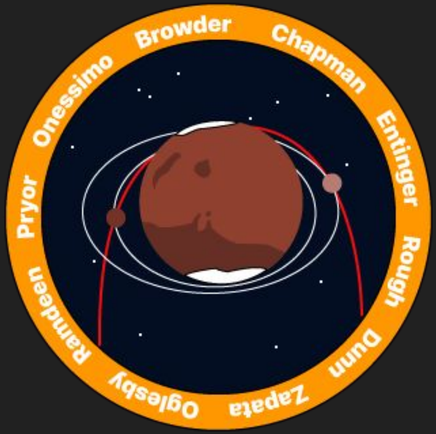
Aithos



<u>Team Members:</u>
Zane Chapman, Cameron Rough, Maria Zapata, Devindra Ramdeen, Vincent Onessimo, Zachary Entinger, Hunter Dunn, Robert Oglesby, Devin Pryor, Alexander Browder

Mission Statement

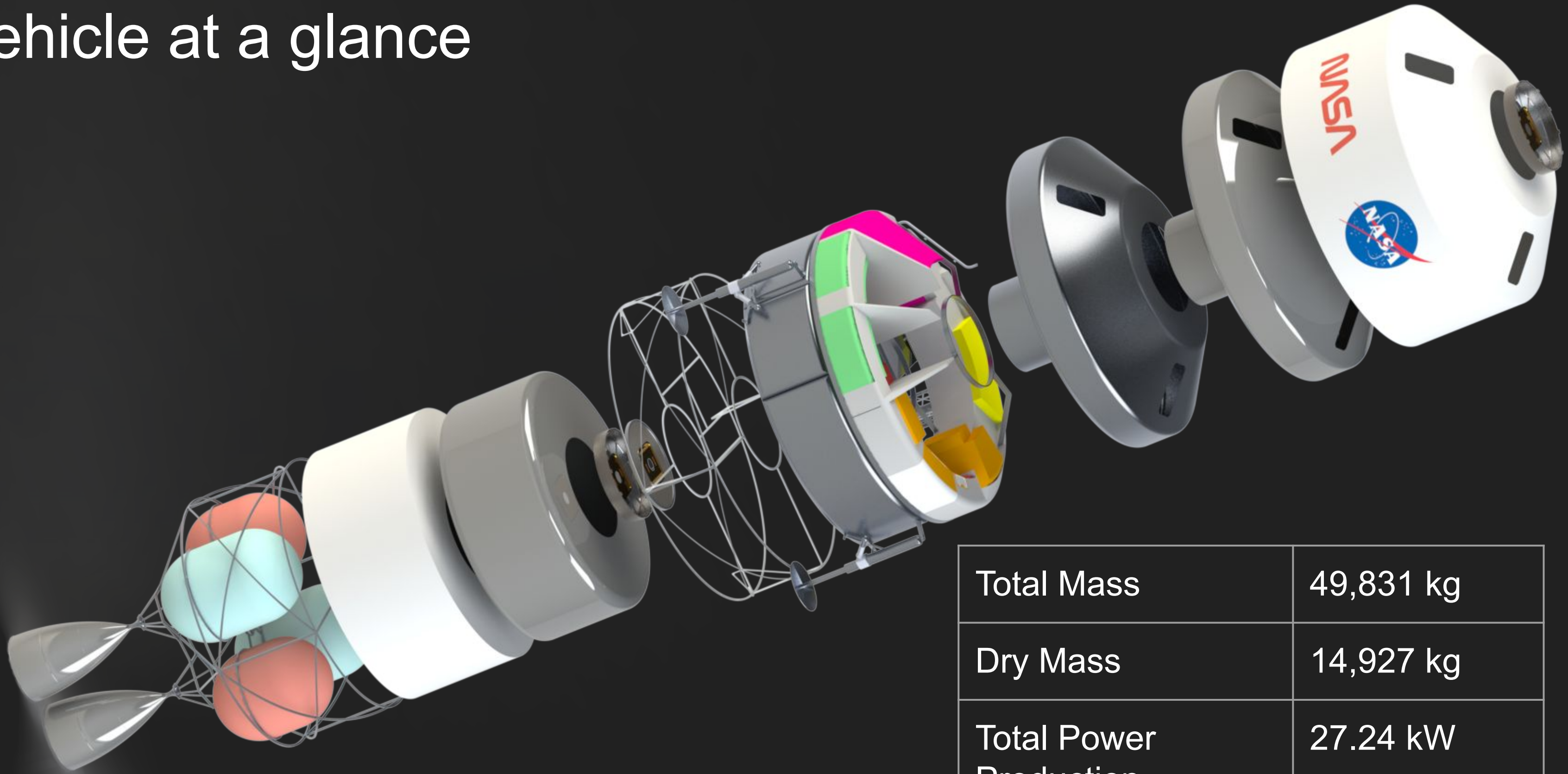
Provide a complete exploration vehicle design for manned transit to, and exploration of, both Mars moons and safe return of crew and samples to the transit vehicle

Mission Overview

- Launch from Earth roughly 2 years before DST arrives
- Hohmann Transfer to Mars 5-sol orbit
- Phasing maneuver and rendezvous with DST
- Travel to Phobos, deploy rover from lander, orbiter images from above
- Sample collection then lander rendezvous with orbiter
- Travel to Deimos, deploy rover from lander, orbiter images from above
- Sample collection then lander rendezvous with orbiter
- Rendezvous with DST

Objectives: Topographical Map, Resource Profile, Autonomous Crew Control, Plant Cultivation Study, Astronomy Origins Study, Material Science Study

Vehicle at a glance

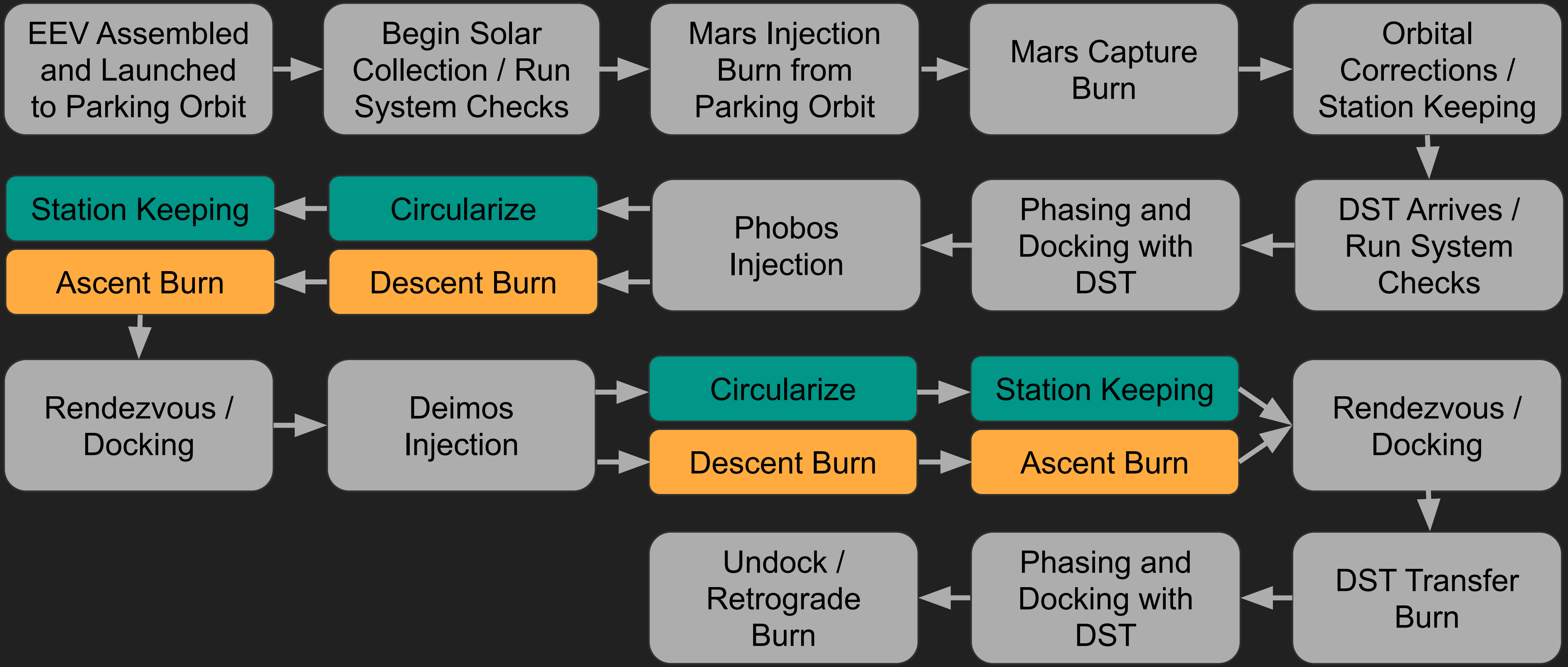


Total Mass	49,831 kg
Dry Mass	14,927 kg
Total Power Production	27.24 kW
Cost	$860 Million

Cost Estimate

System	Cost [$]
Attitude and Control	$4,200,000.00
ECLSS	$187,000,000.00
GNC	$330,000.00
Launch Vehicle	$257,000,000.00
Power Systems	$15,600,000.00
Propulsion	$5,100,000.00
Rover	$100,000,000.00
Scientific Objectives	$4,000,000.00
Structures	$375,000.00
Telecommunications	$21,500,000.00
Thermal	$264,780,000.00
Total	$859,885,000.00

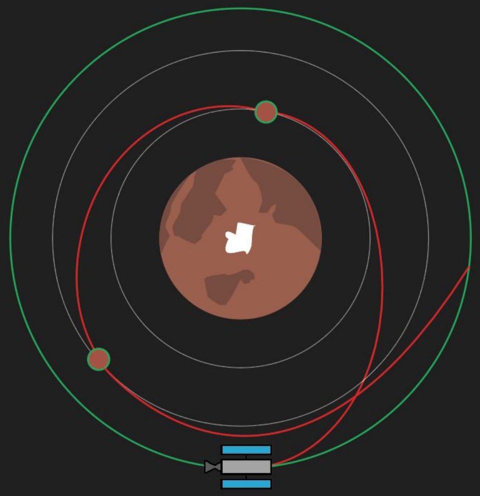
Concept of Operations



Trajectory Design

Visiting Sequence

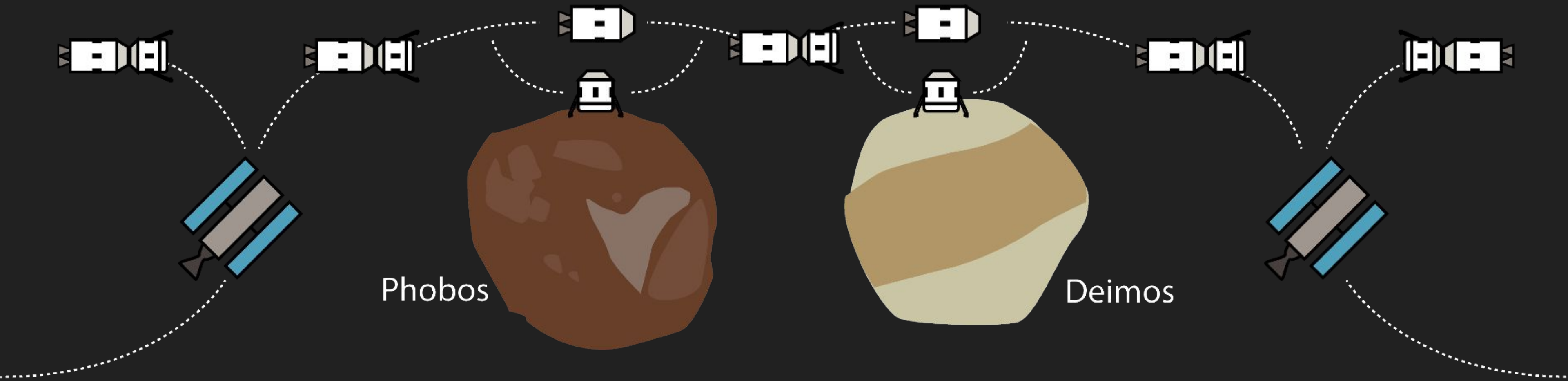
- How best to minimize Δv requirements
- Multiple sorties
  - Difficult to plan appropriate burn windows
  - Much longer mission times



Sorties			**Single Sortie - Phobos First**			**Single Sortie - Deimos First**			**Multiple Sortie - Phobos First**			**Multiple Sortie - Deimos First**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Δv	0.4	km/s	3.733	9.5	3.8	4.091	6	2.4	3.679	10	4	3.792	9	3.6
Mission Time	0.3	hrs	276	10	3	342	8.5	2.55	364	8	2.4	366	7.75	2.33
Phobos Orbit Duration	0.15	hrs	98	9	1.35	143.33	5	0.75	94.5	9.25	1.39	102.5	8.5	1.28
Deimos Orbit Duration	0.15	hrs	93	8.75	1.31	110	7.5	1.125	109	7.6	1.14	114	7	1.05
Overall Value					**9.46**			**6.83**			**8.93**			**8.25**

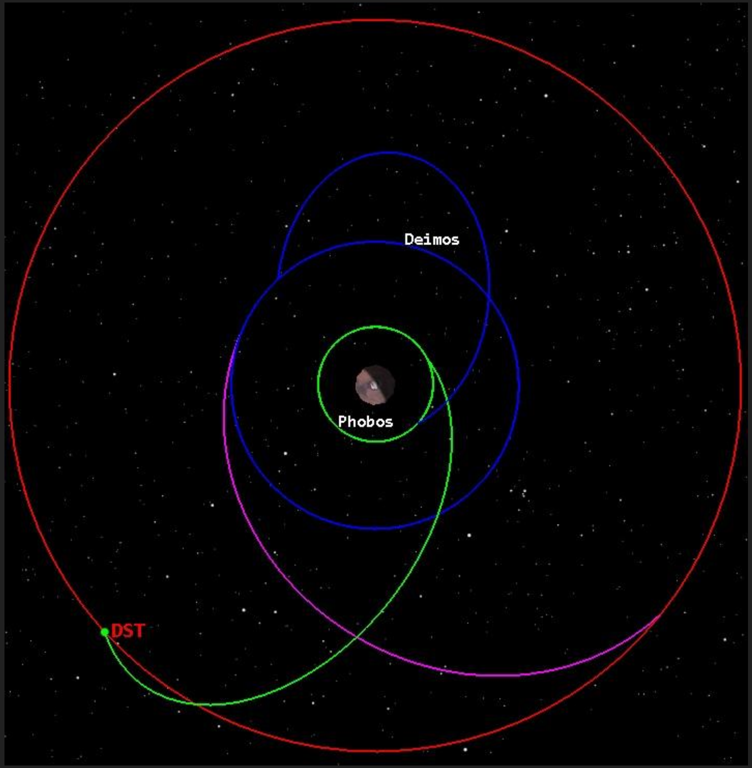
Visiting Sequence

- Phobos to Deimos sequence - low Δv, more reasonable time spent in orbit, overall shorter mission
- Shorter trips - improve crew psychology, more favorable burn windows for lower Δv and mission planning



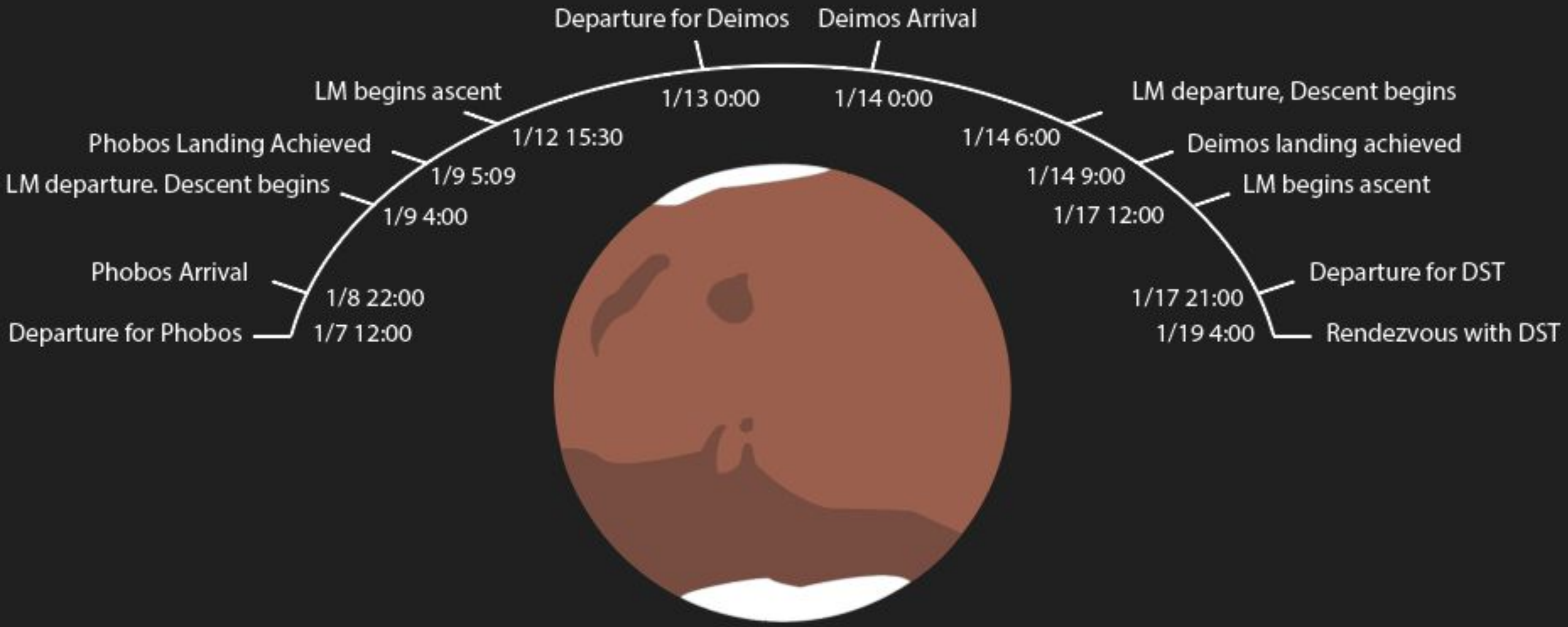
Trajectory Design

- Descent begins a few hours after entry to each respective moon's orbit
- Arrival back into orbit a few hours before leaving
- Burn windows for transfer between Phobos and Deimos are sparse



Mission Timeline

Mission Timelines



Phasing Delta-v Requirements

- Mission designed to minimize the Δv requirement while allowing ample time for sample collection
- Δv very small for descent and ascent

	burn epoch	transfer duration (hrs)	Δv1 (km/s)	Δv2 (km/s)	Δv (km/s)	arrival time	orbit duration
DST to Phobos	1/7/2040 12:00	34	0.45187	0.81811	1.26998	1/8/2040 22:00	4 days 2 hr
Phobos to Deimos	1/13/2040 0:00	24	1.00973	0.95092	1.96065	1/14/2040 0:00	3 days 21 hrs
Deimos to DST	1/17/2040 21:00	31	0.27242	0.22953	0.502	1/19/2040 4:00	
Total		**89**			**3.73258**		**7 days 23 hrs**
Trip duration							**11 days 12 hrs**

EEV System Design

Crew Psychology

- Can reduce the probability of mission failure
  - Stressors impact crew health, motivation, and performance
  - Not every psychological event will be avoidable, but it will help the crew deal with them as efficiently as possible

- Main Psychological Constraints
  - Work/Rest Schedule
  - Communications
  - Physical Environment
  - It is assumed that constraints such as crew personality have been accounted for before the arrival of the DST

Crew Psychology

- Work/Rest Schedule
  - It will allow the crew to have a well-balanced schedule between work and rest
    - Being underworked and overworked have negative impacts on crew health

Example Schedule	
Activity	**Time [h]**
Sleep	8.50
Breakfast	0.75
work	4.00
Dinner	0.75
work	4.00
Exercise	2.00
Lunch	0.75
Relaxation	3.25

Crew Psychology

- Communications
  - Crew needs to be able to contact the DST, ground control, and their family as quickly and efficiently as possible
    - Contact with DST and ground control will allow them to know any necessary information such as mission changes, weather conditions, etc.
    - Contact with family will be during their resting period and certain emergencies.
    - Due to time lag, crew will be need to be re-trained on mission goals and emergency response on the DST before departure

Crew Psychology

- Physical Environment
  - Each crew member must be in an environment where they:
    - Will be in comfortable environmental conditions (air quality, temperature, humidity, etc)
    - Will have personal space for sleep, stowage, and communication with their family

Crew Habitation			Temporary Sleep Station (TeSS)			ISS Crew Quarters		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Ventilation System	0.30	experience	okay	6.0	1.8	great	10.0	3.0
Average Temperature (Sleeping)	0.25	°C	22.9	7.9	2.0	18.0	10.0	2.5
Personal Storage Space	0.20	m^3	0.1	10.0	2.0	0.1	10.0	2.0
Habitable Volume	0.25	m^3	1.57	7.5	1.9	2.10	10.0	2.5
Overall value					7.6			**10.0**

Crew Health

- Medical Technology for deep space travel is still being researched and developed
    - Current systems are only enough for basic first aid and operations

    - Three medical packs currently used in the ISS will be included in the EEV
        - Convenience Medication Pack
        - Oral Medication Pack
        - Emergency Medical Treatment Pack

    - The emergency medical treatment pack should give the crew enough time to get to the DST

Oxygen Generation Systems (OGS)

- Requirements

Oxygen Use	1 Crew (kg/day)	2 Crew (kg/day)
Crew Metabolism	0.89	1.78
O2 Nominal Daily Leakage (0.5%)		0.57
Misc		0.50
Total:	**0.89**	**2.85**
Levied Requirement:		**3.00**

- Trade Study

Oxygen Generation Systems			Fixed Alkaline Electrolyser			ISS OGA		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Oxygen Produced per Day	0.35	kg O_2/day	2.5	10	3.5	1.8	7.2	2.5
Oxygen Recovered	0.35	percent	75	10	3.5	40	5.3	1.9
Volume	0.15	m^3	0.11	5.6	0.8	0.06	10	1.5
Mass	0.15	kg	55	10	1.5	70	7.9	1.2
Overall value					**7.3**			**7.1**

- Total Oxygen: 27 kg

Carbon Dioxide Removal Assembly (CDRA)

- Requirements

Carbon Dioxide	Value
Max $ppCO_2$	0.4 kPa
Crew Production	1 kg/p-d
Total CO_2 produced (mission):	24 kg

- Trade Study

Carbon Dioxide Removal Assembly			4BMS			LiOH			Adsorbent Astrine		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
CO_2 Removed per Day	0.30	kg CO_2/day	2.08	10	3.0	2.0	9.6	2.9	2.0	9.6	2.9
Average CO_2 Partial Pressure	0.30	kPa	0.26	10	3.0	0.39	6.7	2.0	0.27	9.6	2.9
Volume	0.20	m^3	0.3	7.0	1.4	0.4	4.8	1.0	0.2	10	2.0
Mass	0.20	kg	60.0	7.0	1.4	42.0	10	2.0	44.5	9.4	1.9
Overall value					**8.8**			**7.8**			**9.7**

Trace Contaminant Control System (TCC)

- Requirements

Trace Contaminant Control Requirements	ISS Nominal Values
Concentration of Trace Gases	< SMAC Levels

- System Design
  - HEPA filter
    - Removes particles as small as 0.2 μm
  - Fixed charcoal bed
    - Filters compounds with low molecular mass gas contaminants
  - High temperature catalytic oxidizer
    - Filters compounds with high molecular mass gas contaminants

Temperature and Humidity Control (THC)

- Requirements

Temperature and Humidity Requirements	ISS Nominal Values
Temperature	18.3°C - 23.9°C
Humidity	30% - 70%

- System Design
  - For ECLSS we will only focus on the Condensing Heat Exchanger (CHX)
    - Plate-fin CHX
    - 2 Step Process
      - Moisture is condensed due onto the water-cooled fins
      - Condensate and air are forced into a rotary separator where they are separated
  - There are observed issues with the CHX coating losing its hydrophilicity

Pressure Control Assembly (PCA)

- Requirements

Pressure Requirements	ISS Nominal Values
Total Pressure	99.9 kPa - 102.7 kPa
Oxygen, partial pressure (ppO_2)	19.5 kPa - 23.1 kPa
Nitrogen, partial pressure (ppN_2)	79 kPa
Max O_2 Percentage	0.30

Pressurant Gas Use	N_2 (kg/day)
Nominal Daily Leakage (0.5%)	1.53
Misc	0.40
Total:	**1.93**
Levied Requirement	**2.00**

- System Design
  - System consists of valves, regulators, heaters, and pressure sensors to monitor the atmosphere.
  - Cabin pressurization calculations were done using the following cabin pressure
    - Total pressure: 101 kPa
    - ppO_2 : 22 kPa
    - ppN_2 : 79 kPa
    - $ppCO_2$: 0.27 kPa
- Total Nitrogen: 87 kg

Fire Response System (FRS)

- Fire Alarms
  - Current fire alarm technology is insufficient for deep space
    - It is unable to detect certain fires (depends on the material and particle size)
    - A new fire alarm is currently under development, but technical details are not publicly available.

- Trade Study

Fire Response System			CO2 based Extinguisher			Fine Water Mist Extinguisher		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Breathing Apparatus Required	0.35	experience	yes	0	0	no	10	3.5
Discharge Time	0.15	seconds	45.0	10	1.5	50.0	9.0	1.4
Weight	0.25	kg	6.6	10	2.5	6.7	9.9	2.5
Cost	0.25	$	209.2	10	2.5	302.5	6.9	1.7
Overall value					**6.5**			**9.0**

Water Recovery and Management (WRM)

- Requirements

Water Use	1 Crew (kg/day)	2 Crew (kg/day)	%Recycled (kg/day)	Supplied (kg/day)
shower	2.70	5.40	98%	0.11
Oral Hygiene	0.37	0.74	98%	0.01
Urine Flush	0.50	1.00	75%	0.25
Laundry	12.50	25.00	98%	0.50
Consumption/Food Preparatio	3.50	7.00	75%	1.75
Metabolic O2 Production	1.00	2.00	75%	0.50
Nominal Leak O2 Makeup	0.32	0.32	0%	0.32
Misc	1.36	2.72	75%	0.68
Total:	**21.93 kg**	**44.18 kg**		**4.12 kg**
Levied Requirement:		**45 kg**		**5 kg**

- System Design
  - Comprised of the Water Processor Assembly and the Urine Processor Assembly
  - All wastewater is mixed and treated to several chemical processes
  - Remaining contaminants are removed by a high temperature catalytic reaction
  - Sensors determine if the water quality is acceptable
    - If not, the water is run through the processor again.

- Total mass of water: 213 kg

Waste Management (WM)

- Requirements

Waste Production	Output (kg/p-d)
Feces	0.03
Fecal water	0.09
Total waste (per day):	**0.24 kg/d**
Total waste (mission):	**0.66 kg**

- System Design
  - The Universal Waste Management System (UWMS) is used
    - 65% smaller and 40% lighter than the current toilet
    - Portable
  - Urine is sent to the WRM to be recycled
  - Feces is stored

ECLSS Contingency Plans

- OGS, PCA, WRM
  - Extra 3 days worth of oxygen, nitrogen, and water is stored in the EEV
- CDRA, TCC, and FRS
  - Breathing apparatus with filters and oxygen cartridges
    - Filters will protect crew from air contaminants
    - Oxygen cartridges are included in case the fire depletes too much of the oxygen
- WM
  - Contingency fecal and urine collection bags

Radiation Shielding

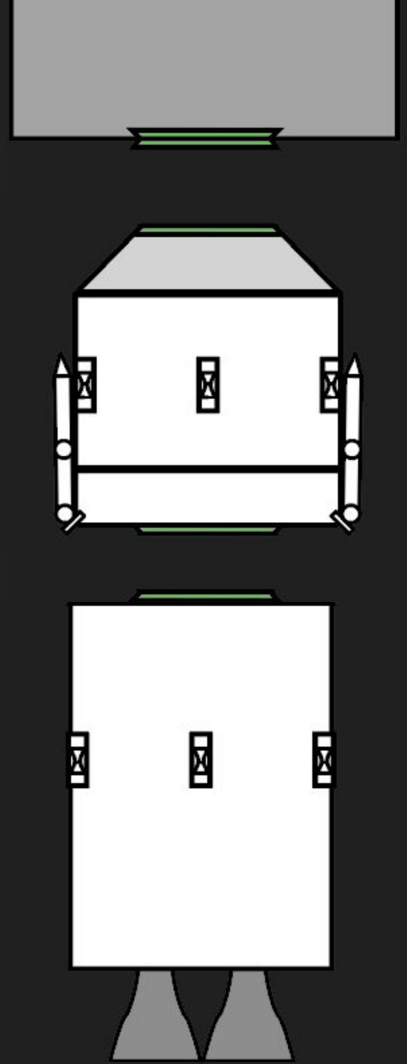
- Solar Cycle
  - Current solar cycle ends in 2035 so solar environment for 2040 is unknown
  - Design was based off a worst-case scenario
    - Solar minimum thus GCR maximum
    - Large SPE event occurs during mission

- Trade Study

Passive Radiation Shielding			Aluminum (Al-Li Alloy)			Boron Nitride Nanotube + 20 wt% H_2			Polyethylene (14 wt% H)		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Areal Density	0.20	g/cm^3	1.6	6.2	1.2	1.3	7.4	1.5	0.96	10	2.0
Dose Equivalent per Day (GCR)	0.25	mSv/day	1.37	8	2.0	1.12	10	2.5	1.24	9	2.3
Dose Equivalent (SPE)	0.25	mSv	200	5	1.3	100	10	2.5	143.00	7	1.7
Cost	0.30	$/kg	2.60	3.6	1.1	1.06E+06	0	0.0	0.93	10	3.0
Overall value					**5.6**			6.5			**9.0**

Docking System

- Axial Docking
- Three Berthing Ports
  - Two Berthing Ports on Landing Module
  - One Berthing Port on Service Module
- Crossfeed
  - Fuel
  - ECLSS
  - Power
  - Cargo
  - Crew



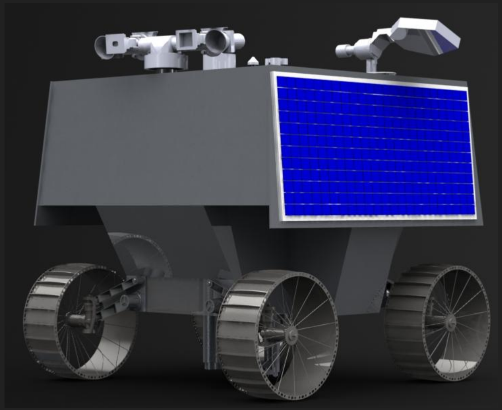
Surface Mobility System

- The EEV will remain stationary upon landing
  - Scientific objectives will be carried out from the landing zone and rover
- A rover will be deployed to each moon to extend the range of exploration
- An orbiter module will remain in orbit during the sorties

Means of Exploration			Stationary Only			Re-Landing			Wheels			Stationary with Rovers		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Complexity	0.20	N/A	...	9.0	1.8	...	6.5	1.3	...	6.5	1.3	...	8.0	1.6
Cost	0.20	$	...	10	2.0	...	7	1.4	...	6	1.2	...	8	1.6
Feasibility	0.30	N/A	...	9.3	2.8	...	6.7	2.0	...	6.7	2.0	...	9.3	2.8
Utility	0.30	N/A	...	2.0	0.6	...	5.0	1.5	...	7.0	2.1	...	8.0	2.4
			...	...	...	...	...	...	...	...	...	...	...	...
Overall value					**7.2**			**6.2**			**6.6**			**8.4**

Surface Rover

- Relies upon the NASA VIPER rover design
- Performs entirety of sample extraction
- Remote operation
  - Commands sent from the EEV during sorties
  - Continued commands sent post-mission direct from Earth via X-band radio waves
- Solar-rechargeable lithium-ion battery power
  - Peak power of 450W
- Mass and volume properties
  - 552 kg mass
  - 1.71 x 1.54 m length and width and 1.67 m height
  - Top speed of 0.8km/h and minimum speed of 0.4km/h
- MastCAM Imaging System
  - High-quality panoramic color images
  - Developed for and demonstrated by Perseverance



A 3D render of the rover

Scientific Experiment Equipment

Equipment Characterisation

EEV Equipment

- Orbiter Camera Surface Imaging System (OCSIS)
- Lunar Orbiter Laser Altimeter Topography Mapping System (LOLA)
- Veggie Plant Growth Chamber

Rover Excursion Equipment

- Trident Drill Sample Retriever
- Mass Spectrometer
- Neutron Spectrometer
- Near-Infrared Volatiles Spectrometer System
- MastCAM Imaging System

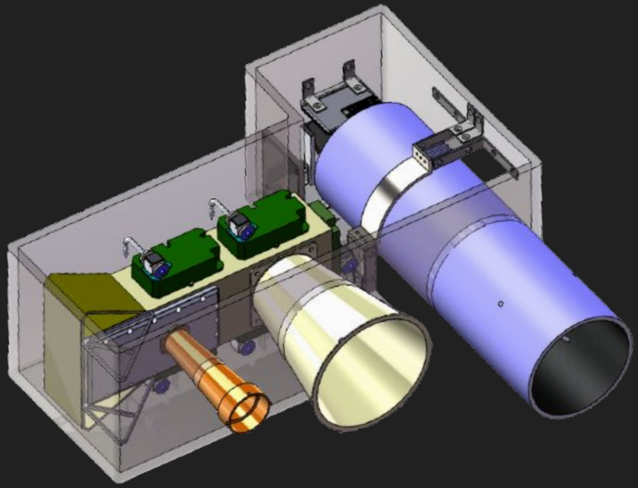
See Appendix for more details

EEV Equipment Mission Objectives

- OCSIS Objectives
  - Determine future landing sites by mapping the surface of each moon
  - Provide insight into the light profile of both moons
  - Identify locations ideal for rover travel or future mission exploration
- LOLA Objectives
  - Create topographical map of the moon’s surface
  - Identify dangerous geometries that the rover or future explorations should avoid
  - Better ascertain the oblateness of each moon
  - Identify regions permanently shadowed from sunlight
- Veggie Objectives
  - Test the psychological impact plant growth has on astronauts
  - Analyze plant response to deep space environment conditions onboard the EEV

Camera System & Laser Altimeter

- Cassegrain Telescope
- LOLA Lunar Reconnaissance Orbiter
- Orbiter will adjust position with ACS
  - Map 94.4% of Phobos
  - Map 78.4% of Deimos

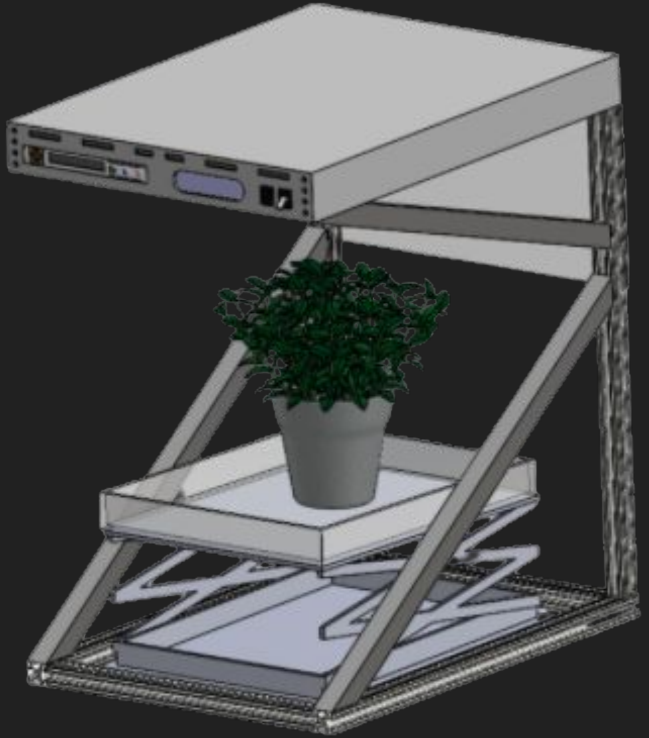


Camera Feature	Stats for Phobos
Exposure	10 ms
Primary Mirror Diameter	120mm diam
Altitude PHOBOS	8.5 km
Chip Dimensions	72mm X 48mm
Primary Mirror Radius of Curvature	-1.5m
Secondary Mirror Radius of Curvature	3m
Pixels	5120 x 3413 px
Total Focus	35 mm
Lens 1 Radius of Curvature	0.45m
Lens 2 Radius of Curvature	-2.66m

Criteria	Value (km)
Deimos HFOV	3.316
Deimos VFOV	2.211
Phobos HFOV	1.748
Phobos VFOV	1.165

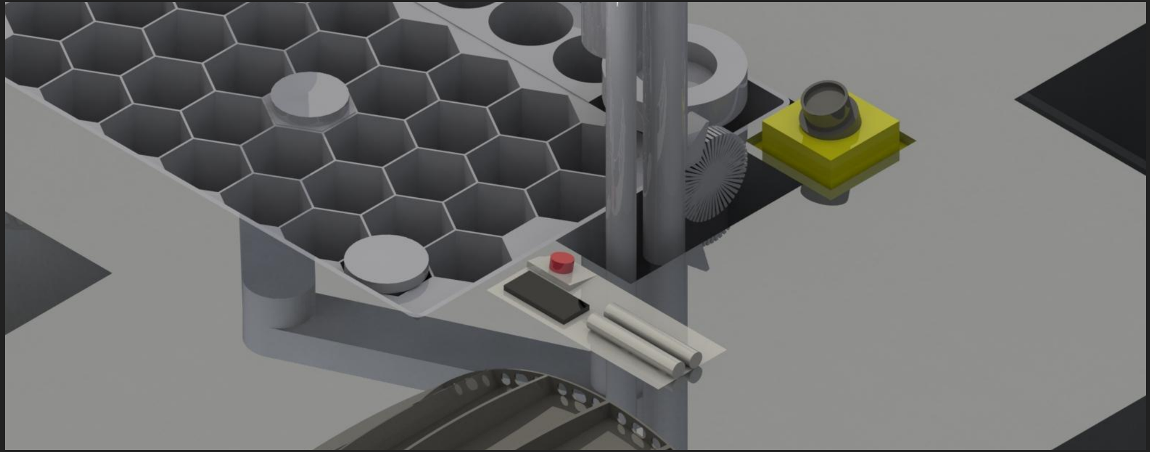
Veggie Plant Growth Chamber

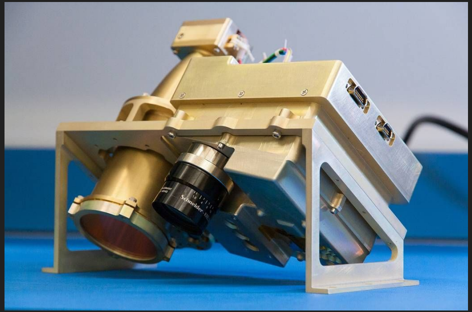
- Capable of facilitating up to six plants at once
  - 0.11 m^2 growing area with max height of 45 cm
  - Plant pillows sewed prior to takeoff
  - Romaine Lettuce Selected Plant
- Will be carried on from the DST during EEV astronaut transfer
  - 30 mins/day crew attention
  - Only 1 astronaut will tend to it



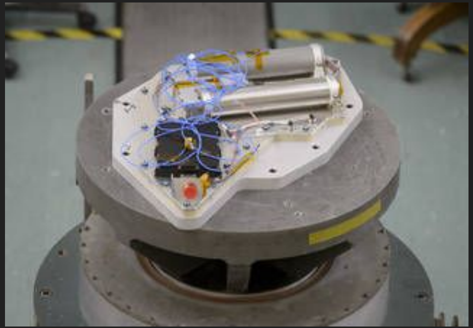
Sample Spectrometry

- Use an array of spectrometers mounted on the rover to analyze sample compositions to determine sample characteristics and identify subsequent collection sites during the sorties
- Mass Spectrometer and Neutron Spectrometer
  - Identify the elemental compositions of samples
- Near-Infrared Volatiles Spectrometer System
  - Detect presence of hydrogen and elemental composition of ices





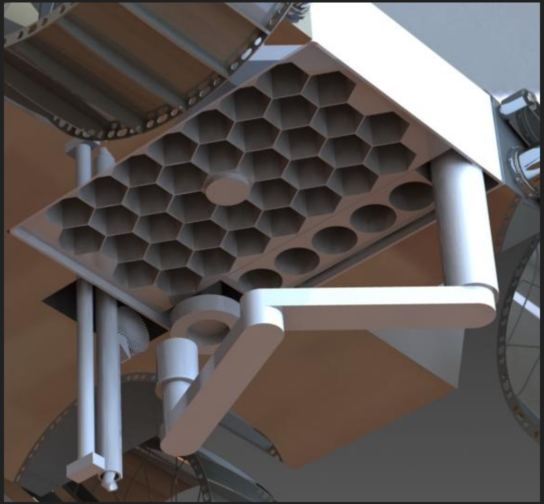
The Near-Infrared Volatiles Spectrometer (NIRVSS) System



A test version of the VIPER rover’s neutron spectrometer

Sample Retrieval

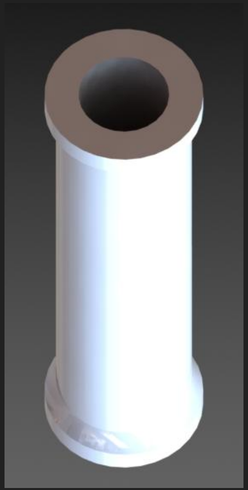
- Trident Drill (TRIDENT) integrated into rover will perform sample extraction
  - 3.28-foot (1-meter) can drill up to 3 feet below the surface
- Approximately 60000 cm^3 of sample collection required to achieve mission goals (50 kg per moon)
  - Determined from the average densities of both moons

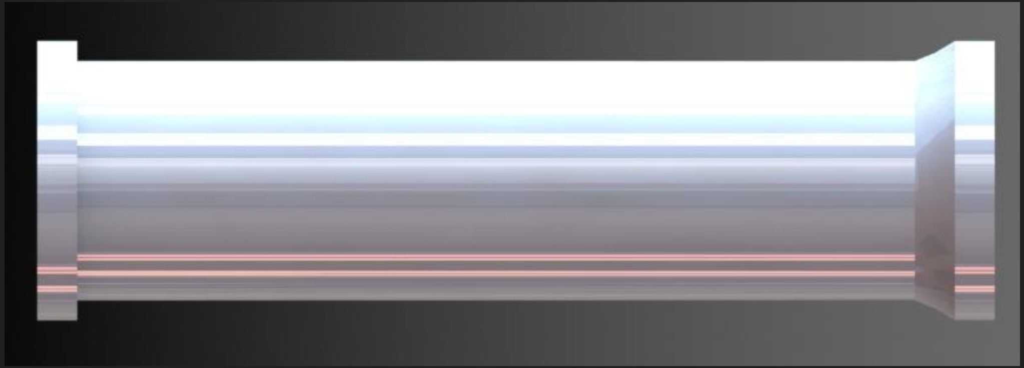


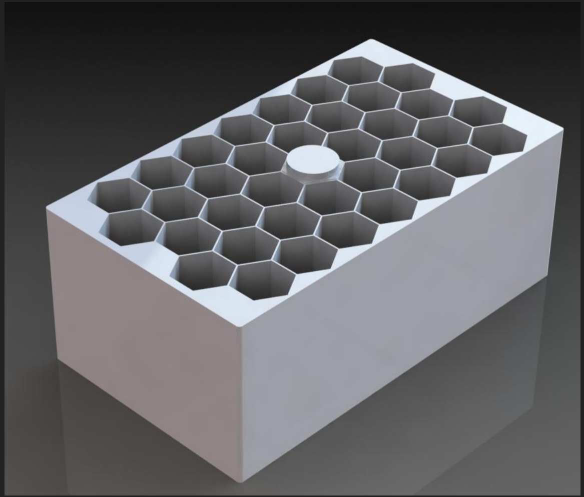
Mass Retrieval Method			Drill			Explosives			Traditional Methods		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Cost	0.10	$	okay	6.0	0.6	fair	4.0	0.4	fair	4.0	0.4
Feasibility	0.30	hours	great	10.0	3.0	good	8.0	2.4	poor	2.0	0.6
Retrieval Capabilitie	0.30	experience	good	8.0	2.4	fair	4.0	1.2	okay	6.0	1.8
Utility	0.30	experience	great	10.0	3.0	okay	6.0	1.8	okay	6.0	1.8
Overall value					9.0			5.8			4.6

Sample Storage

- Extracted regolith deposited into sample collection tubes
    - Titanium cylindrical tubes (3.5 cm (radius) x 21 cm (height))
    - Will require approximately 50 tubes per moon in order to collect 50 kg of regolith.
- Sample tubes are stored in sample caches that will progressively fill up throughout the mission







Internal Sample Handling

- Sample tubes are cycled through with the assistance of a robotic arm
  - Similar to the “adaptive caching assembly” utilized by the Perseverance
  - 3 degrees of freedom
- Once a sampling cache is filled, rover refills at EEV refill station
  - Filled sample caches are replaced with unfilled caches and stored away for transfer to DST

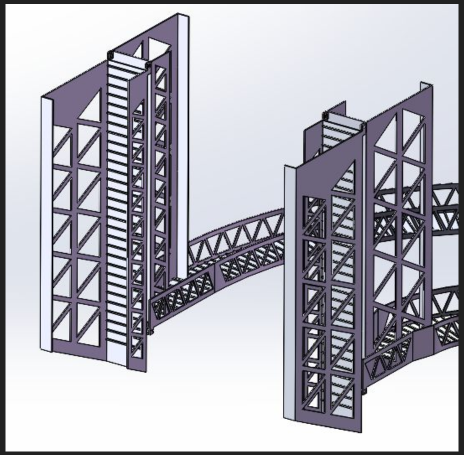
A schematic of the assembly for autonomous sample caching assembly

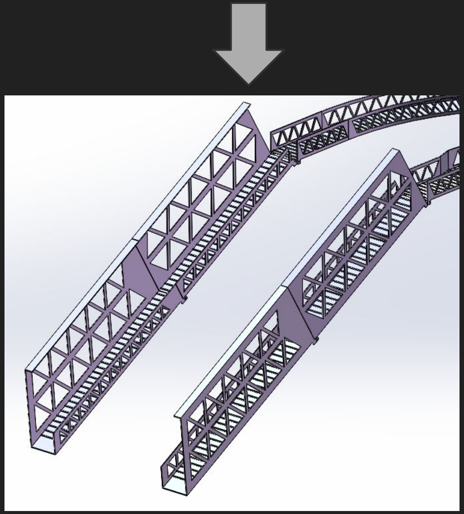
Rover Storage and Deployment

- Deployment: Folding Ramp
  - Wheel ceiling ensures traction on descent/ ascent

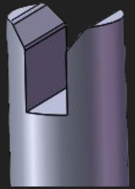
Rover Deployment Method			Ramp with Guide			Lowered Platform		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Complexity	0.3	Qualitative	Good	8.0	2.40	Okay	6.0	1.80
Return Time	0.2	sec	30	6.7	1.33	20	10.0	2.00
Vehicle Accessibility	0.3	Qualitative	Great	10.0	3.00	Okay	6.0	1.80
Mass	0.2	kg	70	7.1	1.43	50	10.0	2.00
Overall value					**8.16**			**7.60**

- Storage: Walled Track
  - Track geometry → Ensure rover position
  - Shaft passed through wheels to secure rover in payload bay





Sample Transfer

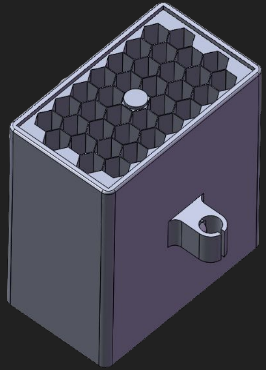


- Rover → EEV
  - Rover’s internal caching system transfers sample caches to/from the rover and the EEV’s sample storage container

Sample Recovery Method			Robotic Arm			Discharge Mechanism			Motified Caching System		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Complexity	0.3	Qualitative	Okay	6.0	1.80	Good	8.0	2.40	Great	10.0	3.00
Sample Preservation	0.3	Qualitative	Great	10.0	3.00	Bad	2.0	0.60	Great	10.0	3.00
Mass	0.3	kg	13	1.5	0.46	8	2.5	0.75	2	10.0	3.00
Service Ability	0.1	Qualitative	Good	8.0	0.80	Ineffective	0.0	0.00	Ineffective	0.0	0.00
Overall value					**6.06**			**3.75**			**9.00**

- EEV → DST
  - Rail Mechanism: transfers sample container from storage bay to the to DST

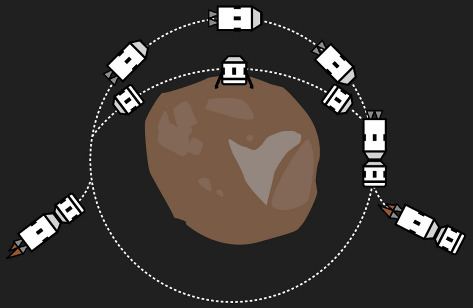
Sample Transfer Method			Transfer Container			Exterior Rail		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Complexity	0.3	Qualitative	Bad	2.0	0.60	Okay	6.0	1.80
Mass	0.2	kg	135	4.1	0.81	55	10.0	2.00
Crew Exposure/Safety	0.3	Qualitative	Fair	4.0	1.20	Great	10.0	3.00
Overall value					**2.61**			**6.80**



EEV Subsystem Design

Propulsion

Propulsion Overview

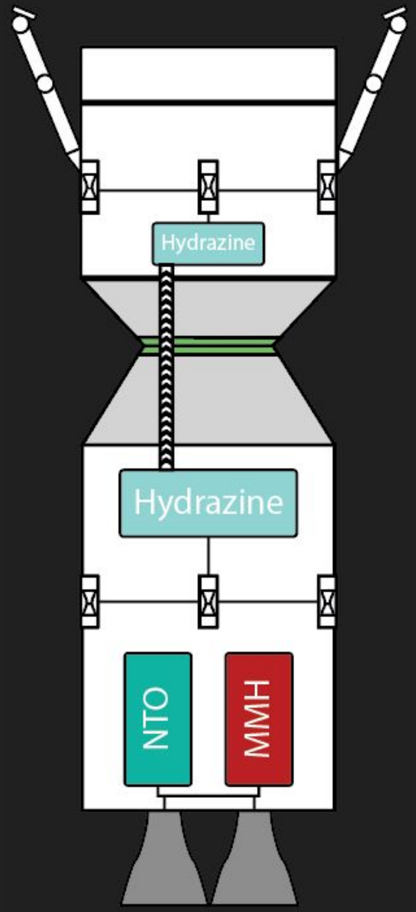


Propellant Mass

- 34,668 kg NTO & MMH
- 236 kg Hydrazine

- 2 Stages
  1. Service Module (SM)
     a. Main Propulsion → Bipropellant (NTO/MMH)
     b. ACS → Monopropellant (Hydrazine)
  2. Landing Module (LM)
     a. ACS → Monopropellant (Hydrazine)

- Increases LM Mass and Volume Efficiency



Main Propulsion Trade Studies

SM MAIN PROPULSION SYSTEM			Monopropellant			Bipropellant			Hybrid		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Achievable Thrust	0.4	N	3100	3.9E-03	1.6E-03	8E+06	10.0	4.0	1E+06	1.3	0.5
Achievable Specific Impulse	0.4	sec	240	5.2	2.1	465	10.0	4.0	325	7.0	2.8
Complexity	0.2	Qualitative	Low	8.0	1.6	High	2.0	0.4	Moderate	6.0	1.2
Overall value					**3.67**			**8.40**			**4.50**

BIPROPELLANT			LOX/LH2			LOX/MMH			Liquid Flourine/LH2			NTO/Hydrazine			NTO/MMH			NTO/UDMH			NTO/50-50		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Specific Impulse	0.3	sec	381.0	9.5	2.86	300.0	7.5	2.3	400.0	10.0	3.00	286.0	7.2	2.15	280.0	7.0	2.10	277.0	6.9	2.08	280.0	7.0	2.10
Production Accessibility	0.2	Qualatative	Great	10.0	2.00	Low	2.0	0.4	Low	2.0	0.40	Low	2.0	0.40	Good	8.0	1.60	Okay	6.0	1.20	Okay	6.0	1.20
Bulk Density	0.2	g/mL	0.3	2.7	0.54	1.0	8.3	1.7	0.4	3.2	0.65	1.2	10.0	2.00	1.2	9.7	1.95	1.1	9.6	1.91	1.2	9.8	1.97
Fuel Boiling Point	0.15	K	20.3	0.5	0.08	360.7	9.3	1.4	20.3	0.5	0.08	386.7	10.0	1.50	360.7	9.3	1.40	336.2	8.7	1.30	343.2	8.9	1.33
Oxidizer Boiling Point	0.15	K	90.2	3.1	0.46	90.2	3.1	0.5	85.0	2.9	0.43	294.8	10.0	1.50	294.8	10.0	1.50	294.8	10.0	1.50	294.8	10.0	1.50
Overall value					**5.94**			**6.17**			**4.56**			**7.55**			**8.55**			**7.99**			**8.10**

Main Propulsion Configuration			2 Aestus II			4 AJ-190			4 Aestus I		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Propellant and Engine Mass	0.3	kg	21,287.0	10.0	3.00	24,267.0	8.8	2.63	23,238.0	9.2	2.75
Total Burn Time	0.3	sec	1,056.0	9.9	2.97	1,194.0	8.8	2.63	1,045.0	10.0	3.00
Redundancy	0.2	Qualitative	Okay	6.0	1.20	Good	8.0	1.60	Good	8.0	1.60
Engine footprint	0.1	m^2	2.7	10.0	1.00	4.3	6.3	0.63	5.5	4.9	0.49
Propellant Tank Volume	0.1	m^3	18.1	10.0	1.00	20.3	8.9	0.89	19.6	9.2	0.92
Overall value					**9.17**			**8.38**			**8.76**

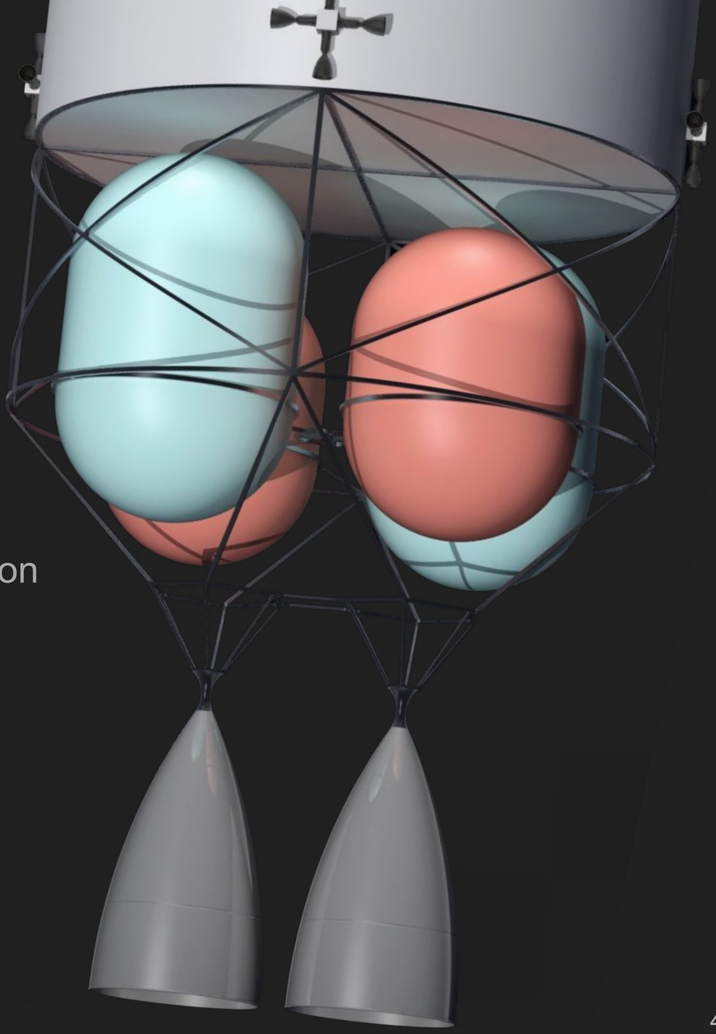
ACS Trade Studies

ACS PROPULSION SYSTEM			Monopropellant			Bipropellant			Hybrid		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Achievable Thrust	0.1	N	3100	3.9E-03	3.9E-04	8,000,000	10.0	1.0	1,000,000	1.3	0.1
Achievable Specific Impulse	0.2	sec	240	7.1	1.4	340	10.0	2.0	325	9.6	1.9
Complexity	0.4	Qualatative	Low	8.0	3.2	High	2.0	0.8	Moderate	6.0	2.4
ASC/RCS Compatability	0.2	Qualitative	Great	10.0	2	Good	8.0	1.6	Bad	2.0	0.4
Overall value					**6.61**			**5.40**			**4.84**

ACS PROPULSION CONFIGURATION			MR-107S			MR-104H			MR-104J		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Pulses	0.1	Number	30,300.0	10.0	1.00	6,520.0	2.2	0.22	6,600.0	2.2	0.22
Isp	0.2	sec	236.0	10.0	1.99	237.0	10.0	2.00	223.0	9.4	1.88
Cumulative Burn Time	0.2	sec	1,227.0	4.6	0.92	2,654.0	10.0	2.00	2,654.0	10.0	2.00
Dry Weight	0.2	kg	17.6	10.0	2.00	38.4	4.6	0.92	103.0	1.7	0.34
Feed Pressure	0.2	kPa	3,500.0	8.1	1.61	2,890.0	9.8	1.95	2,820.0	10.0	2.00
Steady State Thrust	0.1	N	275.0	5.4	0.54	510.0	10.0	1.00	440.0	8.6	0.86
Overall value					**8.07**			**8.08**			**7.30**

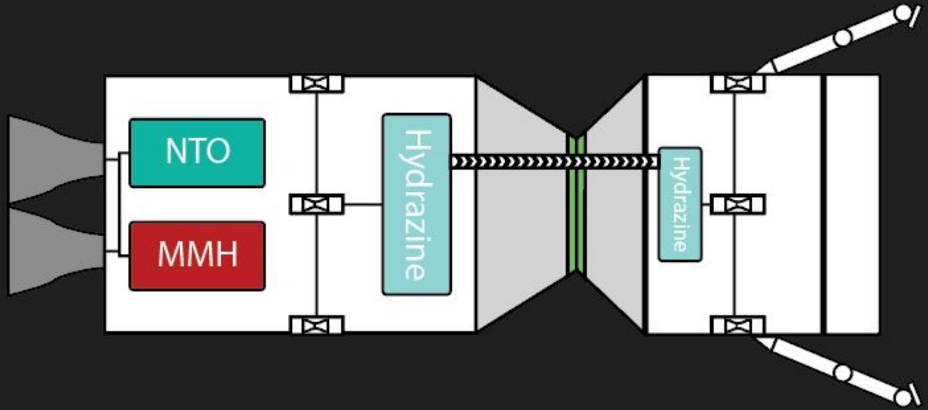
Main Propulsion

- Bipropellant
  - Complex but High Thrust and Efficiency
- NTO/MMH
  - Hypergolic → Easily Restarted
  - High Density → Low Volume Storage
  - Storable at High Temperatures → Minimizes Insulation
- 2 Aestus II (RS-72) Engines
  - Designed for Ariane 5 Upper Stage
  - Total Thrust: 110.8kN Thrust
  - Isp: 340s
  - Turbopump Fed



Attitude Control System

- Monopropellant Hydrazine
  - Simple → Cheap and Reliable
- 32 MR-104H
  - Thrust : 510N
  - Isp: 237s
  - 4 Modules of 4 Thrusters on each Stage
  - Manufacturer: Aerojet Rocketdyne
- Fuel Crossfeed Between Stages
  - Reduce Propellant Mass on LM
  - Increases Crew Space on LM



Thermal Management

Thermal Management Overview

Requirements

- All heat loads are calculated with a safety factor of 1.2
- *the peak heat produced by the orbiter occurs while still attached to the lander, the peak heat of the orbiter separated is 2.5 kW

Active Systems

- EATCS (External Active Thermal Control System) - Ammonia Loop
- IATCS (Internal Active Thermal Control System) - Water Loop

Passive Systems

- MLI (Multi Layered Insulation)
- Aluminized Beta cloth
- Aluminized Kapton

	Peak Thermal Load with 1.2 SF (kW)	Max Heat Dissipation	Power Usage of Thermal Systems (kW)	Mass of Thermal Systems (kg)
Lander	33.98	38.072	5.98	2844.5
Orbiter	4.17*	3.89	.5	262.22
Sun	1.7			
Total	39.9	41.96	6.48	

System Selection

- A system based on the ISS ATCS was chosen for its proven durability and high safety factor
- It was also able to handle the high thermal loads of our craft
- The system met our requirement to be able to separate when the lander and orbiter split
- The system is both heavy and consumes lots of power, but proper thermal management was deemed integral to the mission and its success

EATCS

- Ammonia Loop responsible for dissipating heat via two externally mounted radiators
- Total system weight 2844.55 kg
- Power Consumption 5.98 kW
- Dissipates 38.07kW per loop
- The EATCS will handle the majority of heat dissipation on the lander and when the craft is not seperated

IATCS

- Water Loops (2) that dissipates heat into the EATCS via IFHX
- Is responsible for 3.89 kW of heat dissipation and handling the orbiter while it is seperated

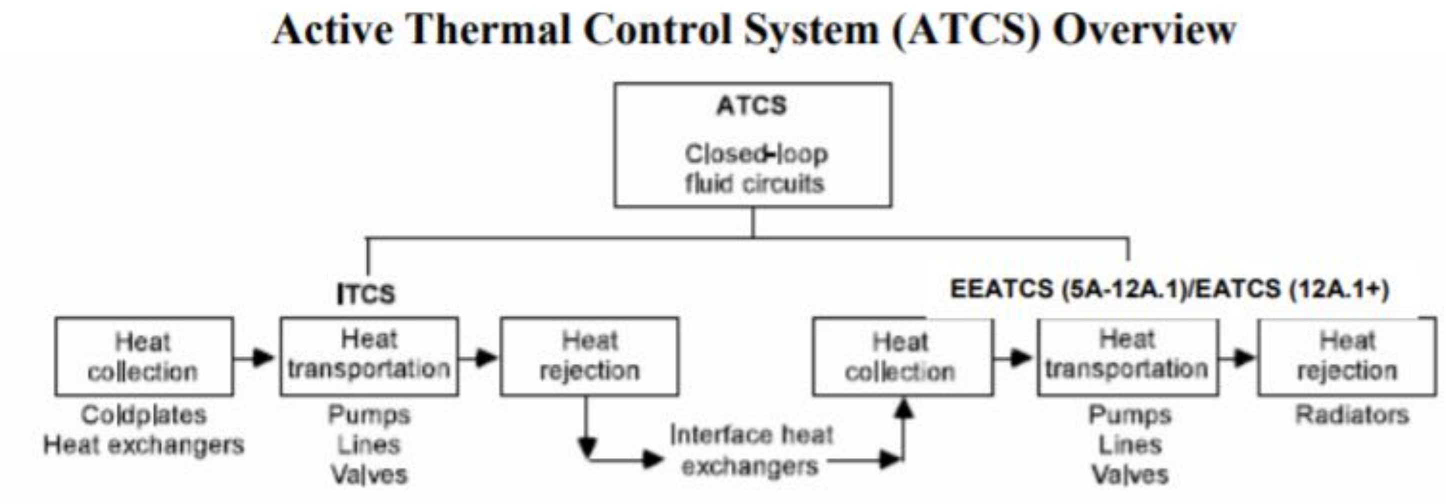
LTL (Low Temperature Loop)

- Used for Electronics with low temperature requirements, experiments, and ECLSS

MTL (Medium Temperature Loop)

- Used for avionics and experiments

How the EATCS and IATCS Interact



Active Thermal Control System Architecture

Passive Systems

MLI

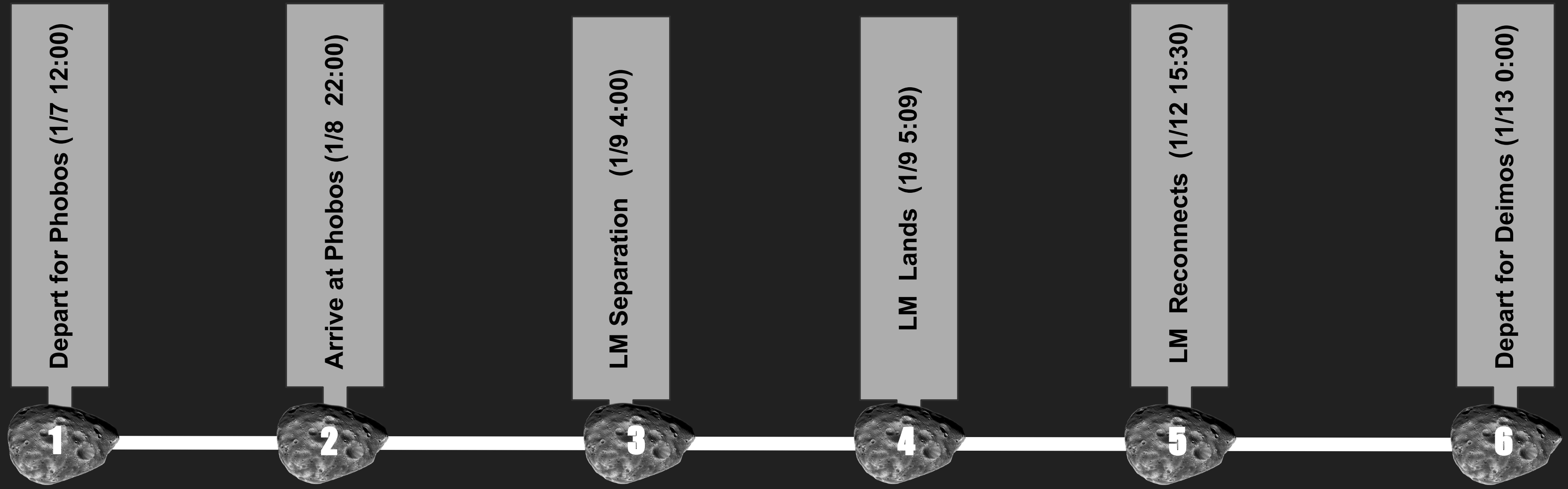
- Aluminized Beta cloth
- Aluminized Kapton
- Insulate the EEV externally and systems internally
- Reduces risk of static discharges
- Provide protection against large temperature spikes

Power System

Power Requirement

- Note: This is not reflective of the total expected power of operation
  - Lists power requirement of individual systems, does not account for how long they're active or when they're active

Classification	Item	Avg Power (kW)	Peak Power (kW)
ECLSS Atmosphere Management	Pressure Control	1.0E-01	1.0E-01
ECLSS Atmosphere Management	Air Revitalization System	2.3E+00	2.3E+00
ECLSS Atmosphere Management	Fire Response System Fire Detector	9.0E-06	9.0E-06
ECLSS Atmosphere Management	Oxygen Generation System Structure	6.0E-01	6.0E-01
ECLSS Water Management	Primary Water Procesessor	1.1E+00	2.2E+00
ECLSS Water Management	Water Quality Monitor	6.0E-02	6.0E-02
ECLSS Wet Waste Processing	Wet Waste Processing (Toilet)	4.5E-02	4.5E-02
ECLSS Quality of Life	Housekeeping Vaccum	4.0E-01	4.0E-01
ECLSS Quality of Life	Personal Stowage Closet Space	7.0E-01	7.0E-01
ECLSS Quality of Life	Gally and Food System Microwave	9.0E-01	9.0E-01
ECLSS Quality of Life	Maintenance Test Equipment	1.0E+00	1.0E+00
Scientific Equipment	Orbiter Metric Camera	4.1E-02	4.1E-02
Scientific Equipment	Veggie Plant Growth Chamber	9.0E-02	1.2E-01
Scientific Equipment	Lunar Orbit Laser Altimeter	3.5E-02	3.5E-02
Mechanisms	Solar Retract Motor Lander	2.4E-01	2.4E-01
Mechanisms	Solar Array Glove Motor Orbiter	2.4E-01	2.4E-01
Mechanisms	Solar Array Linear Actuator Lander	2.4E-01	2.4E-01
Mechanisms	Solar Array Globe Motor Lander	2.4E-01	2.4E-01
Thermal System	ECLSS Active Heat Transport Control	5.0E-01	5.0E-01
Thermal System	Complete Thermal System Lander	6.0E+00	6.0E+00
Thermal System	Complete Thermal System Orbiter	5.0E-01	5.0E-01
Attitude Control	Orbiter (12 valves)	2.5E-01	6.4E-01
Attitude Control	Orbiter (4 valves) heating	3.2E-02	8.1E-02
Attitude Control	Lander (12 valves)	2.5E-01	6.4E-01
Attitude Control	Lander Heating (4 valves)	3.2E-02	8.1E-02
Power Distribution Power Loss	Battery Charging Losses Orbiter	1.3E-01	1.3E-01
Power Distribution Power Loss	Battery Charging Losses Lander	1.2E+00	1.2E+00
Power Distribution Power Loss	Array to Load Losses Orbiter	1.4E-01	2.7E-01
Power Distribution Power Loss	Array to Loads Losses Lander	1.6E+00	2.2E+00
Power Control System	DC to AC conversion	1.5E+00	1.6E+00
Power Control System	Peak Power Tracker System	1.1E+00	1.2E+00
Battery Storage	Battery Charging Req Orbiter	5.0E-01	5.0E-01
Battery Storage	Battery Charging Req Lander	4.5E+00	4.5E+00
Telecommunications	Orbiter Telecom System	1.0E-01	1.0E-01
Telecommunications	Lander Telecom System	1.0E-01	1.0E-01
Propulsions	Main Engine Orbiter	2.5E-01	6.3E-01
Guidance Navigation and Control	Star Tracker System	1.0E-03	1.0E-03
Guidance Navigation and Control	Terrtain Relative Navigation	4.0E-01	4.0E-01
TOTAL		2.741E+01	3.079E+01



1-2 Combined Running
ECLSS Systems
Thermal Systems
Power System Control & Loss
Orbiter Telecom System
GNC Star Tracker System
Propulsions Main Engine
Veggie Plant Growth Chamber

Avg Power Consumption:
13.8 kW

2-3 Combined Running
ECLSS Systems
Thermal Systems
Power System Control & Loss
Orbiter Telecom System
GNC Star Tracker System
Veggie Plant Growth Chamber
Battery Charger

Avg Power Consumption:
17.8 kW

3-4 Lander & Orbiter
ECLSS Systems
Thermal Systems
Power System Control & Loss
Mechanisms
Veggie Plant Growth Chamber
Attitude Control System
Camera and LOLA
Both Telecom Systems
Both Terrain and Star GNC

Avg Power Consumption:
14.6 kW, 1.13 kW

4-5 Lander & Orbiter
ECLSS Systems
Thermal Systems
Power System Control & Loss
Veggie Plant Growth Chamber
Battery Charger
Camera and LOLA
Altitude Control System
Both Telecom Systems
GNC Star Tracker System

Avg Power Consumption:
16.9 kW, 1.53 kW

5-6 Combined Running
ECLSS Systems
Thermal Systems
Power System Control & Loss
Orbiter Telecom System
GNC Star Tracker System
Propulsions Main Engine
Veggie Plant Growth Chamber
Battery Charger

Avg Power Consumption:
17.5 kW

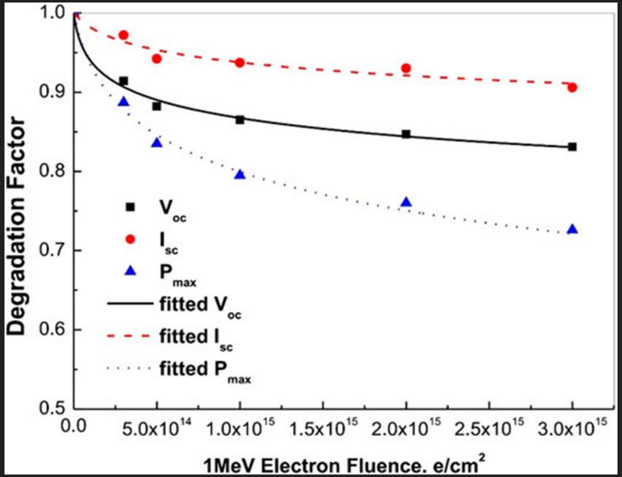
Preliminary Power Source Selection

- Selection by standardizing four power sources to 1kW generation
  - SRG based mostly on the MMRTG used on Perseverance rover
  - FPS based on NASA's KRUSTY project
  - Solar arrays utilize modern day solar cells fitted into a rigid honeycomb substrate

Power Systems at 1kW Generation			Static Radioisotope Generator (SRG)			Fission Power System (FPS)			Silicon Solar Cells (25.5% Efficient)			Multijunction Solar Cells (31% Efficienct)		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
System mass	0.275	kg	426	1.2	0.3	750	0.7	0.2	52.7	9.9	2.7	52.2	10.0	2.8
Volume in Faring	0.275	m^3	4.00	0.3	0.1	0.454	2.5	0.7	0.140	8.2	2.3	0.115	10.0	2.8
Lifetime	0.100	Years	17.0	10.0	1.0	10.0	10.0	1.0	10.0	10.0	1.0	33.0	10.0	1.0
Safety	0.250	Qualitative	Great	10.0	2.5	Good	8.0	2.0	Great	10.0	2.5	Great	10.0	2.5
System Cost	0.100	Million USD	0.891	3.4	0.3	15.0	0.2	0.0	0.300	10.0	1.0	0.500	6.0	0.6
Overall value					4.3			3.9			9.5			9.6

Power System Selected Solar Cell

- Selected 6 Junction Metamorphic Multi Junction
  - Conversion Efficiency: 37%
  - Tested Temperature: 300 K
    - Expected 319.25 K
  - 1 MeV Fluence: 4.46×10^{13}
    - Expected Lifetime to 15% degradation 33 years
  - Total of 4 Arrays
    - 2 Orbiter & 2 Lander



	Blanket Area	Total Mass	Power Production
Lander	144.9 m^2	1339.6 kg	25.31 kW
Orbiter	10.9 m^2	93.1 kg	1.90 kW

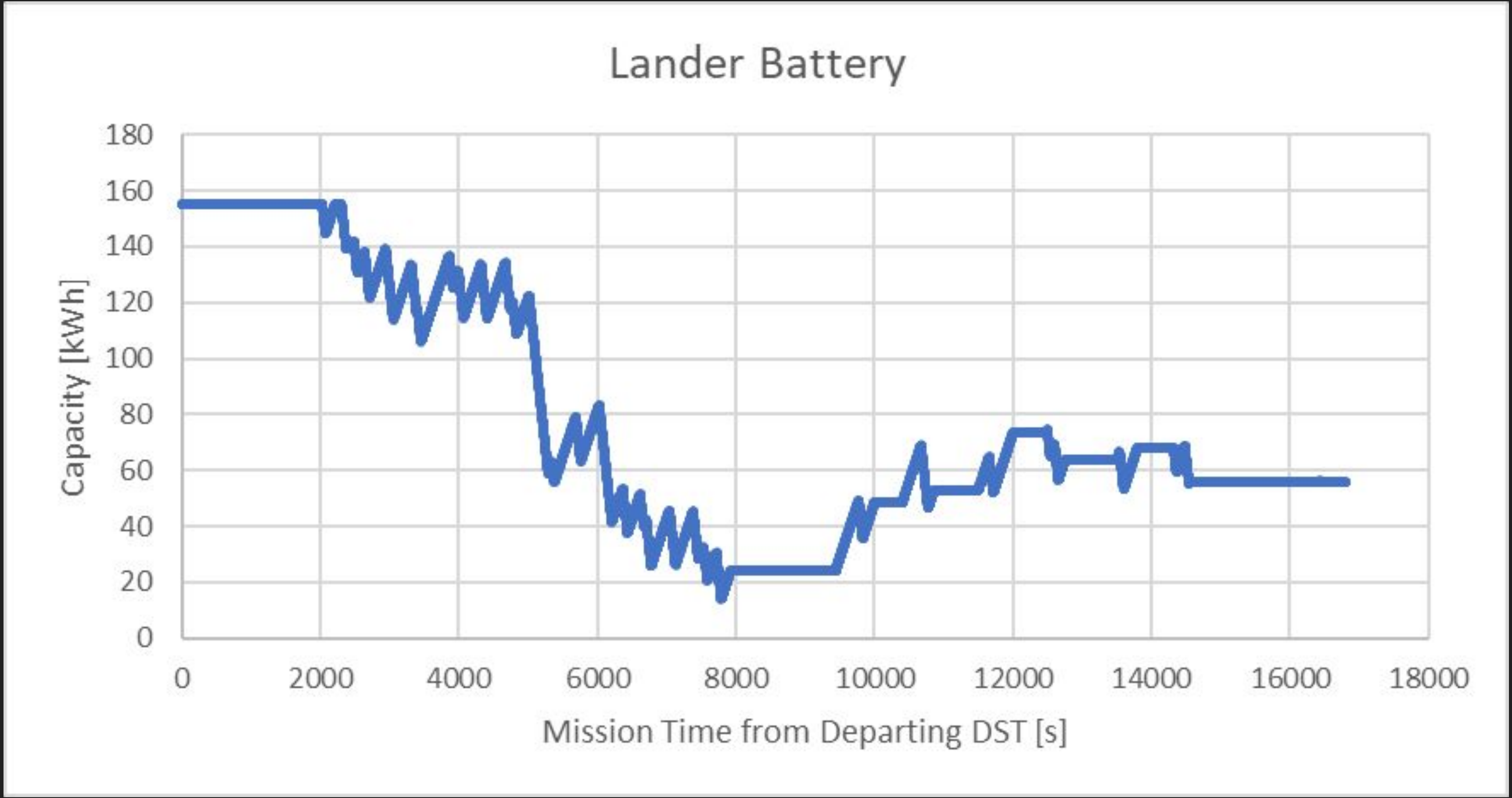
Discoloration	η_uv	0.98
Thermal Cycling	η_cy	0.99
Cell Mismatch	η_m	0.975
Cell Interconnections	η_I	0.98
Cell Contamination	η_con	0.99
Pointing Loss Factor	L_p	0.985
Operating Temp	η_t	0.91
Radiation Damage	η_rad	0.976

Power Systems Battery Selection

- Final Decision: Lithium-Ion cells with Silicon Nanowire Anode Technology

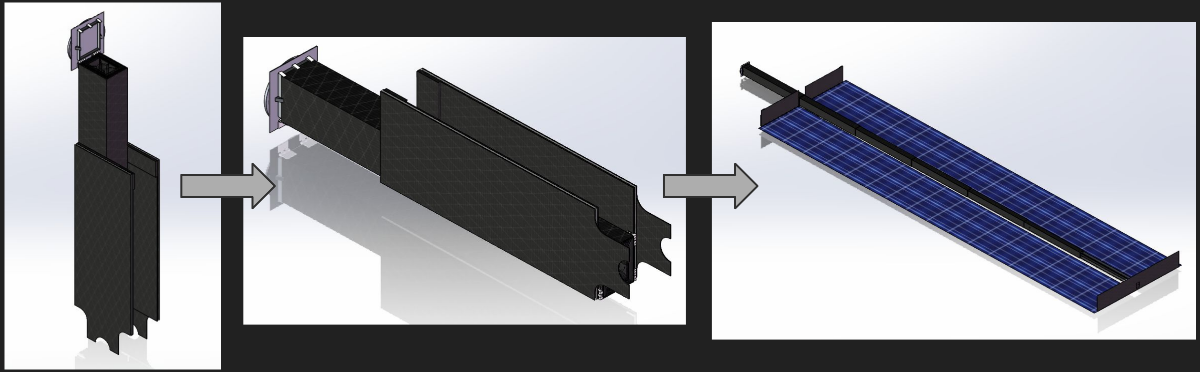
Operational Specific Energy	406 Wh/kg
Energy Density	1125 Wh/L
Lander Battery Pack Mass	381.7 kg
Lander Battery Capacity	155 kWh
Lander Battery Recharge Rate	4.5 kW
Orbiter Battery Pack Mass	24.63 kg
Orbiter Battery Capacity	10 kWh
Orbiter Battery Recharge Rate	0.5 kW

Battery System			Lithium ion			Nickel-Cadmium			Nickel-Hydrogen			Silver-Zinc		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Specific energy	0.30	Wh/kg	100	10.0	3.0	25	2.5	0.8	30	3.0	0.9	100	10.0	3.0
Energy density	0.25	Wh/L	250	10.0	2.5	100	4.0	1.0	50	2.0	0.5	150	6.0	1.5
Cycle life	0.10	50% DoD	1000	10.0	1.0	1000	10.0	1.0	1000	10.0	1.0	100	1.0	0.1
Operable Temperature Range	0.20	ΔK	60	10.0	2.0	40	6.7	1.3	40	6.7	1.3	40	6.7	1.3
Charge Efficiency	0.15	%	95	10.0	1.5	80	8.4	1.3	80	8.4	1.3	70	7.4	1.1
Overall value					**10.0**			**2.8**			**2.4**			**4.6**


Lander Battery
Capacity [kWh]
180
160
140
120
100
80
60
40
20
0
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Mission Time from Departing DST [s]

Power System Folding Method

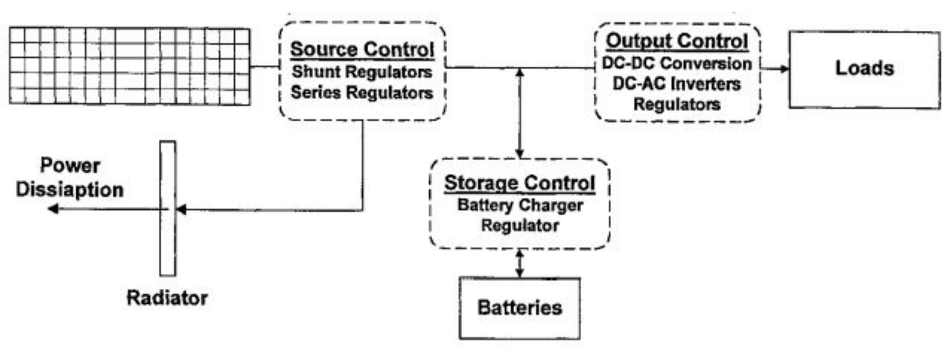
- Selected Compact Telescoping Array
  - Lander Motor Retractable
  - Orbiter Tension Cable Non-Retractable



Solar Array Fairing Folding Method (for 50 kW demand)			Compact Telescoping Array			Roll-Out Solar Array			ATK UltrAFlex Array			ISS Solar Array		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Structural Packaging Density	0.4	kW/m^3	60.00	10.0	4.0	51.40	8.6	3.4	33.00	5.5	2.2	12.00	2.0	0.8
Blanket Volume Fraction	0.3	Ratio	0.07	10.0	3.0	0.06	8.6	2.6	0.04	5.5	1.7	0.01	2.0	0.6
Structural Mass Fraction	0.3	Ratio	0.40	8.1	2.4	0.60	5.4	1.6	0.33	10.0	3.0	0.75	4.3	1.3
Overall value					**9.4**			**7.6**			**6.9**			**2.7**

Power Control Systems & Contingency

- Source Control: Control Solar Array Output
  - Peak Power Tracker
  - Disconnect Switch & Intellirupter
- Storage Control
  - Battery Charge Regulator
- Output Control: Control Bus Voltage
  - Fully Regulated Bus
- Contingency
  - Maximum expected peak power: 22.4 kW Lander, 1.68 kW Orbiter
    - 11.5% Contingency



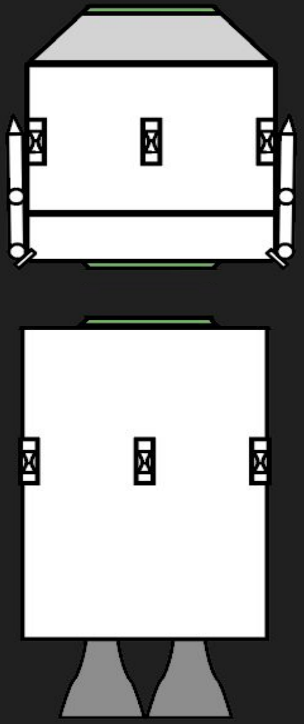
Power Control Losses DC to AC conversion	0.933
Power Control Peak Power Use	0.95

Transfer Efficiency - Array to Battery	0.790
Transfer Efficiency - Battery to Eclipse Loads	0.912
Transfer Efficiency - Array to Normal Loads	0.912

Structure

Staging

- Two Stage Design
  - Service Module - Remains in Orbit, Responsible for Large ΔV Maneuvers
  - Landing Module - Responsible for Landing and Precision Maneuvers
- Benefits
  - Resource Management and Optimization
  - Redundancy
  - Crew Space
  - Experimentation Opportunities
  - Cost
- Drawbacks
  - Orbital Planning Complexity and Station Keeping
  - ΔV Budget



Staging

			Single Stage			Multi Stage		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value
Delta-V Required	0.15	km/s	2.273	10.0	1.500	2.298	9.9	1.484
Resource Managment/Optimization	0.10	research	None	0	0.00	Great	10	1.00
Redundancy	0.10	research	Poor	2	0.20	Great	10	1.00
Crew Space	0.25	cubic m	5.7	6.951	1.74	8.2	10	2.50
Experimentation Opportunities	0.15	research	Okay	6	0.90	Great	10	1.50
Orbital Planning Difficulty	0.15	maneuvers	7	10	1.50	17	4.1	0.62
Cost	0.10	Million $	228.4	8.153	0.82	186.2	10	1.00
Overall value					**6.65**			**9.10**

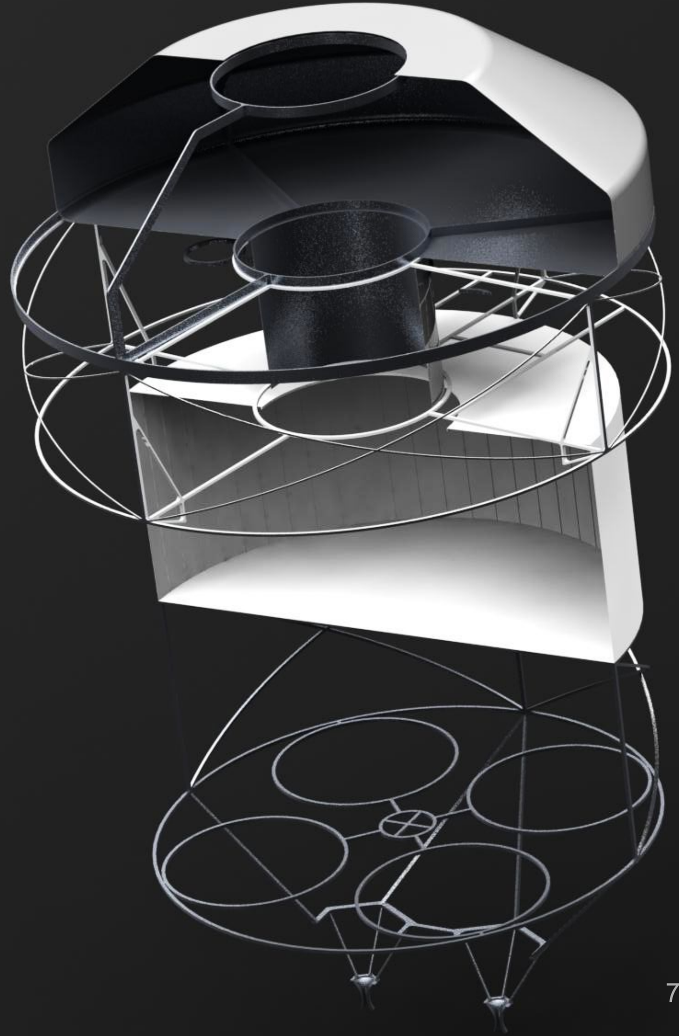
Material Selection

- Aluminum Alloys
  - Extremely Light Weight
  - Excellent Heat Treatment Options
  - Wide Selection of Alloys for a Variety of Properties
  - Inexpensive
  - High Thermal Conductivity

Structure Shell			2219-T851 AL			6061-T6 AL			7075-T73 AL			2024-T3 AL		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Density	0.3	g/cm^3	2.9	9.5	2.9	2.7	10	3	2.8	9.68	2.9	2.78	9.7	2.9
Allowable Tensile Ultimate Stress	0.25	MPa	420	9.1	2.3	290	6.3	1.6	460	10	2.5	430	9.3	2.3
Allowable Compressive Yield Stress	0.25	MPa	320	8.4	2.1	240	6.3	1.6	380	10	2.5	280	7.4	1.8
Modulus of Elastcity	0.1	GPa	72	10	1	69	9.6	1	71	10	1	73	10	1
Coefficient of Thermal Expansion	0.1	10-6/°C	22.1	9.5	1	22.9	9.9	1	22.1	9.5	1	23.2	10	1
Overall value					**9.2**			**8.1**			**9.8**			**9.1**

Support Structure

- Desirable Properties:
  - Lightweight
  - Rigid
  - Resistant to Common Modes of Failure
  - Efficient Stress Transfer
  - Integration With Other Subsystems
- Trusses For Non-Pressurized Areas
- Semi-Monocoque for SM Crew Cabin
- Internal Support Frame for LM Crew Cabin
- Minimum Factor of Safety of 1.65



Hull Design

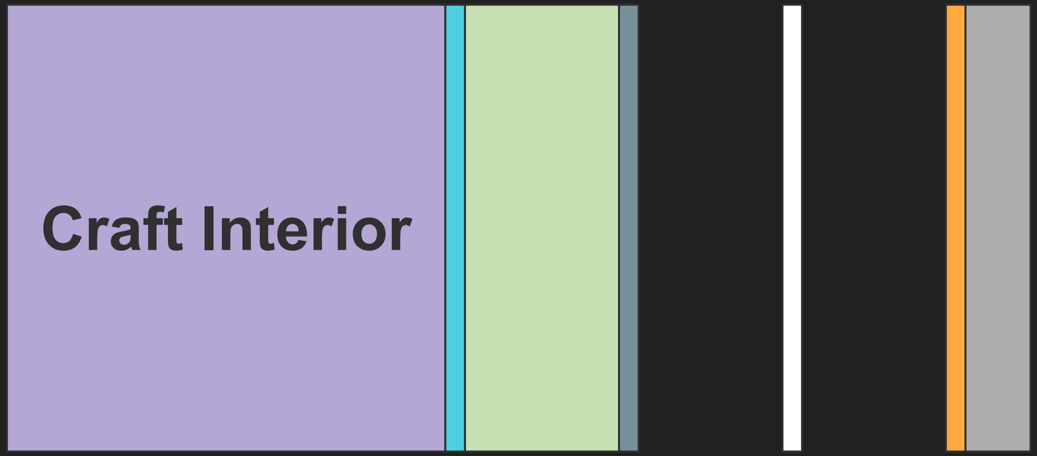
WALL DESIGN			Single Wall			Whipple			Stuffed Whipple			Inflatable		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Areal Density	0.35	Qualitative	Great	10	3.50	Okay	6	2.10	Fair	4	1.40	Fair	4	1.40
Impact Resistance	0.20	Qualitative	Poor	2	0.40	Okay	6	1.20	Great	10	2.00	Okay	6	1.20
Radiation Reduction	0.30	Qualitative	Poor	2	0.60	Poor	2	0.60	Good	8	2.40	Great	10	3.00
Thickness	0.15	Qualitative	Great	10	1.50	Okay	6	0.90	Okay	6	0.90	Poor	2	0.30
Overall value					**6.00**			**4.80**			**6.70**			**5.90**

BACKING WALL			Aluminum			UHMWPE			Metallic Glass			Al-Lined UHMWPE		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Mean Density	0.25	kg/m^3	2705	3.51	0.88	950	10.00	2.50	6100	1.56	0.39	1050	9.05	2.26
Burst Resistance	0.25	Qualitative	Great	10	2.50	Okay	6	1.50	Fair	4	1.00	Good	8	2.00
Relative Radiation Dose (SPE 10-1989)	0.40	Sv	9.35	6.48	2.59	6.06	10.00	4.00	13.1	4.63	1.85	6.12	9.90	3.96
Cost of Material	0.10	$/kg	2.69	3.28	0.33	0.82	10.00	1.00	33.08	0.25	0.02	0.93	8.86	0.89
Overall value					**6.30**			**9.00**			**3.26**			**9.11**

BETA CLOTH			Ceramic/Para-aramid			Fiberglass/Para-aramid			UHMWPE		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Areal Density Per Layer	0.30	kg/m^2	0.188	5.80	1.74	0.294	3.71	1.11	0.109	10.00	3.00
Average Fiber Strength	0.20	MPa	3300	10.00	2.00	1770	5.36	1.07	2900	8.79	1.76
Outgassing (Total Mass Loss)	0.20	%	2.77	4.98	1.00	3.13	4.41	0.88	1.38	10.00	2.00
Relative Radiation Dose (SPE 10-1989)	0.30	Sv	10	9.30	2.79	10.5	8.86	2.66	9.3	10.00	3.00
Overall value					**7.53**			**5.72**			**9.76**

Hull Design

- Advanced Stuffed Whipple Design
- Multilayer Insulation (MLI) Provides Insulation and Radiation Protection
- Lined Composite Overwrap Pressure Vessel (COPV) Design Allows Mass Reduction Compared to Traditional Construction Techniques
- Outer Aluminum Wall and Ultra-High Molecular Weight Polyethylene (UHMWPE) Beta Cloth Provide Micrometeorite Protection



- Inner Aluminum Wall
- UHMWPE Pressure Vessel
- Carbon Fiber Overwrap
- UHMWPE Beta Cloth
- MLI
- Outer Aluminum Wall

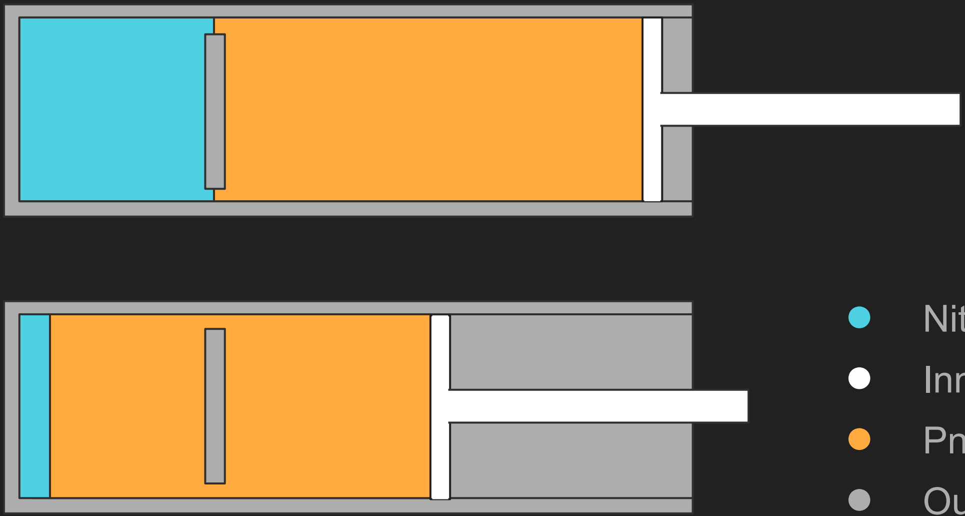
Landing Legs

- Desired Traits
  - Simplicity to Reduce Likelihood of Failure
  - Recoil Prevention to Ensure No Bouncing Occurs
  - Minimum Mass

Landing Legs			**Fixed Metal**			**Friction Stroke**			**Pneumatic**			**Crushed Honeycomb**		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Complexity	0.10	Qualitative	Great	10.00	1.00	Okay	6.00	0.60	Fair	4.00	0.40	Okay	6.00	0.60
Recoil Prevention	0.40	Qualitative	Poor	2.00	0.80	Okay	6.00	2.40	Great	10.00	4.00	Okay	6.00	2.40
Efficiency	0.30	%	8	1.14	0.34	15	2.14	0.64	70	10.00	3.00	40	5.71	1.71
Mass (Standardized Dimensions)	0.20	kg	2.18	10.00	2.00	4.36	5.00	1.00	13.43	1.62	0.32	4.79	4.55	0.91
Overall value					**4.14**			**4.64**			**7.72**			**5.62**

Landing Legs

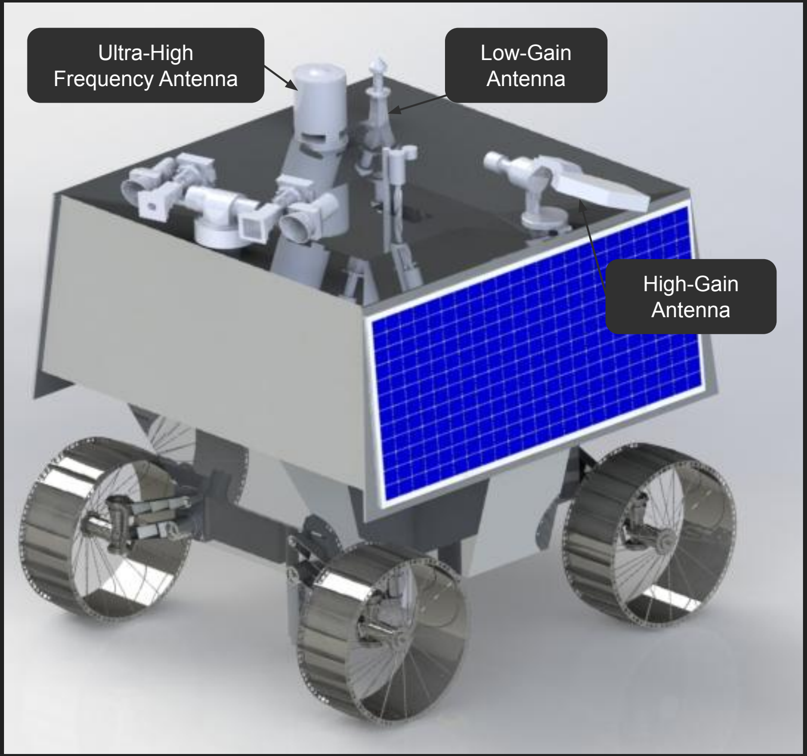
- Three Degrees of Freedom Ensures Maximum Deceleration and Firm Footing
- Oleo-Pneumatic Structure Allows Significant, Non-Destructive Deceleration



- Nitrogen
- Inner Piston
- Pneumatic Fluid
- Outer Cylinder

Telecommunication System

- Ultra-High Frequency Antenna
  - Communication with service module in lunar orbit
  - Primary communication during mission sortie
- High-Gain Antenna
  - Communication direct to Earth
  - Communication with DST en-route to Mars
  - Primary communication with rover post-mission
- Low-Gain Antenna
  - Communication direct to Earth
  - Omni-directional - provides robust means of communication



Launch Vehicle

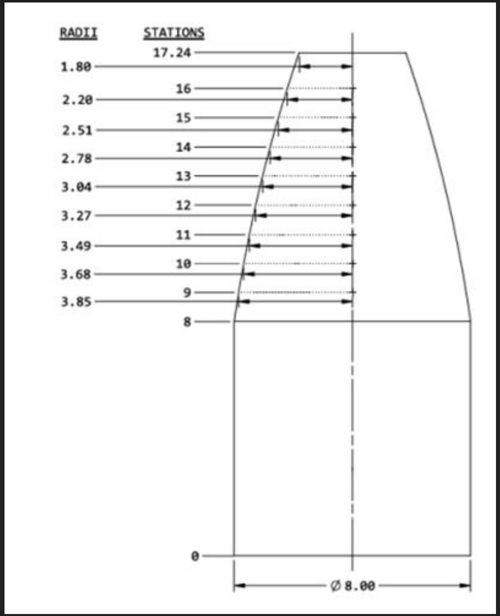
Payload Mass Estimate

- Mass
  - Wet: 49,831 kg
  - Dry: 14,927 kg
  -
- Fairing Size Requirement
  - Max Radius: 3.77 m
  - Height: 12.53 m
- Masses Brought from DST
  - 7.2 kg Veggie Plant Chamber
  - 130 kg Two Astronauts
  - 138 kg Food

Classification	Item	Mass (kg)
ECLSS Crew Accommodations	Galley and Food System	9.8E+01
ECLSS Crew Accommodations	Personal Hygiene	1.3E+01
ECLSS Crew Accommodations	Recreational Equipmet and Personal Stowage	1.0E+02
ECLSS Crew Accommodations	Housekeeping	2.2E+01
ECLSS Crew Accommodations	Operational Supplies and Restriants	5.7E+01
ECLSS Crew Accommodations	Maintenance	5.5E+02
ECLSS Crew Accommodations	Sleep Acommodations	3.1E+02
ECLSS Crew Accommodations	Crew Health Care	1.1E+01
ECLSS Support Systems	Fire Response System	1.5E+01
ECLSS Support Systems	Oxygen Generation System	6.9E+01
ECLSS Support Systems	Air Revitalization System	2.5E+02
ECLSS Support Systems	Pressure Control System	9.3E+01
ECLSS Support Systems	Water Recovery System	5.0E+02
ECLSS Support Systems	Waste Collection	6.2E+01
EEV Scientific Equipment	OCSIS & LOLA	7.9E+01
Moon Rover	Scientific Equipment (Spectrometers & Cameras)	3.1E+01
Moon Rover	Assembly (Body, Wheels, Power System)	4.3E+02
Moon Rover	Sample Retrieval Mechanism	4.8E+01
EEV Rover Components	Rover Ramp	7.0E+01
EEV Rover Components	Sample Caching Storage and Transport	6.4E+01
Thermal System	Temperature and Humidity Control	1.8E+02
Thermal System	Complete Thermal System	3.1E+03
Telecommunications	Data Storage and Signaling Hardware	5.0E+02
Telecom & Power Distribution	Data and Power Cableing	9.2E+02
Power System	Power Control & Distribution System Hardware	1.6E+03
Power System	All Orbiter & Lander Arrays Including Motors	1.4E+03
Power System	Secondary Li-ion Batteries	4.1E+02
Propulsions	2 Aestus II Engines	2.2E+02
Propulsions	Fuel Storage	3.5E+04
Altitude Control System	4 Orbiter ACS Cluster Modules	4.4E+01
Altitude Control System	4 Lander ACS Cluster Modules	4.4E+01
Structures	Docking & Berthing Mechanisms	1.4E+03
Structures	Lunar Module Legs	2.6E+02
Structures	Radiation Protection LM	4.0E+02
Structures	LM Body, Supports, Wire Frames	6.6E+02
Structures	Orbiter Body and Wire Frames	8.9E+02
Guidance Navigation and Control	Star Tracking & Terrain Mapping Hardware	1.9E-01
TOTAL WET MASS		**4.9831E+04**
TOTAL DRY MASS		**1.4927E+04**

Trade Study and Selection

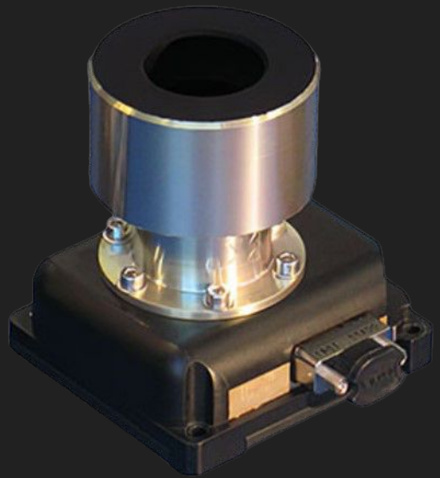
- Starship Selected
  - Meets mass requirement for one trip if fuel transfer
  - Is expected to cost $257,000,000 to launch EEV
  - Meets height and radius constraint on fairing



LAUNCH VEHICLE			SLS Rocket			Saturn V			Starship			Falcon Heavy			New Glenn		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Fairing Height	0.23	meter	31.0	10.0	2.3	8.5	6.8	1.5	17.2	10.0	2.3	13.1	10.0	2.3	13.0	10.0	2.3
Fairing Max Radius	0.23	meter	10.0	10.0	2.3	6.6	8.8	2.0	8	10.0	2.3	5.2	6.9	1.6	7	9.3	2.1
Availability	0.10	Qualitative	Good	8.0	0.8	Poor	2.0	0.2	Great	10.0	1.0	Great	10.0	1.0	Great	10.0	1.0
Cost	0.45	$/kg to MTO	43478.26	1.2	0.6	30750.00	1.7	0.8	5357.14	10.0	4.5	5357.14	10.0	4.5	13333.33	4.0	1.8
Overall value					**5.9**			**4.5**			**10.0**			**9.3**			**7.1**

Guidance, Navigation, and Control

EEV Navigation and Guidance System

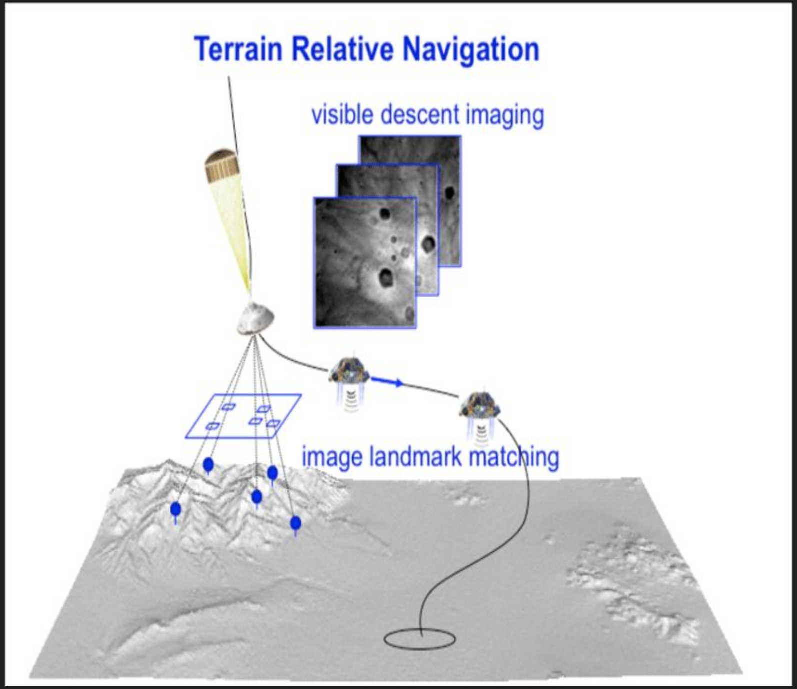


- Small perturbations from the gravity of Mars, Deimos, Phobos, and the Sun affect the orbit of the EEV
- Navigation system is required to keep EEV in a circular orbit and on track when transferring to destination
- Star Tracker Navigation system
  - Second Generation Star Tracker (ST-16RT2) - Sinclair Interplanetary

Star Tracker			Star Tracker VST-41M			Star Tracker VST-68M			ST-16RT2 - Short Baffle		
Objective	Weighting Factor	Parameter	Mag.	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Power Consumption	0.3	W	2.5	7	2.1	3	6	1.8	1	10	3
Volume	0.2	m^3	0.00144	5	1	0.000497	7	1.4	0.000236	9	1.8
Field of View	0.2	degrees	14 x 14	10	2	14 x 14	10	2	8 x 8	6	1.2
Accuracy	0.3	arcsec	18	5	1.5	5	10	3	5	10	3
Overall Value					**6.6**			**8.2**			**9**

Landing Module Navigation and Guidance System

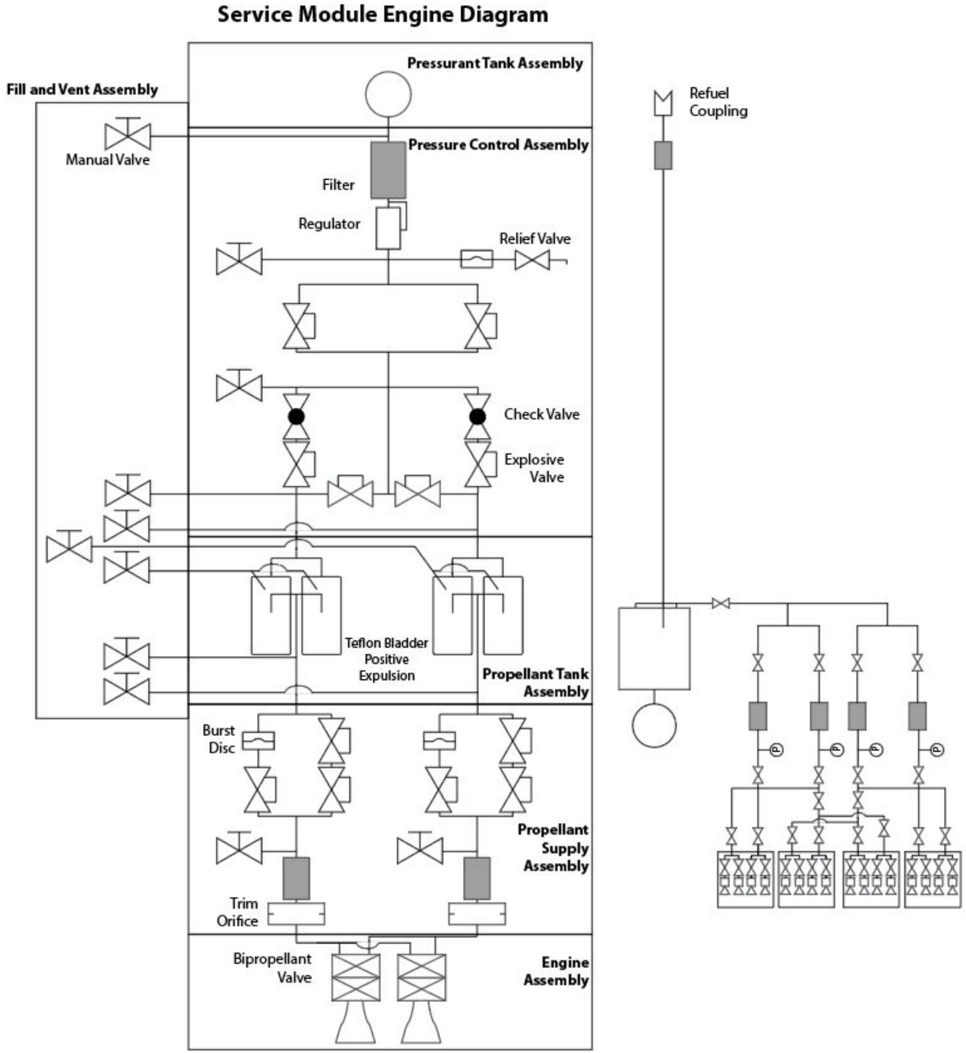
- Needed in order to ensure the landing module lands in a viable spot within decided landing zone
- Terrain Relative Navigation (TRN) used for entry and landing on the surface of each moon
    - Used on the Perseverance rover



Dust mitigation

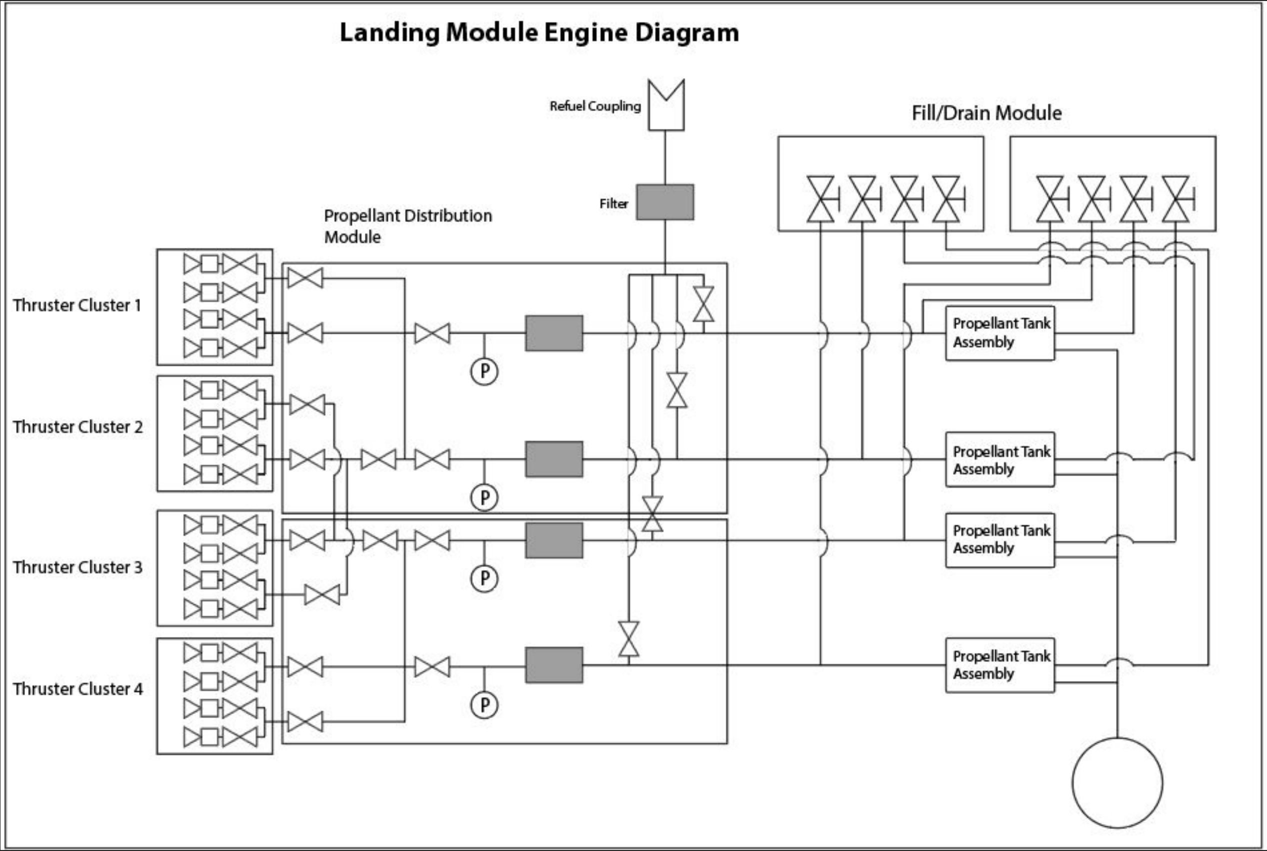
- Simple canvas covers for exposed instrumentation
  - Star Trackers
  - TRN
- Stow solar panels and radiators for landing operations
  - Redeploy on surface

APPENDIX



Piping and Instrumentation (P&ID)

Piping and Instrumentation (P&ID)



Thermal Load Breakdown

Lander

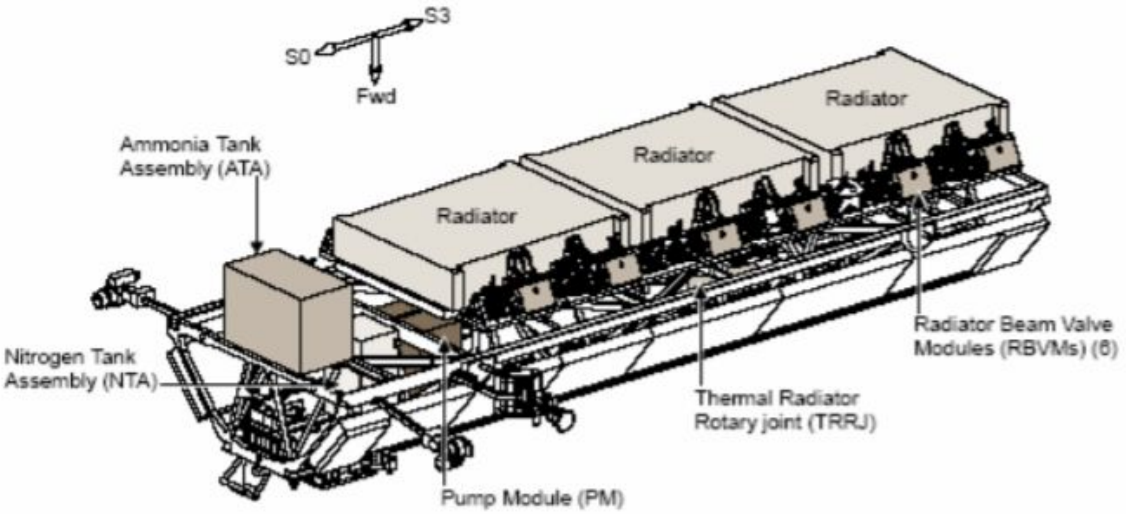
Lander	Thermal Load (kW)
Pressure Control	0.131579
Air Revitalization System	5.394737
Fire Response System Fire Detector	1.18E-05
Oxygen Generation System Structure	0.789474
Primary Water Procesessor	2.894737
Water Quality Monitor	0.078947
Wet Waste Processing (Toilet)	0.059211
Housekeeping Vaccum	0.526316
Personal Stowage Closet Space	0.921053
Gally and Food System Microwave	1.184211
Maintenance Test Equipment	1.315789
Veggie Plant Growth Chamber	0.151316
Solar Array Linear Actuator Lander	0.315789
ECLSS Active Heat Transport Control	0.657895
Complete Thermal System Lander	7.868421
Lander (12 valves)	0.328799
Lander Heating (4 valves)	0.041484
Battery Charging Losses Lander	1.572463
Array to Loads Losses Lander	2.864648
Peak Power Tracker System	1.540679
Battery Charging Req Lander	5.921053
Lander Telecom System	0.131579
Star Tracker System	0.001316
Terrtain Relative Navigation	0.526316

Orbiter

Orbiter	Thermal Load (kW)
Orbiter Metric Camera	0.053947
Lunar Orbit Laser Altimeter	0.046053
Complete Thermal System Orbiter	0.657895
Orbiter (12 valves)	0.844737
Orbiter (4 valves) heating	0.106579
Battery Charging Losses Orbiter	0.174718
Array to Load Losses Orbiter	0.320675
Battery Charging Req Orbiter	0.657895
Orbiter Telecom System	0.131579
Main Engine Orbiter	0.824671

EATCS System Configuration Example

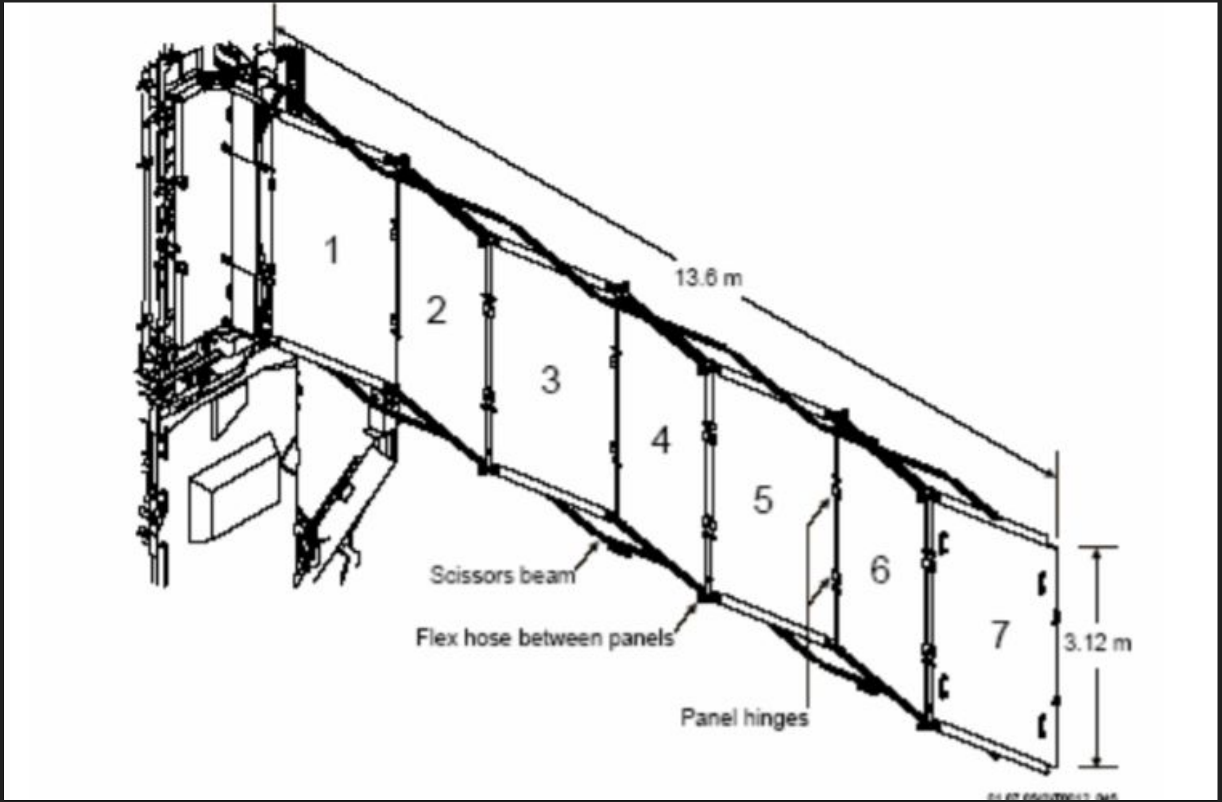
Fluid Supply

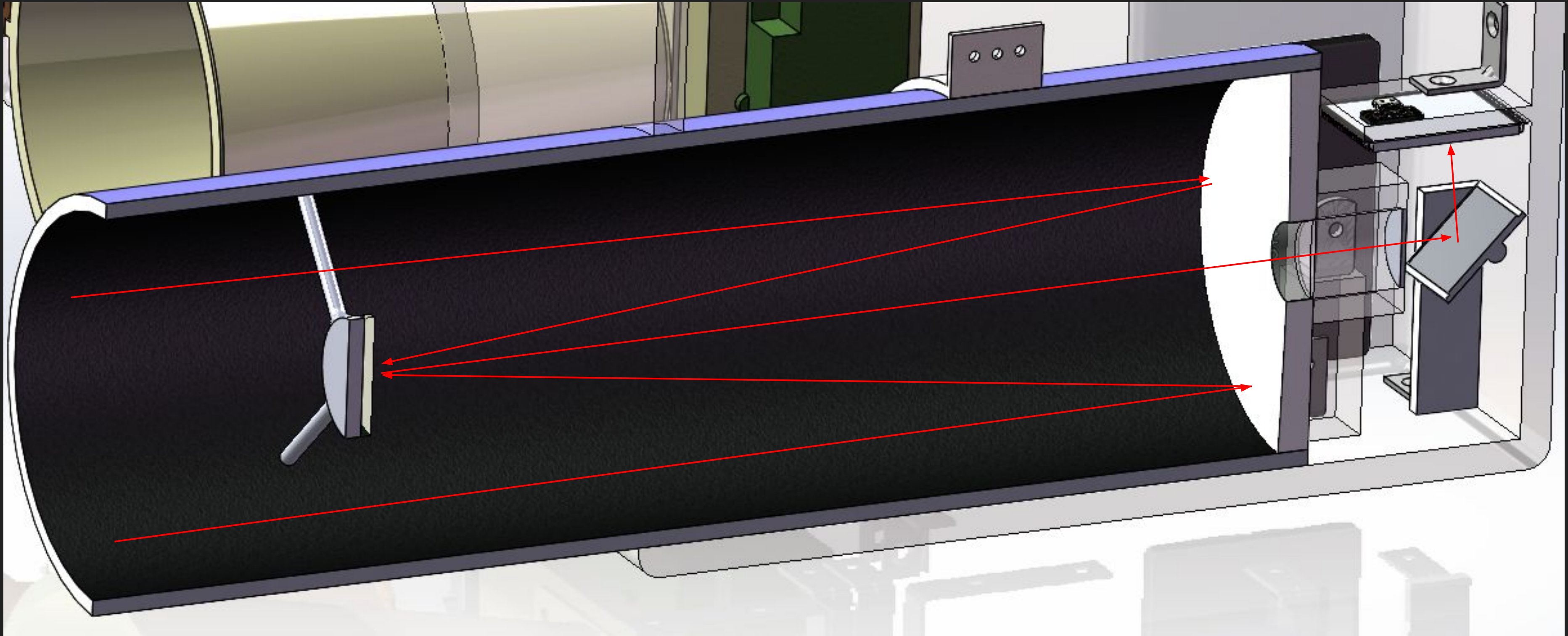


Note: Loop A components on the S1 Truss segment shown. Loop B components on the P1 Truss segment are identical; however, the orientation is reversed. All three radiators are retracted.

Ammonia re-supply capability for the EATCS and the eight PVTCS located on P6, P4, S4 and S6 is provided by the **Ammonia Tank Assembly (ATA).**

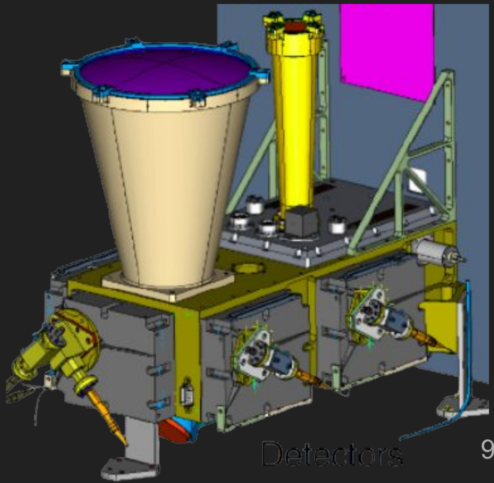
Radiator (EATCS)





Lunar Orbiter Laser Altimeter (LOLA)

- Based on Lunar Reconnaissance Orbiter Laser Altimeter
- How it works
  - Transmitter (right) pulses a laser through a diffractive lens that splits it into 5 beams
  - Beams are reflected off lunar surface and return to the Receiver (left)
- Data Collected
  - LOLA measures time of flight, pulse spreading, return energy of each laser to determine altitude, surface roughness, and surface sloping
- Working with the camera system
  - Works with camera system to determine instantaneous altitude for camera adjustments
  - Mounted Parallel to Metric Camera toward the orbiter's nadir
- Functions autonomously



Crew Habitation

- ISS Crew Quarters
  - Ventilation
    - Uses cabin air for ventilation
    - Use fans with three speeds to increase air flow rate
      - Low (1.8 m^3/min)
      - Medium (2.3 m^3/min)
      - High (2.6 m^3/min)
  - Acoustic Blankets
    - Interior blankets: Gore-Tex®, Kevlar felt, Nomex®
    - Exterior blankets: Gore-Tex®, BISCO®, durette felt, Nomex®

Crew Habitation

- ISS Crew Quarters
    - Radiation Shielding
        - UHMWPE “bricks”
            - 35 cm x 35 cm x 2.54 cm
            - Two bricks are pinned together for a thickness of 5.08 cm
            - Wrapped in a Nomex® sleeve and aluminum tape
        - Brick configuration is considered a crew preference (all configurations are acceptable)
            - Configurations that provide the most protection:
                - 6 bricks on back wall (high)
                - 2 on floor, 3 vertically on back wall, 1 on sleep wall (med/high)

Crew Habitation

- ISS Crew Quarters
  - Lighting Requirements
    - 0.5 Lux during a Class 1 alarm or loss of electrical power
    - 108 Lux in general area
    - 323 Lux on reading surfaces
    - Lighting is adjustable
  - Caution and Warning System
    - 3 Speakers
      - 2 for Class 1 alarms
      - 1 for Class 2 and Class 1 alarms
        - Also serves
    - 4 Airflow monitoring devices
      - Detect mechanical failure of the fans
      - Detect airflow failure

Crew Health

- There is a concept of how deep space medical technology should be
  - There will be a minimum of one fully licensed physician
  - All of the crew must have an undetermined level of medical training
  - Equipment shall be easy to operate and shall keep the user well informed of the situation
    - Should be able to guide the user through various procedures including surgery

- A guide on how to develop ethical medical standards is available
  - “Health Standards for Long Duration and Exploration Flight" by the Institute of Medicine
  - Design will evolve depending on the regulations implemented with this guide

Convenience Medication Pack

- Antibiotics
- Antidiarrheal
- Antihistamine
- Decongestants
- Lubricants
- Pain Relievers
- Sleep Aids
- Steroids
- Stimulants

Oral Medication Pack

- Altitude Sickness
- Antibiotics
- Antifungals
- Antihistamines
- Antiseizure
- Antiviral
- Behavioral Health
- Cardiac
- Decongestant
- Hormone
- Pain Relievers
- Anti-Nausea
- Steroids
- Stimulants
- Stomach
- Urinary

Emergency Medical Treatment Pack

- ALS Medication Kit
- Severe Allergic Reaction
- Basic Airway Management
- Nasal Airway Kit
- Biohazard Trash Bags
- General Use
- Intraosseous Device Start Kit

Emergency Medical Treatment Pack

- ALS Medication Kit
- Sever Allergic Reaction
- Basic Airway Management
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- Biohazard Trash Bags
- General Use
- Intraosseous Device Start Kit

Trace Contaminant Control System (TCC)

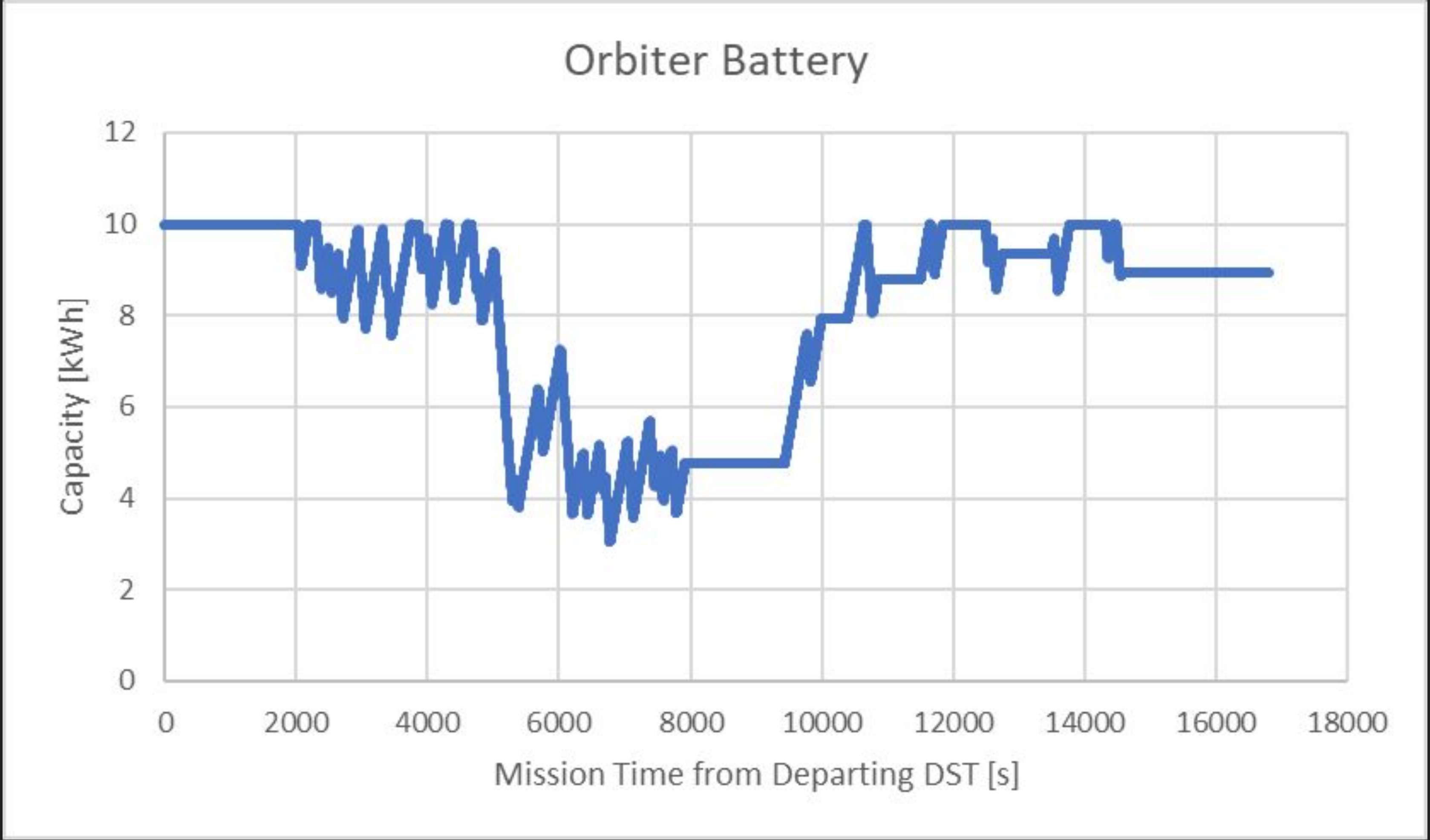
- Inactive period between launch and DST arrival (1088 days)
  - Due to inactive systems, contamination builds up in the atmosphere
  - SMAC levels will be above allowable limits when the DST arrive
  - J. L. Perry, “Trace Contaminant Control for the International Space Station’s Node 1 – Analysis, Design, and Verification,” NASA, Huntsville, Alabama, USA, Rep. TP-2017-218235, Apr. 2017.
    - Inactive period of 455 days
    - Ventilation between the EEV and the DST for 24 hours
      - Toxic hazard index to is reduced to 1 or below
  - Ventilation between the EEV and DST is required for a minimum of 3 days before crew can enter to begin system check

Radiation Shielding

- Active Shielding
  - Very new field of research
  - Based on earth’s magnetic field. Will provide magnetic field to deflect radiation
  - Expected to reduce structural, mass, and power requirements
    - Less passive shielding needed
    - The biggest challenge is reducing the mass of the coil
    - Cryocooler will have to be developed to maintain coil temperature
  - Currently being researched for larger vehicles such as the DST
    - It’s already thought of as the probability for protecting from deep space radiation
    - Later on, smaller systems for vehicles such as the EEV will be researched

Radiation Shielding

- Storm Shelter
  - In case of random large SPE expected to last 36 hours
  - Concept uses available resources
    - Food, water, human waste, brine, etc.
    - The more hydrogen the better
    - Prevents an increase in mass
  - Will be built in the “thickest” area of the cabin
    - Expected to be where most ECLSS systems are located
      - Particularly the WRM
  - Crew will receive an hours notice from ground control to begin building shelter
    - Will house both crew members
  - To know the maximum radiation reduction of the structure, a Discrete Event Simulation (DES) must be performed to quantify logistics, food, water and waste product.


Orbiter Battery
Capacity [kWh]
12
10
8
6
4
2
0
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Mission Time from Departing DST [s]

Material/Layer	Absorptivity	Conductivity Coefficient [W/mK]	Thickness [m]	Transmissivity
Low Iron Glass	0.01	12	2.00E-04	0.91
Cu+Ag+Hg Contact	0.15	300	2.00E-04	0.85
InGaAs bottom Cell	0.5	5	3.00E-06	0.5
GaAs middle Cell	0.4	65	1.00E-06	0.6
Tunnel Junction	0.017	60	3.50E-06	0.983
GaInP top cell	0.04	73	3.00E-06	0.96
Adhesive	0.02	50	5.00E-04	0.98
Substrate	1	44	3.50E-04	0

AalLnP Window	2.50E-06	m
GaInP BSF Thickness	3.00E-06	m
Buffer Thickness	2.00E-06	m
Total Thickness	1.47E-03	m

Low Iron Glass

P++ InGaAs contact

GaInP BSF

InGaAs Bottom Cell

AlGaInAs Graded Buffer

P++/N++ GaAs Tunnel Junction

GaAs middle cell

P++/N++ AlGaAs Tunnel Junction

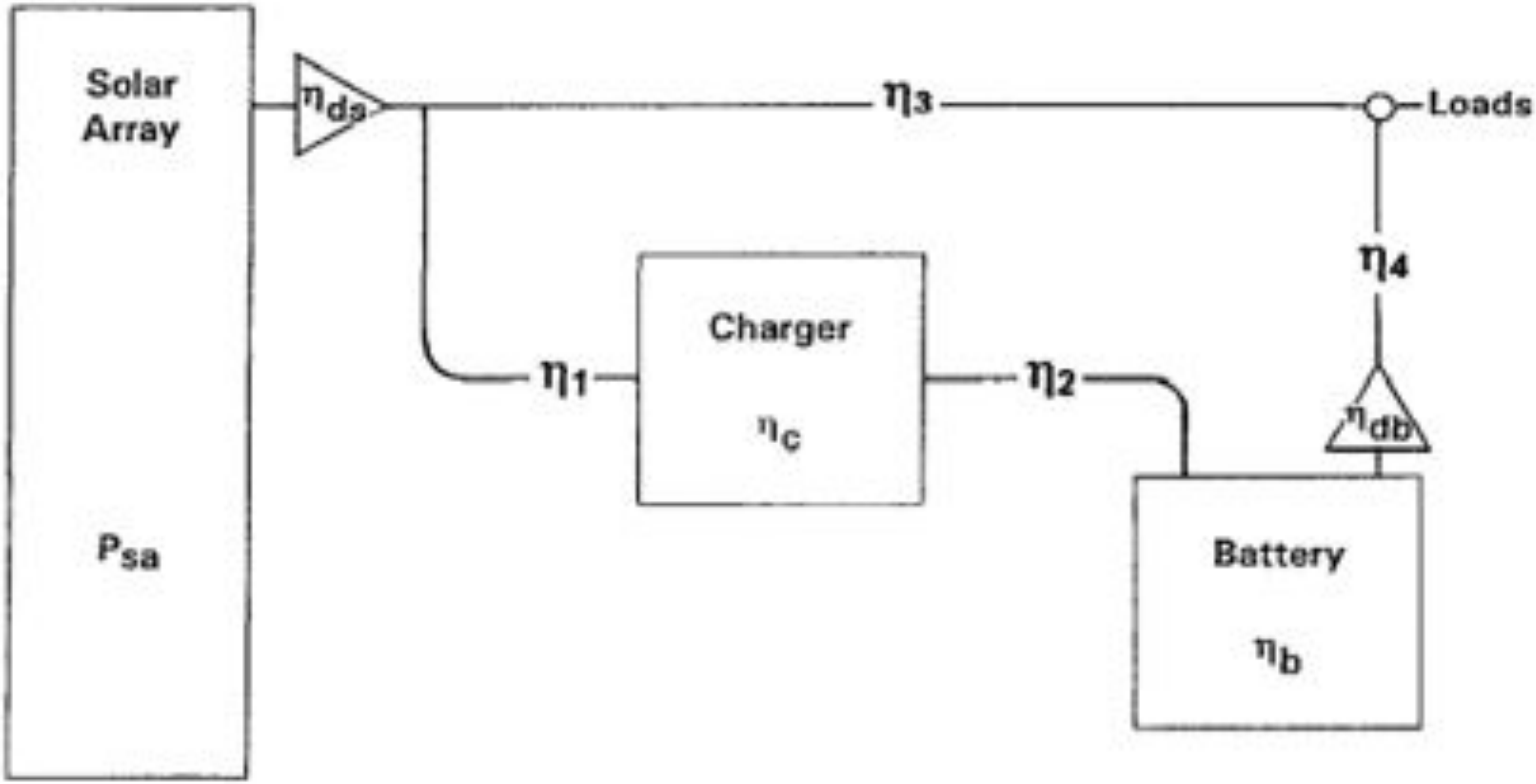
GaInP top cell

AlInP Window

N++ GaAs Contact

Adhesive

N++ GaAs Substrate


Solar Array
P_{sa}
η_{ds}
η_3
Loads
η_4
Charger
η_c
η_1
η_2
η_{db}
Battery
η_b

Equivalent Fluence Power System

Radiation Estimate		
Proton Energy (MeV)	Complete Fluence (1/cm^2)	EQIV 1MeV
9.00E-04	7.91E+15	7.12E+12
1.00E-03	6.74E+15	6.74E+12
2.00E-03	2.35E+15	4.70E+12
5.00E-03	5.82E+14	2.91E+12
1.00E-02	2.03E+14	2.03E+12
2.00E-02	7.06E+13	1.41E+12
5.00E-02	1.75E+13	8.75E+11
1.00E-01	6.09E+12	6.09E+11
2.00E-01	2.12E+12	4.24E+11
5.00E-01	5.26E+11	2.63E+11
1	1.83E+11	1.83E+11
4	5.99E+10	2.40E+11
10	2.38E+10	2.38E+11
Equivilent Fluence	4.46E+13	MeV