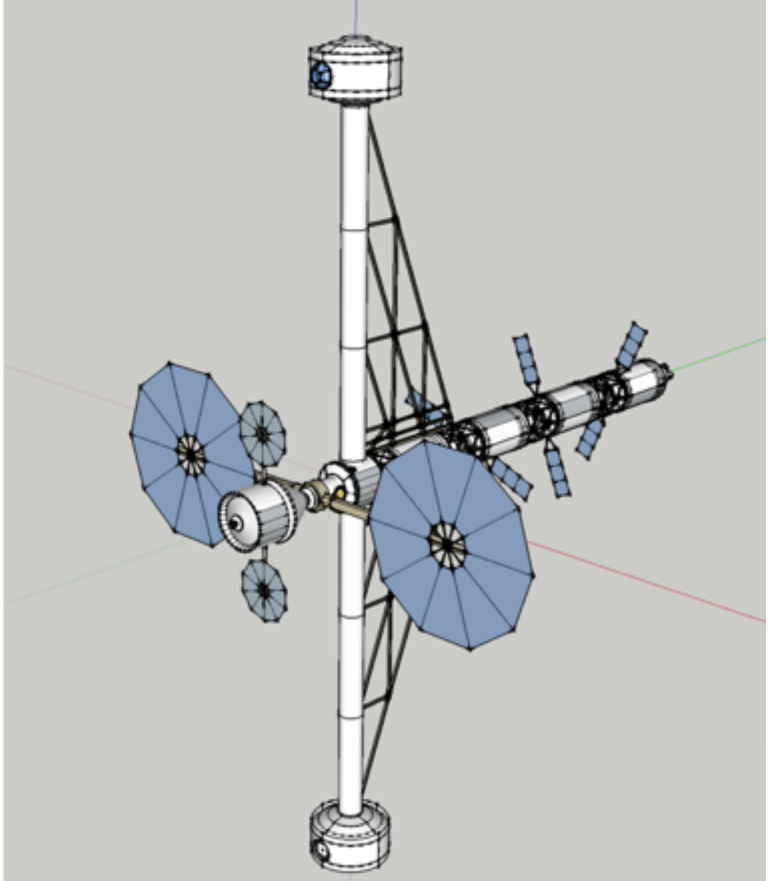
4. Habitat Modules are attached to end of Transfer Tunnels.

SLS payload launch.



5. Propulsion Stages are attached to Tunnel truss structure.

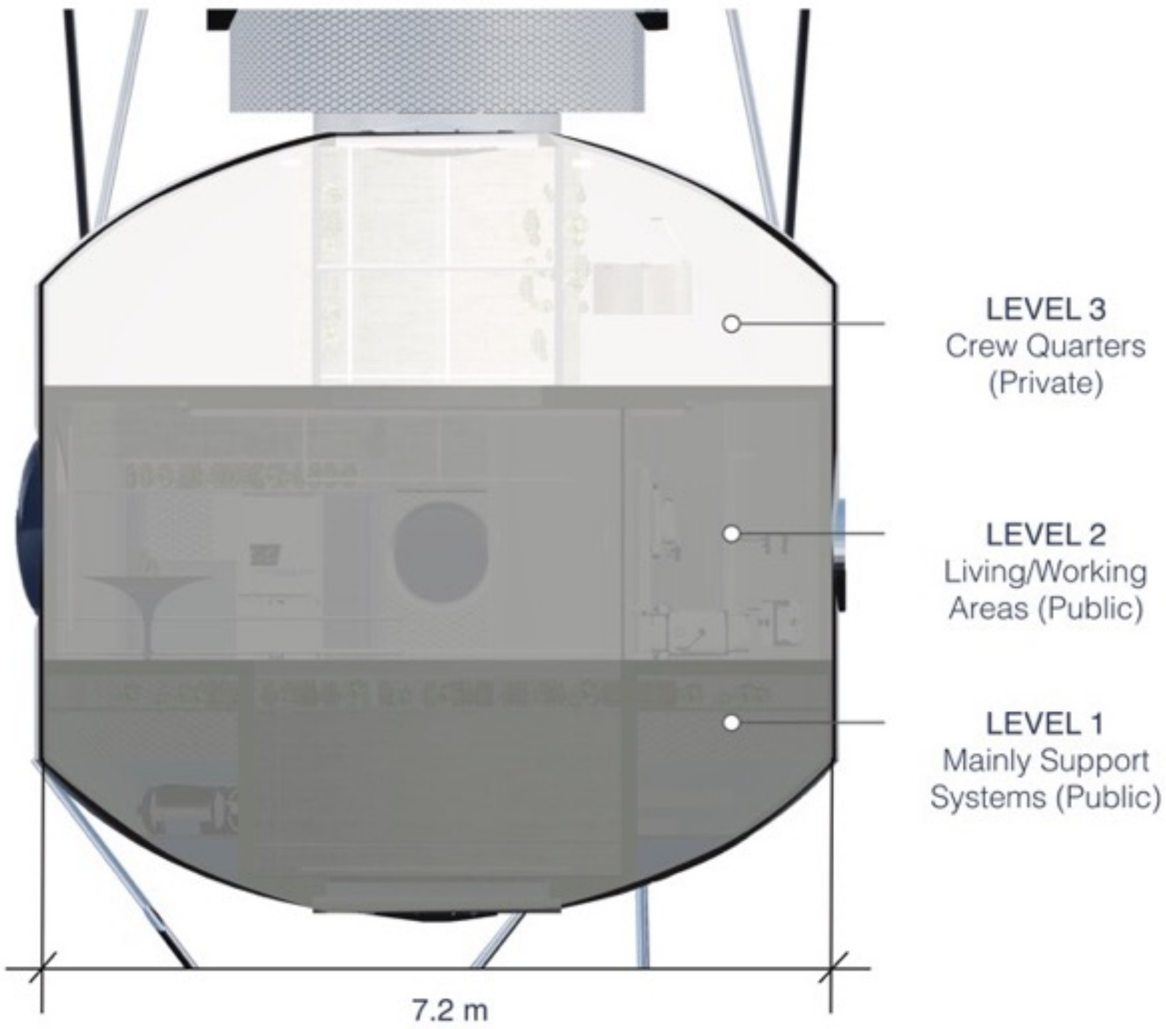
SLS crew launch.



6. Mars Vehicle undocks from Gateway and receives Crew Vehicle.

Habitat Concept

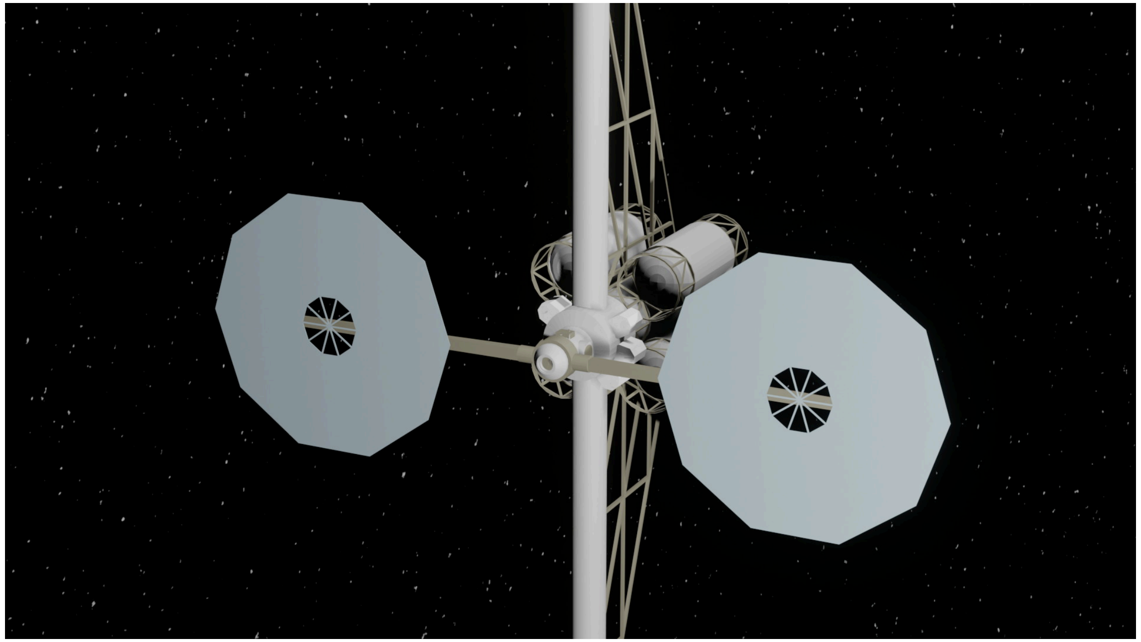
- Common Module (design suitable for both a gravity and microgravity environment) [2]
- Safe-haven Configuration (There are two modules providing redundancy) [1]
  - Level 1 includes all closed loop life support systems for air and water
    - Airlock below provided for Common Module surface applications when integrated to a lander
  - Level 2 includes all work and living areas
    - Galley and open wardroom volume
    - Science and maintenance workstations
    - Medical bay
    - Waste and hygiene compartments
    - Exercise equipment
  - Level 3 includes 2 crew quarters and logistics stowage
    - Tunnel to airlock above provided for Common Module variable gravity vehicle applications



Habitat Concept

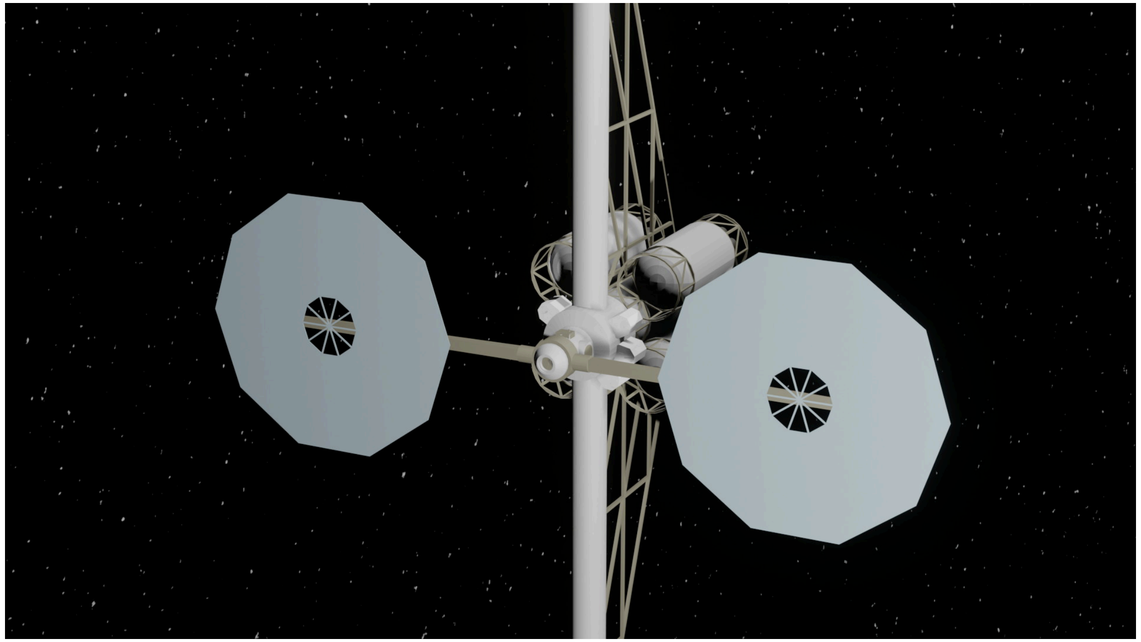
- Interior view from left to right
  - View window of a Common Module used on the surface of Mars
  - Galley table
  - Galey equipment
  - Central stair / ships ladder
  - Enclosed medical bay
  - Exercise equipment
  - Enclosed waste and hygiene compartments

Mission Operations



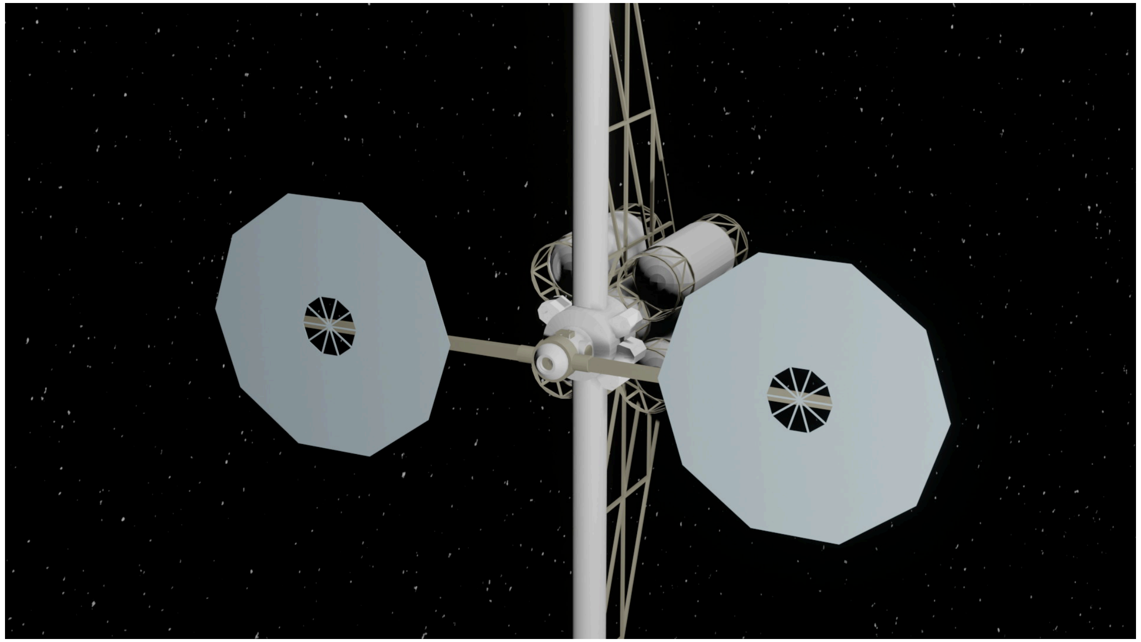
- Lunar operations checkout
  - Servicing at Gateway complete
  - Undock and align vehicle for rotation with solar arrays pointed toward sun
  - Spin up to 2 rpm simulating 1/6-g for checkout
  - De-spin to 0 rpm
  - Prepare for trans-Mars injection (TMI)

Mission Operations



- Earth orbit to Mars orbit operations
  - TMI burn
  - Align vehicle for rotation with solar arrays pointed toward sun
  - Spin up to 3 rpm simulating 1/3-g to condition crew for Mars operations
  - De-spin to 0 rpm
  - Prepare for Mars orbital insertion (MOI) and docking with crew lander
  - Repeat these steps if midcourse corrections are required
- Mars orbit
  - Vehicle remains at 0 rpm during docking operations with Mars landers and ascent vehicles
  - Prepare for Trans-Earth Injection (TEI)

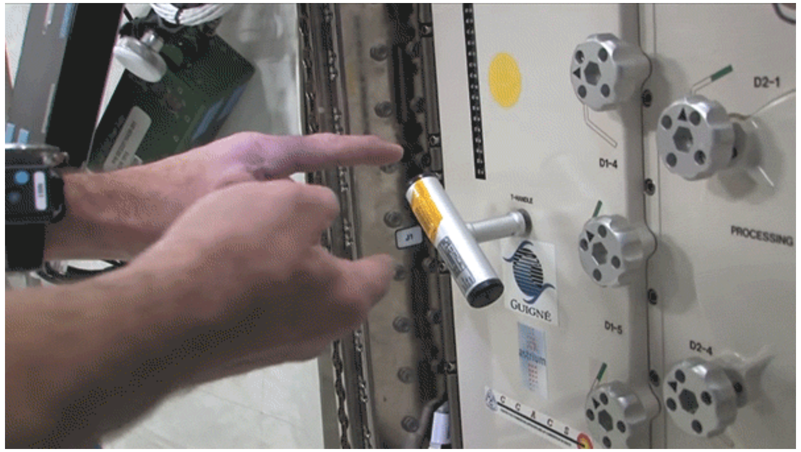
Mission Operations



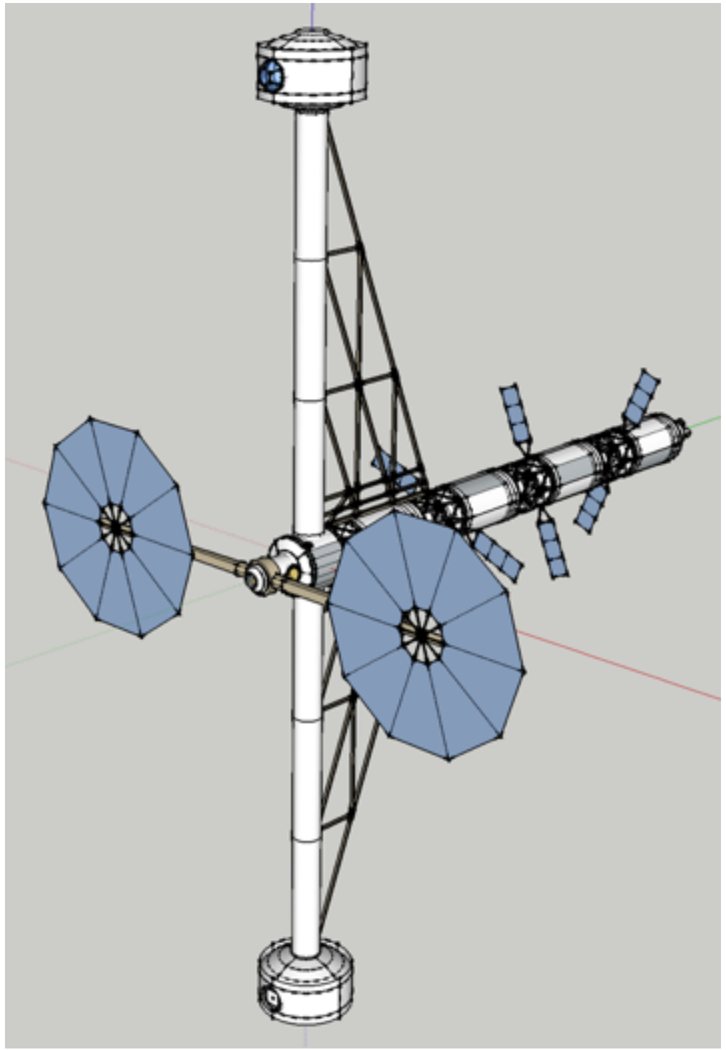
- Mars orbit to Earth orbit operations
  - TEI burn
  - Align vehicle for rotation with solar arrays pointed toward sun
  - Spin up to 5 rpm simulating 1-g to condition crew for Earth return
  - De-spin to 0 rpm
  - Repeat these steps if midcourse corrections are required
- Earth orbit
  - Prepare for Earth orbital insertion (EOI) and docking with crew return vehicle
  - Crew returns to Earth and Mars vehicle returns to Gateway for servicing

Intermediate Axis Theorem

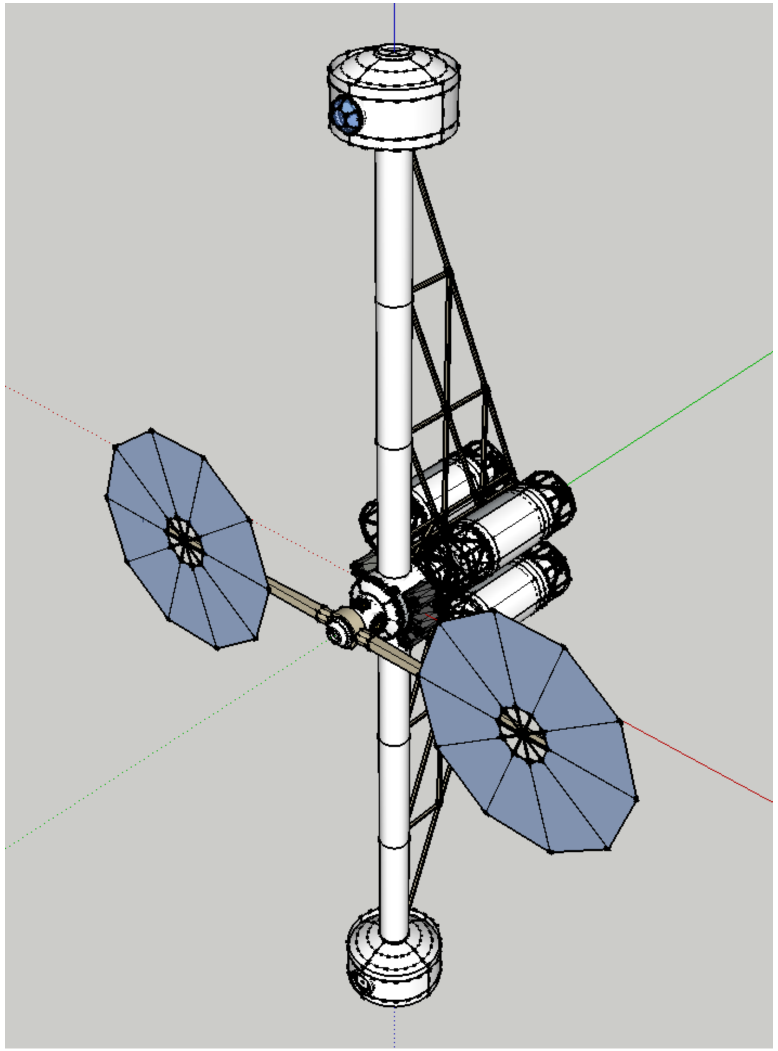
- Issues
  - Baseline vehicle uses multiple oxygen/methane chemical stages.
  - Mass balance varies throughout mission.



Dzhanibekov effect demonstration in microgravity, NASA [3]



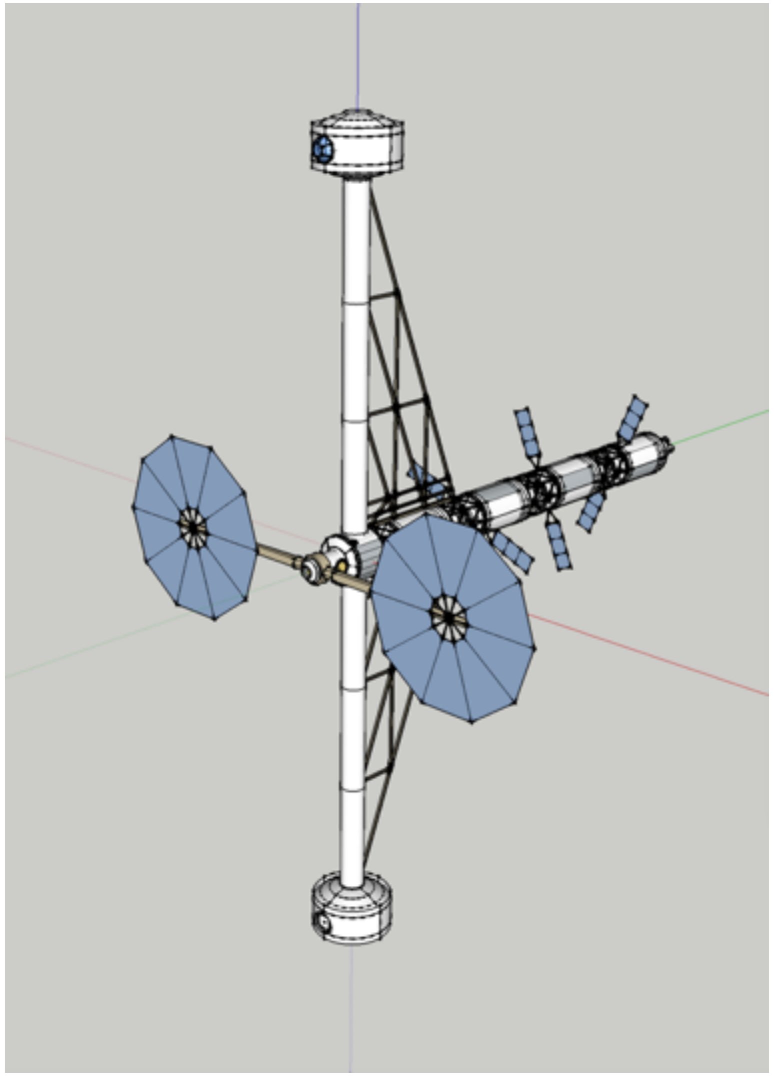
Possible problem or solution?



Possible solution or problem?

Mass

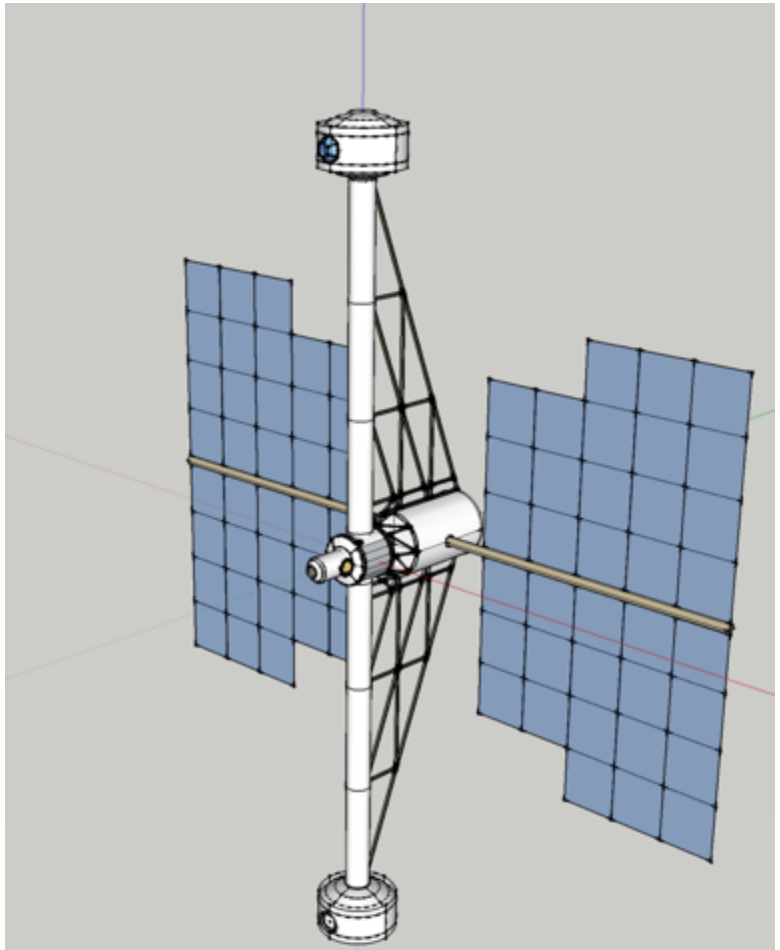
- Notional Mass by element
  - Module A:
    - 20t with logistics
  - Transfer Tunnel:
    - 3t
  - Solar Arrays:
    - 2t
  - Node / Airlock:
    - 10t
  - Transfer Tunnel:
    - 3t
  - Module B:
    - 20t with logistics
  - Up to 30% uncertainty
- Total Habitat Vehicle Mass
  - 58t to 75t without propulsion



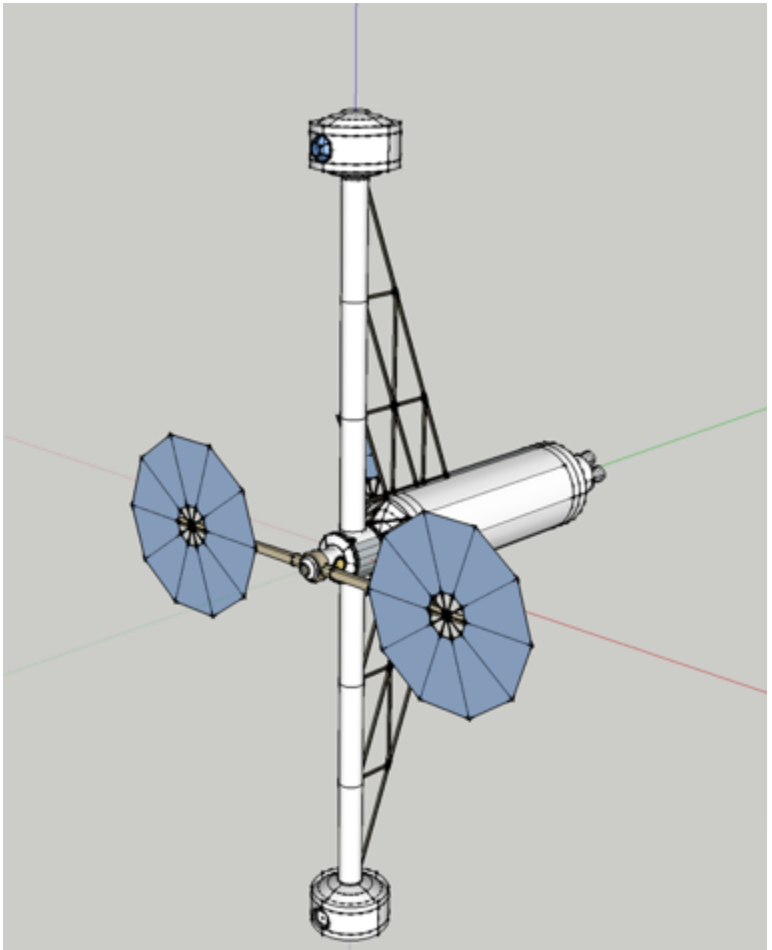
- Notional mass by stage
  - Propulsion Modules:
    - 45t each
  - Beginning mass at Gateway:
    - 4 stages at 180t (minimum)
  - Coast between TMI and MOI:
    - 3 stages at 115t
  - Mars Orbit: 2 stages at 80mt
  - Coast between TEI and EOI:
    - 1 stage at 35t
  - Ending mass at Gateway:
    - 1 stage at 5t
- Total Mass
  - Beginning: 238t to 255t
  - Ending: 63t to 80t

Propulsion Options

- Hybrid Propulsion
  - Probably not feasible since propulsion is ongoing during transit requiring pointing of the solar arrays during rotation
- NTP
  - Possibly feasible if solar arrays are removed and power generated from thermal generators
  - Radiation from the reactor may be a concern for outboard habitat module locations



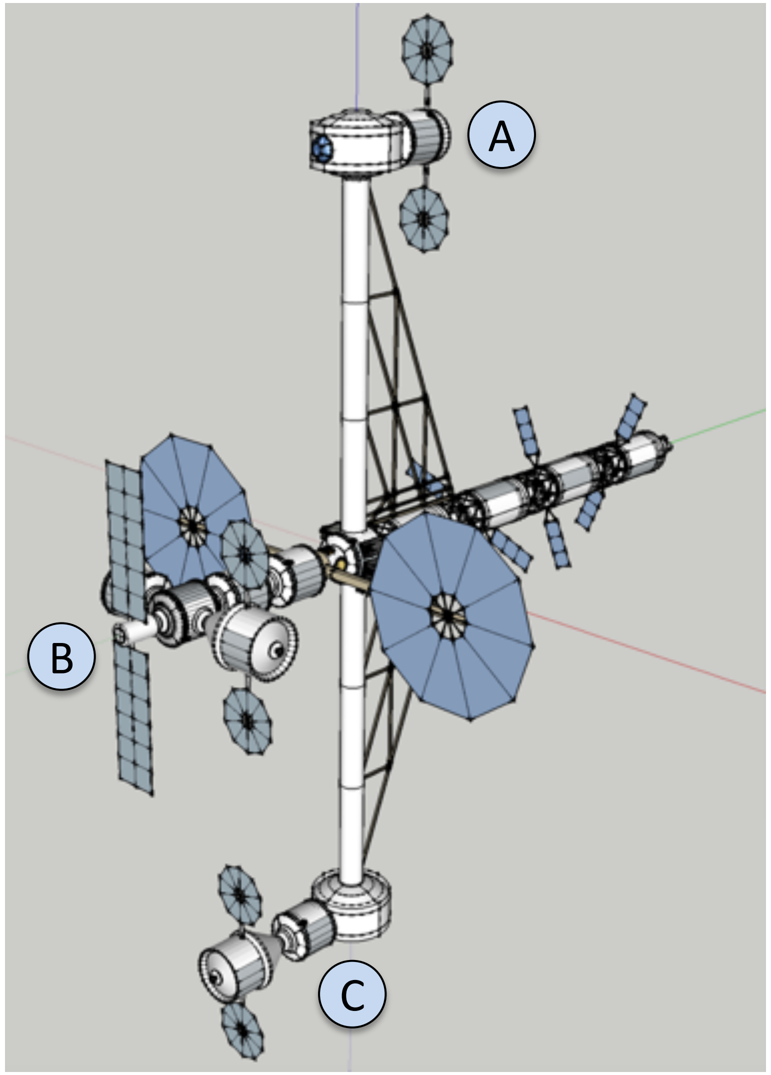
Hybrid Propulsion using storable and solar electric system.



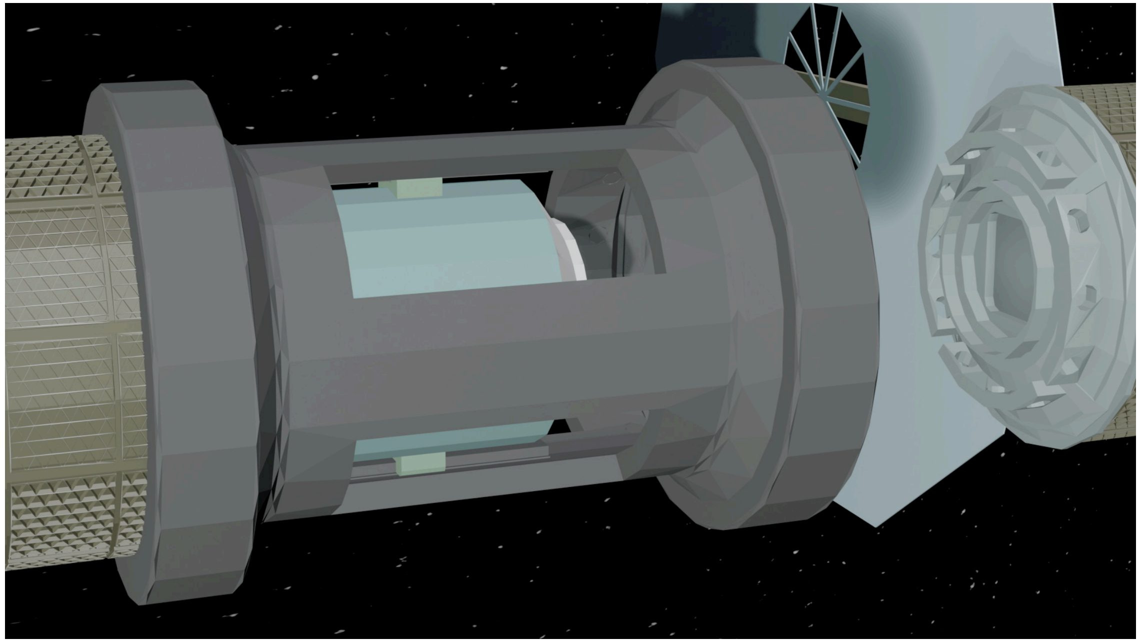
Nuclear Thermal Propulsion (NTP) using hydrogen stage(s).

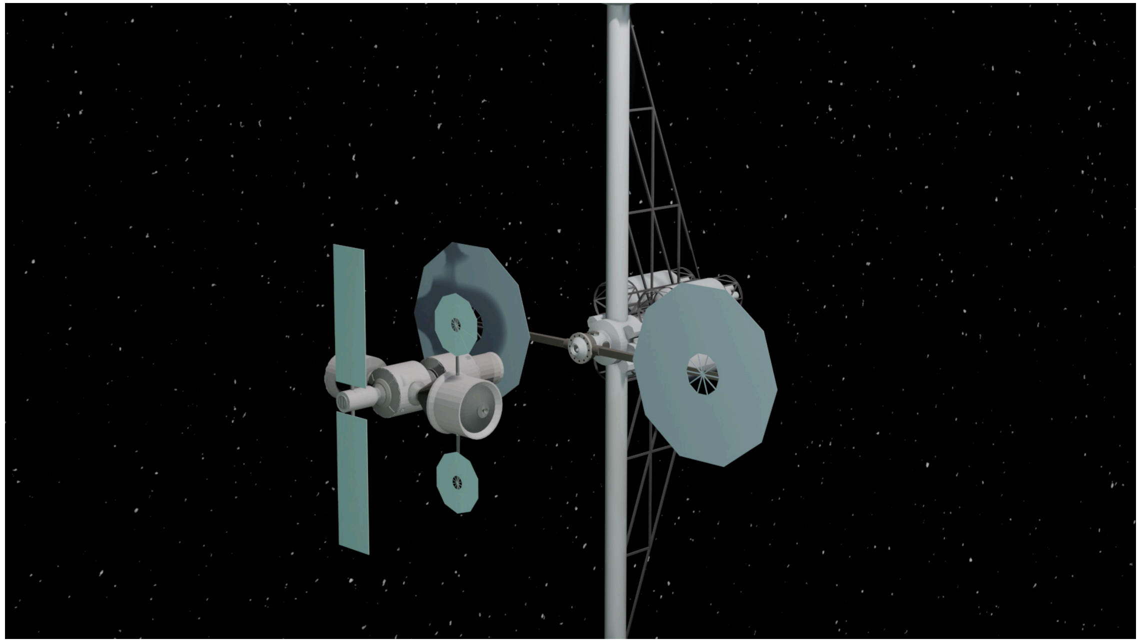
Servicing

- Servicing options
  A. Logistics module docked directly to habitat module
  B. Airlock module docked to Gateway
  C. Crew with logistics module docked to habitat module



Rotational Docking Concepts





Conclusions and Future Work

- Conclusions
  - Artificial gravity configurations need to be explored for long duration missions.
  - Vehicle configuration solutions are possible using current launch and assembly techniques from ISS.
  - The Dzhanibekov effect needs to be examined thoroughly given the large mass variation along the axis of rotation.

- Future Work
  - Develop more detailed concept studies.
  - Determine methods to fine tune the mass balance during rotation
    - Consider an external spin-up and de-spin propulsion system mounted to a rail on the tube structure
  - Verify the Dzhanibekov effect concerns and reconfigure or seek countermeasures as needed.
  - Conduct rotation rate and human adaptation studies

Credits & References

- Authors
  - David Smitherman is a space architect in the Advanced Concepts Office (ACO) at the NASA Marshall Space Flight Center
  - Paola Gonzalez is a former intern with ACO and a graduate from the University of Houston with a Master of Science in Space Architecture
  - Mandy Kiger is a former intern with ACO and is a mechanical engineering student at Oregon State University

- References

1. [1] Smitherman, D., T. Polsgrove, J. Rowe, M. Simon, "Safe Haven Configurations for Deep Space Transit Habitats," Paper No. 10.2514/6.2017-5285, AIAA Space and Astronautics Forum and Exposition, Orlando FL, September 12-14, 2017.
2. [2] Gonzalez Marquez, P., D. Smitherman, "Common Habitat Design for Microgravity, Artificial Gravity and Partial Gravity in a Safe Haven Configuration," Paper No. 3373607, AIAA ASCEND 2020, November 16-18, 2020.
3. [3] Dzhanibekov, V., Dzhanibekov effect demonstration in microgravity, NASA, URL: https://sciencegifs.csullender.com/2017/07/01/The-Dzhanibekov-Effect.html and https://www.youtube.com/watch?v=1x5UiwEEvpQ [retrieved August 14, 2020].