Space Architecture

Master's Thesis Project

Jain, Abhishek Dec. 2nd, 2013

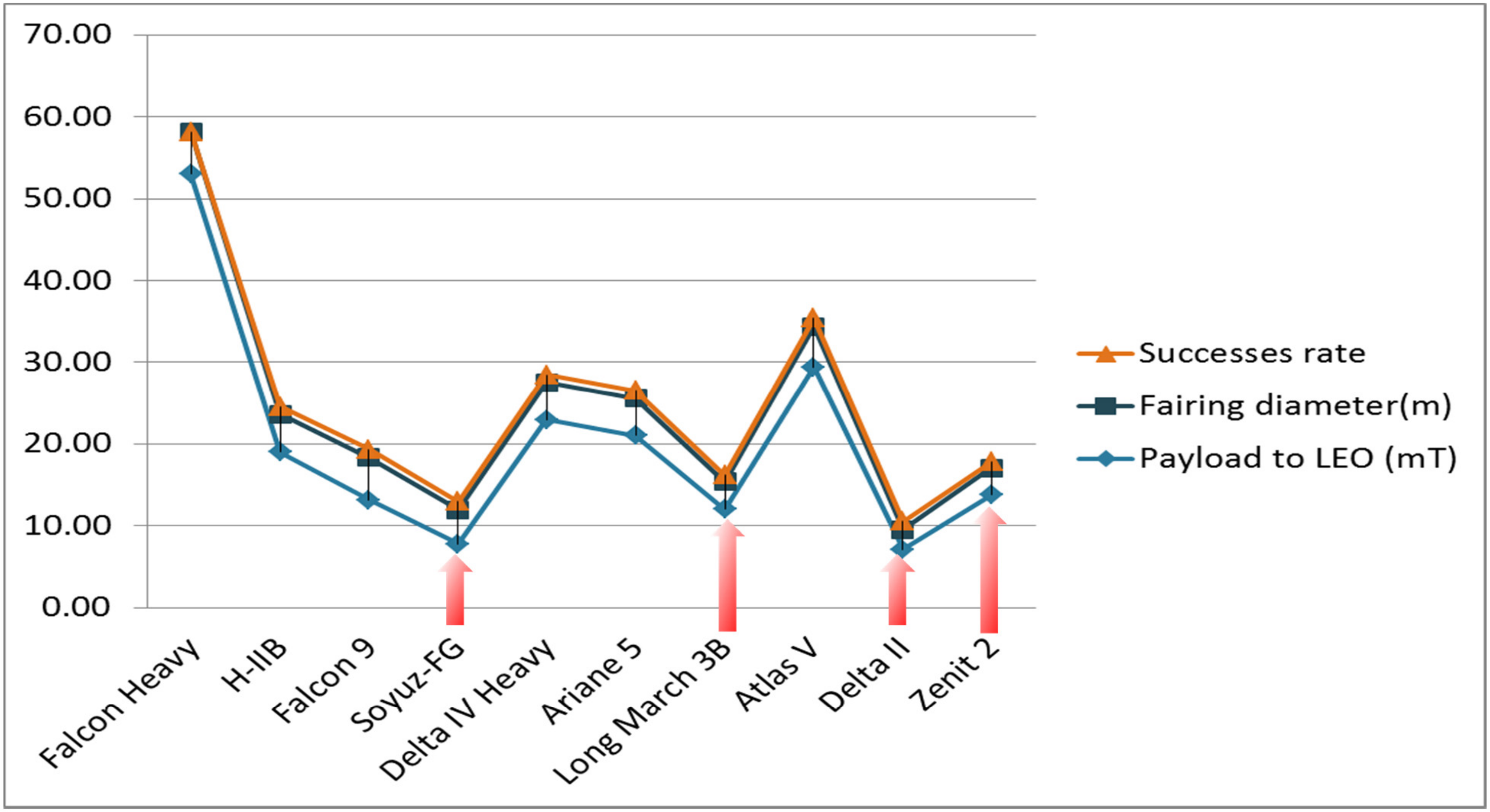
SICSA Sasakawa International Center for Space Architecture
University of Houston College of Architecture

Contents

Medium Lift Launch Vehicles Study

Funding	Status	Producer	Country	Vehicle name	Payload to LEO (mT)	Fairing diameter(m)	Successes rate
Private	Under dev	Space-X	US	**Falcon Heavy**	**53.00**	**5.2**	0%
Government	Active	Mitsubishi Heavy Industries	Japan	**H-IIB**	**19.00**	**4.6**	100%
Private	Active	Space-X	US	**Falcon 9**	**13.15**	**5.2**	100%
Government	Active	TsSKB-Progress	Russia	**Soyuz-FG**	**7.80**	**4.11**	100%
Private/Government	Active	United Launch Alliance	US	**Delta IV Heavy**	**22.95**	**4.57**	95%
Government	Active	ESA (Astrium)	EU	**Ariane 5**	**21.00**	**4.57**	94%
Government	Active	CALT	China	**Long March 3B**	**12.00**	**3.35**	80%
Government	Active	United Launch Alliance	US	**Atlas V**	**29.40**	**5**	97%
Government	Active	United Launch Alliance/Boeing	US	**Delta II**	**7.10**	**2.44**	98%
Government	Active	Yuzhnoye Design Bureau	Ukraine	**Zenit 2**	**13.74**	**3.3**	71%

Medium Lift Launch Vehicles Comparison

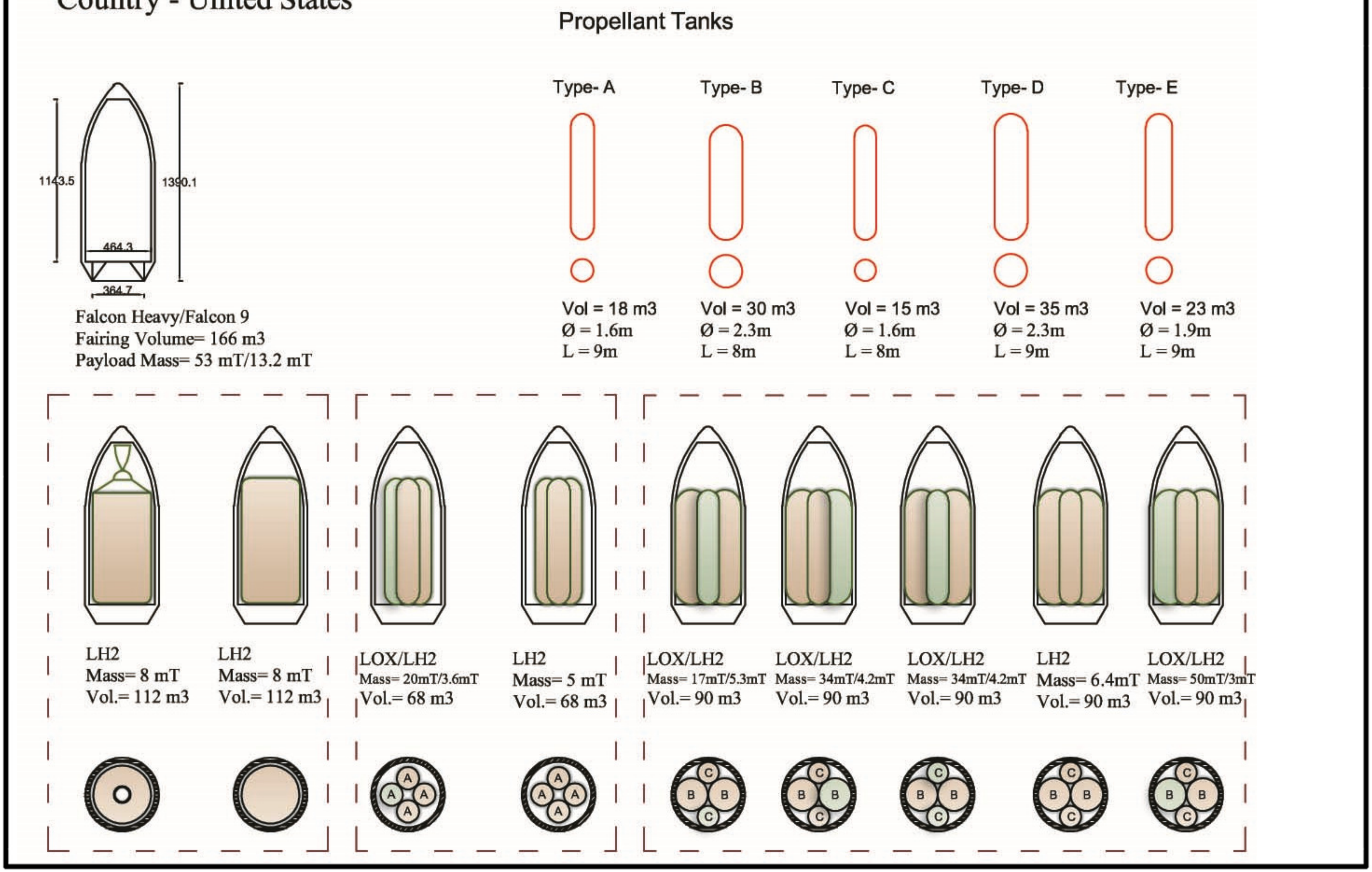


LV Selection Criteria

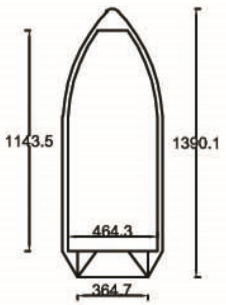
- Capable of human crew transfer
- Maximum payload carrying capacity to LEO < 55,000 Kg
- Preference given to currently active Launch Vehicles
- In order of decreasing fairing diameter
- Success rate

Funding	Status	Producer	Country	Vehicle name	Payload to LEO (kg)	Payload to GTO (kg)	Fairing diameter	Successes rate
Private	Active	Space-X	US	**Falcon 9**	**11,500**	7,000	5.2	100%
Government	Active	United Launch Alliance	US	**Atlas V**	**29,400**	13,000	5	97%
Government	Active	Mitsubishi Heavy Industries	Japan	**H-IIB**	**19,000**	8,000	4.6	100%
Government	Active	ESA (Astrium)	EU	**Ariane 5**	**21,000**	6,950	4.57	94%

Launch Vehicle - Falcon 9/Heavy
Country - United States



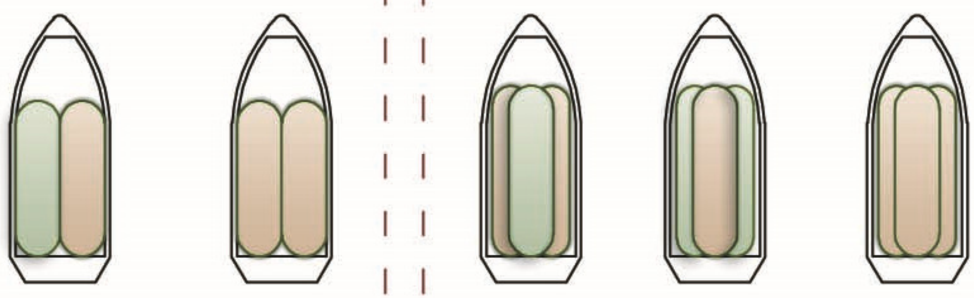
Launch Vehicle - Falcon 9/Heavy
Country - United States



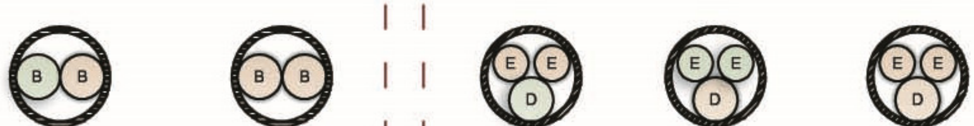
Falcon Heavy/Falcon 9
Fairing Volume= 166 m3
Payload Mass= 53 mT/13.2 mT

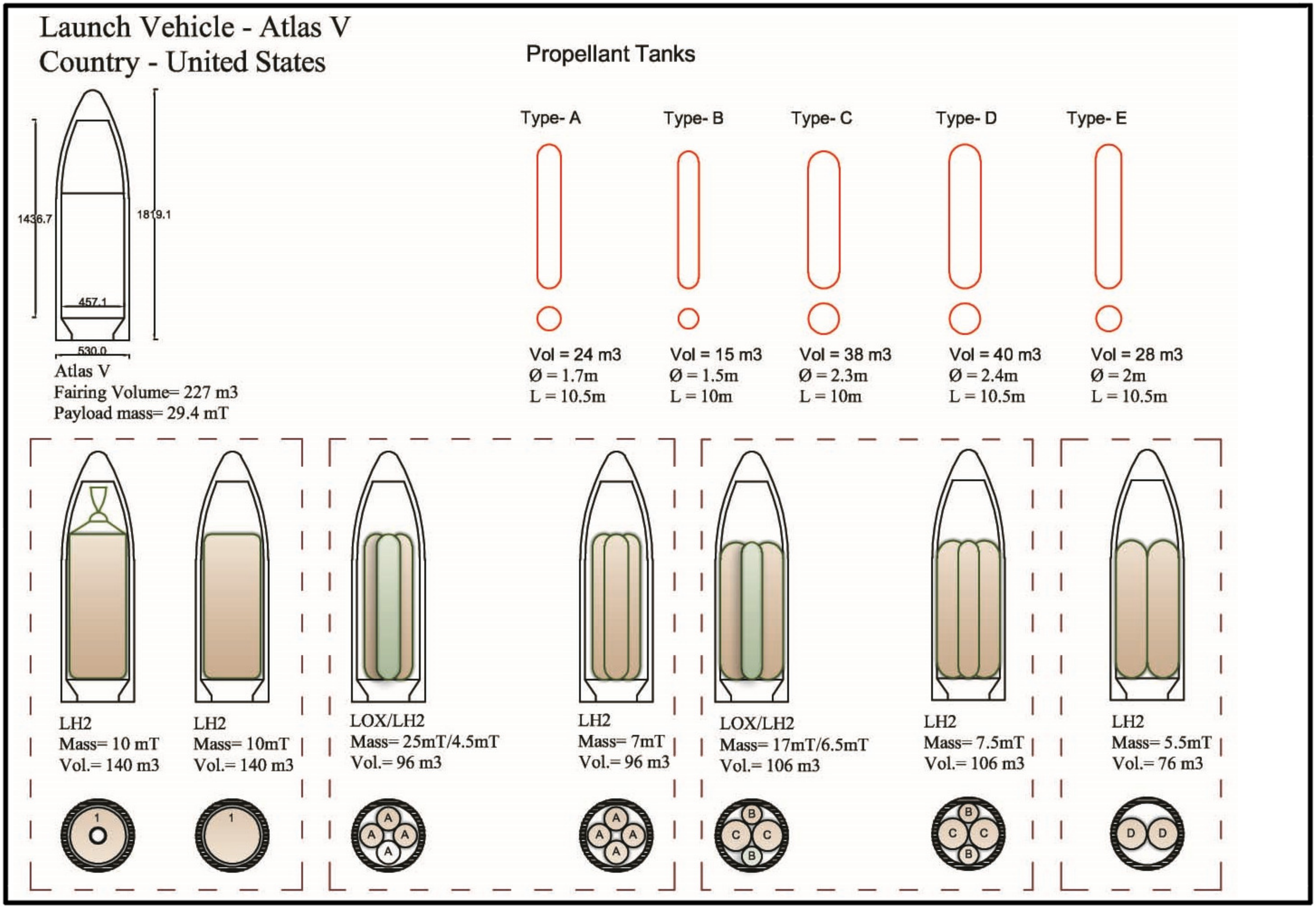
Propellant Tanks

Type- A	Type- B	Type- C	Type- D	Type- E
Vol = 18 m3	Vol = 30 m3	Vol = 15 m3	Vol = 35 m3	Vol = 23 m3
Ø = 1.6m	Ø = 2.3m	Ø = 1.6m	Ø = 2.3m	Ø = 1.9m
L = 9m	L = 8m	L = 8m	L = 9m	L = 9m

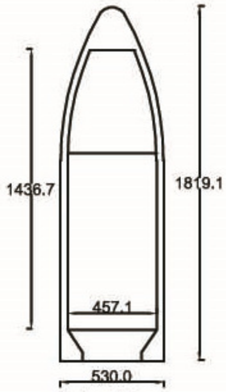


LOX/LH2	LH2	LOX/LH2	LOX/LH2	LH2
Mass= 34mT/2.1mT	Mass= 4.2mT	Mass= 40mT/3.3mT	Mass= 51mT/2mT	Mass= 5.8mT
Vol.= 60 m3	Vol.= 60 m3	Vol.= 81 m3	Vol.= 81 m3	Vol.= 81 m3



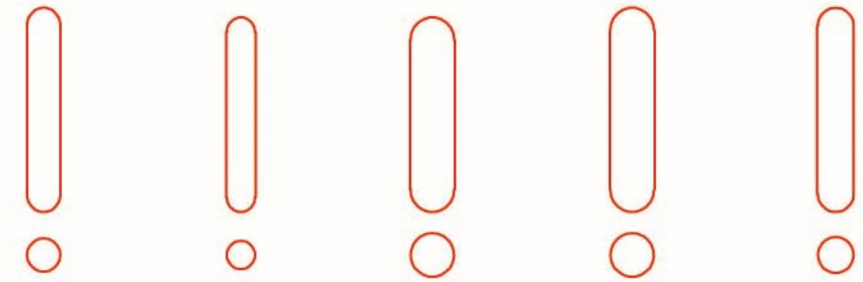

Launch Vehicle - Atlas V
Country - United States
Propellant Tanks
1436.7
1819.1
457.1
530.0
Atlas V
Fairing Volume= 227 m3
Payload mass= 29.4 mT
Type- A
Vol = 24 m3
Ø = 1.7m
L = 10.5m
Type- B
Vol = 15 m3
Ø = 1.5m
L = 10m
Type- C
Vol = 38 m3
Ø = 2.3m
L = 10m
Type- D
Vol = 40 m3
Ø = 2.4m
L = 10.5m
Type- E
Vol = 28 m3
Ø = 2m
L = 10.5m
LH2
Mass= 10 mT
Vol.= 140 m3
LH2
Mass= 10mT
Vol.= 140 m3
LOX/LH2
Mass= 25mT/4.5mT
Vol.= 96 m3
LH2
Mass= 7mT
Vol.= 96 m3
LOX/LH2
Mass= 17mT/6.5mT
Vol.= 106 m3
LH2
Mass= 7.5mT
Vol.= 106 m3
LH2
Mass= 5.5mT
Vol.= 76 m3

Launch Vehicle - Atlas V
Country - United States



Atlas V
Fairing Volume= 227 m3
Payload mass= 29.4 mT

Propellant Tanks

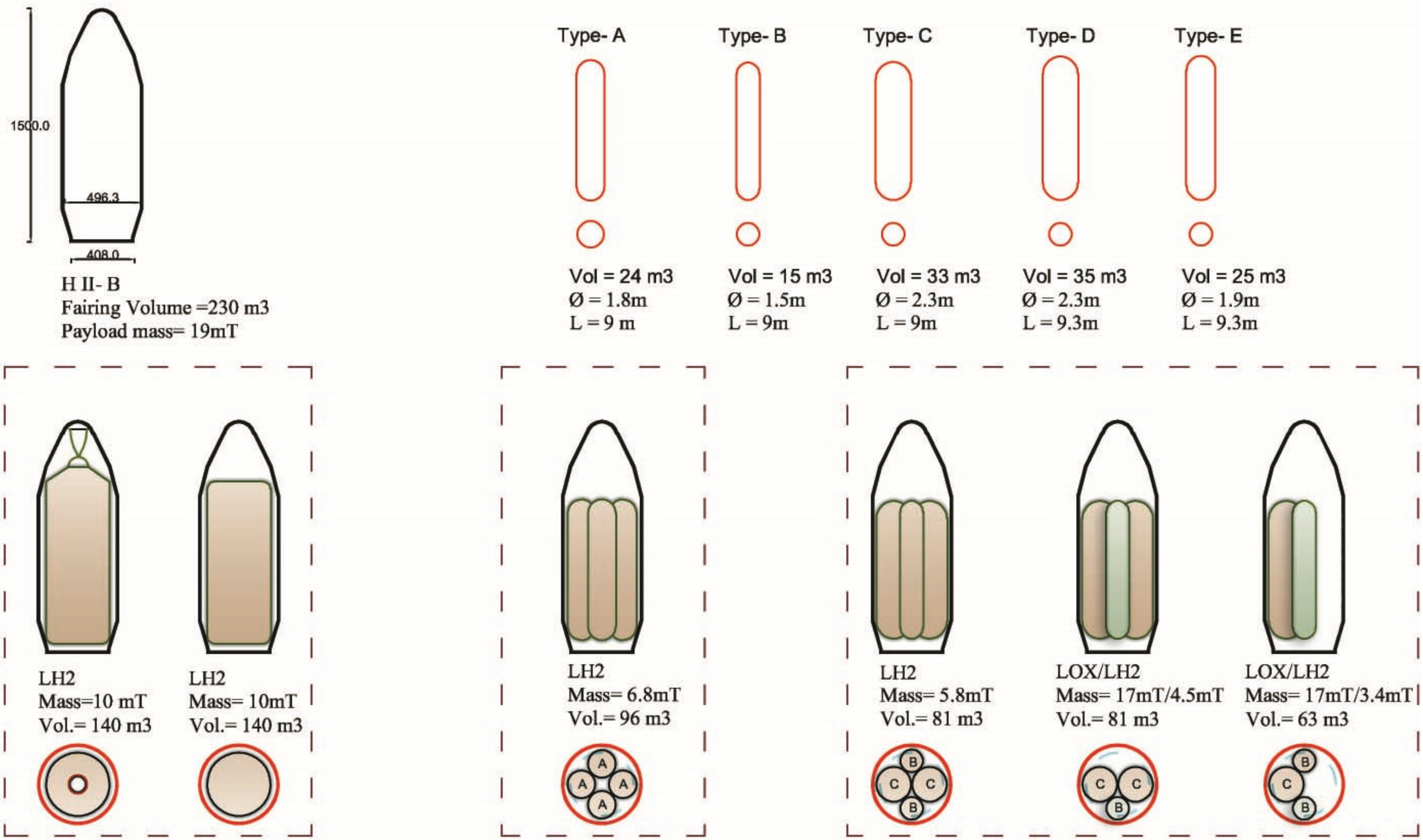


Type- A	Type- B	Type- C	Type- D	Type- E
Vol = 24 m3	Vol = 15 m3	Vol = 38 m3	Vol = 40 m3	Vol = 28 m3
Ø = 1.7m	Ø = 1.5m	Ø = 2.3m	Ø = 2.4m	Ø = 2m
L = 10.5m	L = 10m	L = 10m	L = 10.5m	L = 10.5m

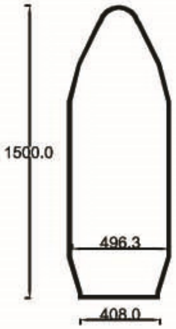
LH2
Mass= 7mT
Vol.= 96 m3

Launch Vehicle - H II- B
Country - Japan

Propellant Tanks



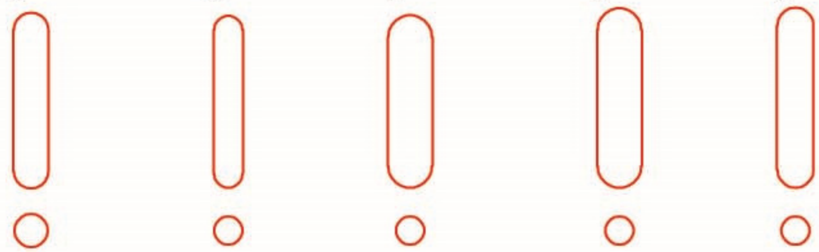
Launch Vehicle - H II- B
Country - Japan



H II- B
Fairing Volume =230 m3
Payload mass= 19mT

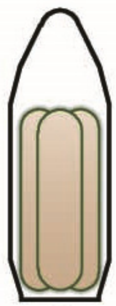
Propellant Tanks

Type- A | Type- B | Type- C | Type- D | Type- E



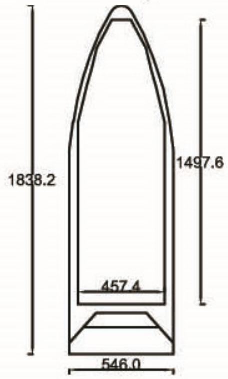
Type- A	Type- B	Type- C	Type- D	Type- E
Vol = 24 m3	Vol = 15 m3	Vol = 33 m3	Vol = 35 m3	Vol = 25 m3
Ø = 1.8m	Ø = 1.5m	Ø = 2.3m	Ø = 2.3m	Ø = 1.9m
L = 9 m	L = 9m	L = 9m	L = 9.3m	L = 9.3m

LH2
Mass= 5mT
Vol.= 70 m3



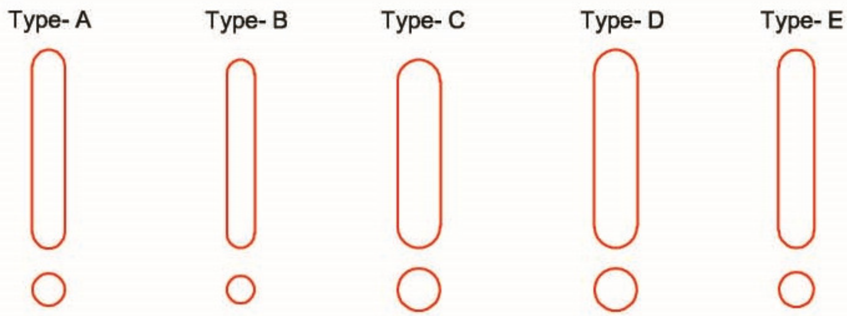
LH2
Mass= 6mT
Vol.= 85 m3

Launch Vehicle -Ariane 5
Country - Europe

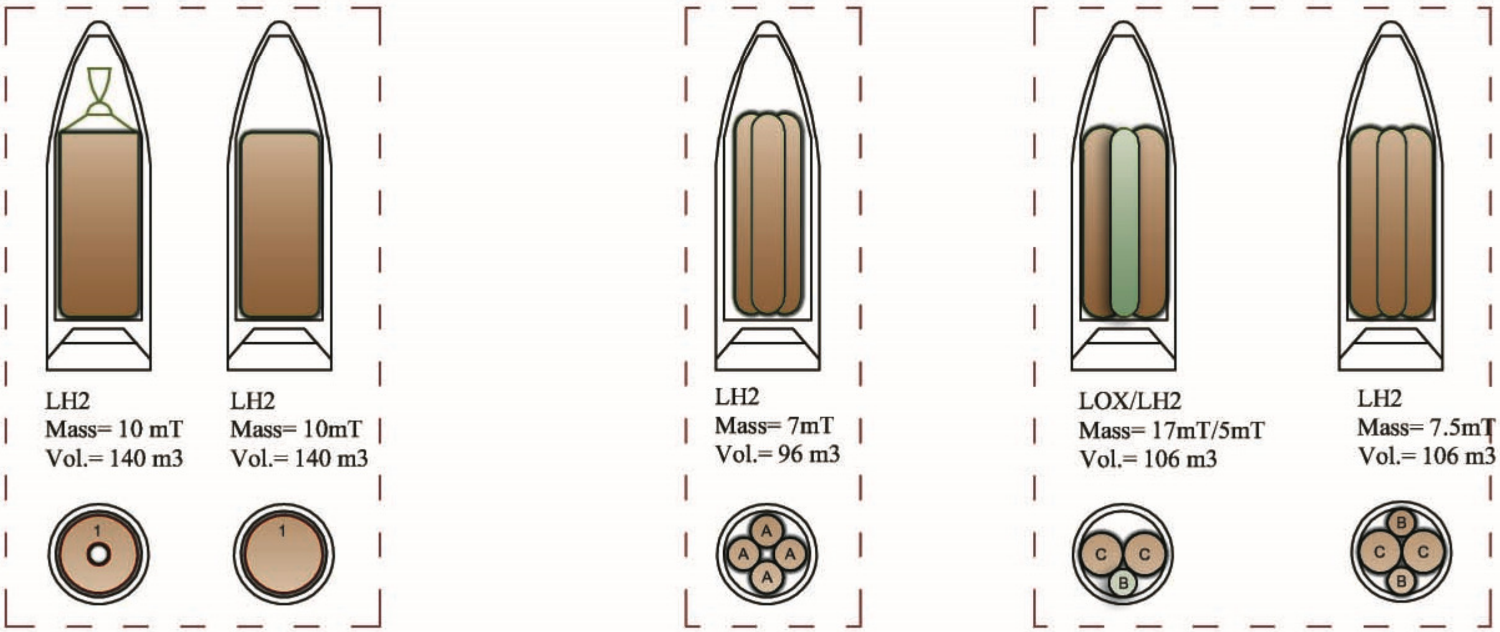


Ariane 5
Fairing volume = 205 m3
Payload mass = 21 mT

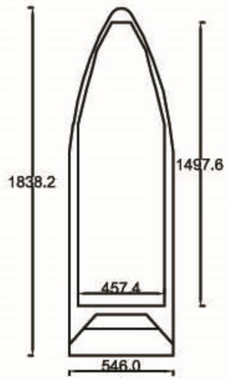
Propellant Tanks



Type- A	Type- B	Type- C	Type- D	Type- E
Vol = 24 m3	Vol = 15 m3	Vol = 38 m3	Vol = 40 m3	Vol = 28 m3
Ø = 1.7m	Ø = 1.5m	Ø = 2.3m	Ø = 2.4m	Ø = 2m
L = 10.5m	L = 10m	L = 10m	L = 10.5m	L = 10.5m

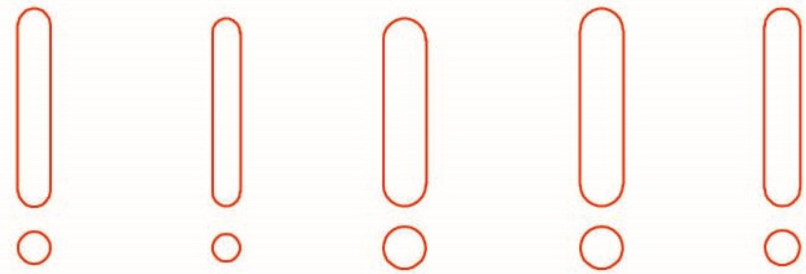


Launch Vehicle -Ariane 5
Country - Europe



Ariane 5
Fairing volume = 205 m3
Payload mass = 21 mT

Propellant Tanks

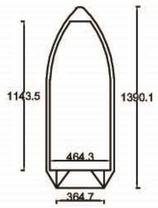


Type- A	Type- B	Type- C	Type- D	Type- E
Vol = 24 m3	Vol = 15 m3	Vol = 38 m3	Vol = 40 m3	Vol = 28 m3
Ø = 1.7m	Ø = 1.5m	Ø = 2.3m	Ø = 2.4m	Ø = 2m
L = 10.5m	L = 10m	L = 10m	L = 10.5m	L = 10.5m

LH2
Mass= 5.5mT
Vol.= 76 m3

LH2
Mass= 7mT
Vol.= 96 m3

Launch Vehicle - Falcon 9/Heavy
Country - United States



Falcon Heavy/Falcon 9
Fairing Volume= 166 m3
Payload Mass= 53 mT/13.2 mT

Mission Components

HAB
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

Cargo
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

HAB
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

Cargo
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

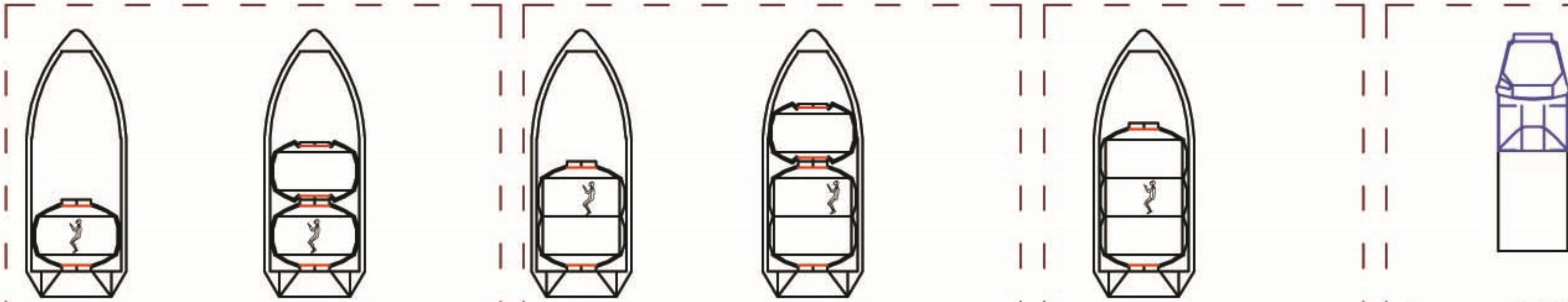
HAB
Mass= 10mT
Vol.= 103 m3
Structure = 2mT

Cargo
Mass=10mT
Vol.= 103 m3
Structure = 2mT

Lunar Lander
Mass= 3mT
Vol.= 35 m3
Structure = 1mT

Dragon/ERV/Science LAB
Mass= 5mT
Vol.= 34 m3
Structure = 2mT

Node
Mass= 1mT
Vol.= 8 m3
Structure = 1mT



HAB
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT
Falcon 9/Falcon Heavy

HAB/Cargo
Mass= 8mT
Vol.= 84 m3
Structure = 1.6mT
Falcon 9/Falcon Heavy

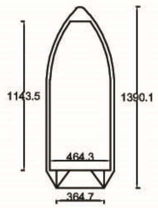
HAB
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT
Falcon 9/Falcon Heavy

HAB/Cargo
Mass= 11mT
Vol.= 115 m3
Structure = 2.3mT
Falcon 9/Falcon Heavy

HAB
Mass= 10mT
Vol.= 103 m3
Structure = 2mT
Falcon 9/Falcon Heavy

Dragon as ERV/Science LAB
Mass= 5 mT
Vol.= Structure = 2mT
Less payload = 46T
Excess Delta V = 4.50 km/s
Falcon 9/Falcon Heavy

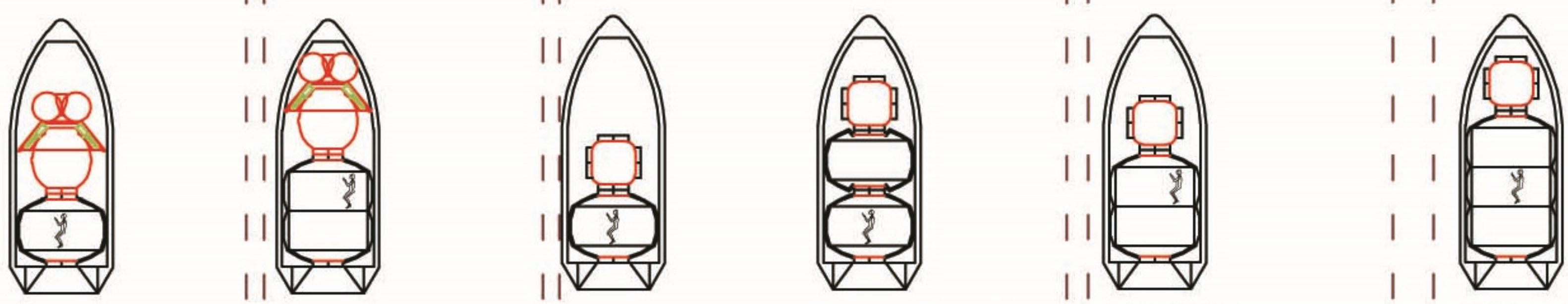
Launch Vehicle - Falcon 9/Heavy
Country - United States



Falcon Heavy/Falcon 9
Fairing Volume= 166 m3
Payload Mass= 53 mT/13.2 mT

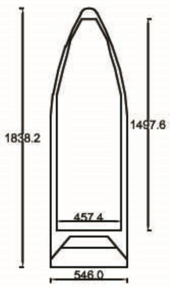
Mission Components

HAB	Cargo	HAB	Cargo	HAB	Cargo	Lunar Lander	Dragon/ERV/Science LAB	Node
Mass= 4mT	Mass= 4mT	Mass= 7mT	Mass= 7mT	Mass= 10mT	Mass=10mT	Mass= 3mT	Mass= 5mT	Mass= 1mT
Vol.= 42 m3	Vol.= 42 m3	Vol.= 73 m3	Vol.= 73 m3	Vol.= 103 m3	Vol.= 103 m3	Vol.= 35 m3	Vol.= 34 m3	Vol.= 8 m3
Structure = 0.8mT	Structure = 0.8mT	Structure = 1.5mT	Structure = 1.5mT	Structure = 2mT	Structure = 2mT	Structure = 1mT	Structure = 2mT	Structure = 1mT



HAB/Lander	HAB/Lander	HAB/Node	HAB/Cargo/Node	HAB/Node	HAB/Node
Mass= 7mT	Mass= 10mT	Mass= 5mT	Mass= 9mT	Mass= 8mT	Mass= 11mT
Vol.= 77 m3	Vol.= 108 m3	Vol.= 50 m3	Vol.= 92 m3	Vol.= 81 m3	Vol.= 111 m3
Structure = 1.8mT	Structure = 2.5mT	Structure = 1.8mT	Structure = 2.6mT	Structure = 2.5mT	Structure = 3mT
Falcon 9/Falcon Heavy	Falcon 9/Falcon Heavy	Falcon 9/Falcon Heavy	Falcon 9/Falcon Heavy	Falcon 9/Falcon Heavy	Falcon 9/Falcon Heavy

Launch Vehicle -Ariane 5
Country - Europe



Ariane 5
Fairing volume = 205 m3
Payload mass = 21 mT

Mission Components

HAB
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

Cargo
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

Module 1
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

HAB
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

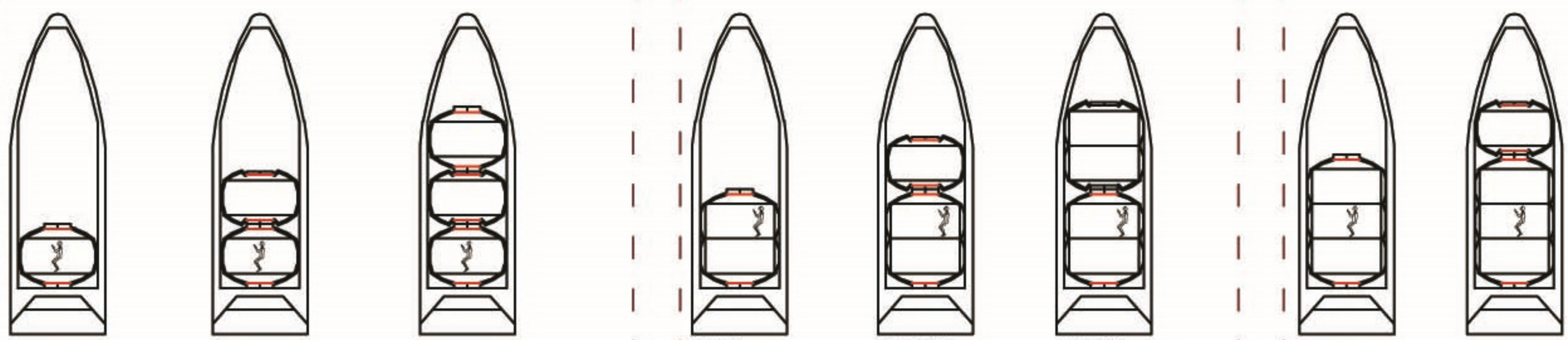
Cargo
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

HAB
Mass= 10mT
Vol.= 103 m3
Structure = 2mT

Cargo
Mass=10mT
Vol.= 103 m3
Structure = 2mT

Lunar Lander
Mass= 3mT
Vol.= 35 m3
Structure = 1mT

Node
Mass= 1mT
Vol.= 8 m3
Structure = 1mT



HAB
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

HAB/Cargo
Mass= 8mT
Vol.= 84 m3
Structure = 1.6mT

HAB/Cargo/Module 1
Mass= 12mT
Vol.= 126 m3
Structure = 2.4mT

HAB
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

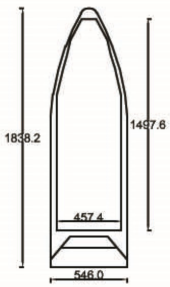
HAB/Cargo
Mass= 11mT
Vol.= 115 m3
Structure = 2.3mT

HAB/Cargo
Mass= 14mT
Vol.= 146 m3
Structure = 3mT

HAB
Mass= 11mT
Vol.= 103 m3
Structure = 2mT

HAB/Cargo
Mass= 15mT
Vol.= 145 m3
Structure = 2.8mT

Launch Vehicle -Ariane 5
Country - Europe



Ariane 5
Fairing volume = 205 m3
Payload mass = 21 mT

Mission Components

HAB
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

Cargo
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

Module 1
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

HAB
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

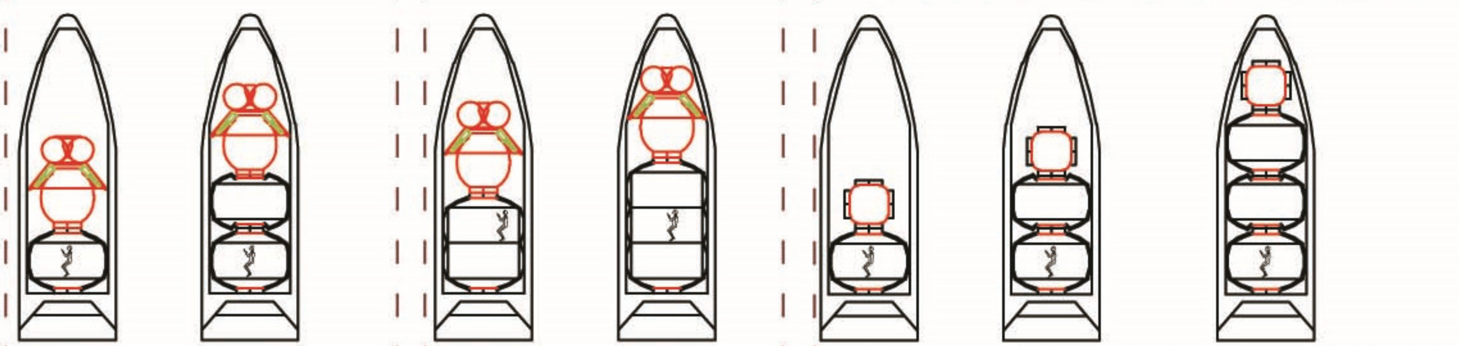
Cargo
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

HAB
Mass= 10mT
Vol.= 103 m3
Structure = 2mT

Cargo
Mass=10mT
Vol.= 103 m3
Structure = 2mT

Lunar Lander
Mass= 3mT
Vol.= 35 m3
Structure = 1mT

Node
Mass= 1mT
Vol.= 8 m3
Structure = 1mT



HAB/Lander
Mass= 9mT
Vol.= 77 m3
Structure = 1.8mT

HAB/Cargo/Lander
Mass= 13mT
Vol.= 119 m3
Structure = 2.6mT

HAB/Lander
Mass= 12mT
Vol.= 108 m3
Structure = 2.5mT

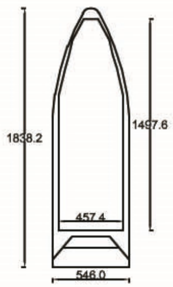
HAB/Lander
Mass= 16mT
Vol.= 138 m3
Structure = 3mT

HAB/Node
Mass= 5mT
Vol.= 50 m3
Structure = 1.8mT

HAB/Cargo/Node
Mass= 9mT
Vol.= 92 m3
Structure = 2.6mT

HAB/Cargo/Module 1/Node
Mass= 13mT
Vol.= 134 m3
Structure = 3.4mT

Launch Vehicle -Ariane 5
Country - Europe



Ariane 5
Fairing volume = 205 m3
Payload mass = 21 mT

Mission Components

HAB
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

Cargo
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

Module 1
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

HAB
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

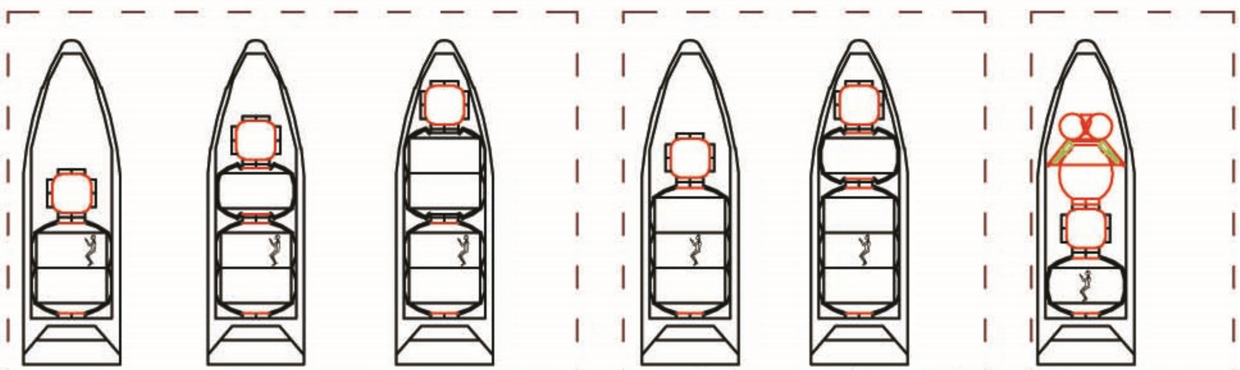
Cargo
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

HAB
Mass= 10mT
Vol.= 103 m3
Structure = 2mT

Cargo
Mass=10mT
Vol.= 103 m3
Structure = 2mT

Lunar Lander
Mass= 3mT
Vol.= 35 m3
Structure = 1mT

Node
Mass= 1mT
Vol.= 8 m3
Structure = 1mT



HAB/Node
Mass= 8mT
Vol.= 81 m3
Structure = 2.5mT

HAB/cargo/Node
Mass= 12mT
Vol.= 123 m3
Structure = 3.3mT

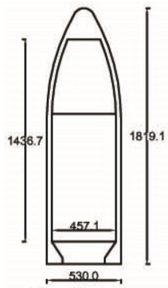
HAB/Cargo/Node
Mass= 15mT
Vol.= 154 m3
Structure = 4mT

HAB/Node
Mass= 12mT
Vol.= 111 m3
Structure = 3mT

HAB/Cargo/Node
Mass= 16mT
Vol.= 153 m3
Structure = 3.8mT

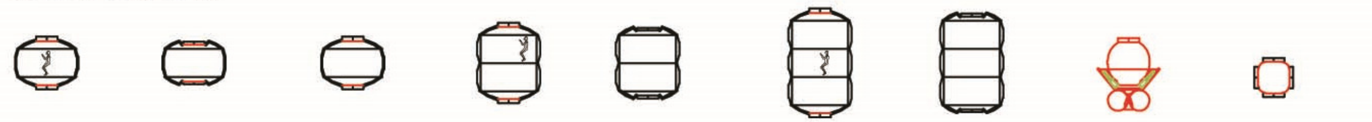
HAB/Node/Lander
Mass= 10mT
Vol.= 85 m3
Structure = 2.8mT

Launch Vehicle - Atlas V
Country - United States



Atlas V
Fairing Volume= 227 m3
Payload mass= 29.4 mT

Mission Components



HAB
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

Cargo
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

Module 1
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

HAB
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

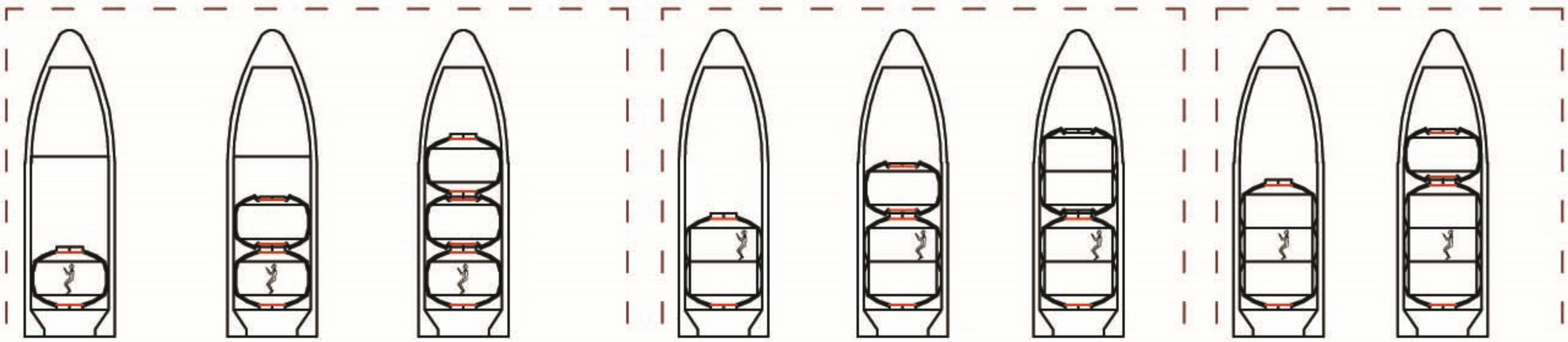
Cargo
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

HAB
Mass= 10mT
Vol.= 103 m3
Structure = 2mT

Cargo
Mass=10mT
Vol.= 103 m3
Structure = 2mT

Lunar Lander
Mass= 3mT
Vol.= 35 m3
Structure = 1mT

Node
Mass= 1mT
Vol.= 8 m3
Structure = 1mT



HAB
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

HAB/Cargo
Mass= 8mT
Vol.= 84 m3
Structure = 1.6mT

HAB/Cargo/Module1
Mass= 12mT
Vol.= 126 m3
Structure = 2.4mT

HAB
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

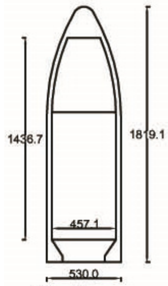
HAB/Cargo
Mass= 11mT
Vol.= 115 m3
Structure = 2.3mT

HAB/Cargo
Mass=14mT
Vol.= 146 m3
Structure = 3mT

HAB
Mass= 11mT
Vol.= 103 m3
Structure = 2mT

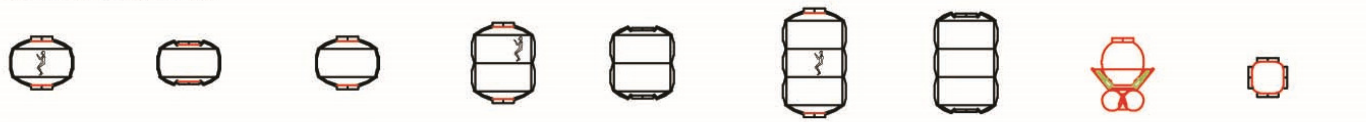
HAB/Cargo
Mass= 15mT
Vol.= 145 m3
Structure = 2.8mT

Launch Vehicle - Atlas V
Country - United States



Atlas V
Fairing Volume= 227 m3
Payload mass= 29.4 mT

Mission Components



HAB
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

Cargo
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

Module 1
Mass= 4mT
Vol.= 42 m3
Structure = 0.8mT

HAB
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

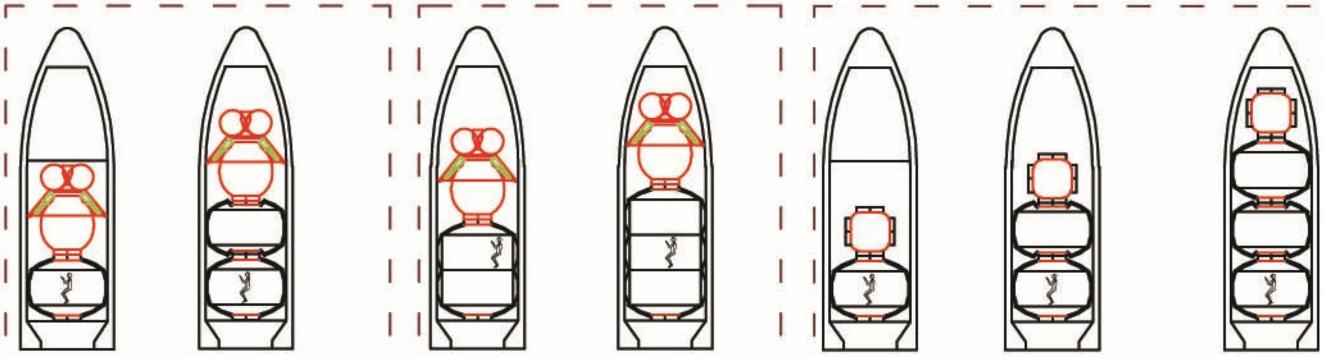
Cargo
Mass= 7mT
Vol.= 73 m3
Structure = 1.5mT

HAB
Mass= 10mT
Vol.= 103 m3
Structure = 2mT

Cargo
Mass=10mT
Vol.= 103 m3
Structure = 2mT

Lunar Lander
Mass= 3mT
Vol.= 35 m3
Structure = 1mT

Node
Mass= 1mT
Vol.= 8 m3
Structure = 1mT



HAB/ Lander
Mass= 7mT
Vol.= 77 m3
Structure = 1.8mT

HAB/Cargo/Lander
Mass= 11mT
Vol.= 119 m3
Structure = 2.6mT

HAB/Lander
Mass= 10mT
Vol.= 108 m3
Structure = 2.5mT

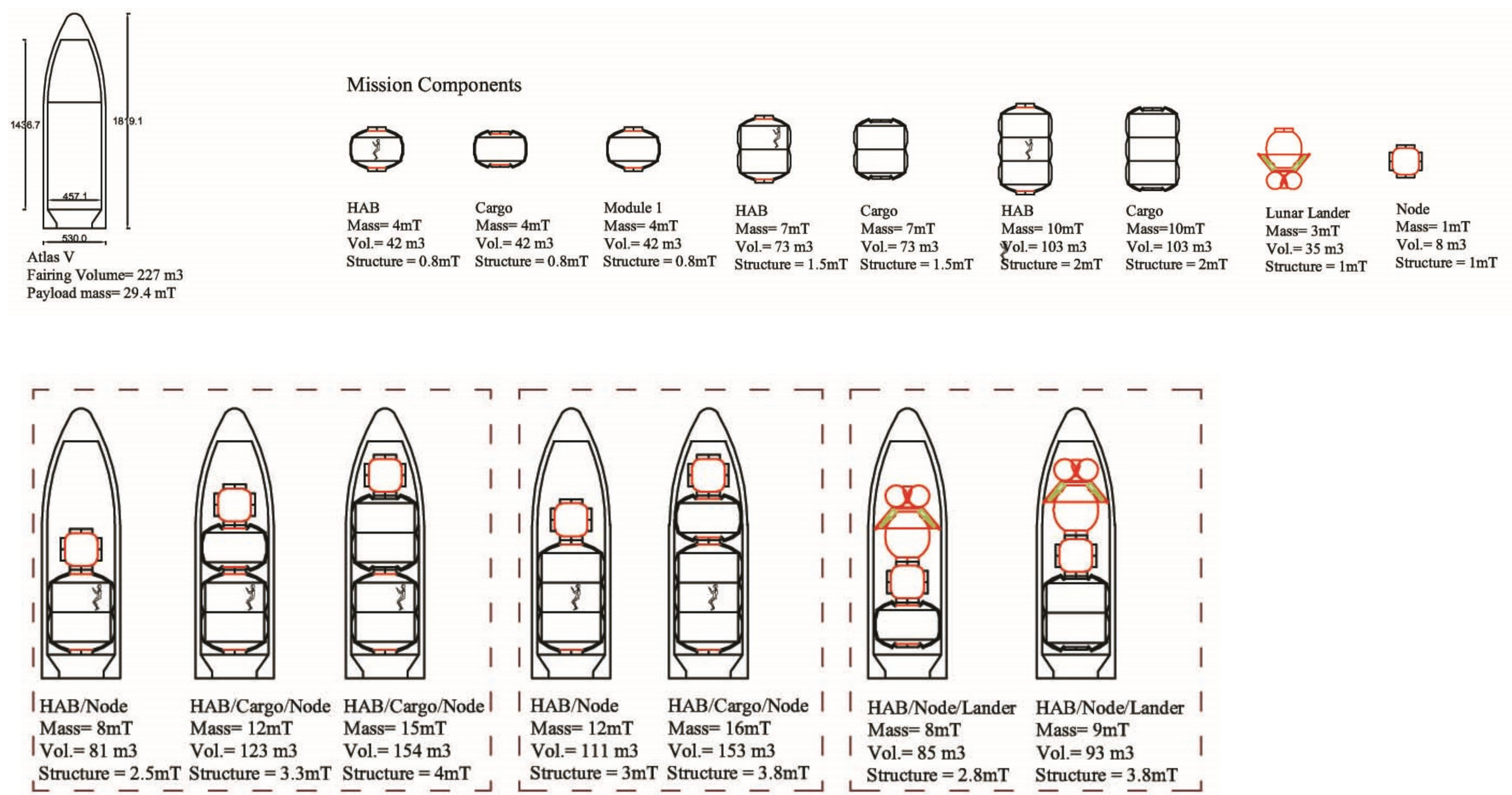
HAB/Lander
Mass= 14mT
Vol.= 138 m3
Structure = 3mT

HAB/Node
Mass= 5mT
Vol.= 50 m3
Structure = 1.8mT

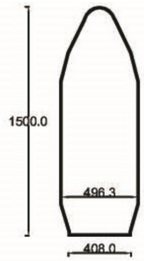
HAB/Cargo/Node
Mass= 9mT
Vol.= 92 m3
Structure = 2.6mT

HAB/Cargo/Module 1/Node
Mass= 13mT
Vol.= 134 m3
Structure = 3.4mT

Launch Vehicle - Atlas V
Country - United States

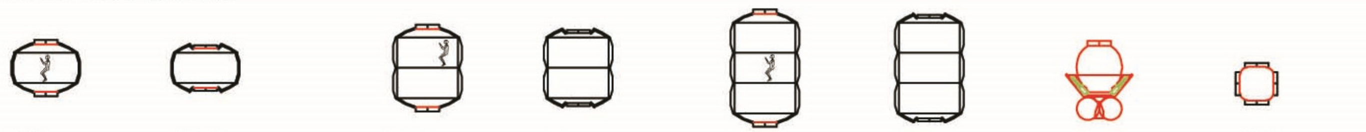


Launch Vehicle - H II- B
Country - Japan

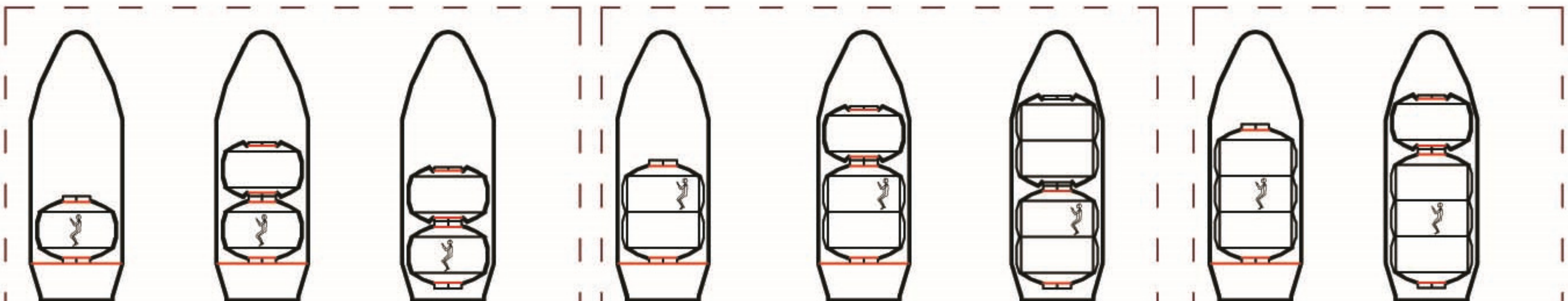


H II- B
Fairing Volume =230 m3
Payload mass= 19mT

Mission Components

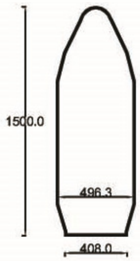


HAB	Cargo	HAB	Cargo	HAB	Cargo	Lunar Lander	Node
Mass= 4mT	Mass= 4mT	Mass= 7mT	Mass= 7mT	Mass= 10mT	Mass=10mT	Mass= 3mT	Mass= 1mT
Vol.= 42 m3	Vol.= 42 m3	Vol.= 73 m3	Vol.= 73 m3	Vol.= 103 m3	Vol.= 103 m3	Vol.= 35 m3	Vol.= 8 m3
Structure = 0.8mT	Structure = 0.8mT	Structure = 1.5mT	Structure = 1.5mT	Structure = 2mT	Structure = 2mT	Structure = 1mT	Structure = 1mT



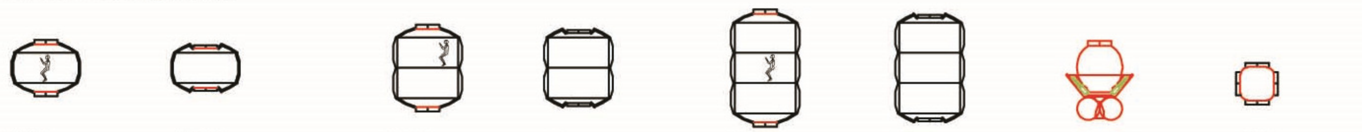
HAB	HAB/Cargo	HAB/Cargo	HAB	HAB/Cargo	HAB/Cargo	HAB	HAB/Cargo
Mass= 4mT	Mass= 8mT	Mass= 12mT	Mass= 7mT	Mass= 11mT	Mass= 14mT	Mass= 11mT	Mass= 15mT
Vol.= 42 m3	Vol.= 84 m3	Vol.= 126 m3	Vol.= 73 m3	Vol.= 115 m3	Vol.= 146 m3	Vol.= 103 m3	Vol.= 145 m3
Structure = 0.8mT	Structure = 1.6mT	Structure = 2.4mT	Structure = 1.5mT	Structure = 2.3mT	Structure = 3mT	Structure = 2mT	Structure = 2.8mT

Launch Vehicle - H II- B
Country - Japan

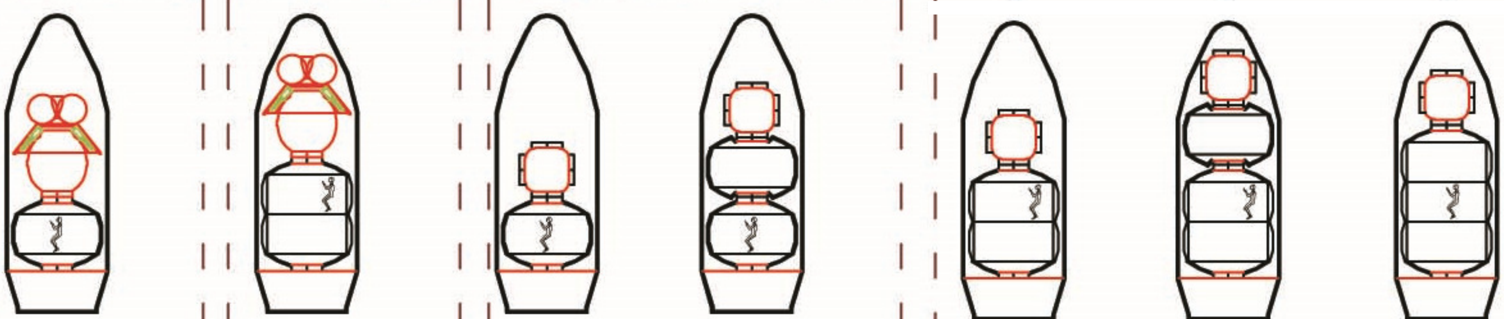


H II- B
Fairing Volume =230 m3
Payload mass= 19mT

Mission Components



HAB	Cargo	HAB	Cargo	HAB	Cargo	Lunar Lander	Node
Mass= 4mT	Mass= 4mT	Mass= 7mT	Mass= 7mT	Mass= 10mT	Mass=10mT	Mass= 3mT	Mass= 1mT
Vol.= 42 m3	Vol.= 42 m3	Vol.= 73 m3	Vol.= 73 m3	Vol.= 103 m3	Vol.= 103 m3	Vol.= 35 m3	Vol.= 8 m3
Structure = 0.8mT	Structure = 0.8mT	Structure = 1.5mT	Structure = 1.5mT	Structure = 2mT	Structure = 2mT	Structure = 1mT	Structure = 1mT



HAB/Lander	HAB/Lander	HAB/Node	HAB/Cargo/Node	HAB/Node	HAB/Cargo/Node	HAB/Node
Mass= 9mT	Mass= 12mT	Mass= 5mT	Mass= 9mT	Mass= 8mT	Mass= 12mT	Mass= 12mT
Vol.= 77 m3	Vol.= 73 m3	Vol.= 50 m3	Vol.= 92 m3	Vol.= 81 m3	Vol.= 123 m3	Vol.= 111 m3
Structure = 1.8mT	Structure = 2.5mT	Structure = 1.8mT	Structure = 2.6mT	Structure = 2.5mT	Structure = 3.3mT	Structure = 3mT

Inspiration Mars Mission

Chemical propulsion

Payload= 15mT

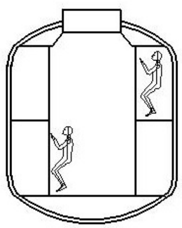
Delta V for Mars C3 transfer = 4.7 Km/s

Transfer Propellant = 30 mT

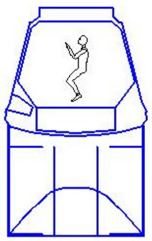
LOX= 25mT

LH2= 5mT

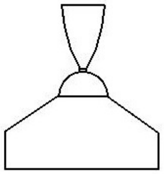
Mission Components



HAB
Mass= 7mT
Vol.= 67 m3
Structure = 1.5mT

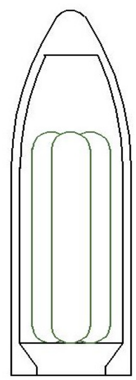


Re-entry Capsule
Mass= 5mT
Vol.= 34 m3



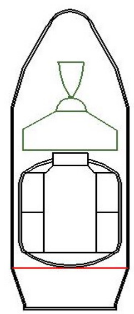
Engine
Mass= 1mT
Vol.= 6 m3

Inspiration Mars Mission



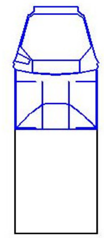
LOX/LH2
Mass= 25mT/5mT
Vol.= 96 m3
Atlas V

Launch 1



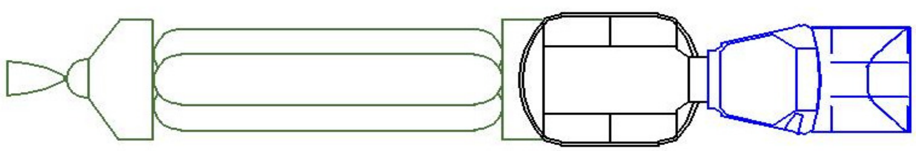
HAB/Engine
Mass= 8mT
Vol.= 81 m3
Structure = 2mT
H II-B

Launch 2



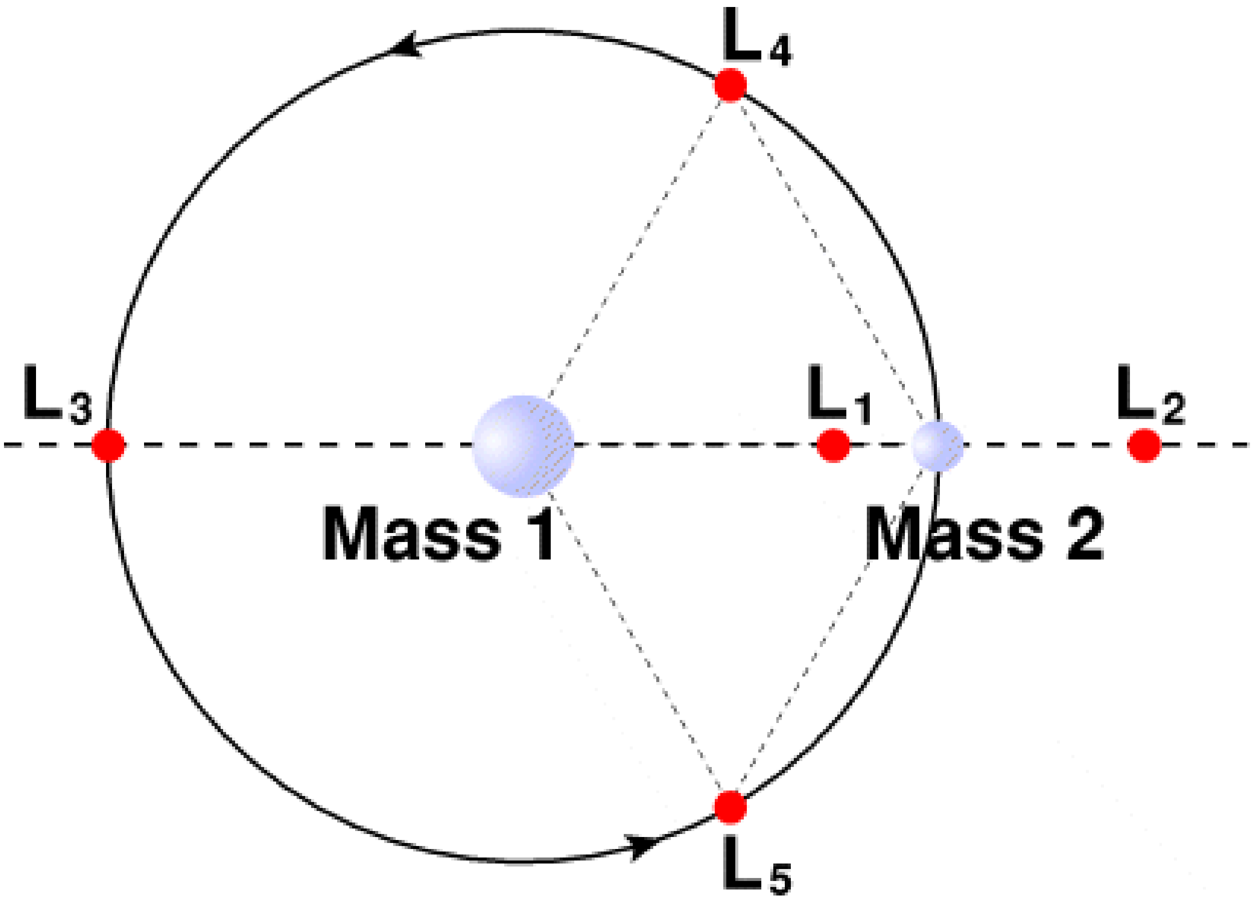
Re- entry vehicle
Mass= 5 mT
Vol.= 34 m3
Falcon 9

Launch 3



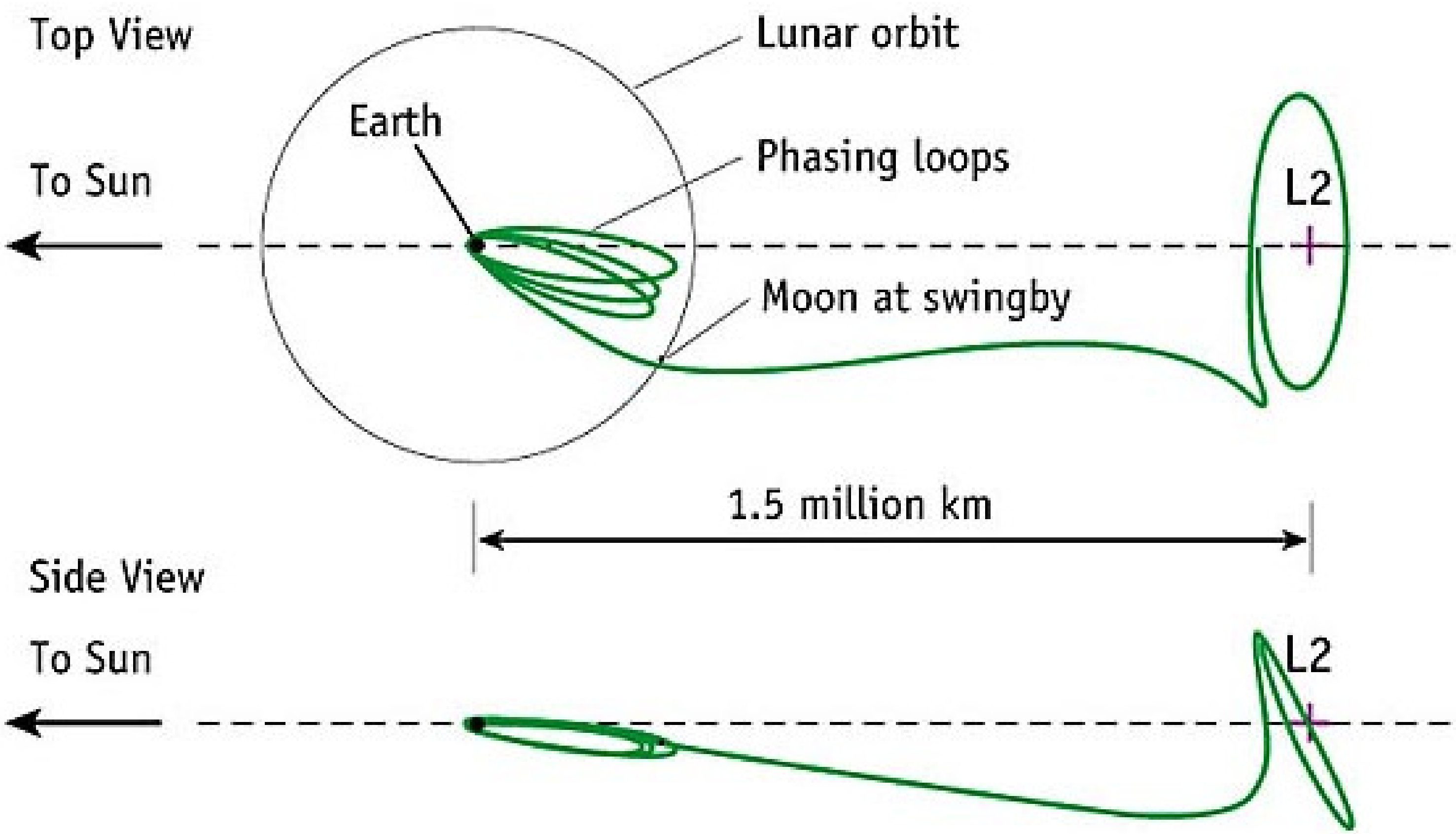
Assembly in LEO

Lagrange L2 Station : Halo Orbit



Trajectory

L2 is ideal for astronomy because a spacecraft is close enough to readily communicate with Earth, can keep Sun, Earth and Moon behind the spacecraft for solar power and (with appropriate shielding) provides a clear view of deep space for our telescopes.



Delta V's — High thrust

ΔV km/s From\To	EML-2	LLO	Moon	Mars Transfer Orbit	LEO-Ken	LEO-Eq	GEO
Earth					9.3 - 10		
Low Earth Orbit (LEO-Ken)	**3.43**					4.24	4.33
Geostationary Orbit (GEO)	1.47				2.06	1.63	
Lagrangian point 1 (EML-1)		0.64	2.52		0.77	0.77	1.38
Lagrangian point 2 (EML-2)	**0.14**	**0.64**	**2.52**		**0.33**	**0.33**	**1.47**
Low Lunar orbit (LLO)	0.65		1.87				
Moon (Moon)	2.53	1.87					
EML-2				**<1.0**			

Mission Overview

BEYOND LOW EARTH ORBIT

AN OUTPOST FOR POSSIBLE LUNAR MISSION

STARTING POINT FOR DEEP SPACE MISSION

GRAVITATIONALLY STABLE ORBIT

RADIATION PROTECTION FROM MOON

LESS ΔV TO TRAVEL TO MOON AND OTHER PLANETS

* L2 point is unstable on a time scale of approximately 23 days, which requires satellites orbiting these positions to undergo regular course and attitude corrections.

Mission Goals

Goals

Primary

- Manned Mission beyond LEO
- Research and Experiments beyond orbit

Mission Tasks

- Test EVA procedures
- Test payload docking and fuel
- Moon survey mission components deployment
- Solar radiation effects on human
- Other human factors

Mission Requirements

- A Habitat
- 2 people on board
- A lander for sortie missions to moon
- Earth return vehicle
- Fuel Depot
- Ergonomic design – user friendliness
- Interior space flexibility – mobility
- Radiation protection solutions
- EVA concepts

Mission Statistics

Year of study	2013
Crew	2
Mission duration	6 months- 1st Phase
Payload mass	≈ 40 MT
Fairing diameter	≈ 5m
Starts in LEO	Yes
Number of deployments from LEO	1
Propulsion	Chemical
H-Lift launches	0
M-Lift launches	4
International cooperation	May be
Coop. with private companies	May be
HAB parking position	L2-HALO Orbit
Stay at Moon	Sortie missions to moon
Assembly in LEO	Yes
Total Mission duration	6.1 months

System Elements

***HAB** – Habitation Module*

***ML** – Moon Lander (sortie missions)*

REV - Re-entry Vehicle

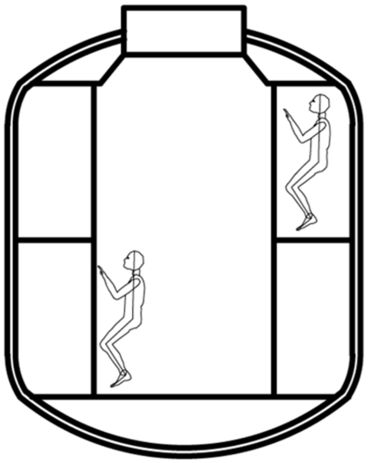
(Use SpaceX Dragon Capsule or Orion)

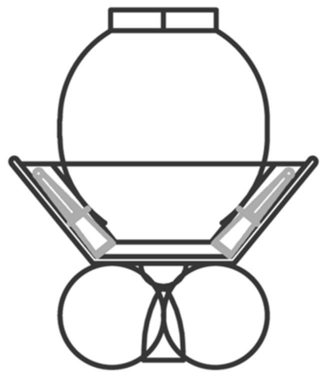
TP - Transfer Propellant

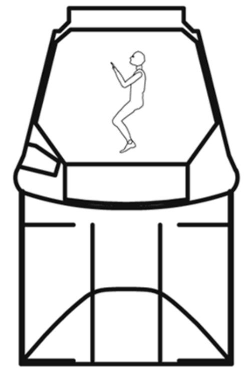
FDP -Fuel Depot Propellant (Ware house)

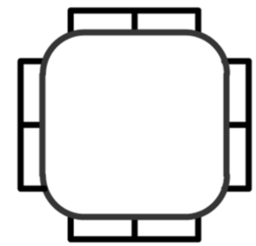
SL – Scientific Laboratory

Mission Components









Station HAB

Mass= 7.5mT

Volume= 67 m3

Structure = 1.5 mT

Lunar Lander

Mass= 3mT

Volume= 35 m3

Structure = 1 mT

ERV/Science Lab

Mass= 5mT

Volume= 34 m3

Structure = 2 mT

Node

Mass= 1mT

Volume= 8 m3

Structure = 1 mT

Crew stay-6 months

Moon Sortie missions

Experiments
Contingency vehicle

Connection

EML2 Mission Design – Propulsion Selection

Chemical propulsion (Isp- 342 s, LOX/LH2)

From LEO to EML2-

40 mt of dry mass ~ 35 mt of propellant

Total Mission mass = 75 mt

LOX= 30mT LH2= 5 mT

Bimodal Nuclear Thermal Reactor - BNTR (Isp – 945 s, LH2)

From LEO to EML2-

40 mt of dry mass ~ 30mt of propellant

Total Mission mass = 70mt

LH2= 30 mT

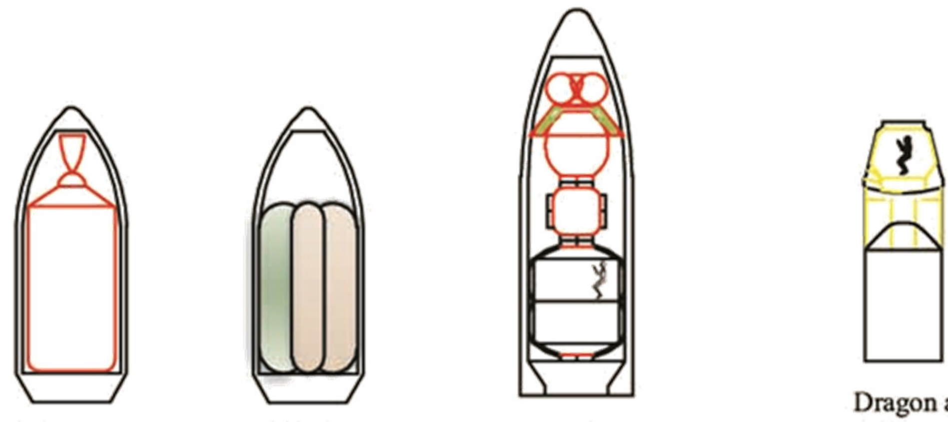
LH2 has a very Low density as compared to LOX.
NTR propulsion requires twice the number of launches required in Chemical propulsion.

Alternative approach

Starting the mission from ISS.

EML2 Mission Design – Catalog application

Chemical Propulsion (LOX/LH2)
Payload = 40 mT
Transfer Propellant = 35 mT
LOX = 30 mT
LH2 = 5 mT
Depot Propellant= 21 mT
LOX = 20 mT
LH2 = 6 mT
Total LOX = 50mT
Total LH2 = 11mT



LH2
Mass= 8 mT
Vol.= 112 m3
Falcon 9

LOX/LH2
Mass= 50mT/3mT
Vol.= 90 m3

HAB/Node/Lander
Mass= 9mT
Vol.= 93 m3
Structure = 3.8mT
Atlas V

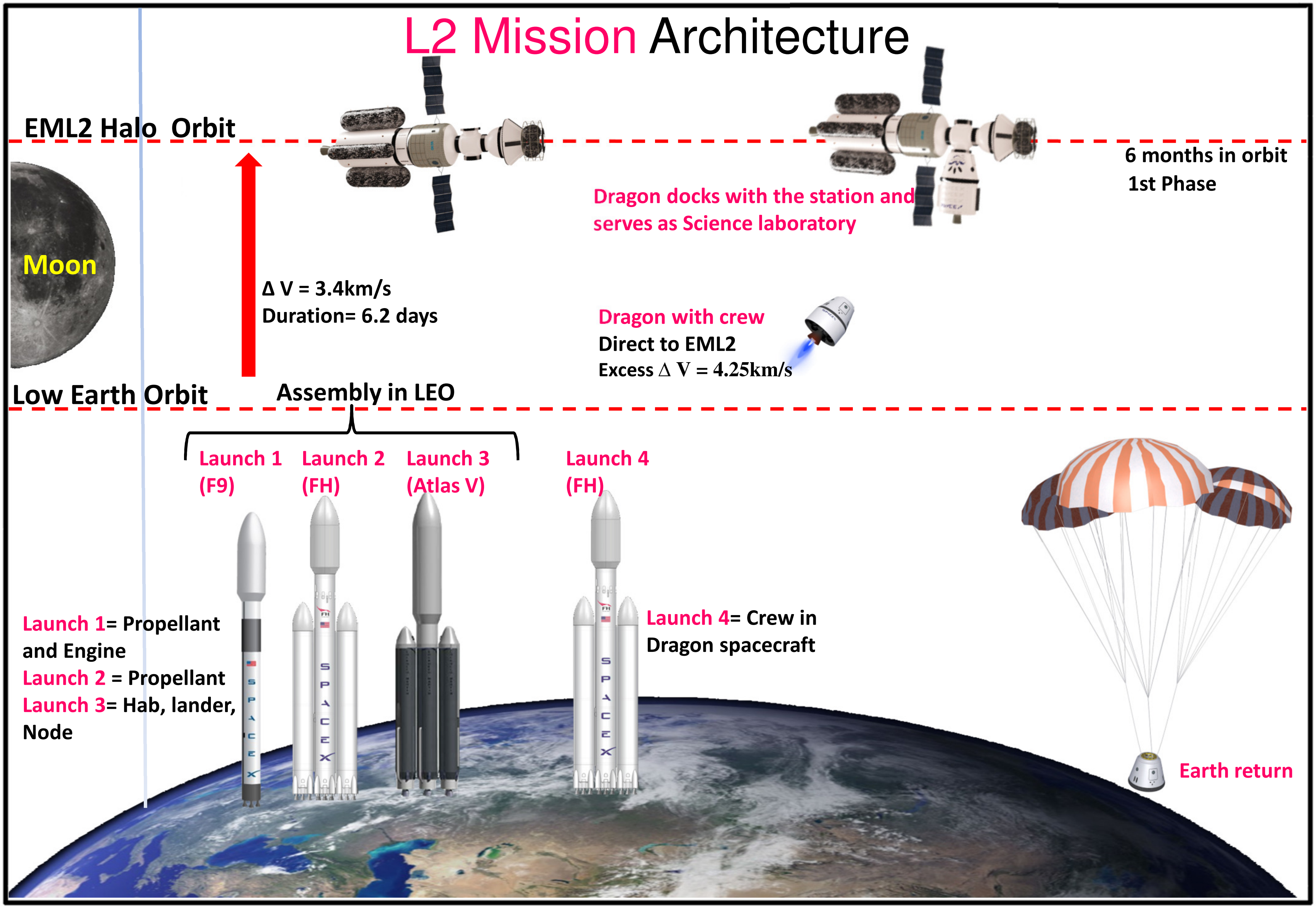
Dragon as ERV/Science LAB
Mass= 5 mT
Structure = 2mT
Less payload = 46T
Excess Delta V = 4.50 km/s
Falcon Heavy

Launch 1 | Launch 2 | Launch 3 | Launch 4

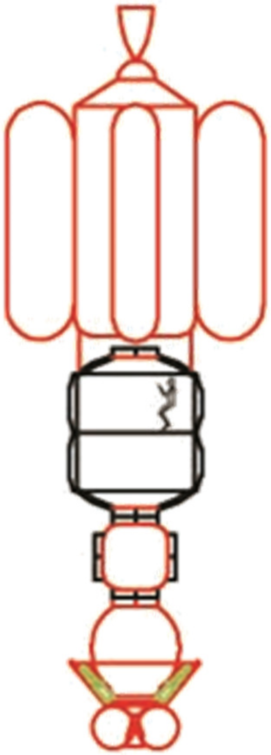
Assembly in LEO

Direct to EML2

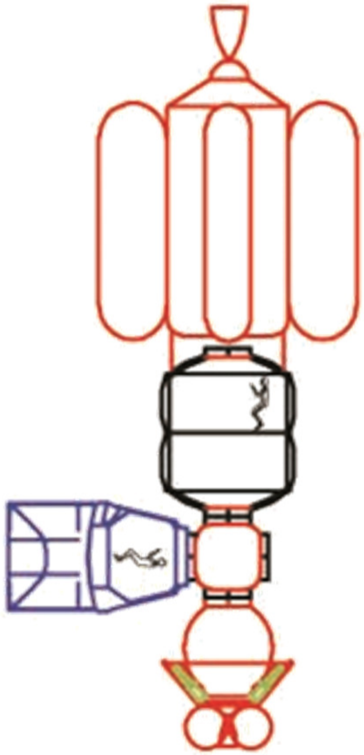
L2 Mission Architecture



EML2 Mission Design - Catalog

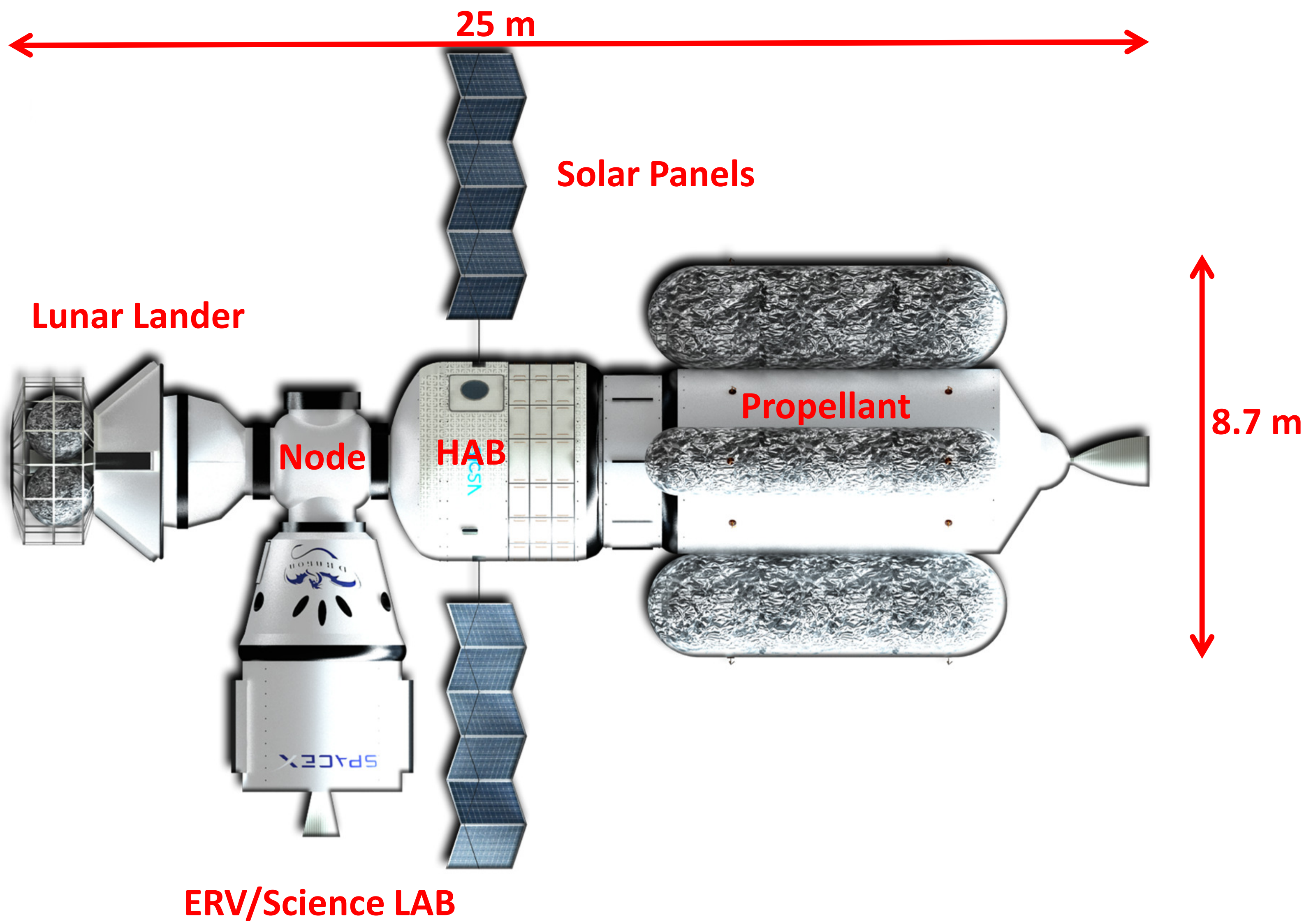


At LEO

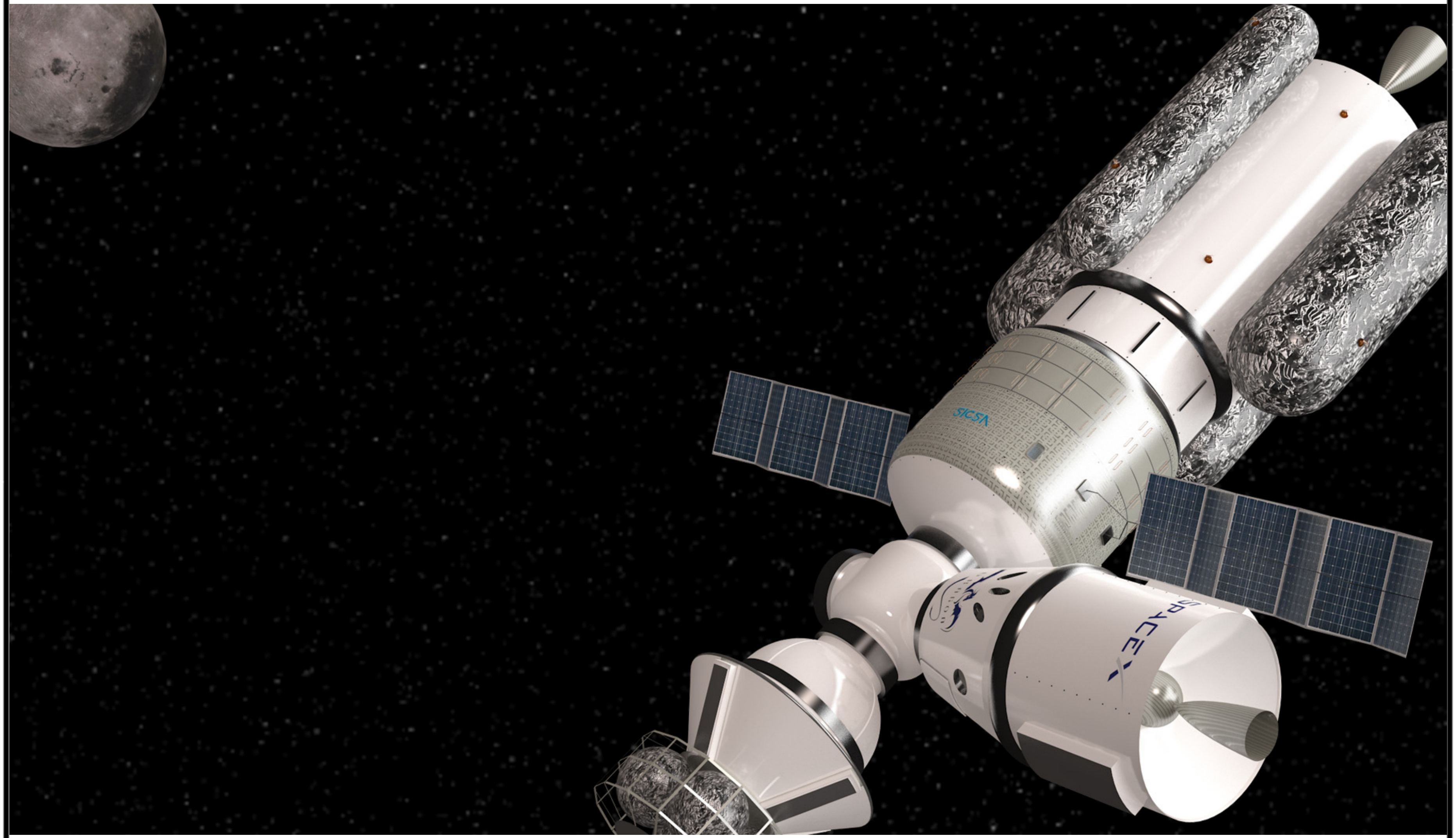


At EML2

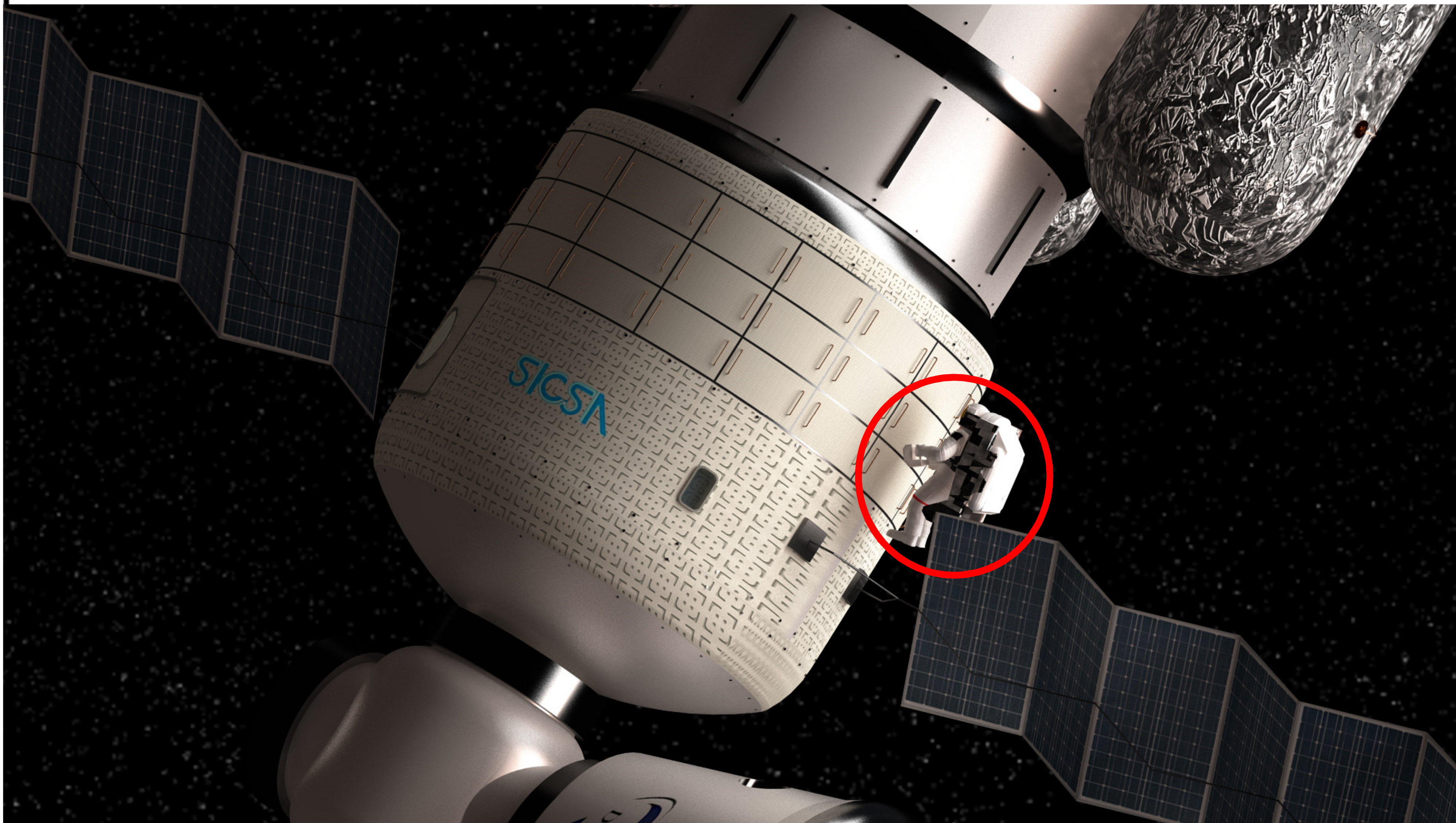
EML2- Station



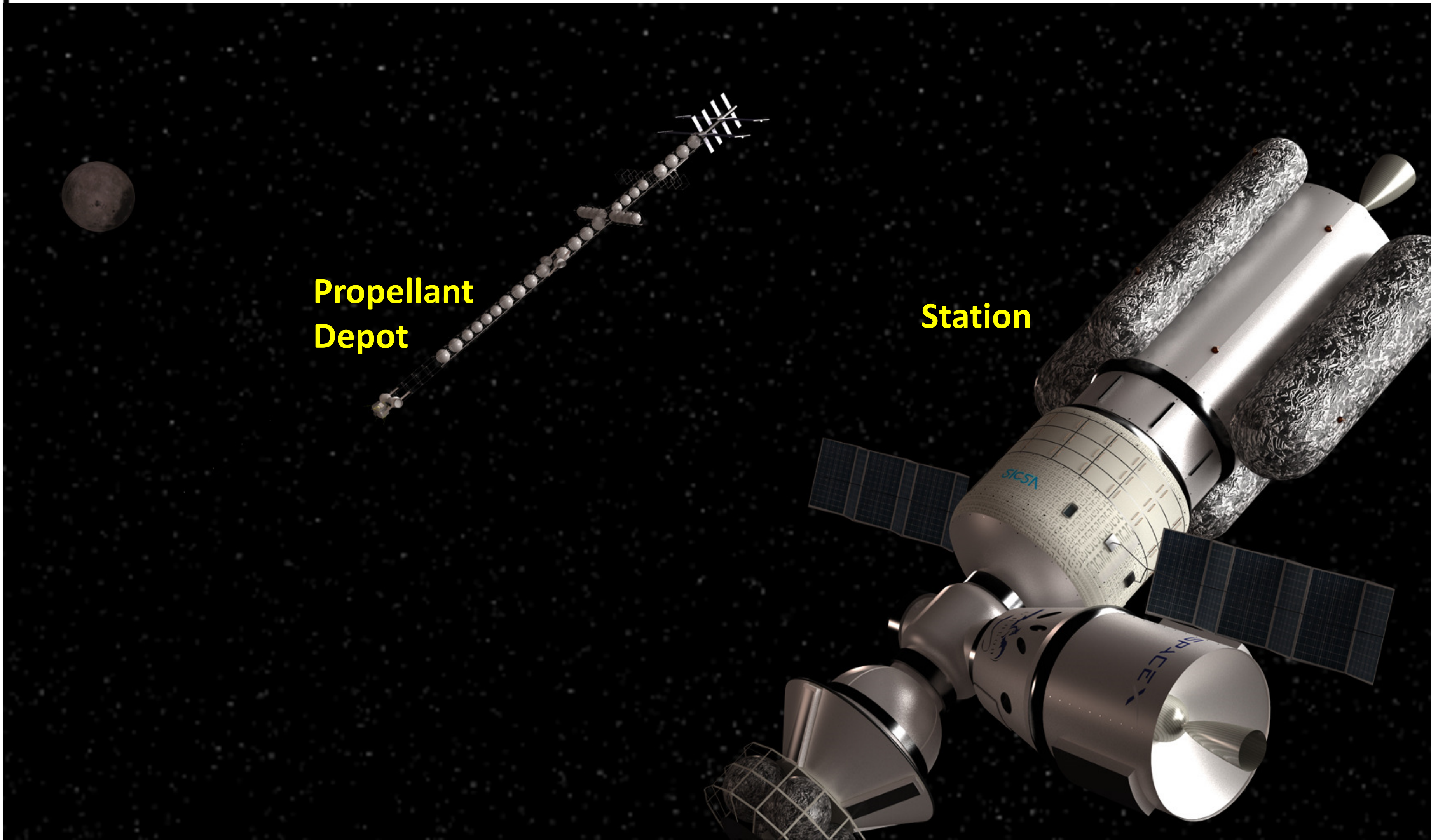
EML2 Station- Halo Orbit



EML2 Station- Performing EVA



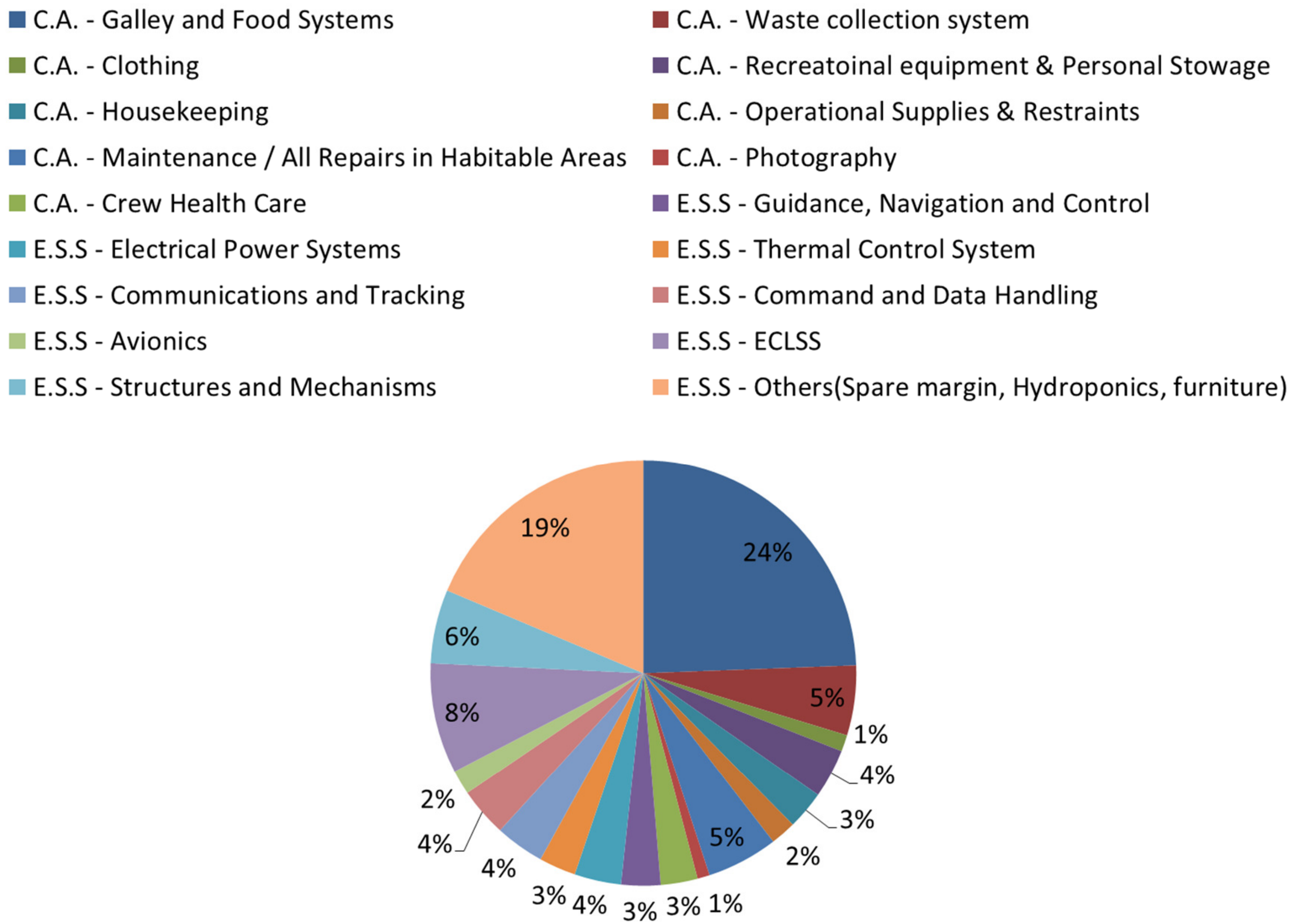
EML2 Station- Future Extension



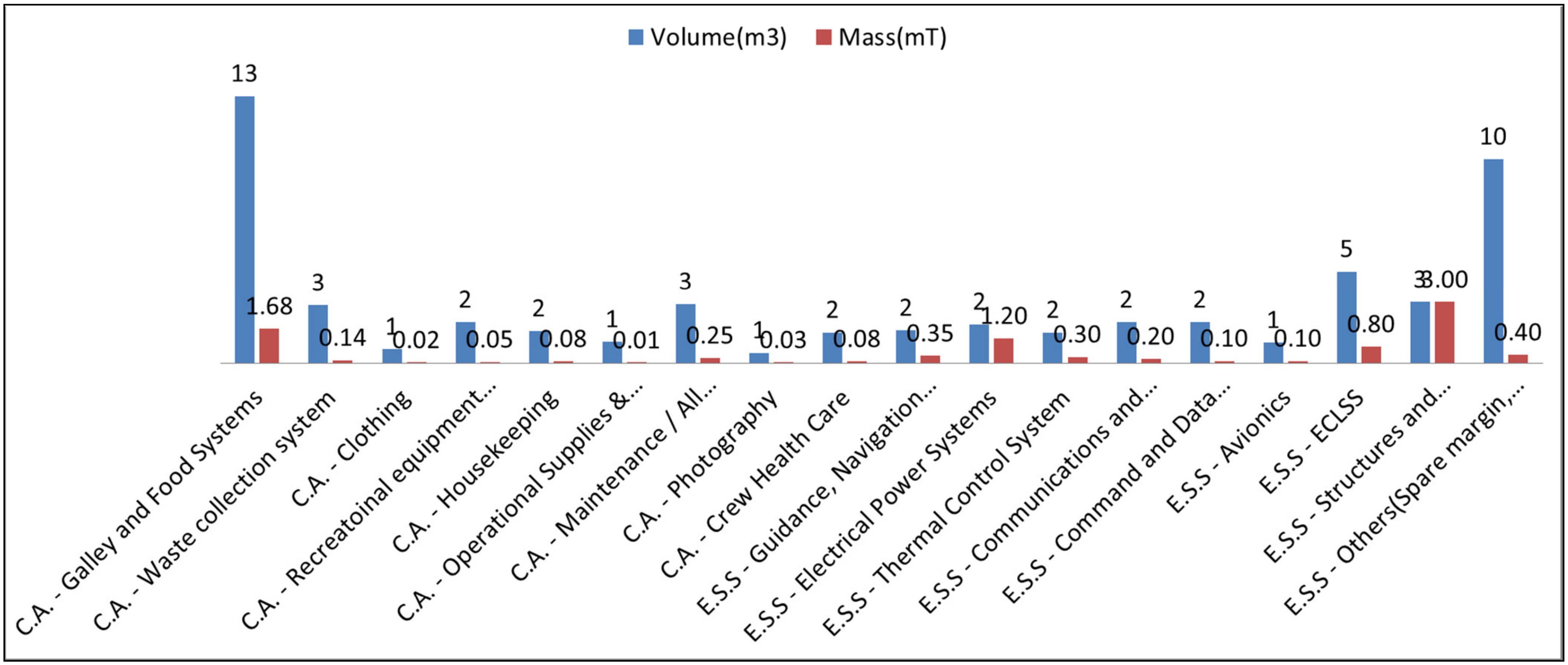
Station HAB – Subsystems Mass-Volume chart

Subsystems	Volume(m3)	Mass(Kg)
C.A. - Galley and Food Systems	13	1677
C.A. - Waste collection system	3	137
C.A. - Clothing	1	20
C.A. - Recreatoinal equipment & Personal Stowage	2	50
C.A. - Housekeeping	2	77
C.A. - Operational Supplies & Restraints	1	80
C.A. - Maintenance / All Repairs in Habitable Areas	3	245
C.A. - Photography	1	25
C.A. - Crew Health Care	2	75
E.S.S - Guidance, Navigation and Control	2	350
E.S.S - Electrical Power Systems	2	1200
E.S.S - Thermal Control System	2	300
E.S.S - Communications and Tracking	2	200
E.S.S - Command and Data Handling	2	100
E.S.S - Avionics	1	100
E.S.S - ECLSS	5	800
E.S.S - Structures and Mechanisms	3	3000
E.S.S - Others(Spare margin, Hydroponics, furniture)	10	400
Total	**54**	**8836**

Station HAB – Subsystems



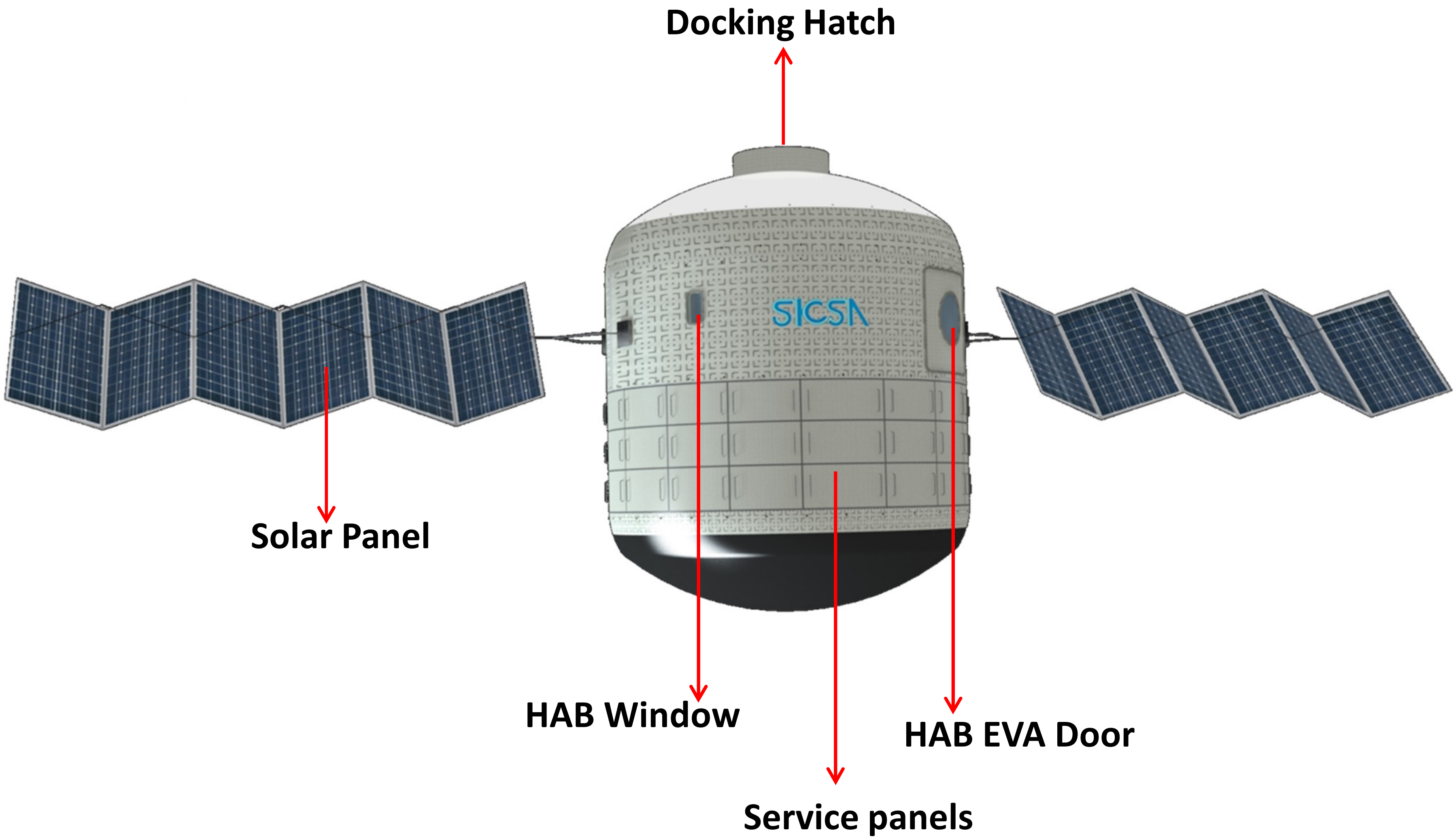
Station HAB – Mass-Volume graph



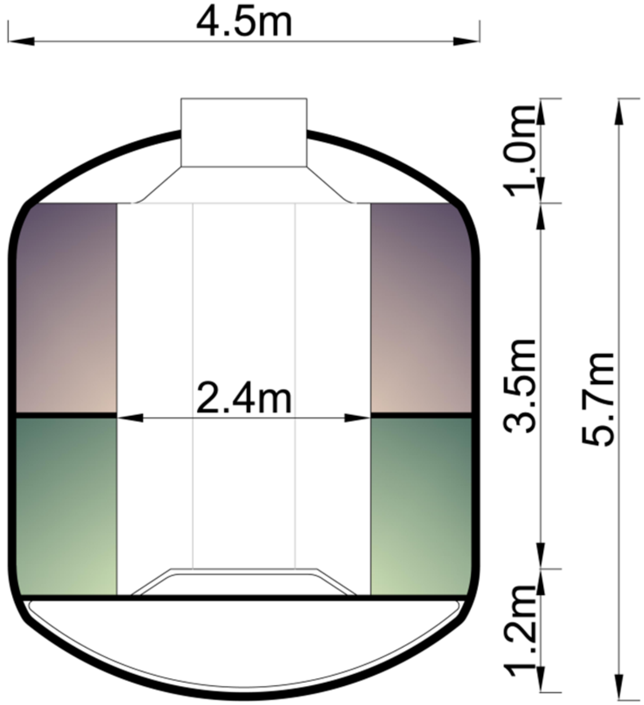
Station HAB – Design Concept

- Modular structure
- Multiple usage of space saves volume
- Less structure
- Reconfigurable interiors

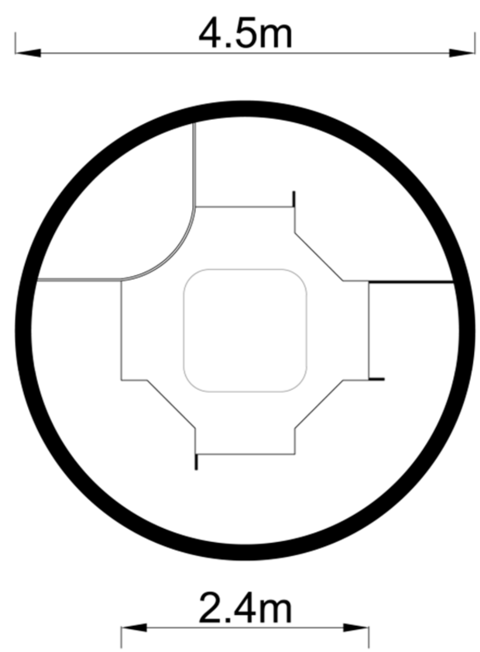
Station HAB - Exterior



Station HAB – Sectional Plans

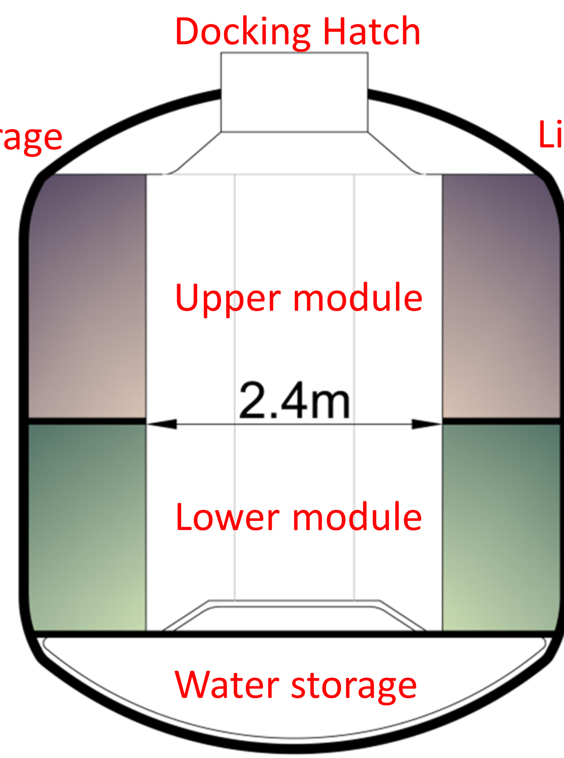


Vertical Section



Horizontal Section

Station HAB – Volume Distribution



Upper Module

Circulation space = 10 m3

Flexible space = 15 m3

Fixed Volume = 3.5 m3

Total volume = 28.5 m3

Docking Hatch

Volume = 3m3

Lower Module

Circulation space = 8 m3

Flexible space = 0

Fixed Volume = 16 m3

Total volume = 24 m3

Water storage

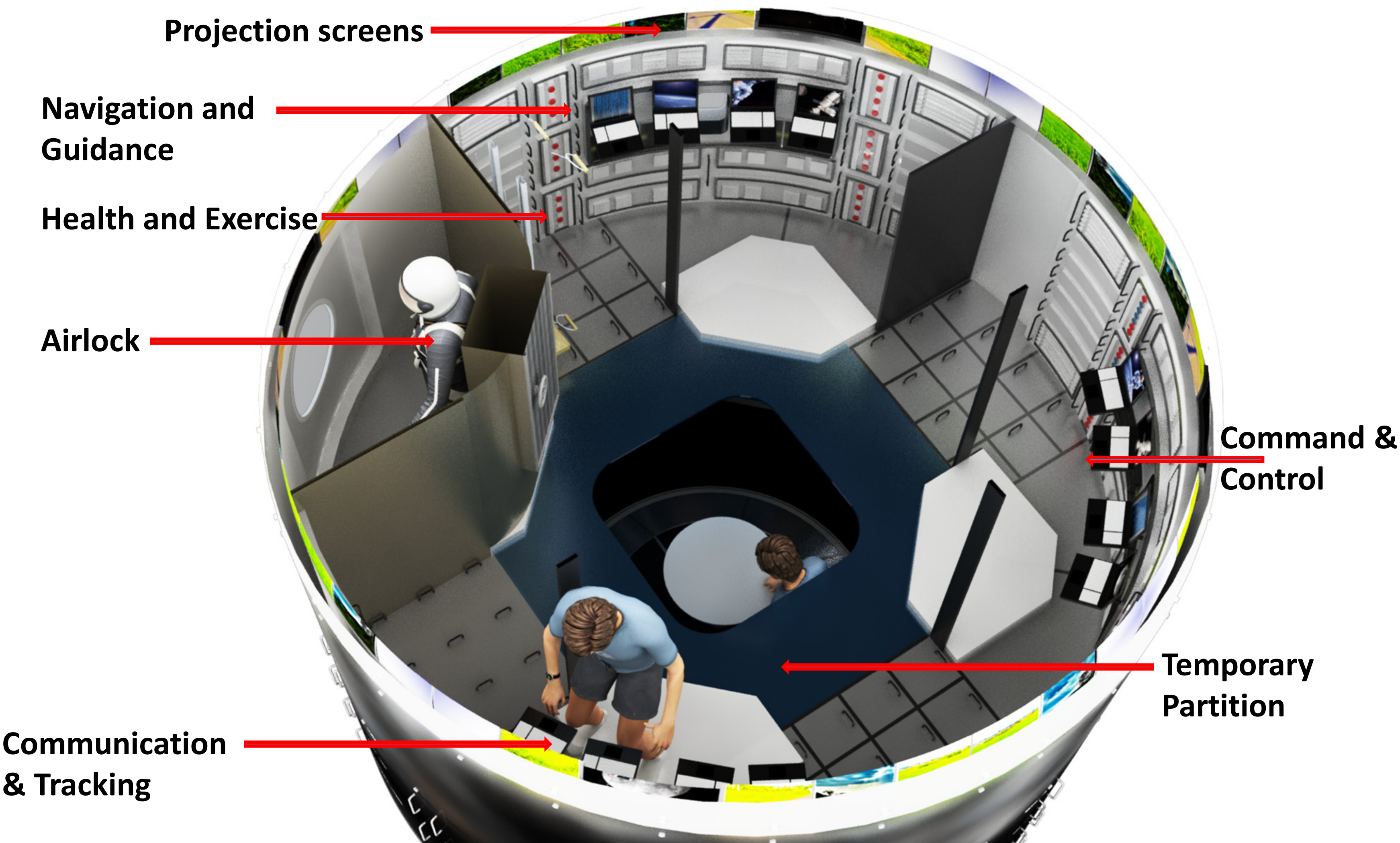
Volume = 5.5m3

Total volume= 67 m3

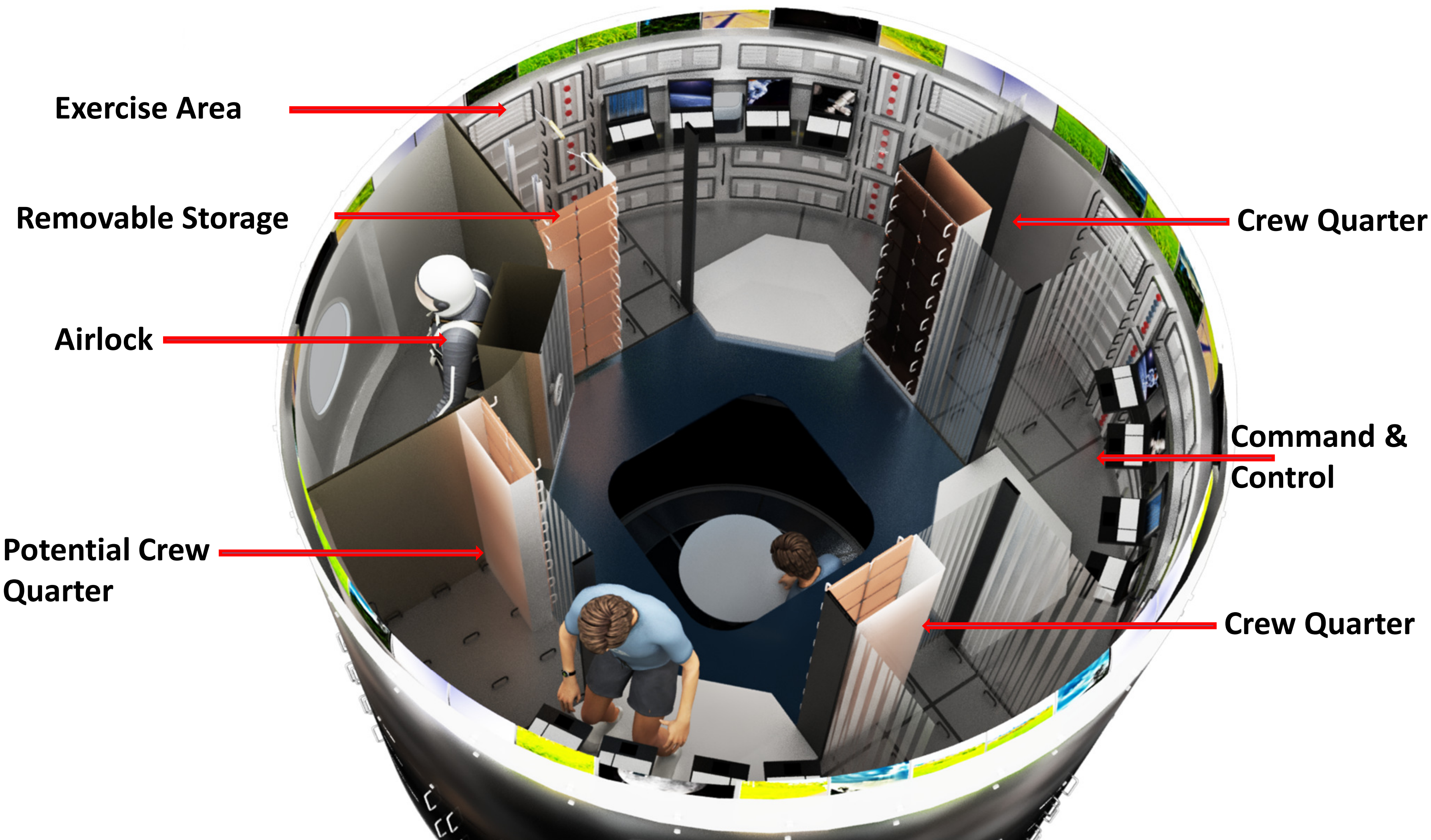
Mass = 9 mT

Usable volume= 61 m3

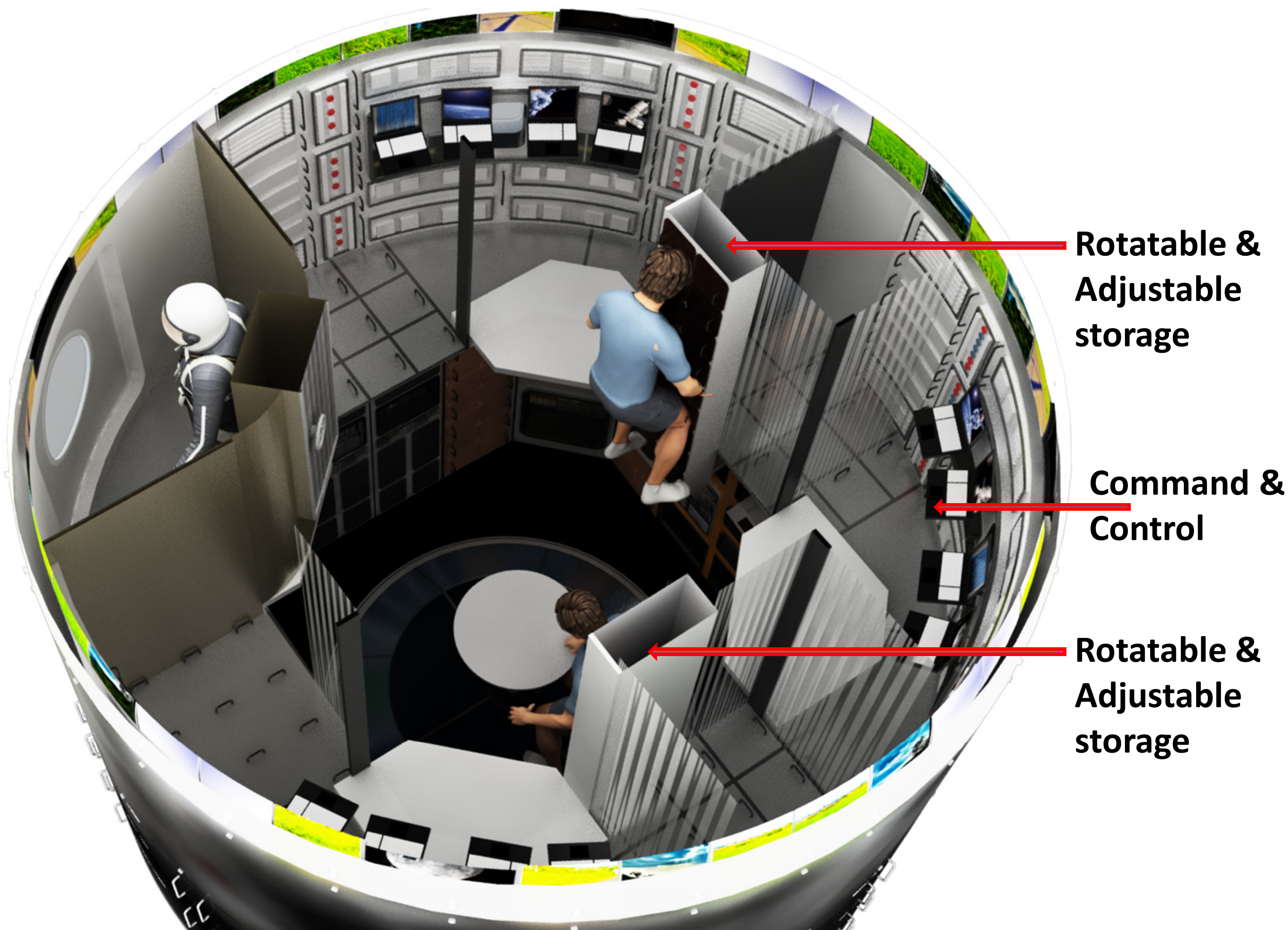
Station HAB – Interior Upper Module



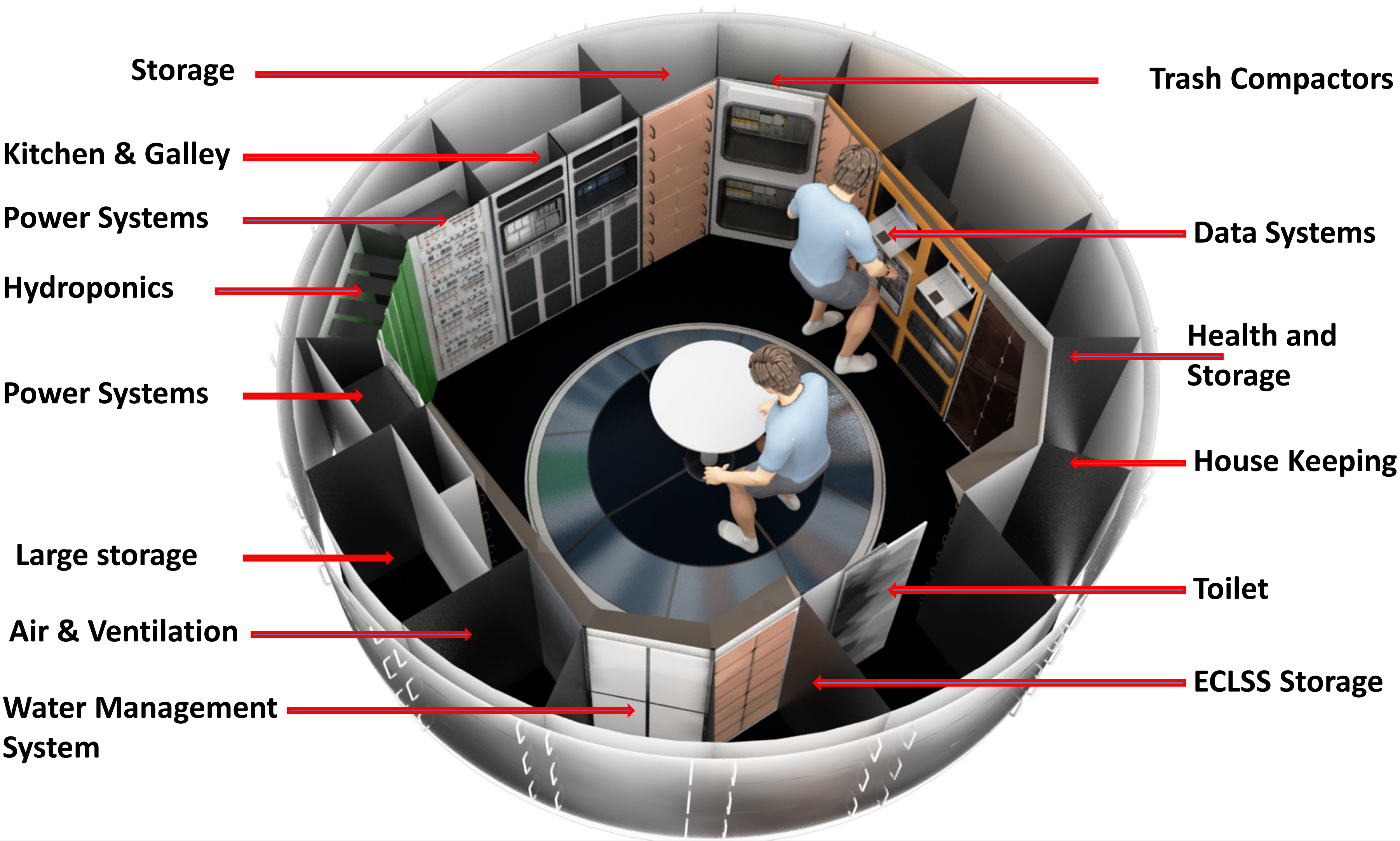
Station HAB – Interior Upper Module



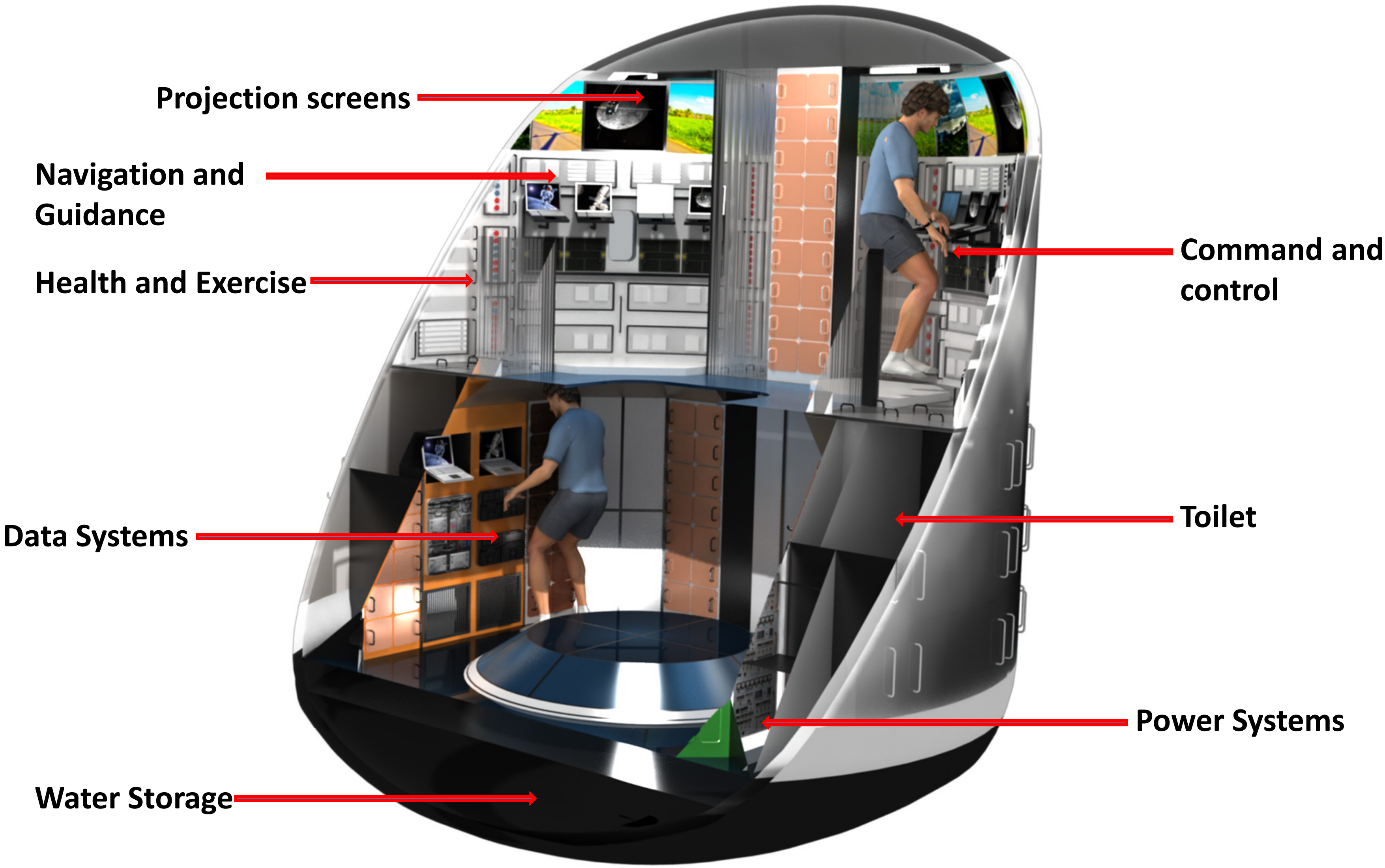
Station HAB – Interior Upper Module



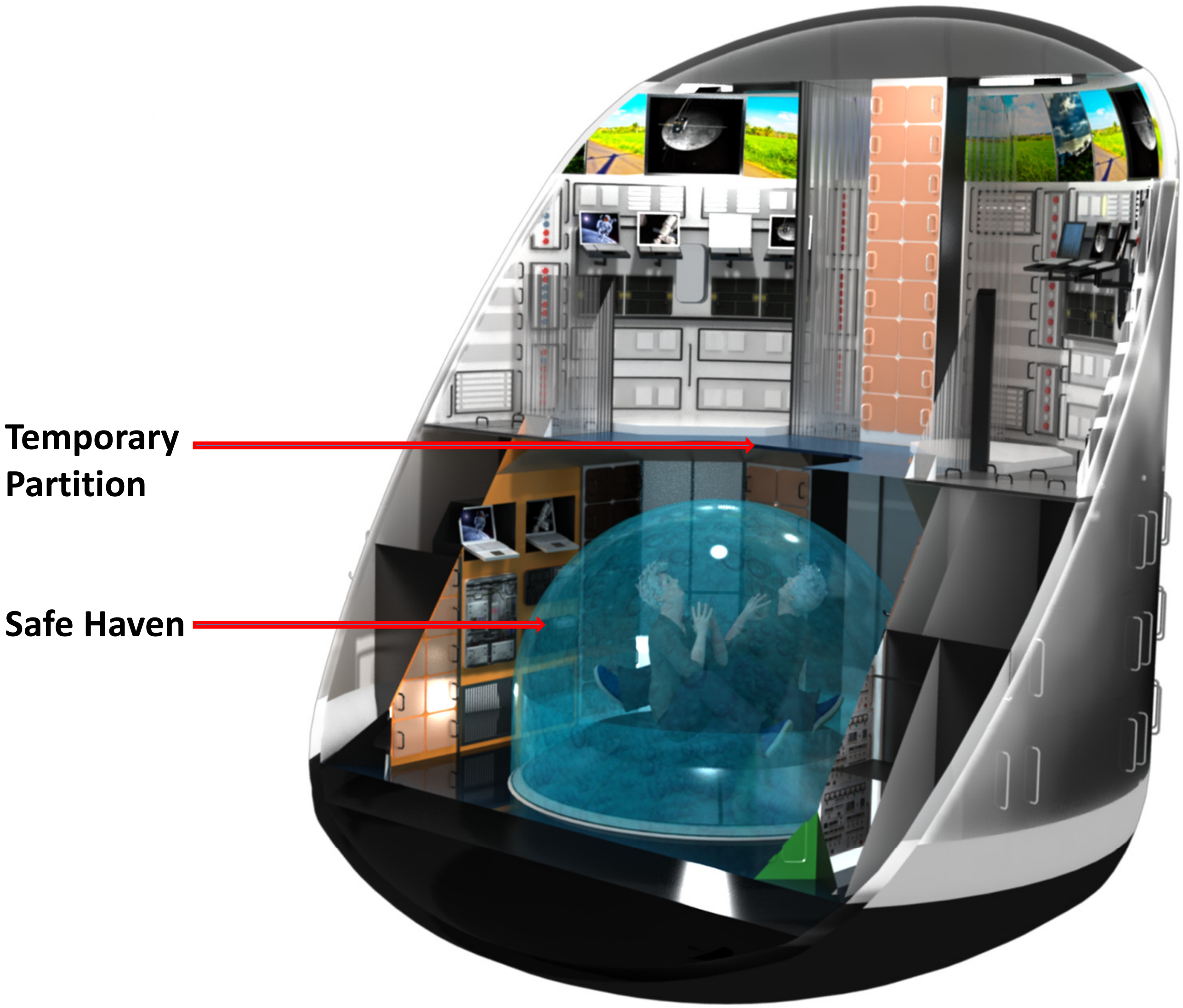
Station HAB – Interior Lower Module



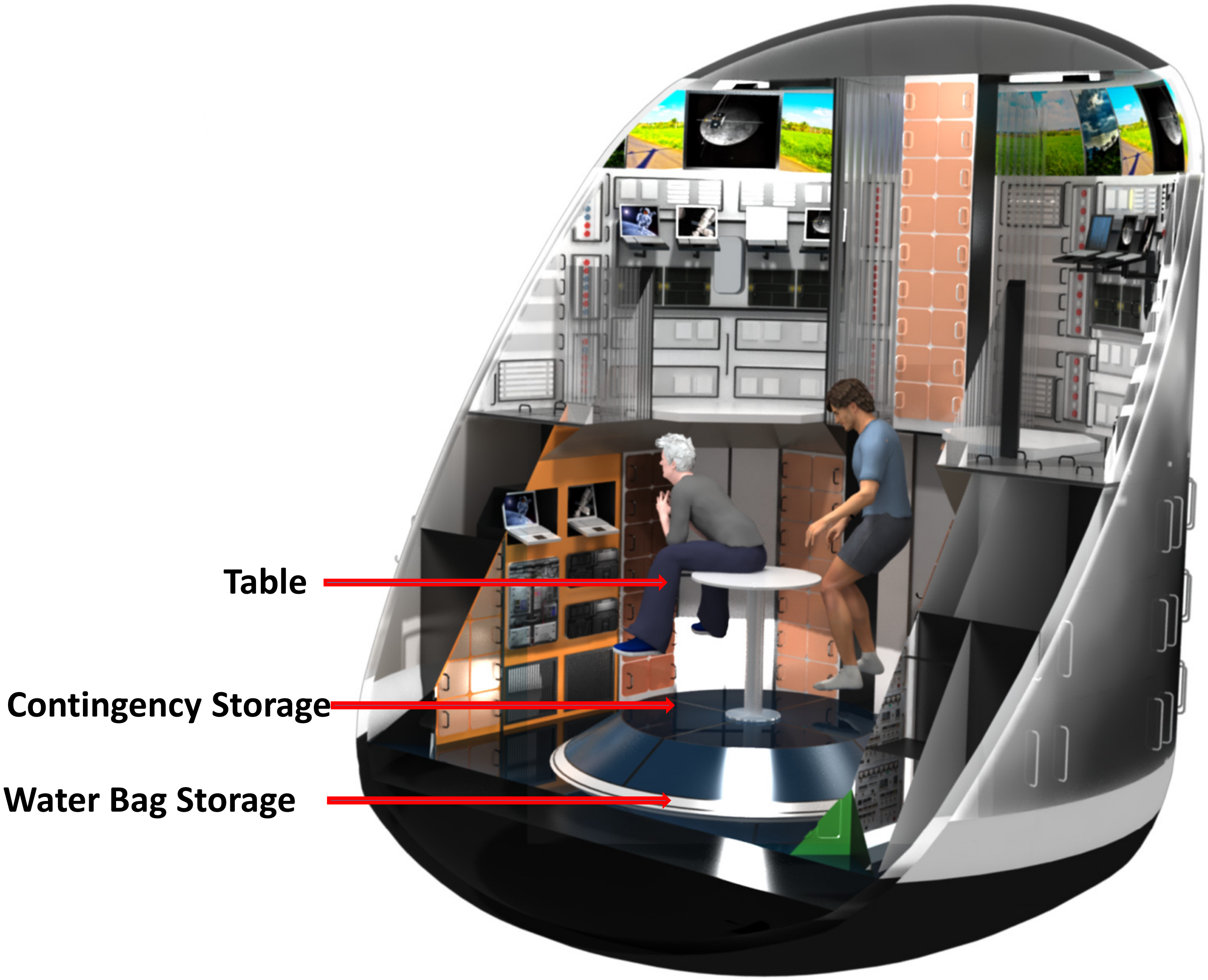
View- 3D Section



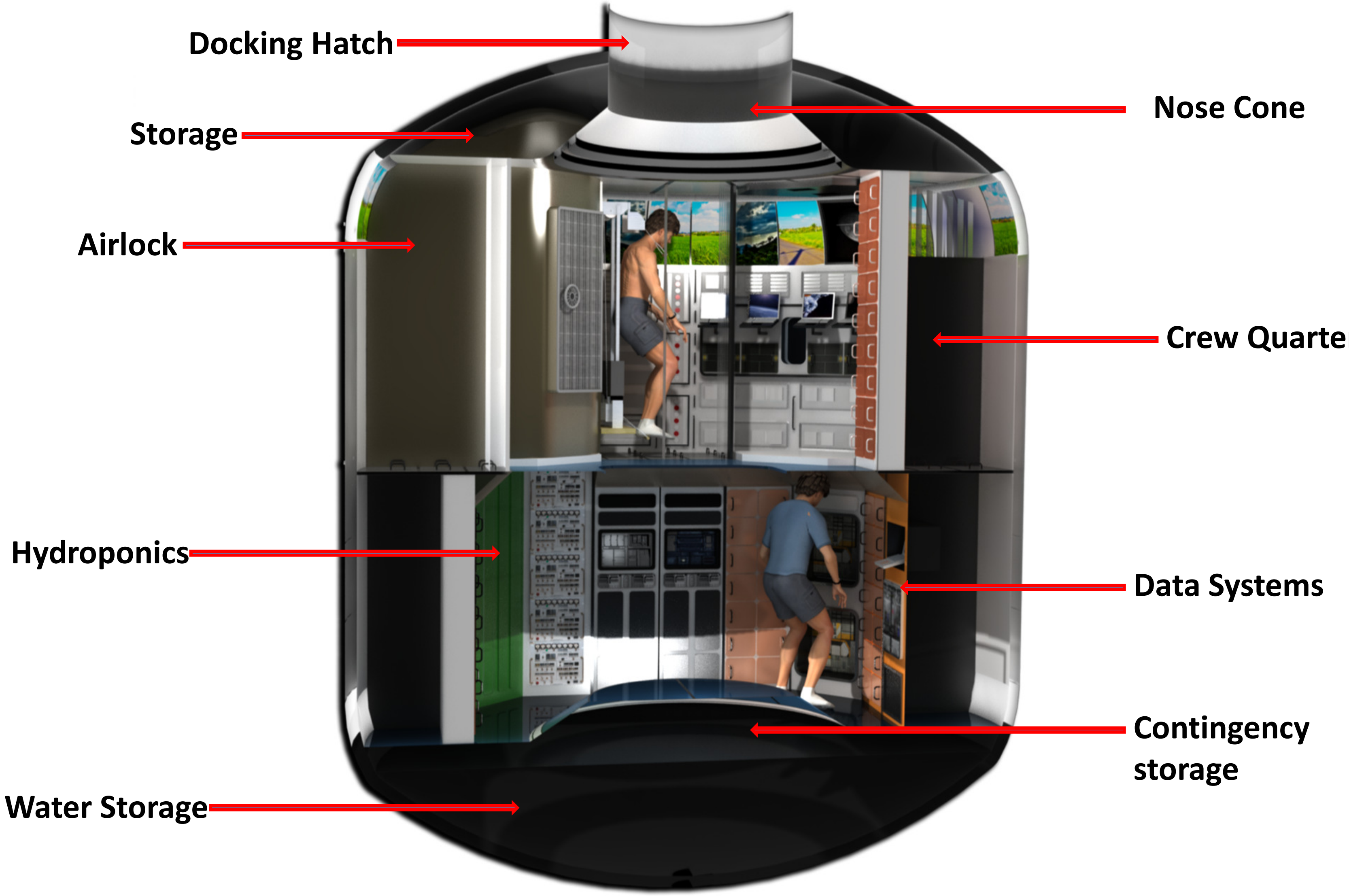
View- 3D Section



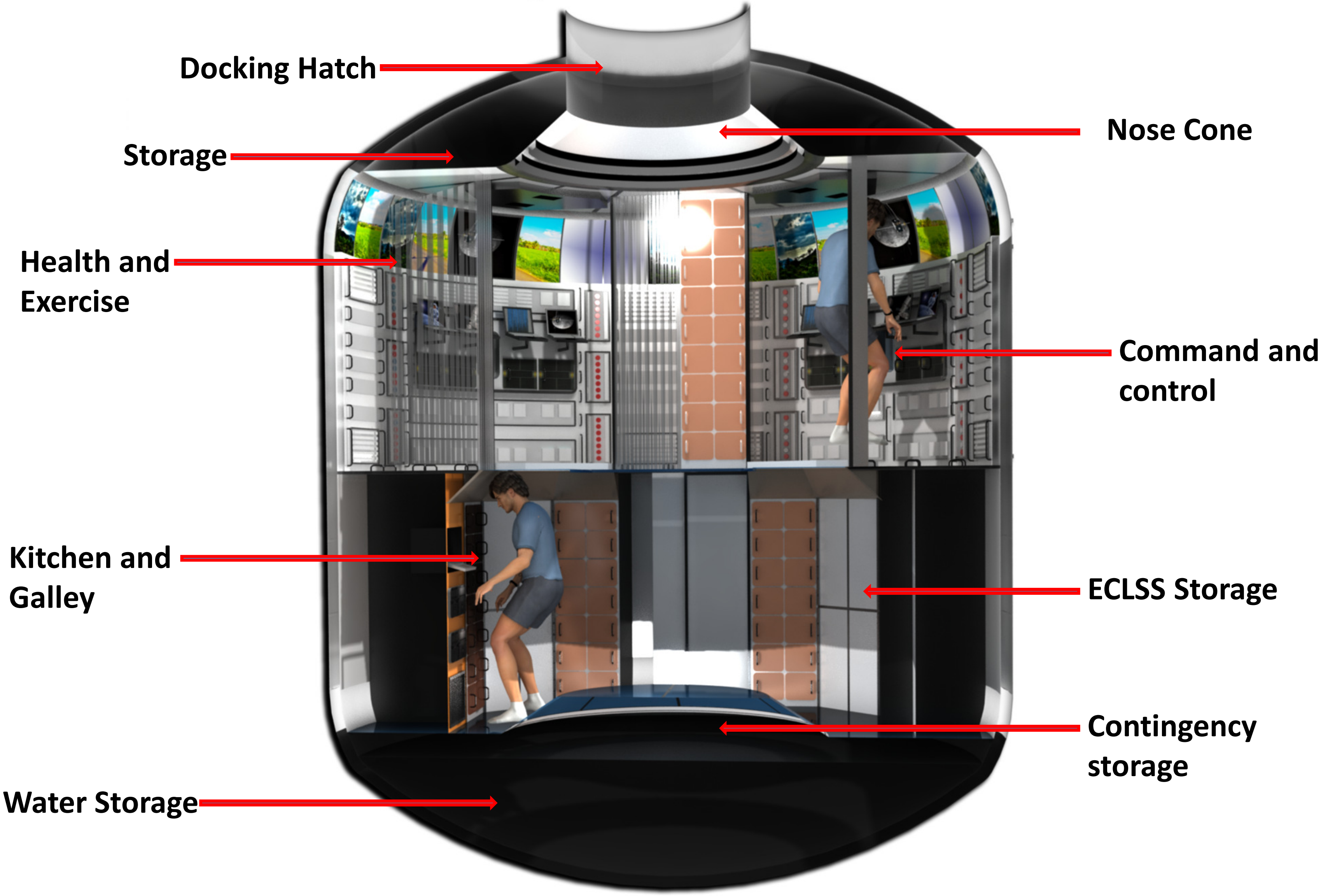
View- 3D Section



View- Longitudinal 3D Section



View- Longitudinal 3D Section



View- Communication and Tracking

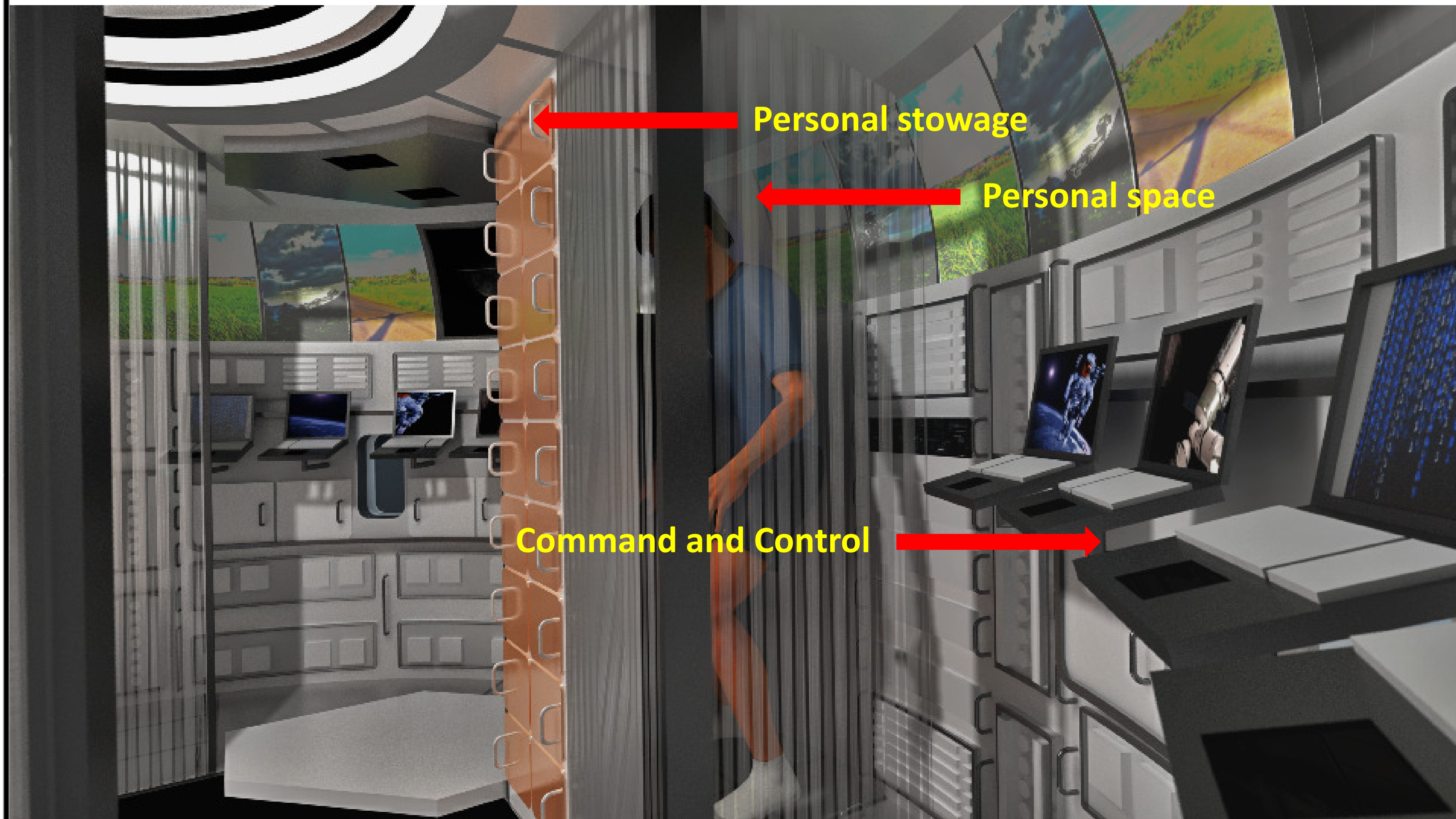
Access to anyone

View- Communication and Tracking

Limited access

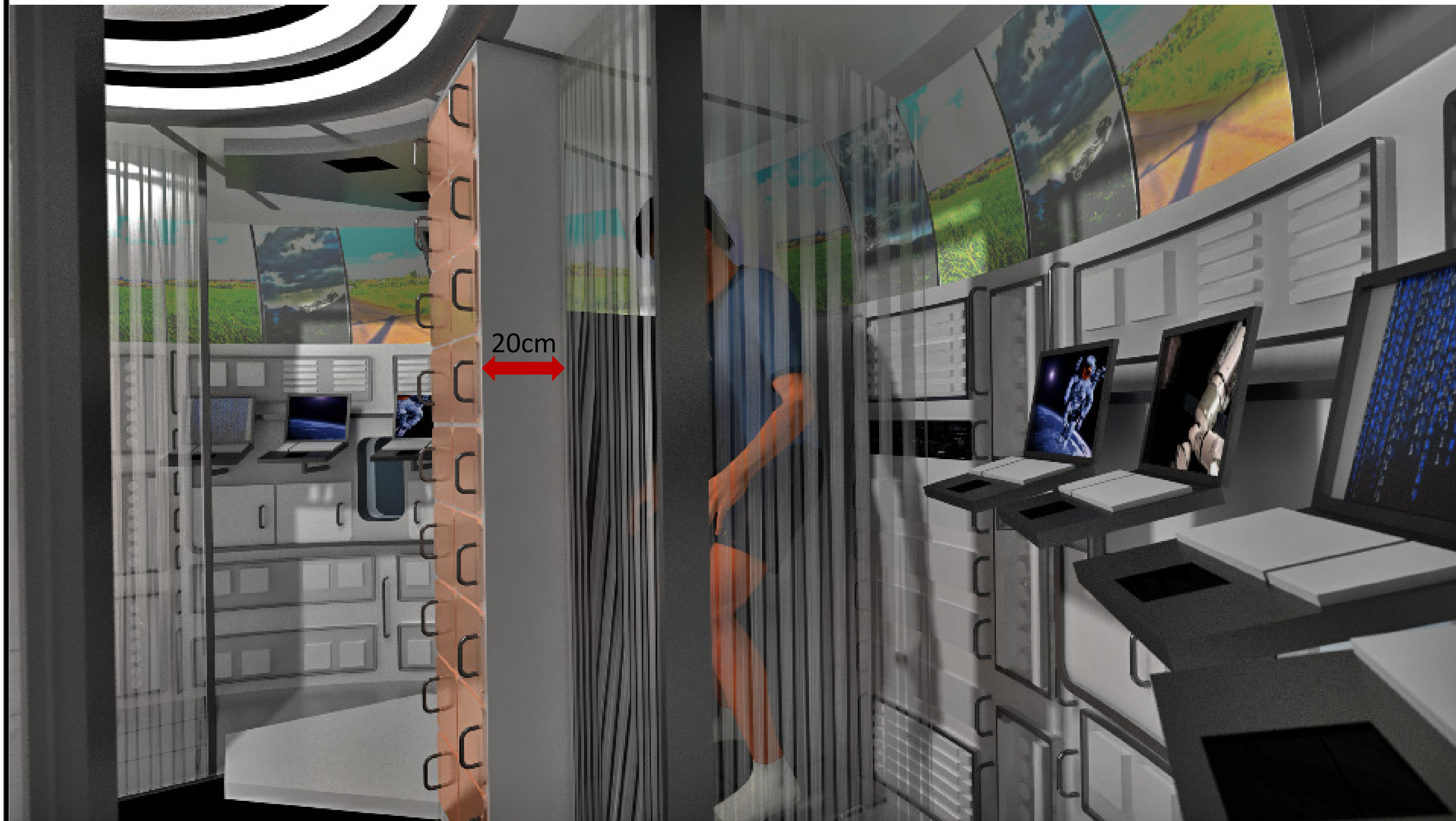
View- Communication and Tracking

View- Personal Space- Command and Control



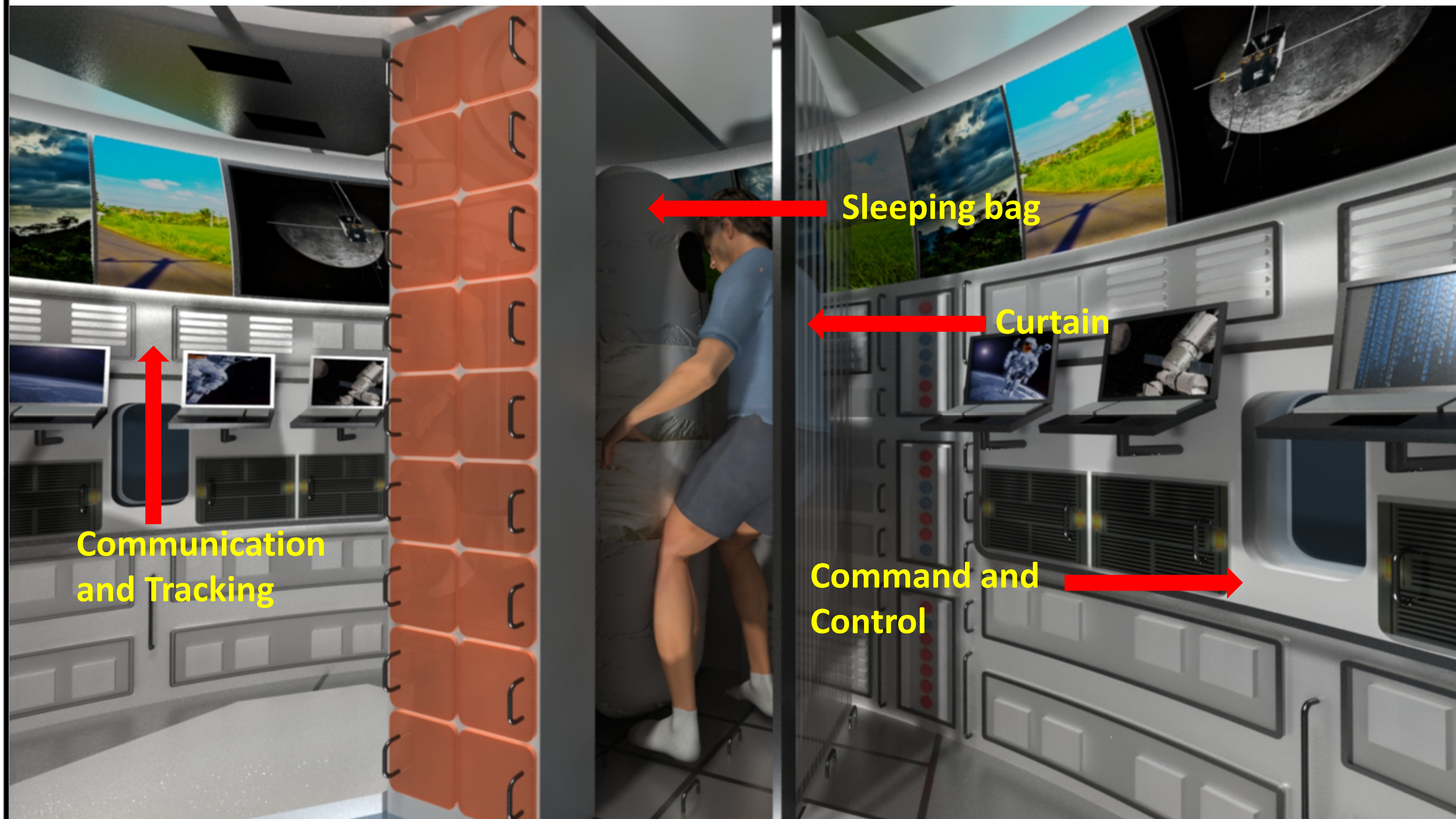
View- Personal Space- Command and Control

View- Personal Space- Command and Control



View- Crew Quarter

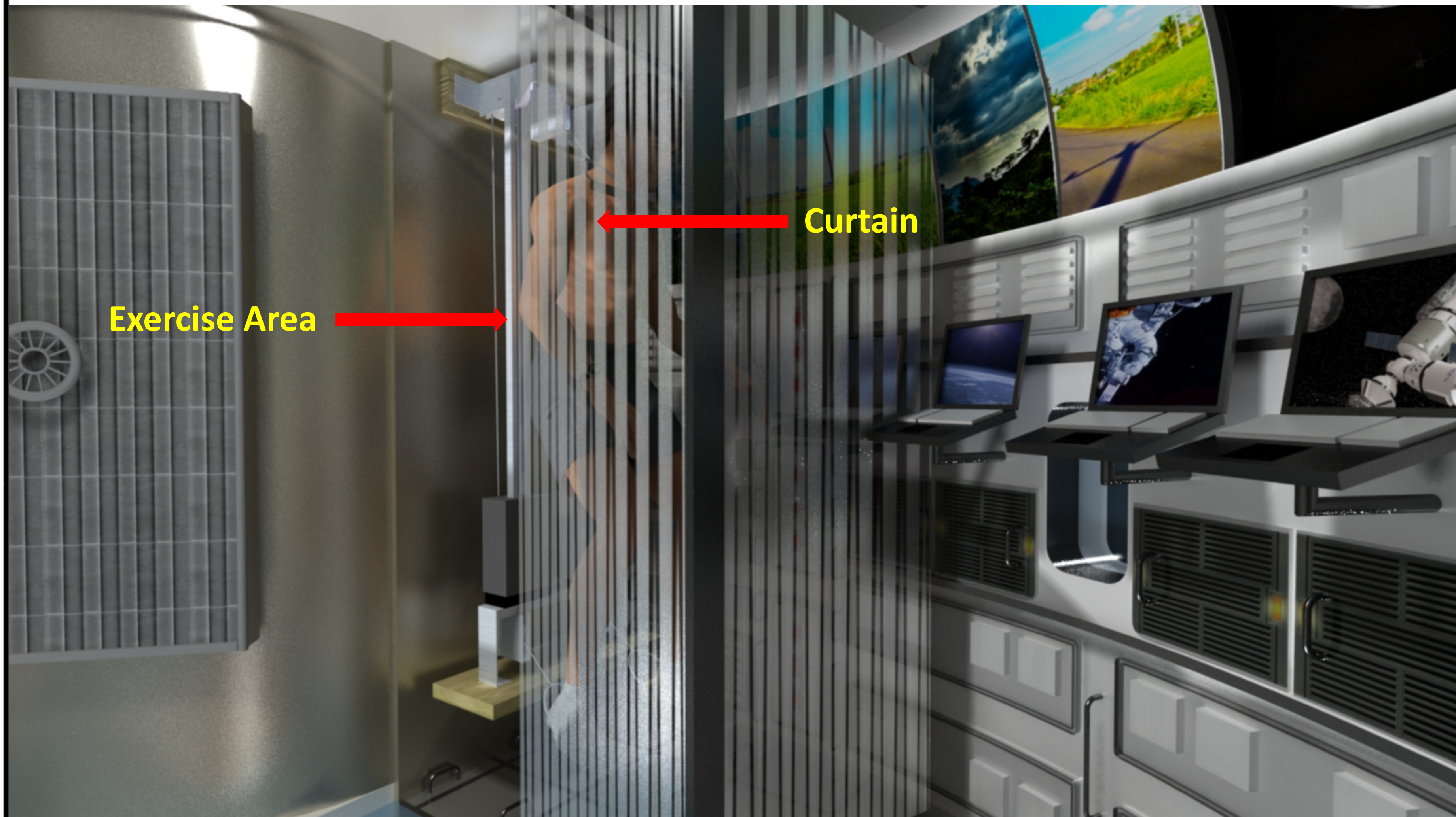
View- Crew Quarter



View- Command and Control

View- Exercise- Navigation and Guidance

View- Exercise- Navigation and Guidance



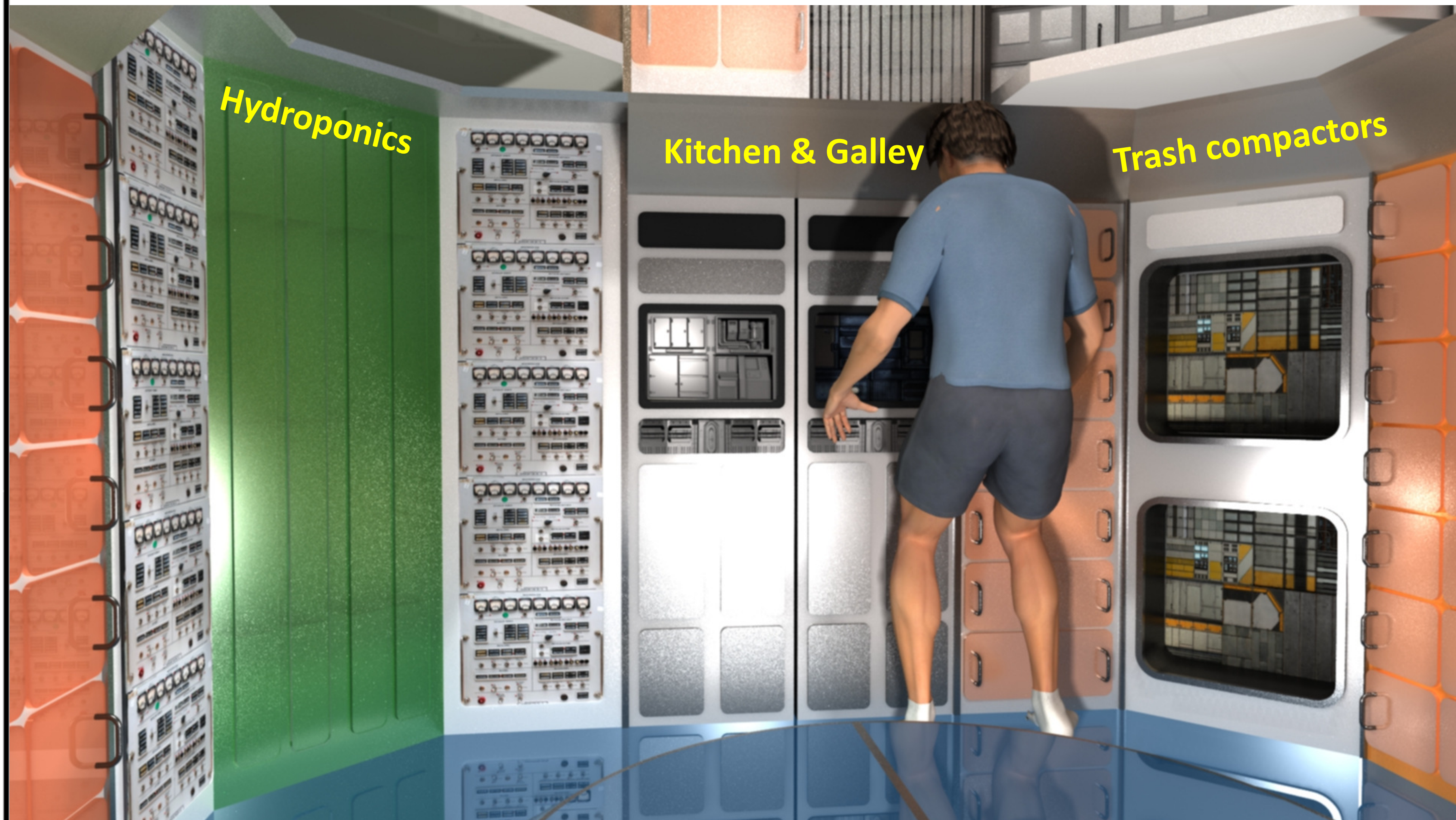
View- Crew accessing storage

View- Limited Access Situation

View- From Upper Module

View- Lower Module

View- Lower Module

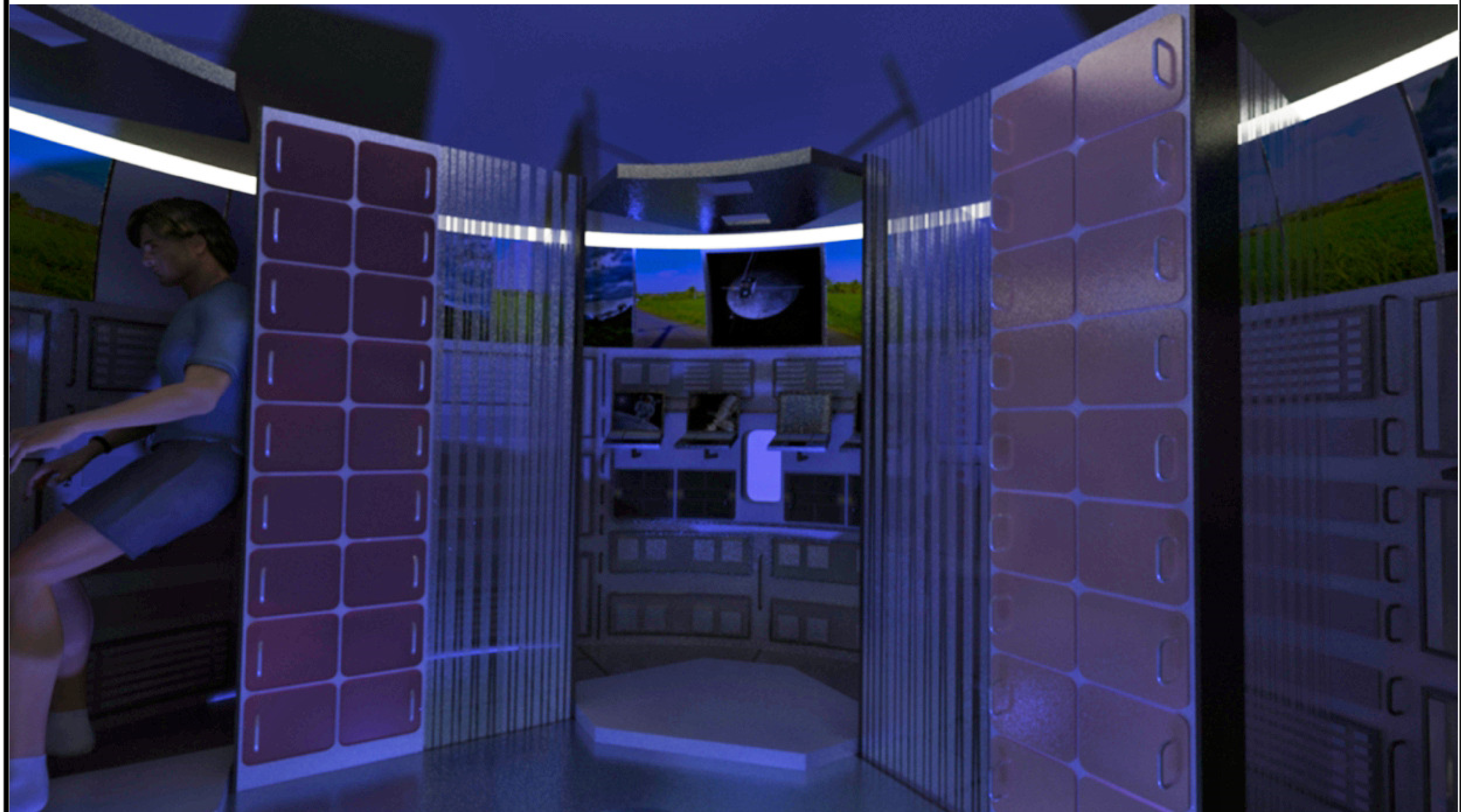


Sasakawa International Center for Space Architecture
University of Houston College of Architecture

View- Radiation Protection

View- Simulating Surrounding

View- Simulating Surrounding



View- Simulating Surrounding

# Acknowledgement

Special gratitude to my professors **Larry Bell, Olga Bannova** and **Bob Sauls** for their patient guidance and support over the entire program.

Thanks to **Larry Toups** for sparing his precious time to take us around NASA and his motivation whenever required.

Thanks to **Nejc** for his help and support in learning new things.

Thanks a lot to the **jury** for being here and for their feedbacks.

References

1. Tito, D., MacCallum, T., Carrico, J., and Loucks, M. "Feasibility Analysis for a Manned Mars Free-Return Mission in 2018 - FISO," *Future In-Space Operations (FISO) telecon colloquium*. Wilshire Associates Incorporated, 2013
2. Technology, A. S. "Expendable Launch Vehicles." Andrews Space & Technology
3. Stan Borowski, “Bimodal” Nuclear Thermal Rocket (BNTR) propulsion for future human mars exploration” missions
4. Marco Tantardini, “Low delta V trajectories to move a small asteroid to a Lagrange point”. Keck institute for space studies
5. Scott D Norris, “Lunar Farside (L2) A Stepping Stone in a series of Exploration Missions “, Lockheed Martin, November, 2011
6. Stacy Henze, “Mars Transfer Vehicle Concept, Utilizing Re-Con!gurable Building System”, SICSA
7. A. Scott Howe, Brent Sherwood, “Out of this world, A new field of Space Architecture”
8. James Doehring, “In Space Propulsion using Modular Building Blocks”