
# ARIES

## Adaptable Rotating Interplanetary Exploration System

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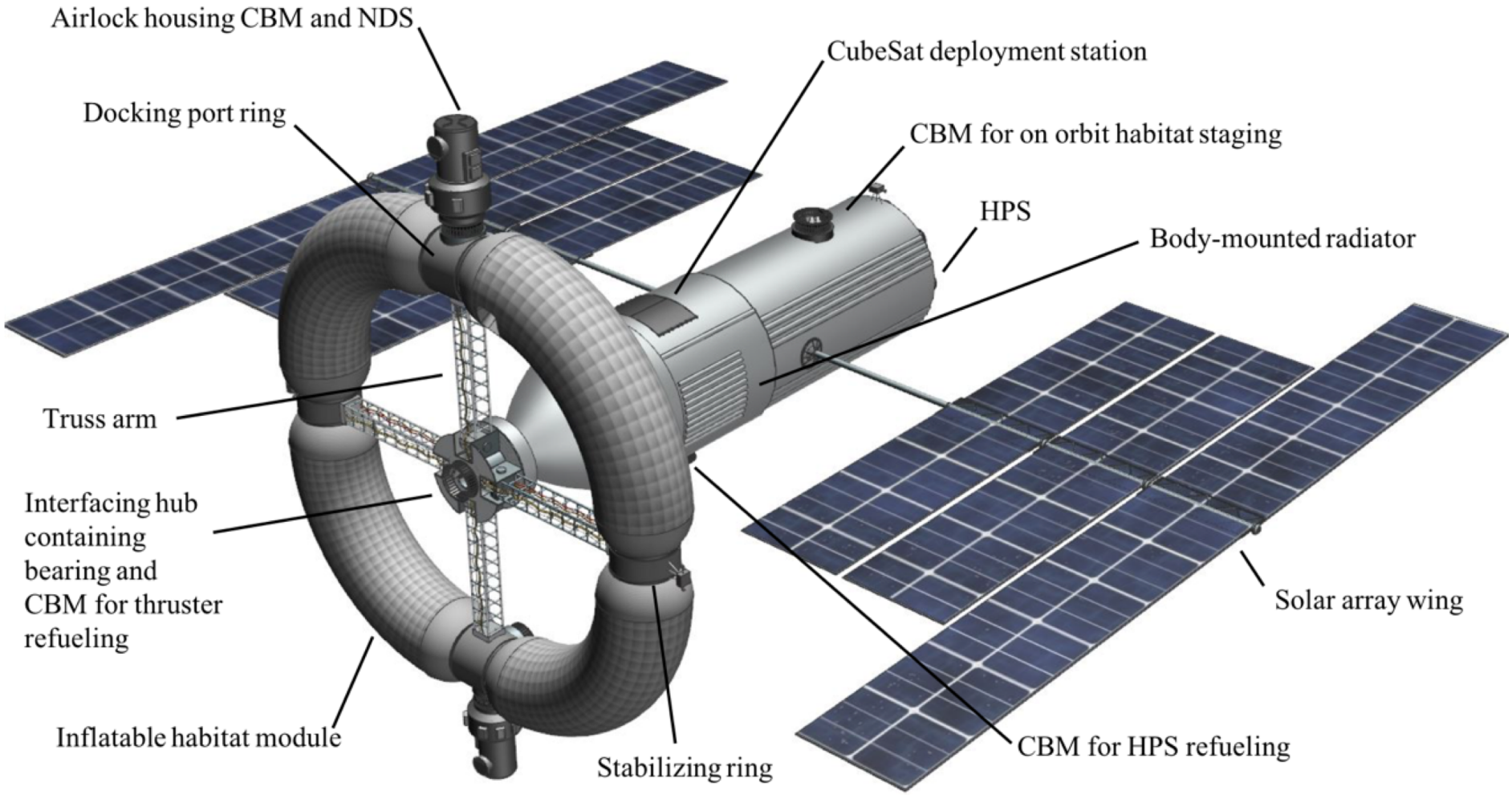
# Agenda

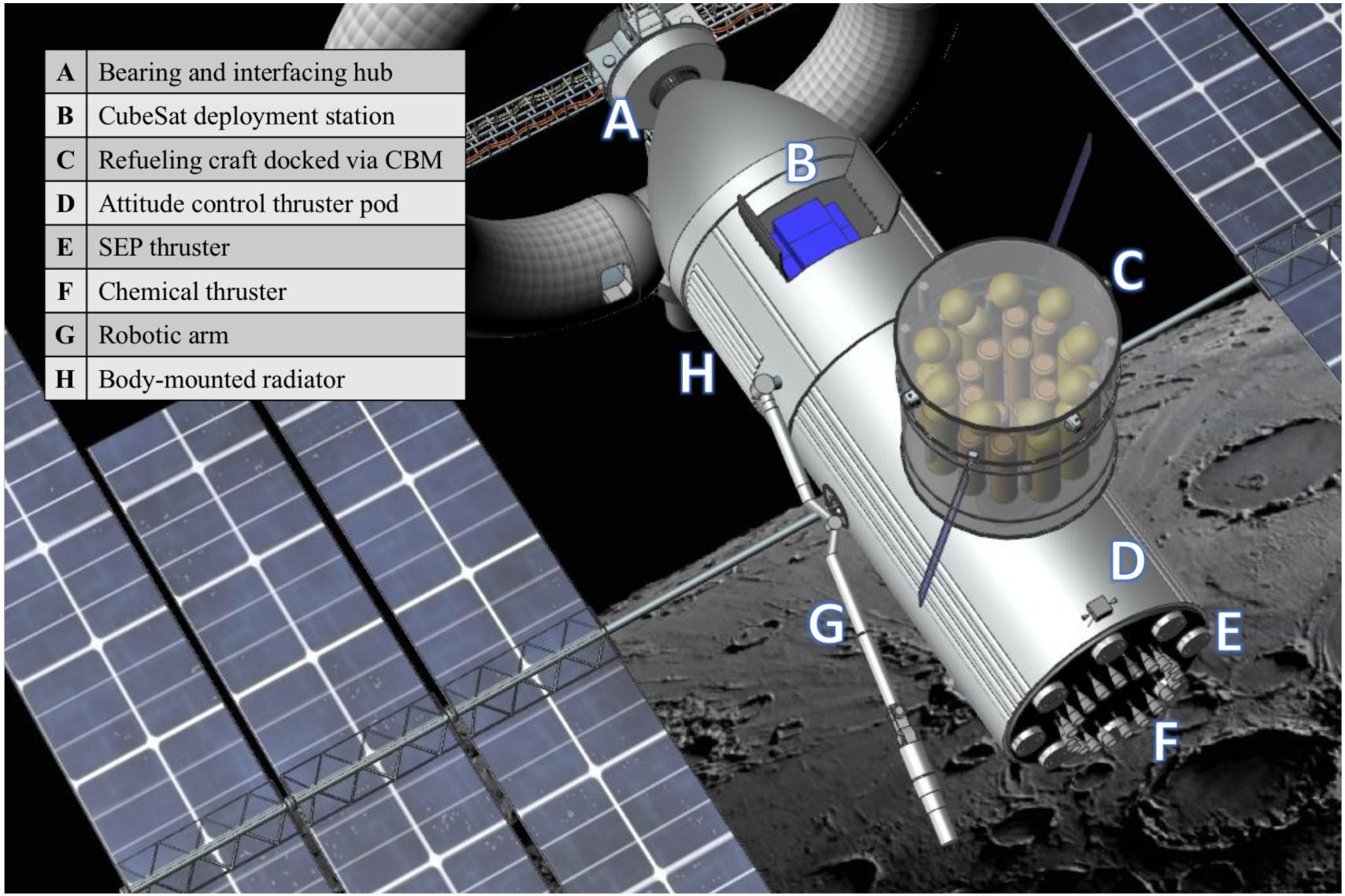
- Vehicle Overview
- Concept of Operations
  - Development and Testing
  - Assembly and Trans-Lunar Injection
  - Conjunction-Class Mission Architecture
- Hybrid Propulsion Stage Specifications
- Artificial Gravity Generation
- Habitat
  - ECLSS
  - Other subsystems
- Risk Analysis
- Budget Analysis


# Vehicle Overview

# Exterior Ports and Structure

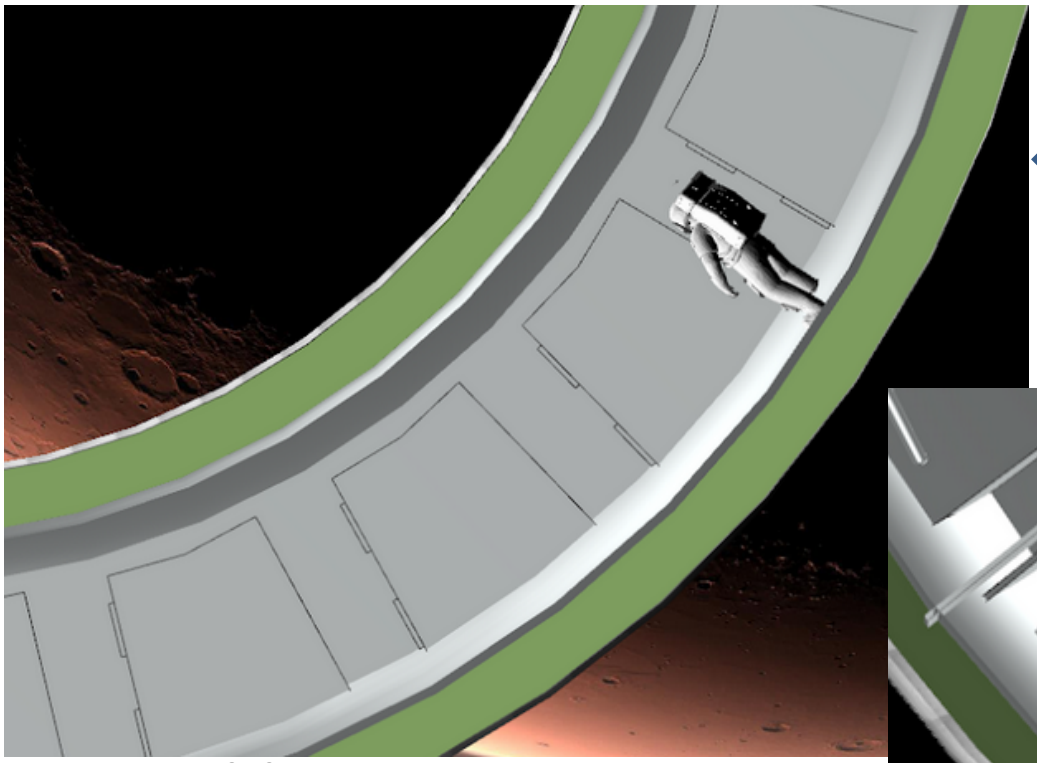


# Hybrid Propulsion Stage Layout




| | |
|---|---|
| A | Bearing and interfacing hub |
| B | CubeSat deployment station |
| C | Refueling craft docked via CBM |
| D | Attitude control thruster pod |
| E | SEP thruster |
| F | Chemical thruster |
| G | Robotic arm |
| H | Body-mounted radiator |

# Habitat Layout

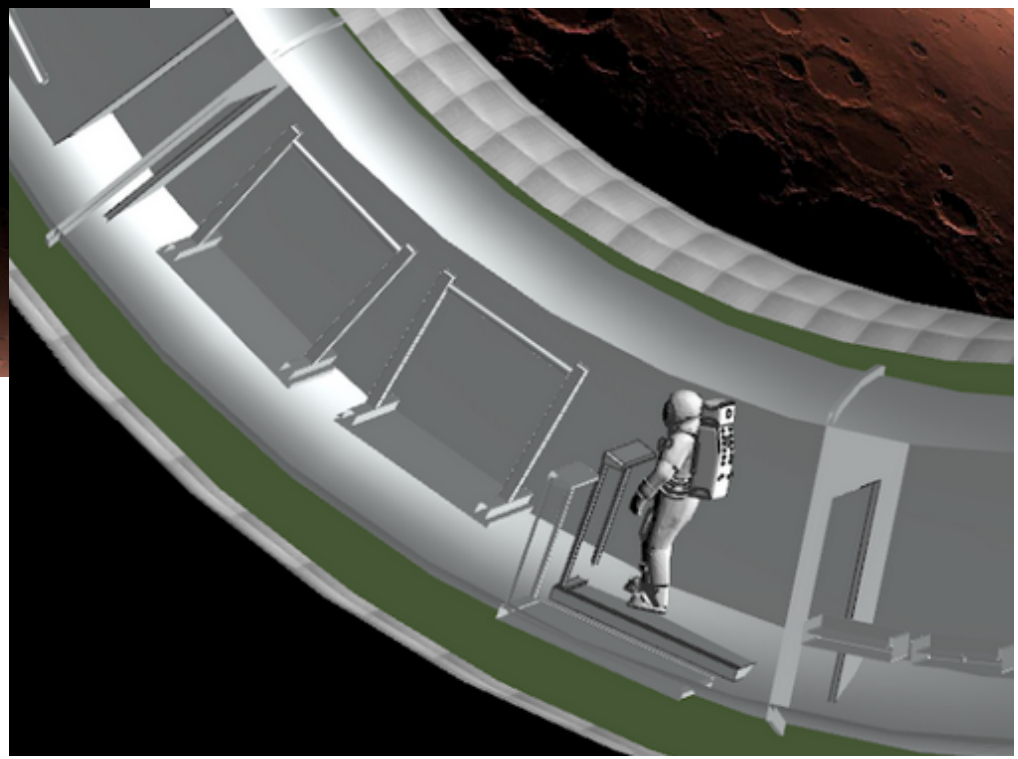


**Storage Module**

- Contains: Redundant systems, Science, Food Storage
- Can be converted to livable space if an inflatable module experiences failure

**Living Module:**

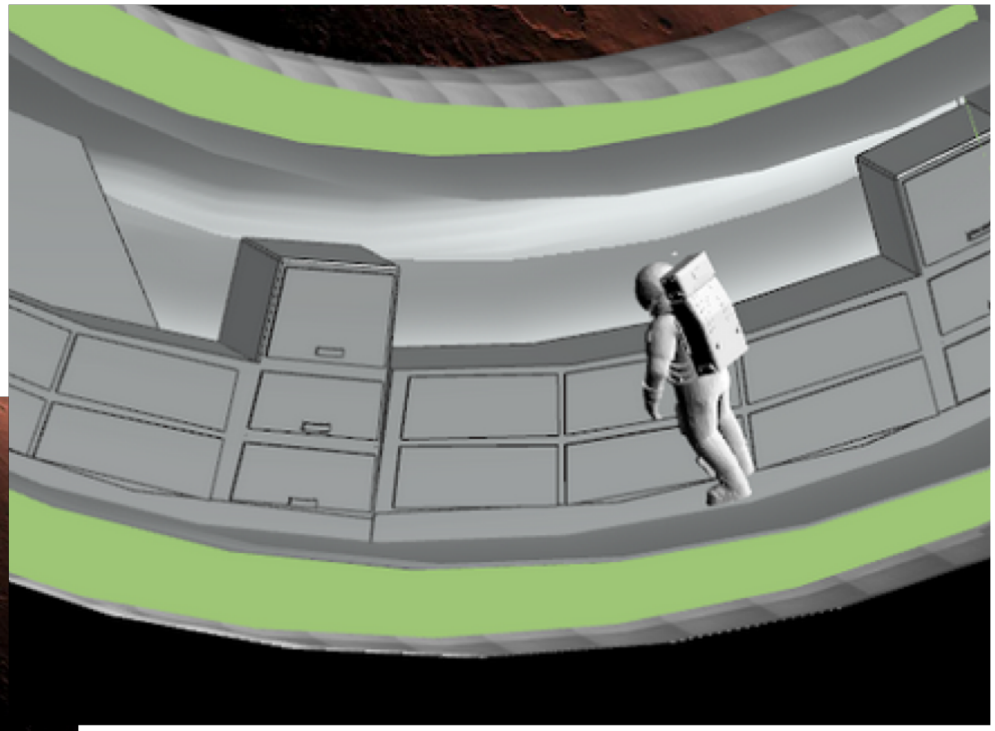
- Exercise Suite
  - COLBERT Treadmills, ARED, Bikes
- Medical Bay
- Hygiene Station
  - Showers double as Wash Machine

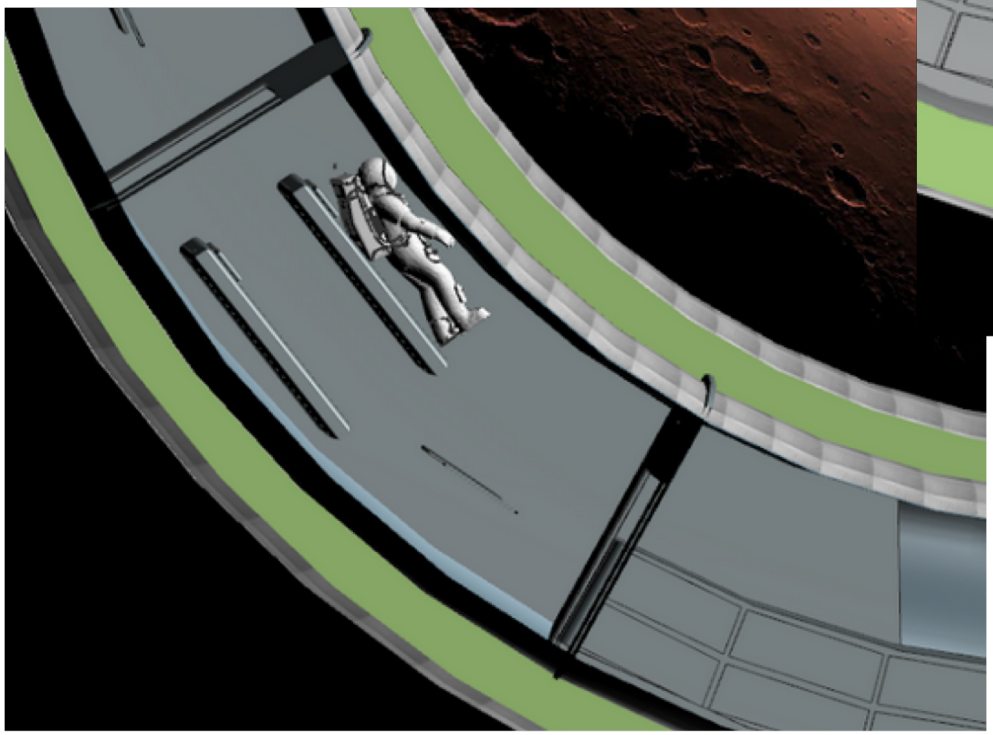


# Habitat Layout

**Research Module**

- Communication Stations
- Vegetation Racks
  - Nutrient Delivery System
- Experimentation Areas





**Habitation Module**

- Sleeping Quarters
  - Personal Quarters following 5.4 $m^3$ guidelines
  - Angled beds
- Galley
- Communal Space


# Concept of Operations

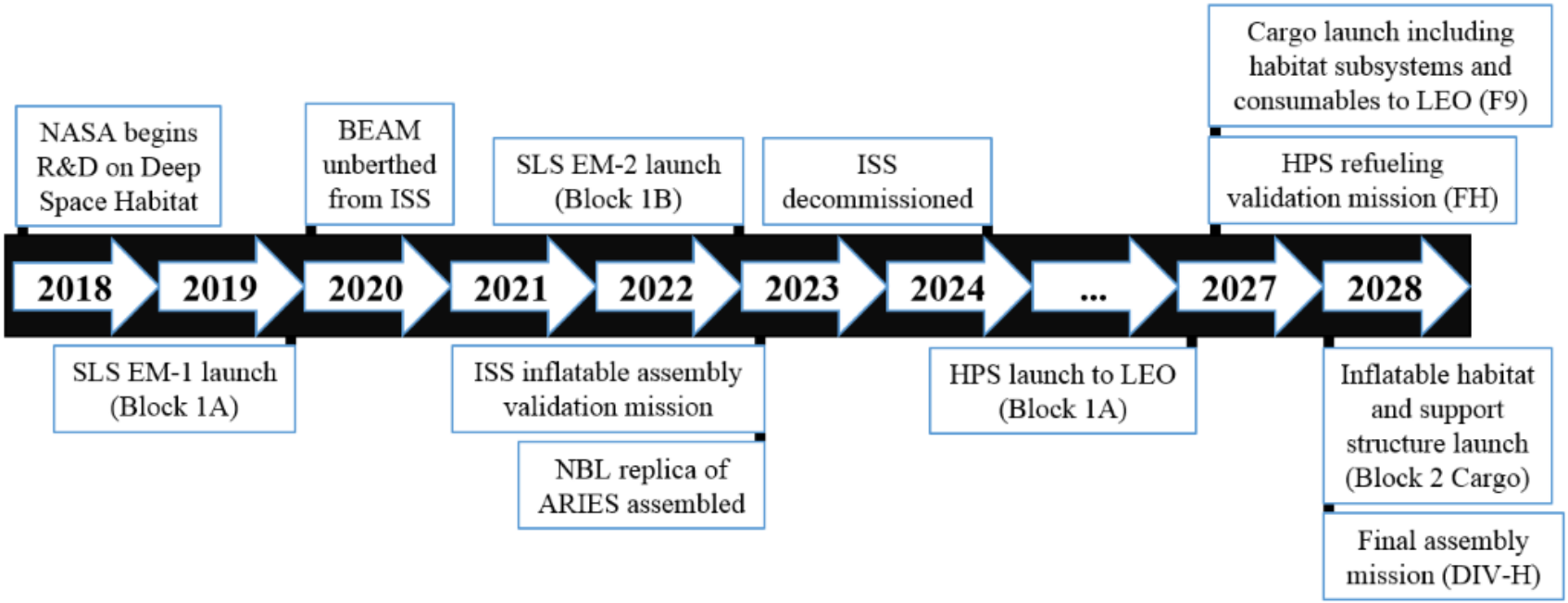
# Concept of Operations

- Development and Testing (2018-2027)
- Assembly and Validation (2027-2029)
- Normal Operation (2029-2044)

# Development and Testing

- Currently ongoing
  - Deep Space Habitat
  - BEAM
- Inflatable Habitat Testing
- ISS Model Replacement
- Artificial Gravity Training

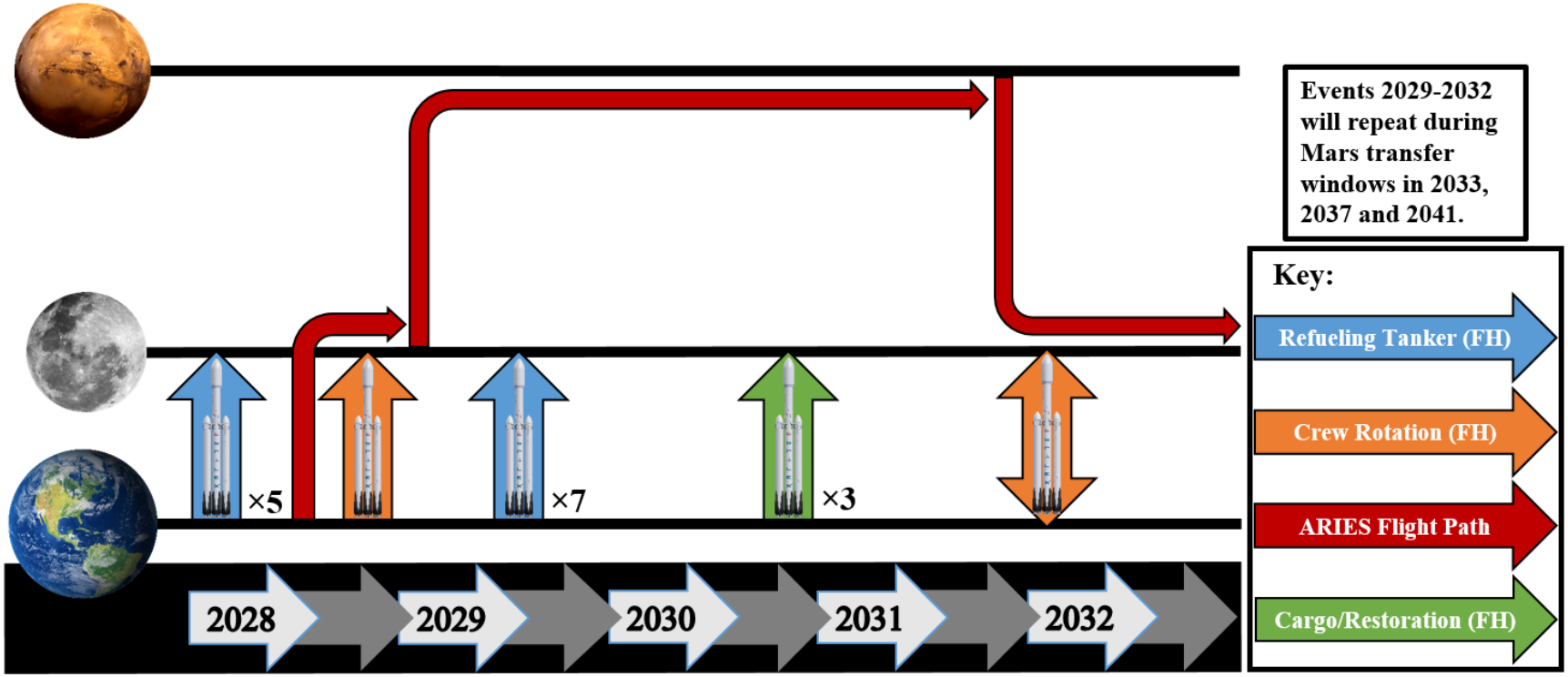
# Development and Testing



# Assembly and Development

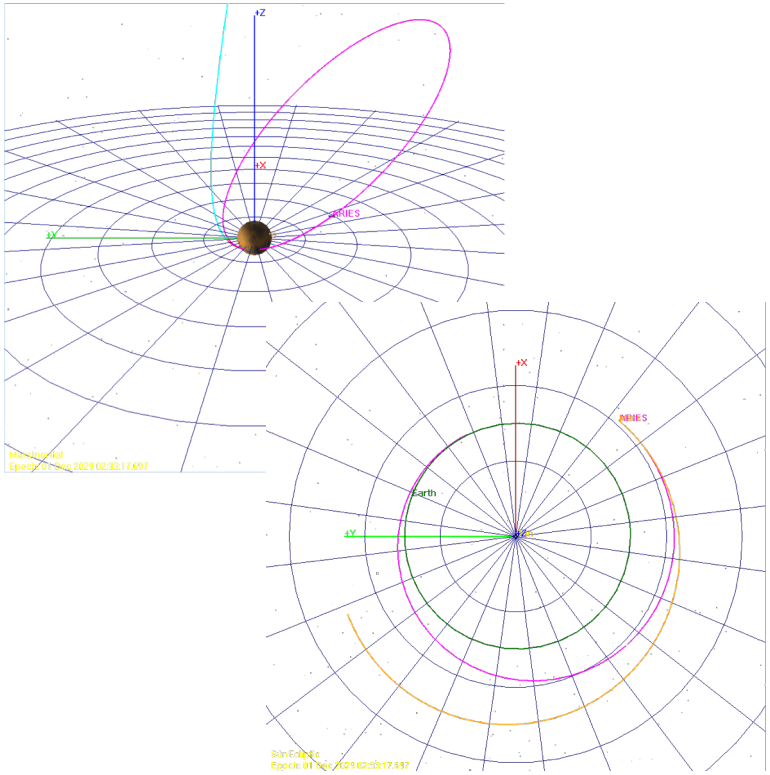
- Hybrid Propulsion Stage (2027)
- Refueling Validation
- Truss & Habitat (2028)
- Assembly Crew
- Low Power Lunar Transit

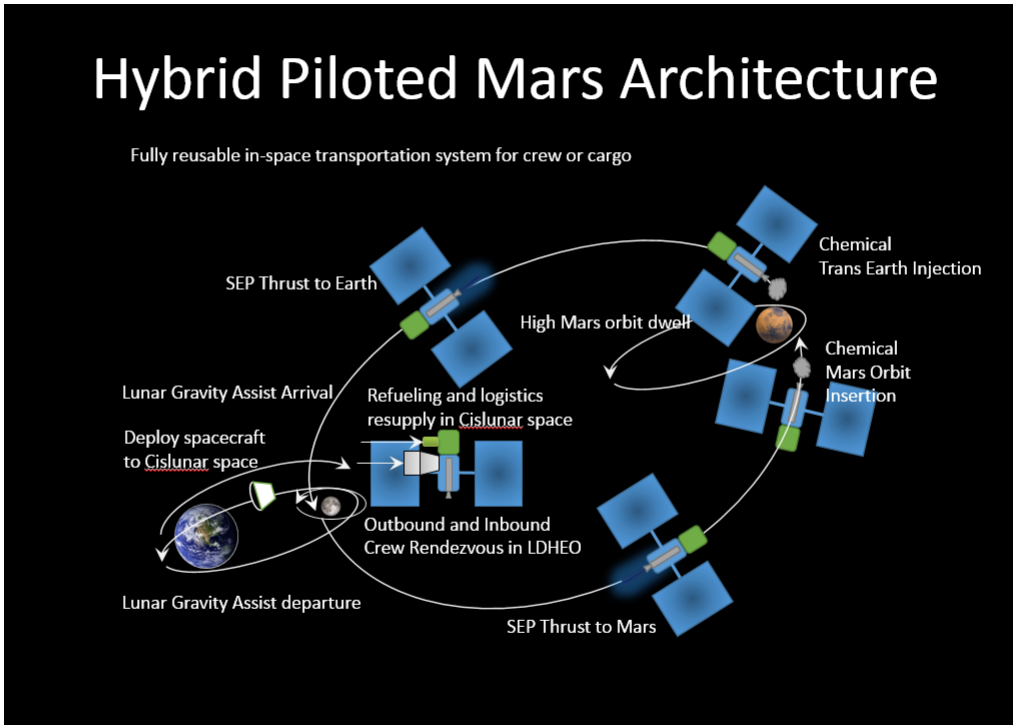
# Assembly and Validation



# Conjunction-Class Mission

- Transfer windows – 2028, 2033, 2037, 2041
- LDRO – LDHEO – MTO – Mars 5 Sol – ETO – LDHEO – LDRO
- SEP – 6,230m/s  Chemical – 765m/s






https://www.exploremars.org/wp-content/uploads/2015/12/Troutman-Evolvable-Mars.pptx


# Hybrid Propulsion Stage

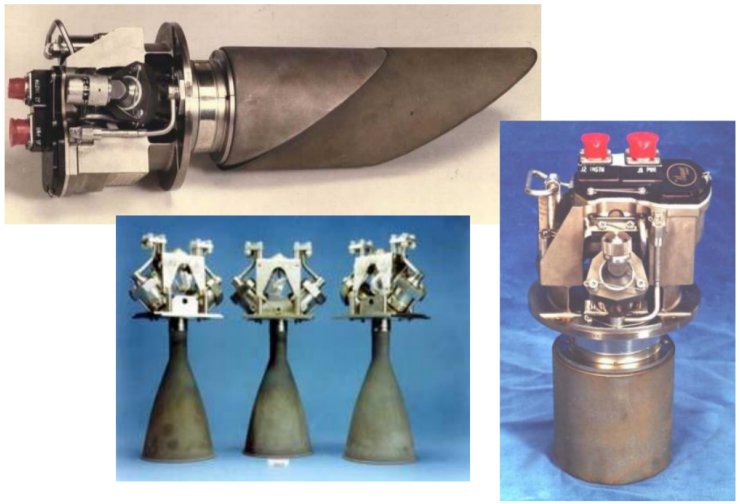
# Solar Electric Propulsion System

- X3 Nested Hall Effect Thruster
- Propellant: Xenon
- Isp: 2650s
- Thrust: 17.12N (2.14N)
- Power: 291.2kW (36.4kW)
- Count: 8

http://pepl.engin.umich.edu/pdf/2014_Florenz_Thesis.pdf

# Chemical Propulsion System

- R-1E: habitat spin
  - 110N, 280s, MMH+NTO, x4
- S22-02: attitude
  - 22N, 288s, MMH+NTO, x32
- R-42DM: propulsion
  - 890N, 327s, hydrazine + NTO, x20



Aerojet Rocketdyne Bipropellant Engine Datasheets

R-1E

Aerojet Rocketdyne Bipropellant Engine Datasheets

R-42DM

*Fig. 1: 22 N Thruster*

SAO/NASA Astrophysics Data System

S22-02

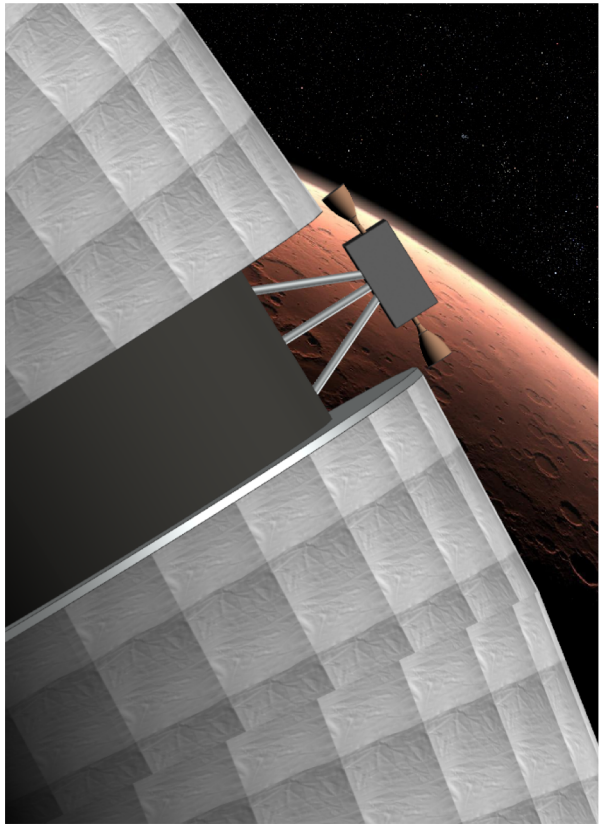
# Attitude Determination and Control

- Sensor Suite
  - Star Tracker
  - Sun Sensor
  - Gyroscope
- Actuators
  - Bipropellant Hydrazine Thrusters
    - Coarse Attitude Adjustment
    - Spin-up Maneuvers
  - Control Moment Gyros
    - Fine Attitude Adjustment


# Artificial Gravity

# Artificial Gravity

- Spin-up, spin-down maneuvers controlled by R-1E thrusters (each provides 110N of thrust)
- Total propellant consumed (5 spin-up, spin-down cycles): 488.7kg NTO, 675.8kg MMH
- Total time for spin-up or spin-down: 32 min
- Crew effects have been minimized
  - Centrifuge rotates at 5.55rpm
    - Agreed upon limit: 6rpm
  - Gravity gradient: 18.2%
    - Agreed upon limit: 20%




# Habitat

# Environmental Control and Life Support Systems

- MMOD Shielding: Aluminum (Al) 6061T6 Whipple
- Radiation Shielding
  - .6m thick wall
  - Five Water Walls – 3.5cm thick
  - Minor coat of Polyethylene
- EVAs will be completed by two Robonauts
  - Robonaut will be attached on SSRMS
- Air filtration: Removing $CO_2$, combing with $H_2$, create $O_2$ and $CH_4$
  - Four bed molecular sieve, Sabiator catalytic conversion, and electrolysis of water
  - Lithium Hydroxide Canisters as backup
- Waste Management:
  - low pressure vacuum, filtration beds, catalytic reactor, electricidal conductivity sensors

# ECLSS

- Bone/Muscle Deterioration:
  - Resistive Exercise Devices, supplements, angled beds
- Sleep loss/Circadian Desynchronization:
  - Sleep Medication, sleep hygiene, naps, caffeine, adjustable LED lighting, sound dampening, no windows in sleeping cabin
- Mental Health
  - Windows in 2/4 sections, fresh produce, entertainment methods, personal space, pre-mission testing and preparation
- Personal Hygiene
  - Showers, sinks will function under artificial gravity
  - Showers will double as clothes washing stations
- Crops
  - Grown using nutrient delivery system
  - Salad crops, ready to eat

# Subsystems

- Communications:
  - Optical and Laser
  - Advanced pointing imaging camera, space security system
  - Proximity system for communications functionality
  - Radio Frequency combination of X-band and Ka-band systems

- Command & Data Handling:
  - Dedicated C&DH computer used to monitor the vehicle's subsystems
  - Issue commands to those subsystems
  - Communicate with ground stations

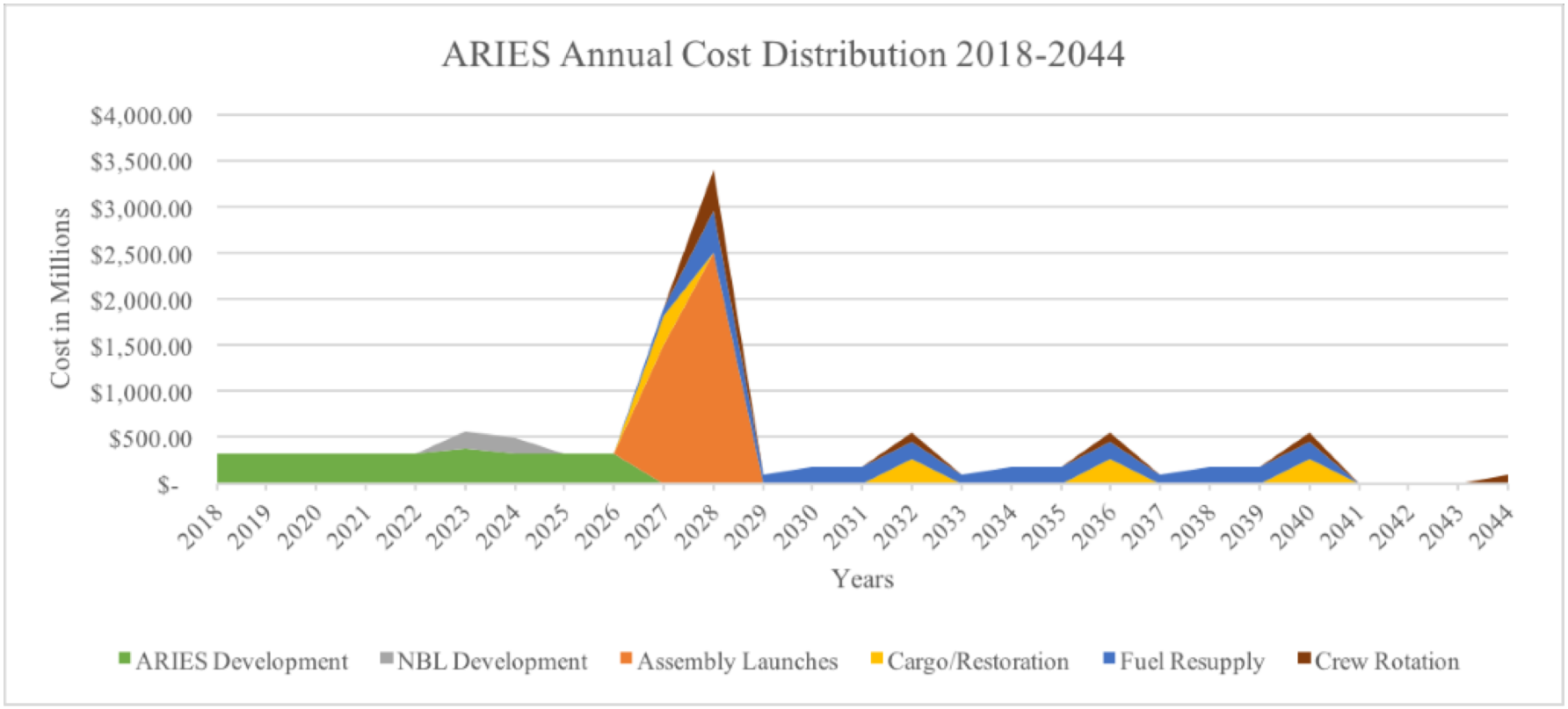

# Risk Analysis

# Risk Matrix

| Risk | Likelihood | Consequence | Level | Mitigation |
|---|---|---|---|---|
| **Exposure to Radiation from EVA** | 4 – High | 4 – Exposure to radiation if repairs necessary outside of Earth's influence | | Robonaut attached to outside of module to execute repairs. |
| **Micro-Meteoroid and Orbital Debris (MMOD) Impact** | 3 – Moderate | 5 - Loss of pressurization or damage to the propulsion stage | | Use a robonaut to complete all repairs from the safety of the module |
| **Artificial Gravity Spin Up/Down Failure** | 1 - Very Low | 4 - Crew will not be adjusted to Mars gravity, quality of life lowered | | Train crew for zero gravity environments, handholds for maneuvering in microgravity, sleeping bags able to be attached to module walls, redundant containment for liquids |
| **Propulsion System Failure** | 2 – Low | 5 – Mission Unable to Continue | | Multiple engines provide redundancy to prevent total propulsion failure, spare electricity for the SEP system |
| **Inflation of Habitat Failure** | 3 – Moderate | 4 – Loss of materials and goods within respective habitat | | Sections will seal individually, manual deployment requiring training , robot for repairs, supplies will be spread out |
| **ECLSs Component Failure** | 2 – Low | 3 – Momentary inability to use part or system | | Spares will be kept in storage upon inflation, 3D printing available |
| **Crew Physical and Mental Health Deterioration** | 4 – High | 4 – Crew members may be unable to perform necessary daily tasks required for survival of crew as a whole | | Windows for viewing, fresh produce, entertainment provided, each crew member will have personal space |
| **Airlock/Docking Port Failure** | 2 – Low | 3 – Supplies may be momentarily suspend for crew use | | Airlocks/Docking locations will each have two possible attachment points for redundancy |

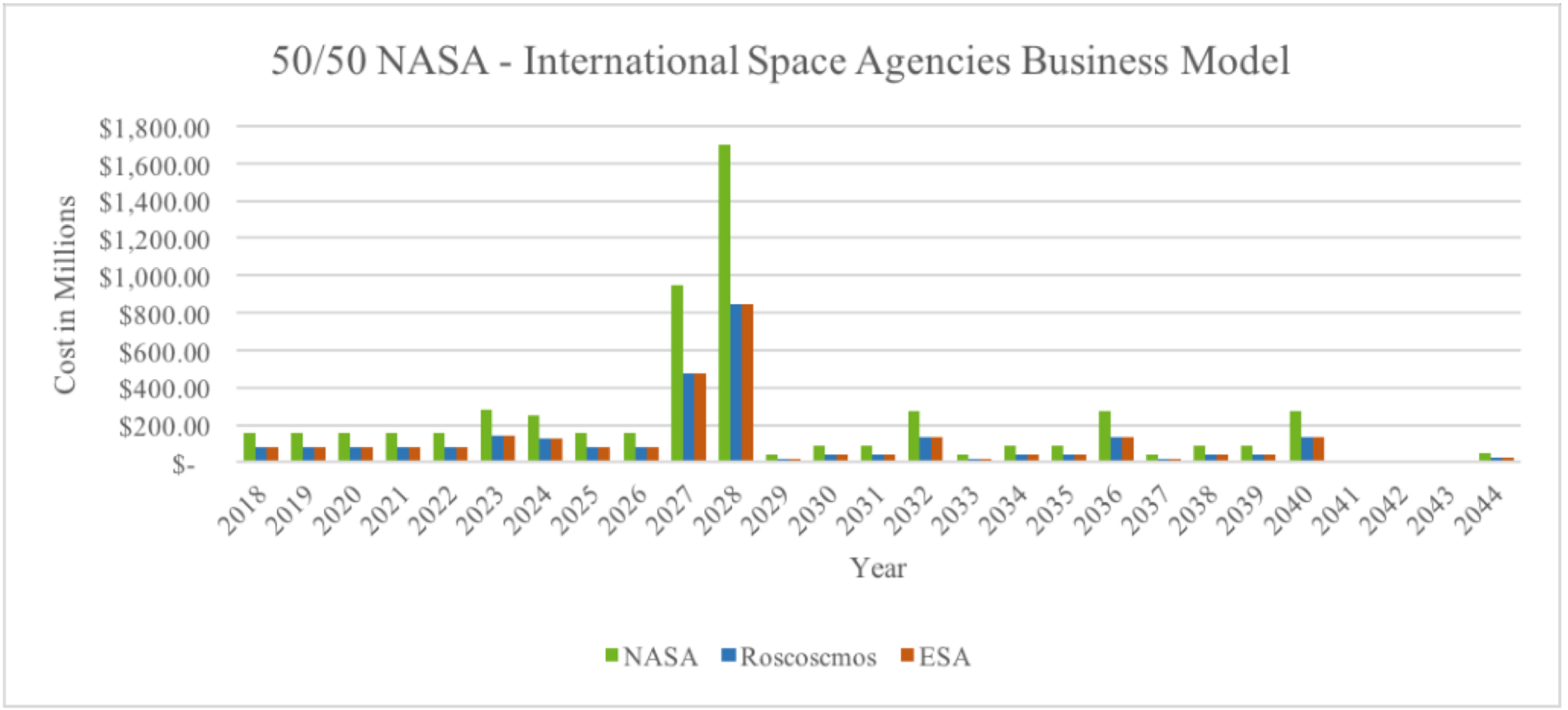

# Budget Analysis

# ARIES Budget




- Total Research, Design, and Development Cost: $2,901 million
- Total Construction Cost: $8,578.8 million
- Cost per ARIES Resupply Mission: $2,863.5 million

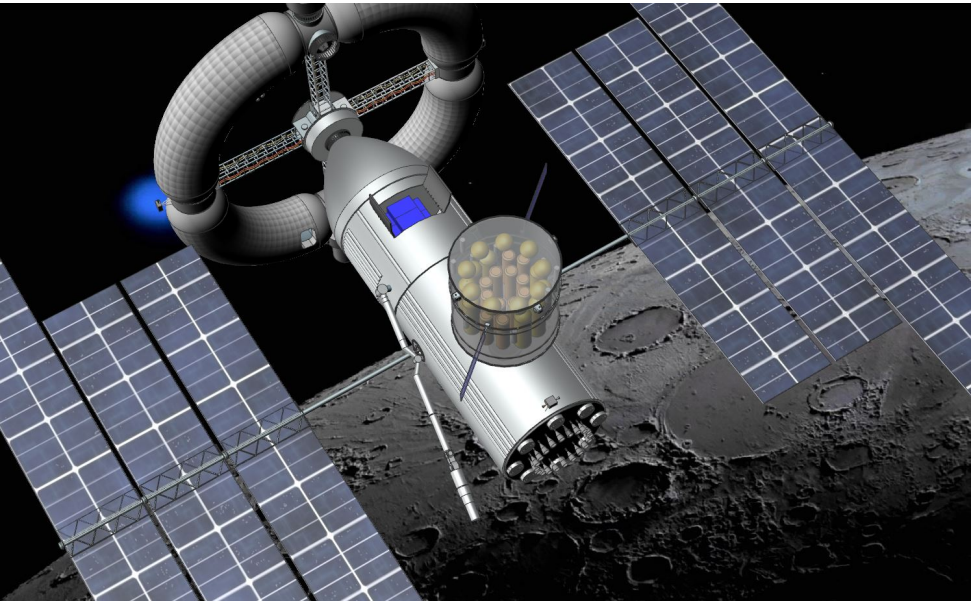
# Business Model

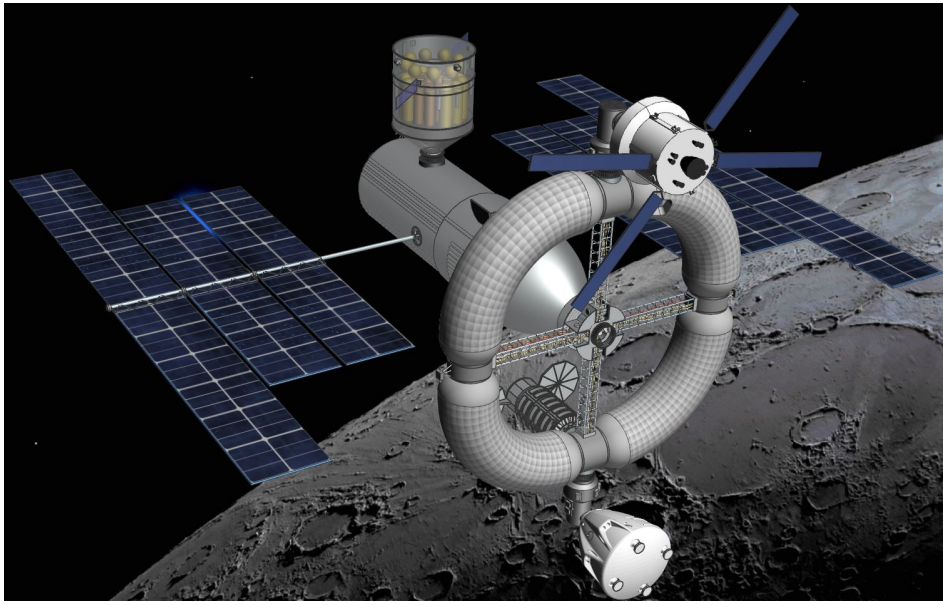



- Total Mission Cost: $11,971 million
- 50% to NASA, 25% to ESA, 25% to Roscosmos

# Conclusion

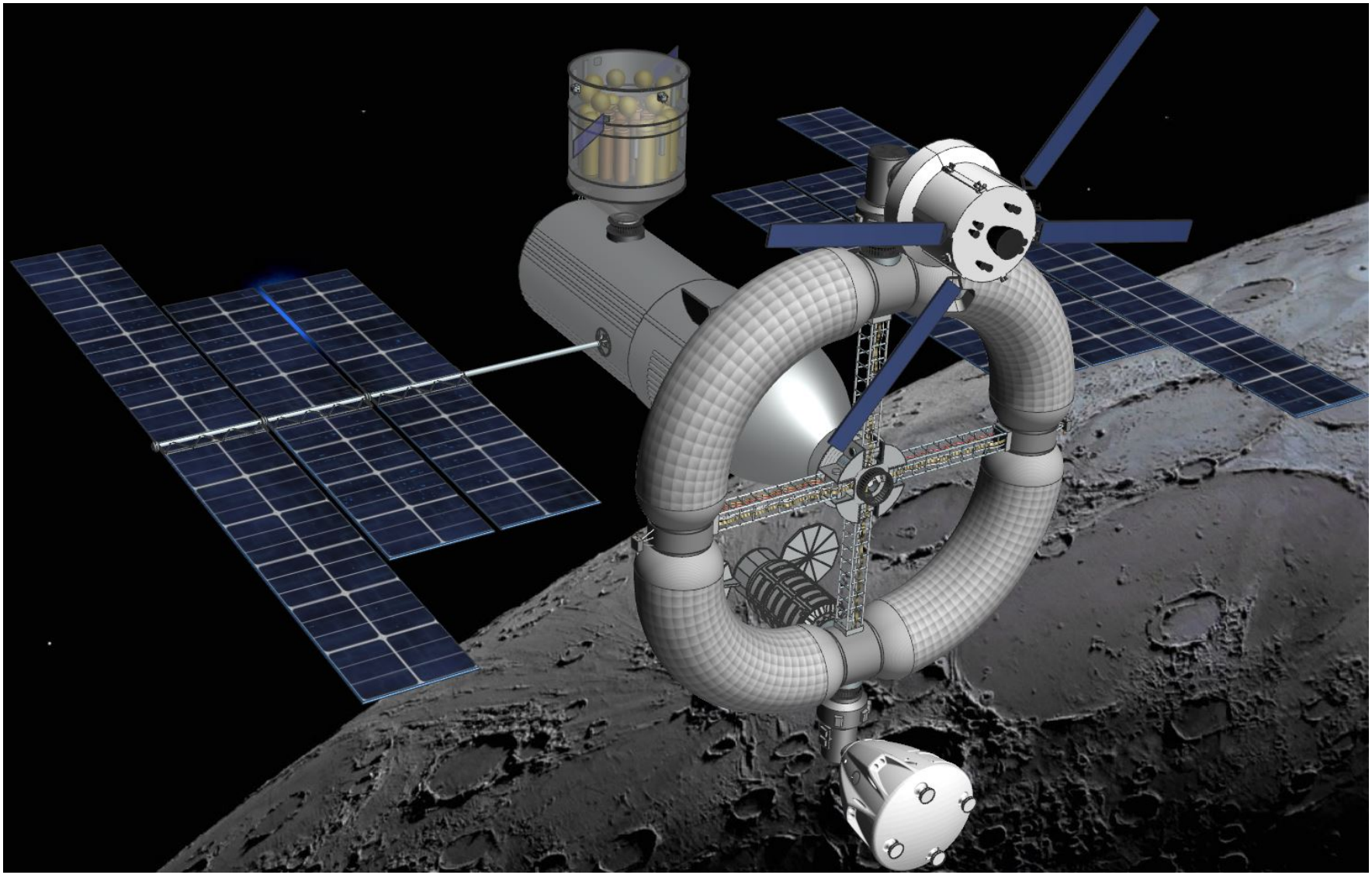
- Unique mix of legacy and innovative technology
- Versatile habitat design capable of supporting alternative missions
- Minimum crew-impact artificial gravity
- Powerful propulsion stage
- Multiple included cost-reduction options






# Supplemental Slides

# ARIES With Berthed Spacecraft

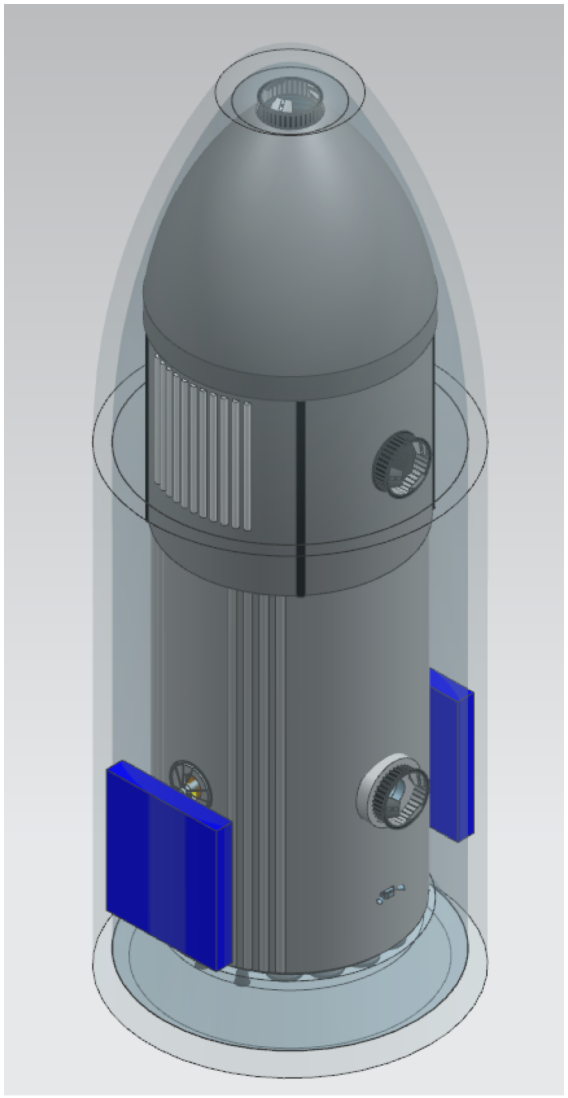


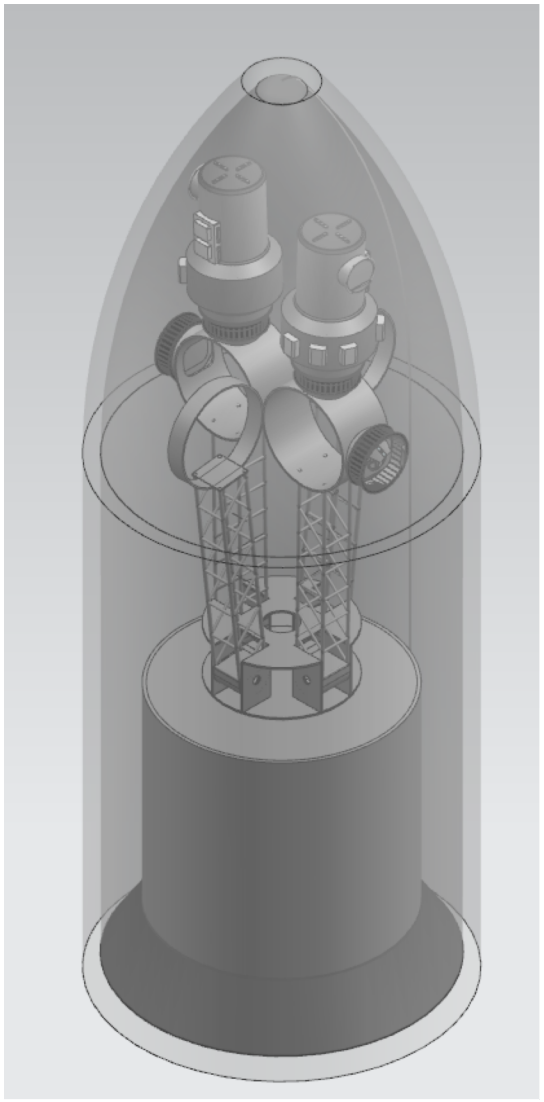
# Master Equipment List

| ARIES System | Mass (kg) | Power (kW) | TRL |
|---|---|---|---|
| **ECLSS** | | | |
| COLBERT Treadmill [17] | 998 | 1.5 | 9 |
| Exercise Bike [18] | 250 | 0.4 | 9 |
| ARED [19] | 1,000 | 0.2 | 9 |
| Air Revitalization [21] | 652 | 2.6 | 9 |
| Temperature Control | 271 | 2.2 | 9 |
| Fire Control [21] | 20 | 0 | 9 |
| Water Systems [21] | 552 | 0.5 | 9 |
| Lighting [21] | 72 | 0.3 | 9 |
| Shielding [21] | 1,461 | 0 | 5 |
| Waste Management [21] | 184 | 0 | 9 |
| **Structures** | | | |
| (4) Inflatable Module | 9,373 | 0 | 9 |
| Truss Assembly | 32,796 | 0 | 6 |
| HPS | 25,506 | 0 | 6 |
| (5) CBM [25] | 5,175 | 1.5 | 9 |
| (2) NDS [27] | 648 | 0.5 | 7 |
| (2) Quest Airlock [29] | 19,847 | 0.3 | 9 |
| SSRMS [30] | 451 | 0.6 | 9 |
| PDGF [31] | 12 | 0.4 | 9 |
| **ADCS** | | | |
| ADCS Sensor Suite [21] | 33 | 0.2 | 9 |
| Star Tracker [32] | 3 | 0.2 | 9 |
| CMGs [33] | 28 | 0.2 | 9 |

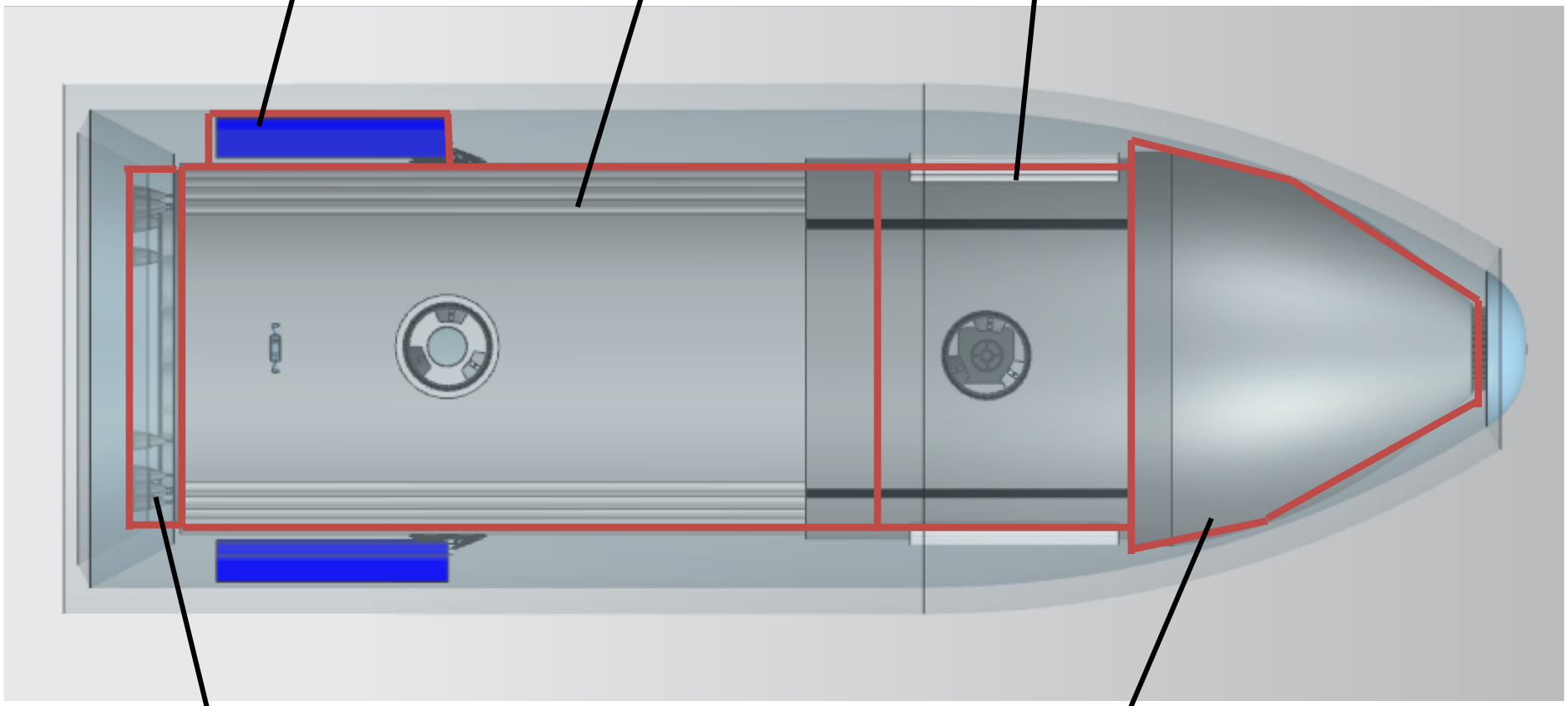
| ARIES System | Mass (kg) | Power (kW) | TRL |
|---|---|---|---|
| **Thermal** | | | |
| (3) Radiators | 2,000 | 0 | 8 |
| **Power** | | | |
| (2) Solar Array Wing [20] | 1,732 | 0 | 8 |
| (13) Battery [22] | 15 | 0 | 9 |
| **Propulsion/Fluids** | | | |
| (10) R-42 DM Thruster [3] | 73 | 0 | 9 |
| (4) R-1E Thruster [3] | 8 | 0 | 9 |
| (32) S22-02 Thruster [23] | 22 | 0 | 6 |
| (8) X3 Thruster [24] | 1,840 | 291.2 | 6 |
| RCS Fuel/Oxidizer | 76,573 | 0 | 9 |
| HPS Fuel/Oxidizer | 1,165 | 0 | 9 |
| **Other Subsystems** | | | |
| C&DH Package [21] | 131 | 1 | 9 |
| Communication Package [21] | 210 | 0.6 | 9 |
| Radio Transceiver [26] | 20 | 0.2 | 9 |
| Power Amplifier [28] | 6 | 0.5 | 9 |
| **Additional Equipment** | | | |
| Stowed Items [21] | 2,476 | 5.0 | 9 |
| Spares and Packaging [21] | 4,710 | 0 | 9 |
| (2) Robonauts | 300 | 0 | 9 |
| Food+30% | 10,473 | 0 | 9 |
| Water+30% | 3,848 | 0 | 9 |
| **Totals** | **204,661** | **310.1** | |

# Payload Fairings





# HPS Sections



# Finite Element Analysis

- Material: Aluminum 6061
- Yield Stress: 276MPa
- Force on each truss arm: 82.7kN
- Force on each interfacing hub joint: 89.2kN