LESSONS LEARNED FROM
ANTARCTICA
APPLIED TO THE PHASED DEVELOPMENT OF A
LONG-TERM MARTIAN STATION

FINAL PRESENTATION
SPAC 6405: ADVANCED DESIGN & ANALYSIS STUDIO & THESIS

SAVANAH LEA

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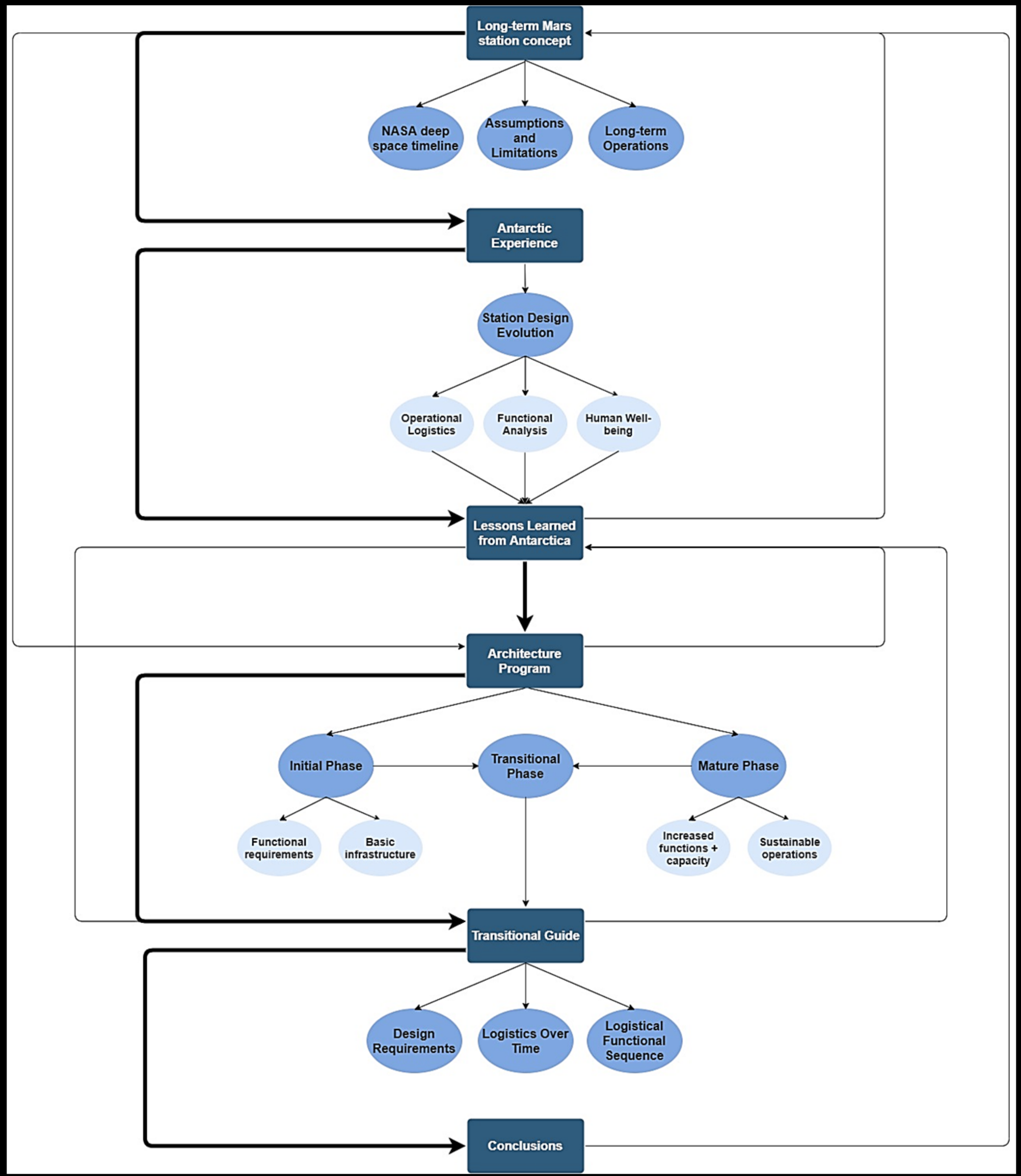
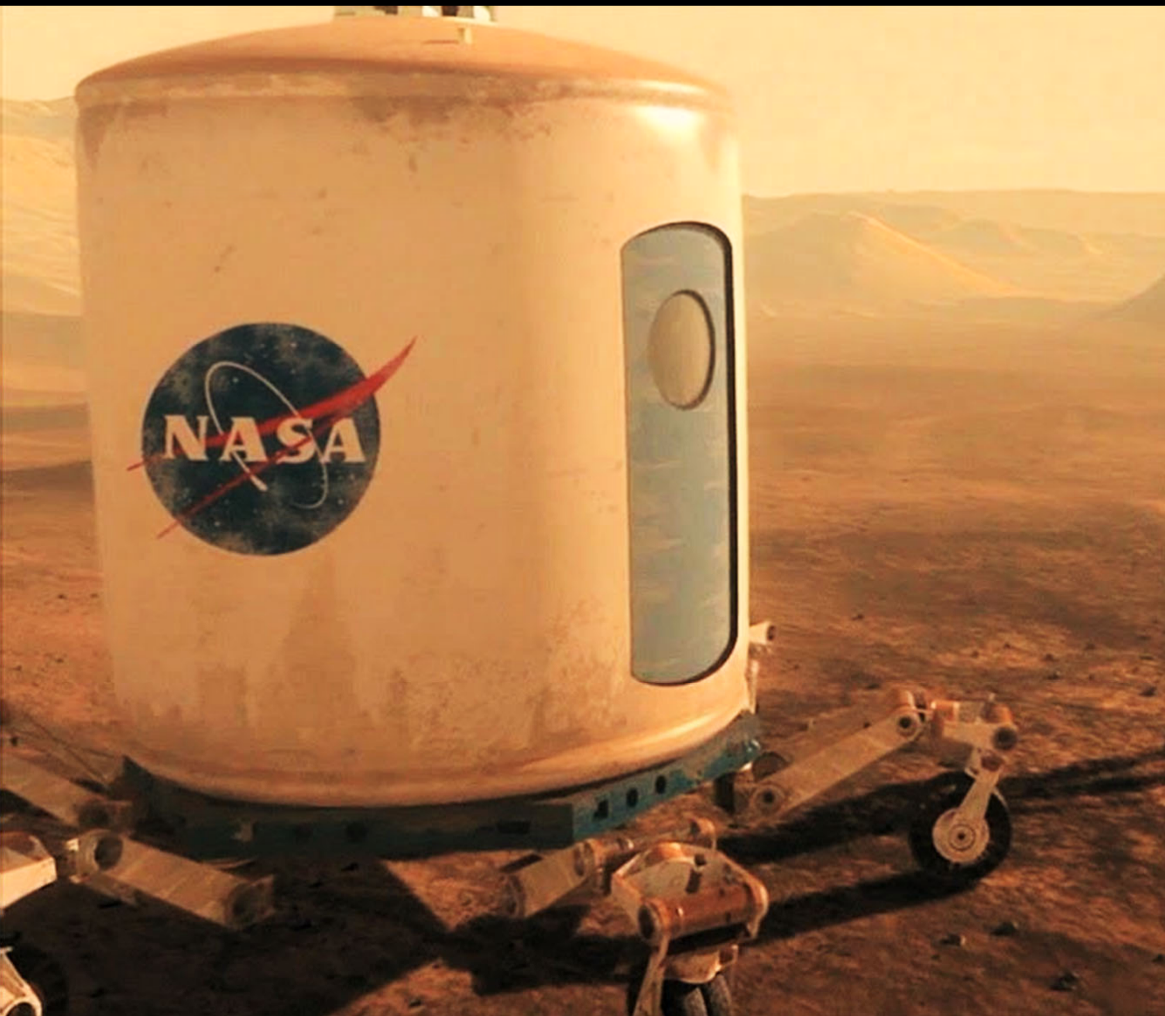
RESEARCH FLOW DIAGRAM



LONG-TERM MARTIAN STATION CONCEPT

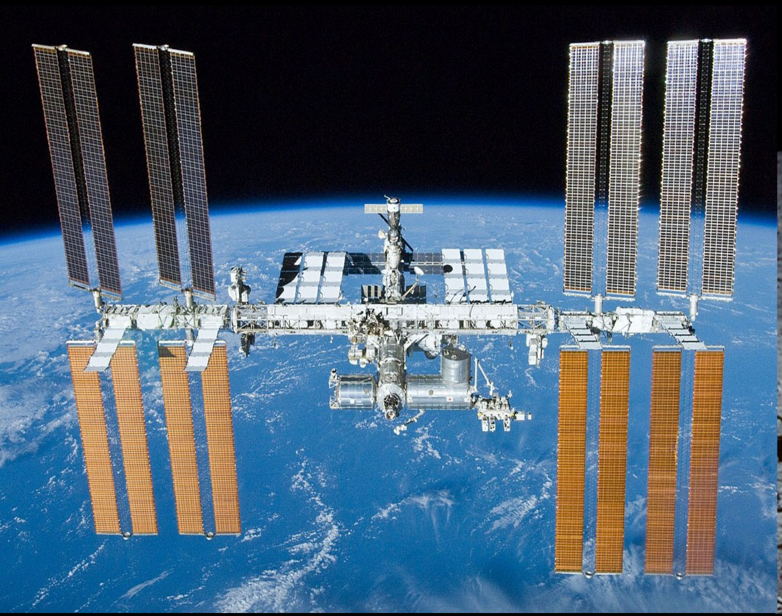


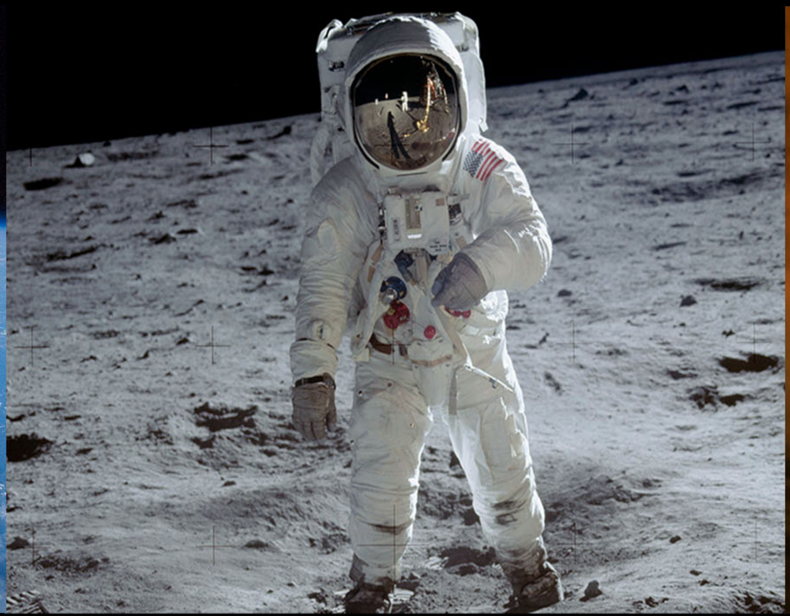
NASA DEEP SPACE TIMELINE

LEO OPERATIONS

LUNAR OPERATIONS

MARTIAN OPERATIONS





1990s - CURRENT
CONTINOUS CREW
OPERATIONS

2024
CREWED RETURN
TO THE MOON

2030s
FIRST CREWED
MISSION TO MARS

LONG-TERM MARTIAN STATION CONCEPT

ASSUMPTIONS AND LIMITATIONS

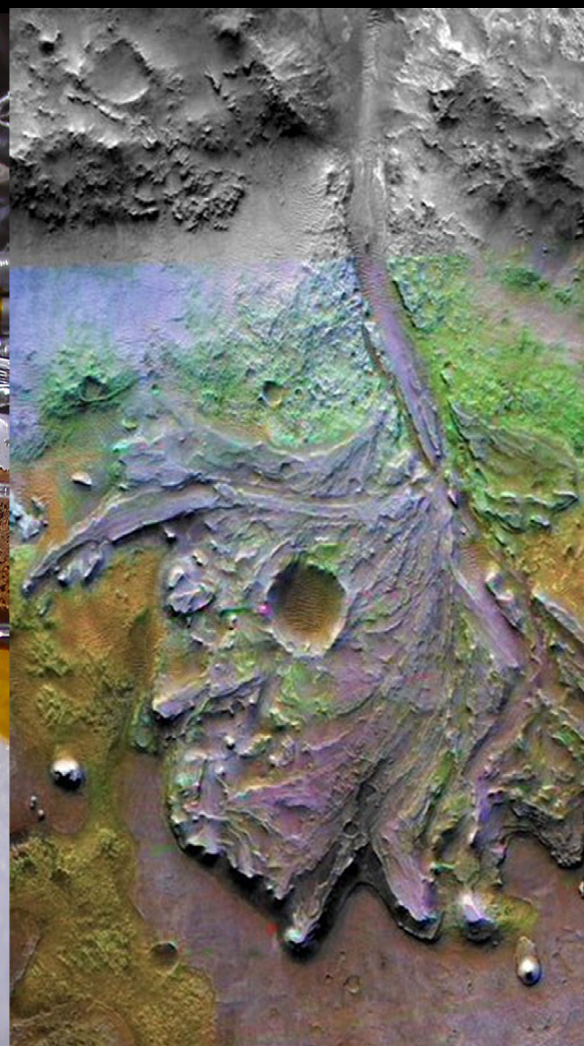
ENVIRONMENTAL	MID-LATITUDE MARS
GRAVITY	≈1/3 G
ATMOSPHERE	>1% Earth atmosphere
ATMOSPHERIC COMPOSITION	96% Carbon dioxide, 2% Argon, 2% Nitrogen, 1% other
TEMPERATURE AVERAGE	-50℃
TEMPERATURE LOW	-60℃
TEMPERATURE HIGH	0℃
HUMIDITY	≈0.01%
ICE CONCETRATION	Sub surface ice
RADIATION	GCR/ SPE radiation
PRESSURE	610 Pa
DAY LENGTH	≈24.6 hours
DAYLIGHT CYCLE	≈12.25 hours light/dark
WEATHER PATTERNS	Dust storms/devils/ 108 kph winds
INVASIVE/ASSAILANTS	Dust mitigation/meteoroid protection

LOGISTICAL	MID-LATITUDE MARS
TRAVEL DURATION	≈6-9 months crew ≈ 12 months cargo
LIMITED WINDOW OF ACCESS	Launch window every 2.1 years
TRANSIT VEHICLE	SLS Block 2 – Cargo + Crew Orion
TRANSIT CAPACITY	45 t
PAYLOAD DIAMETER	10 m
MAV/MDV capacity	22 t landed
CREW ROTATION	16 months - 3 years
ORBITAL INRASTRUCTURE	Orbital satellite system
COMMUNICATION	Satellite relay, 3–24-minute delay
CONSUMABLE SUPPLY	Importation/ hydroponics/ ISRU
MAINTENANCE/REPAIR	General repair workshops/ 3D printing
WASTE MANAGEMENT	Recycled/ stored/ returned to Earth

LONG-TERM OPERATIONS

SEARCH FOR LIFE

SCIENTIFIC RESEARCH

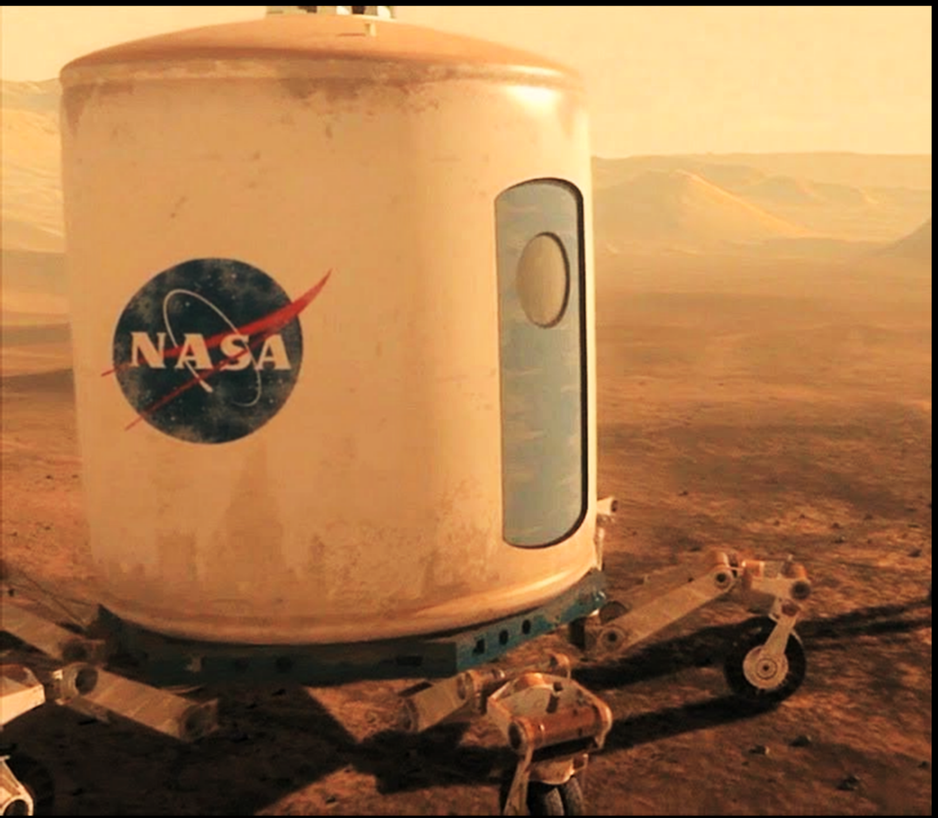


ESTABLISH INFRASTRUCTURE

SUSTAIN HUMAN LIFE

SUSTAINABLE GROWTH

INITIAL STATION



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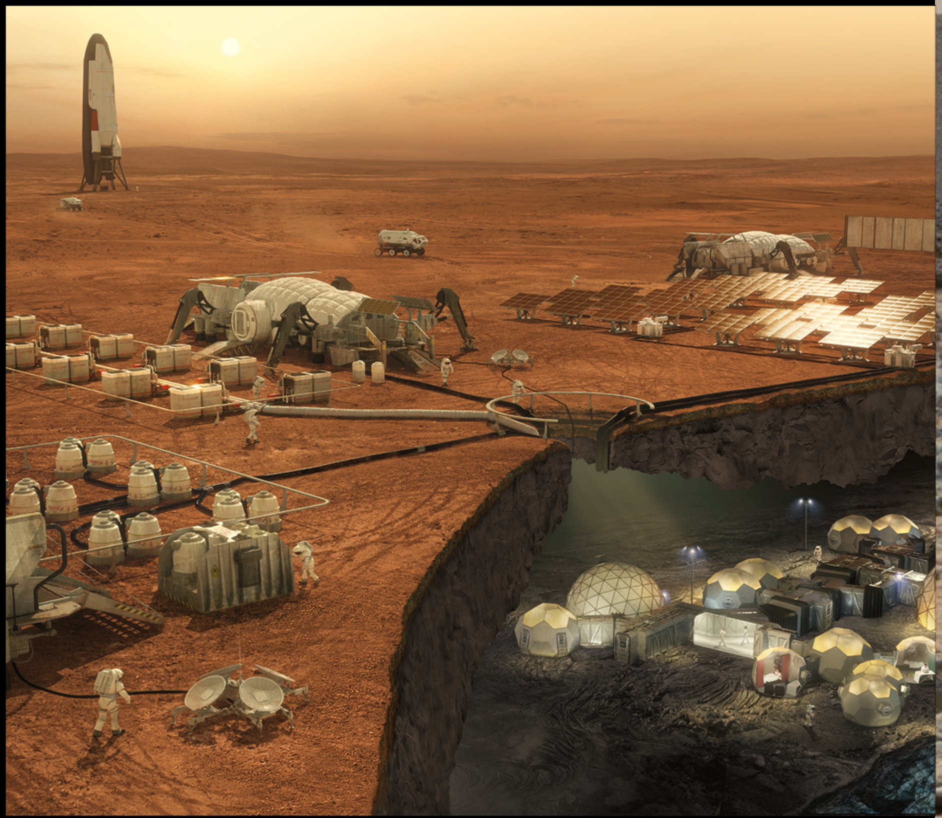
MATURE STATION

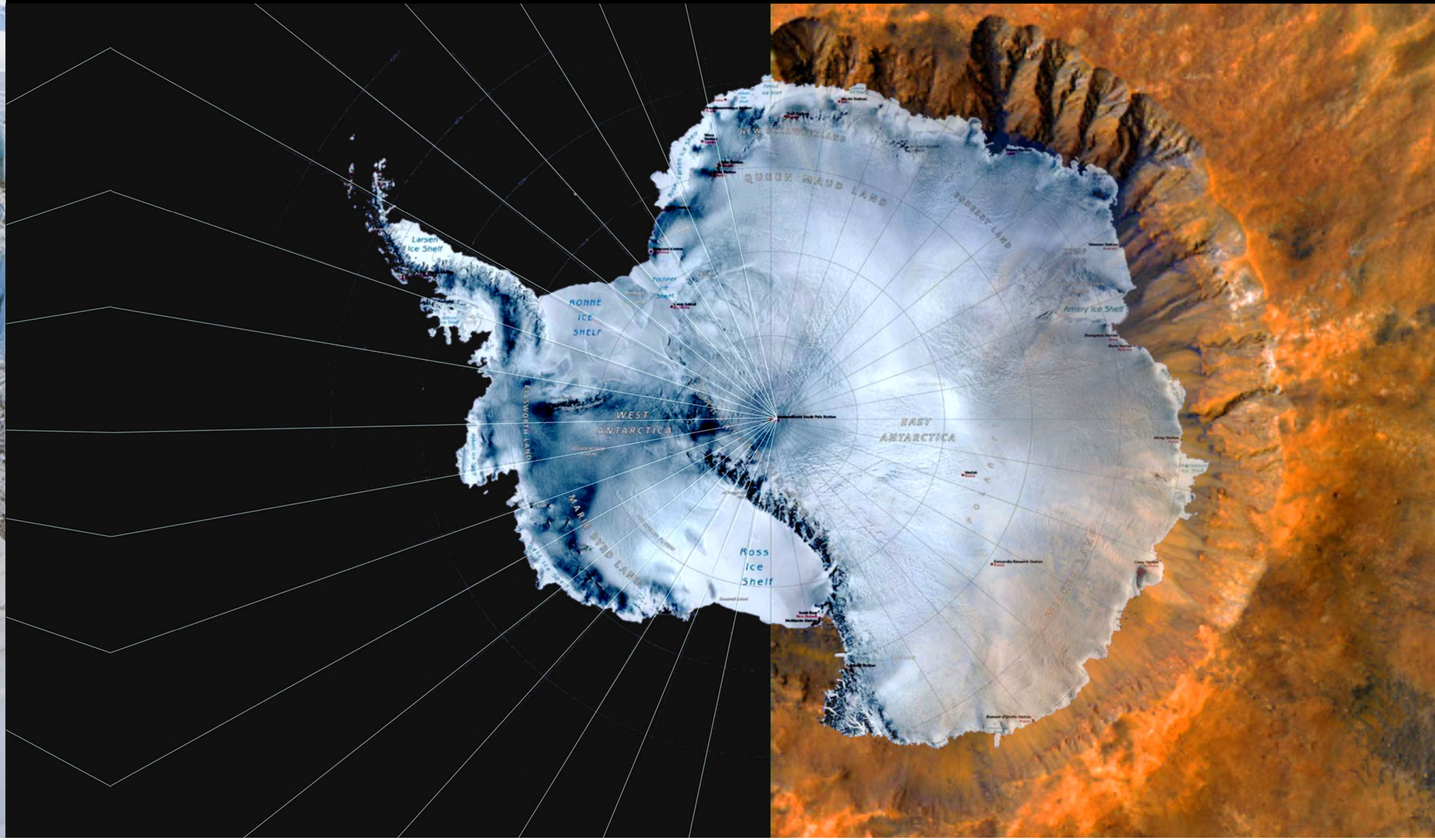


- 6 crew
- Short + periodic occupation
- Closed loop ECLSS
- Initial functions + capabilities
- Importation

- 110 crew*
- Continuous occupation
- Regenerative ECLSS system
- Specialized/extended functions + capabilities
- ISRU + Production + Manufacturing

***Minimum Number of Settlers for Survival on Another Planet** Salotti

ANTARCTIC LESSONS LEARNED



EXPLORATION TIMELINE

MARS

Early Exploration Phase | Expedition Phase | Occupation Phase

- **1964** Mariner 4- 1st successful flyby
- **1969** Mariner 6+7 (flyby)- returned images
- **1971** Mariner 9 (flyby)- Martian surface images
- **1975** Viking 1+2 (orbiter+lander) 1st successful US Mars surface landing
- **1996** Pathfinder (rover)- successful landing
- **1996** Mars Global Surveyor (orbiter)- returned images, spectrometer measurements, altimeter shots
- **2001** Mars Odyssey (orbiter) Mapping and scientific data relay
- **2003** Mars Express (orbiter)- ESA extended mission
- **2003** Spirit + Opportunity (rovers)- scientific exploration
- **2005** Mars Reconnaissance Orbiter- most data returned
- **2007** Phoenix Mars Lander – confirmed presence of water beneath surface
- **2011** Curiosity (rover)- geological sampling/analysis
- **2013** MAVEN (orbiter)- atmospheric research
- **2016** Exomars (orbiter)- European/Russian mission
- **2018** Insight(lander) 1st to explore Mars' deep interior

ANTARCTICA

Early Exploration Phase | Expedition Phase | Occupation Phase

- **1772-1775** Cook– 1st to cross Antarctic circle
- **1820** Bellingshausen – 1st sighting of Antarctica
- **1821** Davis – 1st known landing on Antarctica
- **1898** Gerlache– 1st to survive Antarctic winter
- **1899** Borchgrevink – 1st to overwinter on Antarctica
- **1902** Omond House – 1st permanent structure
- **1911** Amundsen – 1st to reach South Pole
- **1944 -1945** Operation Taberin – 1st permanent mainland bases
- **1947** Operation Highjump – US sent largest ever expedition
- **1949-1952** 1st international expedition
- **1955 -1958** Trans-Antarctic Expedition – 1st successful Antarctic crossing
- **1957-1958** International Geophysical Year
- **1959** Antarctic Treaty signed
- **2009** Princess Elisabeth Station – 1st zero emission station
- **2012** Halley VI Research Station

ANTARCTIC ANALOG

EVOLUTION OF ANTARCTIC STATION DESIGN

HALLEY I · **HALLEY II** · **HALLEY III** · **HALLEY IV** · **HALLEY V** · **HALLEY VI**

1956 · 1967 · 1973 · 1984 · 1991 · 2012

Early Exploration Phase

Expedition Phase

Occupation Phase

1772-1775
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1959
Antarctic Treaty signed

1956 · 1974 · 2008 · 2009

MCMURDO · **AMUNDSEN-SCOTT** · **AMUNDSEN-SCOTT** · **AMUNDSEN-SCOTT** · **PRINCESS ELISABETH**

ANTARCTIC ANALOG

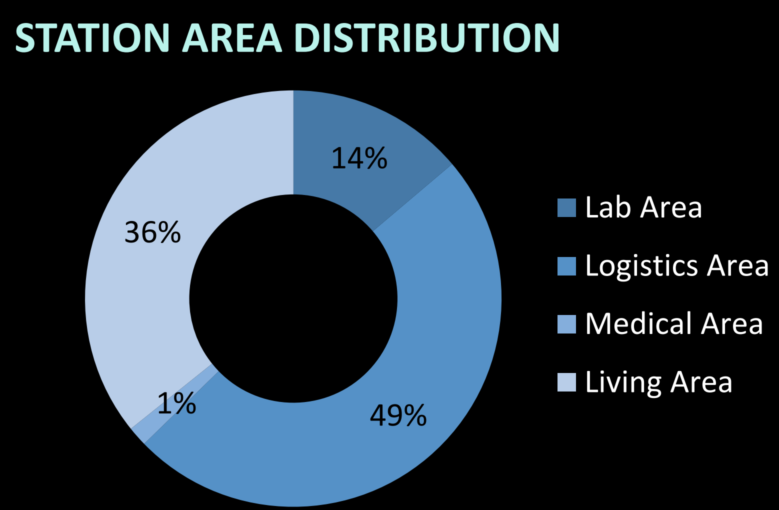
OPERATIONAL LOGISTICS

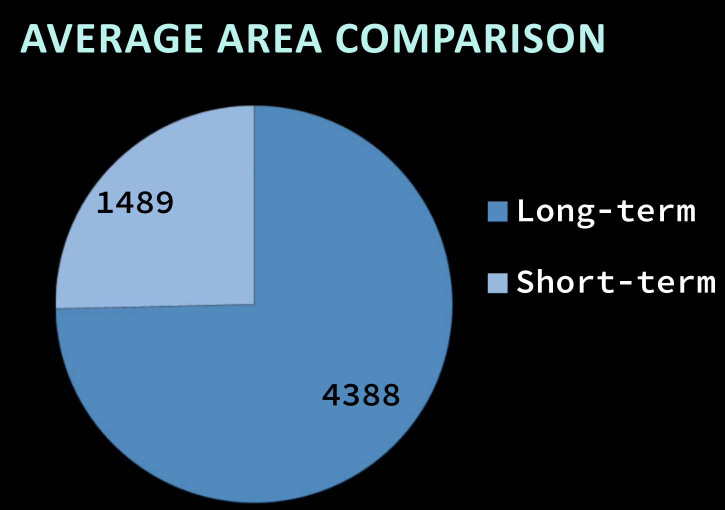
LIMITED WINDOW OF ACCESS	December – March summer period
CREW ROTATION	3 months - 1 year
CONSUMABLE SUPPLY	Importation
MAINTENANCE/REPAIR	ICTS/ electrical/ mechanical/ metal/ plexiglass/ wood/ general repair workshops
WASTE MANAGEMENT	Recycled/ stored/ removed annually/bi-annually

LOGISTICAL LESSONS LEARNED

- Limited window of access + long crew stays = high consumable need + waste accumulation = high logistical stowage requirements
- Recycling + re-use + waste processing is essential to waste reduction and stowage
- ISRU + workshop production supplement consumables
- Modular design + standardized parts reduce consumable load and stowage
- Field stations provide supplemental storage + emergency backup
- Adaptable station design to environmental conditions
- Zero-emission design + green technology reduces energy consumption/waste + increases environmental protection
- Automation should continue station operations during unoccupied periods

FUNCTIONAL ANALYSIS





FUNCTIONAL LESSONS LEARNED

- Logistical stowage accounts for almost half of all volume
- Volume can be specialized as – cold, dry, dirty
- Opposing functions should be separated – noisy vs. quiet, work vs. living, clean vs. dirty
- Must be added first to support additional growth
- Crew size and mission duration limitations
- Long crew stays require increased functions and volume
- Life support systems should be divided to provide redundancy
- As stations grow capabilities move to newer areas + old areas become stowage + recycled

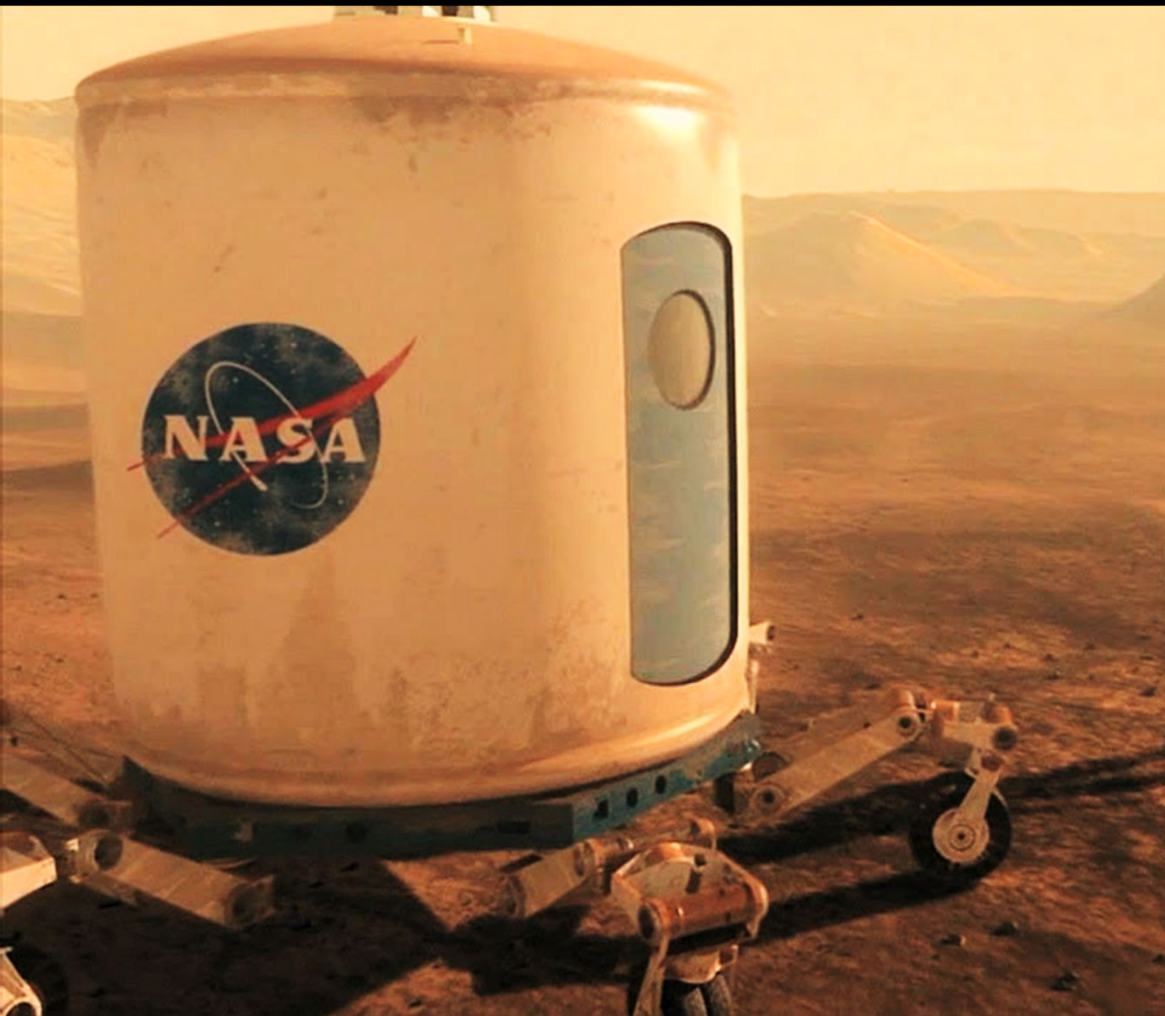
HUMAN WELL-BEING

PHYSICAL TRAVEL TOLL	Altitude sickness/ jet lag
ONGOING PHYSICAL TOLL	Hypoxia/ immune system impairment/ sleep disorders
PSYCHOLOGICAL STRESS	High stress/ risk environment/ sensory depravation/ isolation/ confinement
COMMUNICATIONS	Satellite relay, 3–24-minute delay

HUMAN WELL-BEING LESSONS LEARNED

- Design should minimize physical and psychological stressors
- Longer the stay = higher level of comfort and amenities needed
- Constant medical access will be essential to promote crew health
- Natural light and lighting following circadian rhythm improves sleep patterns
- Crew need a combination of social and private spaces
- Work should be meaningful and balanced with other needs
- Variety of color, texture, and size of spaces alleviates stress + promotes positive emotions
- Crews need to be able to deal with emergency scenarios

ARCHITECTURE PROGRAM




ARCHITECTURE PHASES

INITIAL
ESTABLISHING PRESENCE

TRANSITIONAL
ENABLING GROWTH

MATURE
OPERATING SUSTAINABLY

- Provide support for future growth
- Provide flexibility for changing needs
- Provide adaptable design

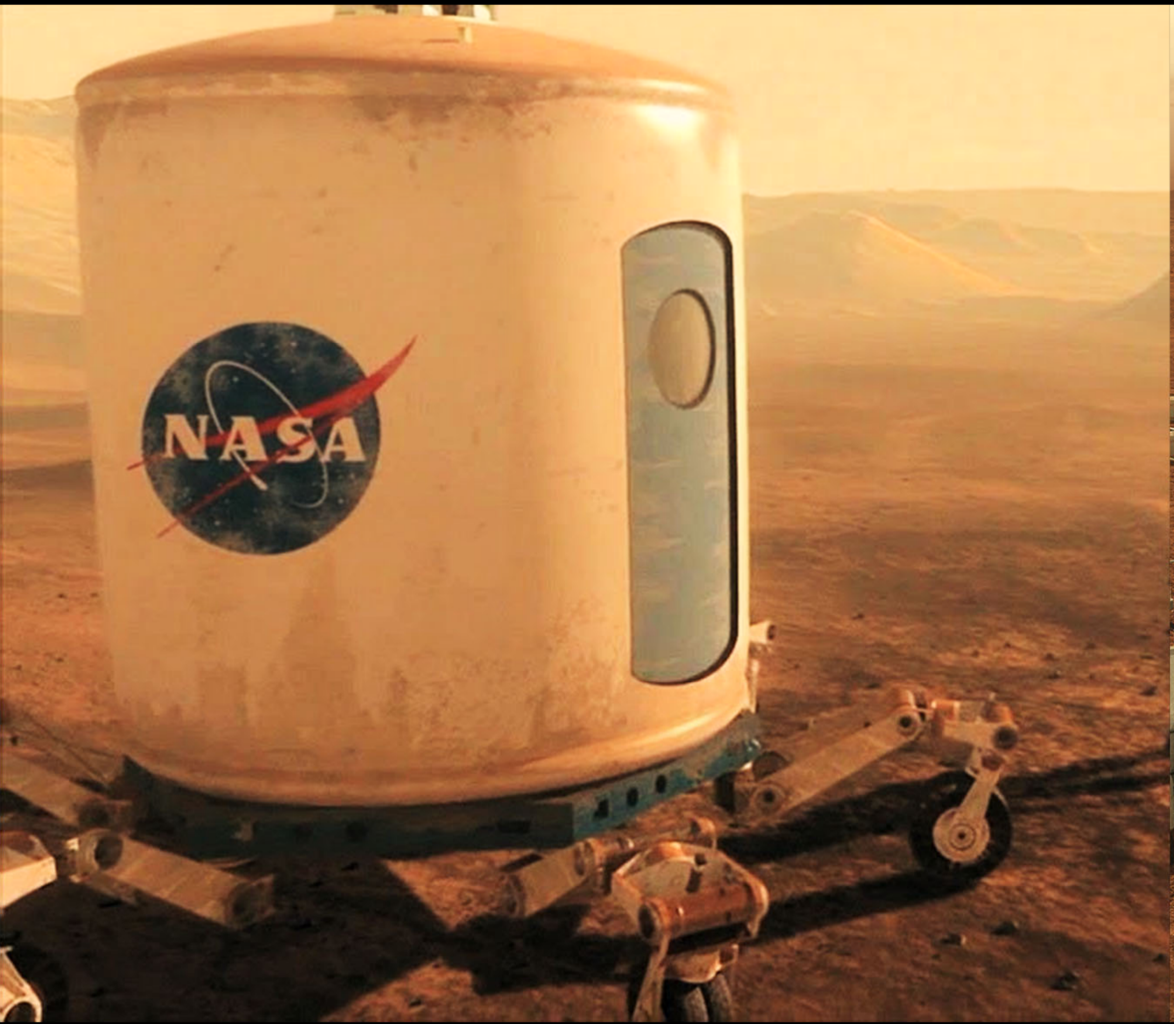
INITIAL STATION PHASE

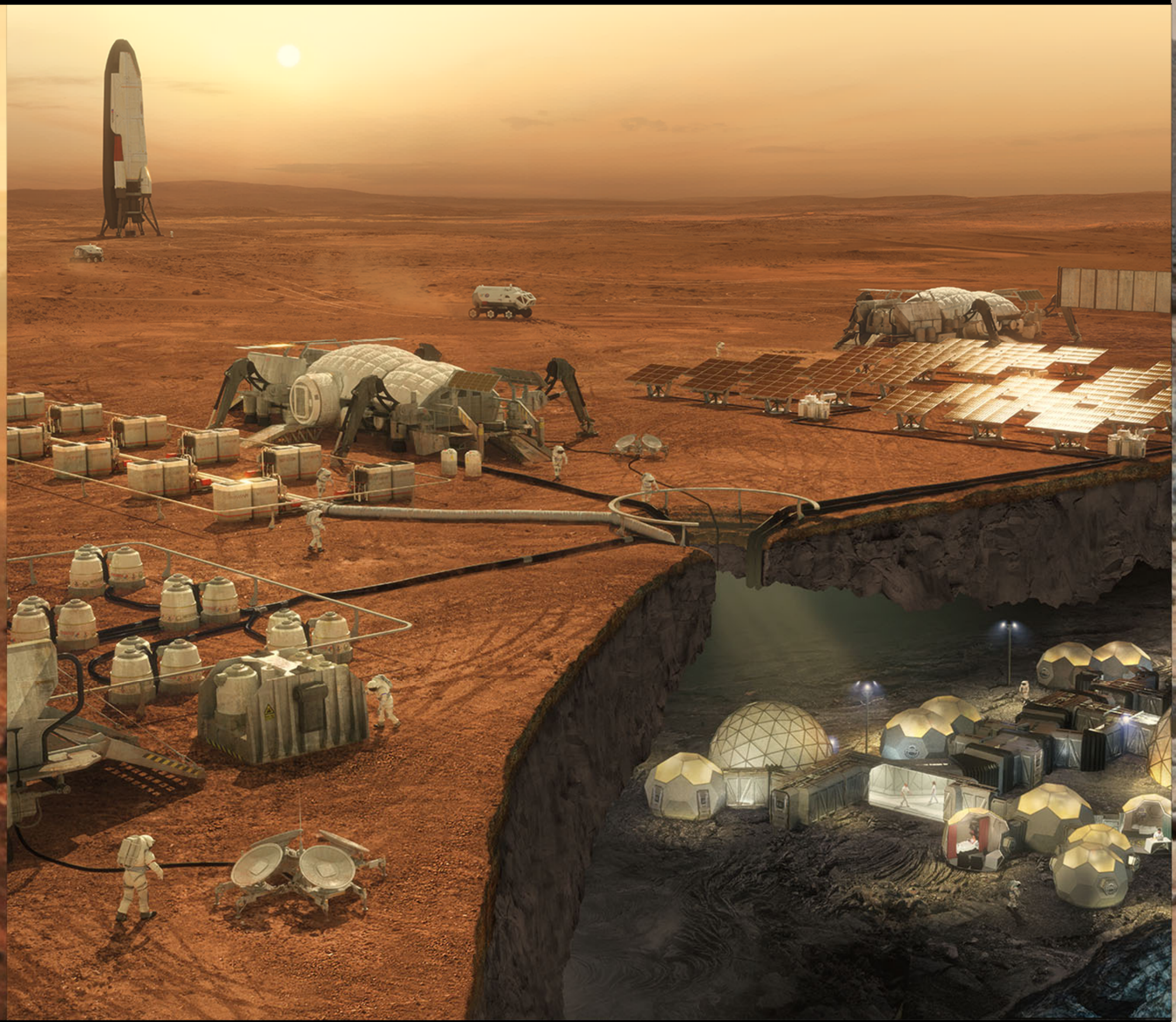
Surface Infrastructure	
Mars Ascent/Descent Vehicle	1 – 22t landing capacity
Launch/Landing Zone	1 – site 5+ km from base • Orbital + surface communication • Environmental monitoring • Operational control
Power	1 – 4x10 kW Nuclear fission reactor/ site 1+ km from habitat modules Energy storage
Transportation	2 – 4t rovers
Pressurized Structures	
Airlock Module	1 – 6t CLASS 1 Pre-integrated Module
Initial Habitat Module	1 – 16t CLASS 1 Pre-integrated Module

NOTIONAL MATURE STATION PHASE

Surface Infrastructure	
Mars Ascent/Descent Vehicle	3 – 22t landing capacity
Landing Zone	4 – site 5+ km from base • Orbital + surface communication • Environmental monitoring • Operational control • Refueling capabilities • Payload processing • Maintenance area • Logistical stowage
Power	5 – 4x10 kW Nuclear fission reactors 1 - 4x10 kW backup generator Energy storage
Transportation	6 – 4t rovers
ISRU production	• H2O production from ice deposit • Propellant production from atmosphere • 3D printing materials from soil
Pressurized Structures	
Airlock Module	1 – 6t CLASS 1 Pre-integrated Module
Initial Habitat Module	1 – 16.5t CLASS 1 Pre-integrated Module
Logistic Module	CLASS 2 hybrid inflatable module
Lab Module	CLASS 2 inflatable lab
Living Module	CLASS 2 hybrid inflatable module
Greenhouse Module	CLASS 2 inflatable greenhouse
Workshop/Manufacturing	CLASS 3 ISRU 3D printed module

TRANSITIONAL GUIDE





TRANSITIONAL NEEDS/REQUIREMENTS

CREW	MASS	VOLUME	POWER
6	6t	34 cu m	1KW

AIRLOCK MODULE

- Class 1 Pre-integrated module
- Minimum 2 connection ports
- Viewing windows into habitat + to exterior
- Power/ECLSS interfacing to habitat
- Rover/habitat interfacing

MASS

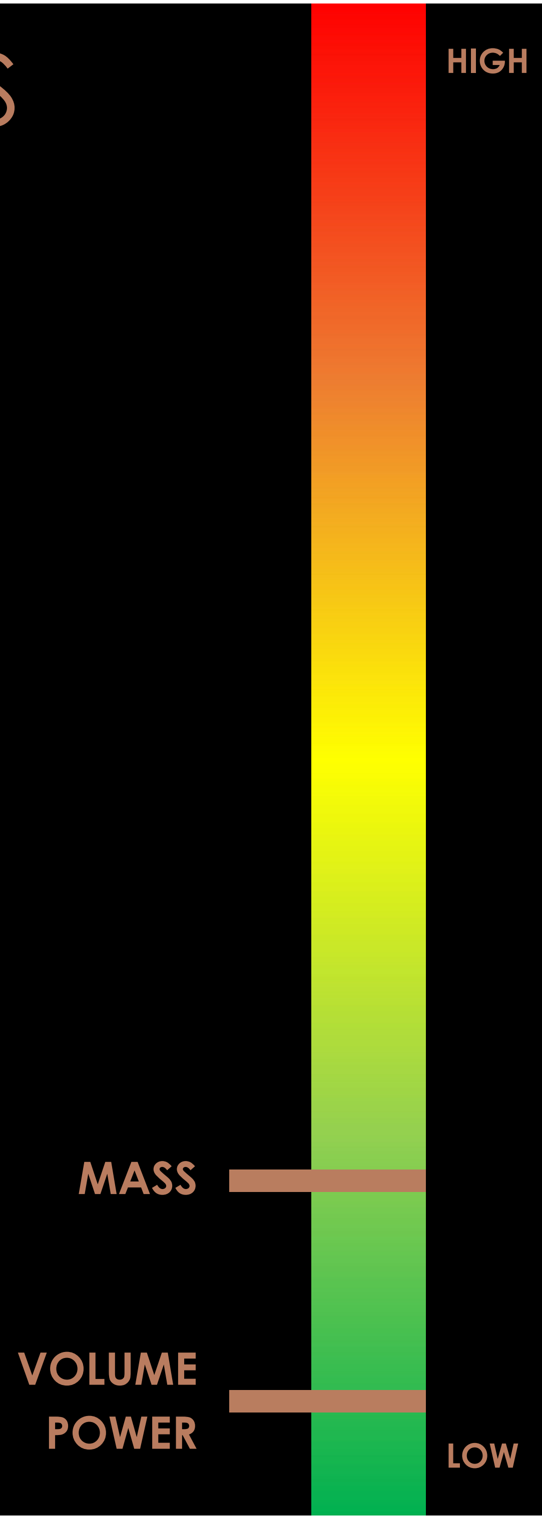
The airlock has relatively low mass with most attributed to the structural components and connections

VOLUME

The airlock requires minimum volume to efficiently pressurize/depressurize the space for crew passage

POWER

The airlock requires minimum power compared to the rest of the station with power consumption spiking during usage for EVAs and remaining lower between uses



TRANSITIONAL NEEDS/REQUIREMENTS

CREW	MASS	VOLUME	POWER
6	16t	250 cu m	11KW

INITIAL HABITAT MODULE

- Class 1 Pre-integrated module
- Minimum 2 connection ports
- Closed loop ECLSS
- 90% H20 recovery
- Connection to nuclear fission unit
- 8t food + 8t water + 2t expendables/spares = 20t consumables

MASS

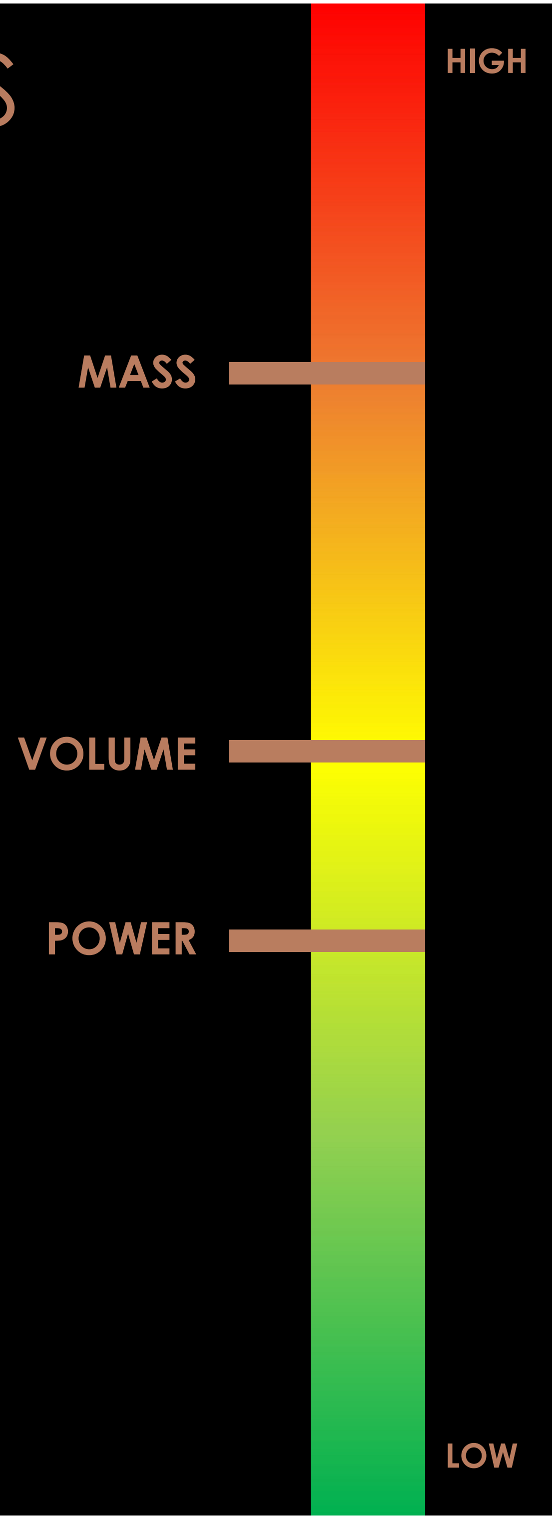
The initial habitat module mass will be fairly high accounting for most of the lander's capacity with a significant portion of the mass being the habitat's internal components and equipment

VOLUME

The initial habitat module will have moderate volume using the max diameter of the transit vehicle to provide the most volume possible from a Class 1 module

POWER

The initial habitat module will consume a medium amount of power depending on the exact capabilities leaving sufficient power to support additional modules



TRANSITIONAL NEEDS/REQUIREMENTS

CREW	MASS	VOLUME	POWER
6	<13t	≈100 cu m	<11KW

LOGISTICS MODULE 1

- Class 2 Pre-fabricated module
- Minimum 3 connection ports
- Site leveling pre installation
- 8t food + 8t water + 2t expendables/spares = 18t consumables*
- <5t stored solid waste capacity*

MASS

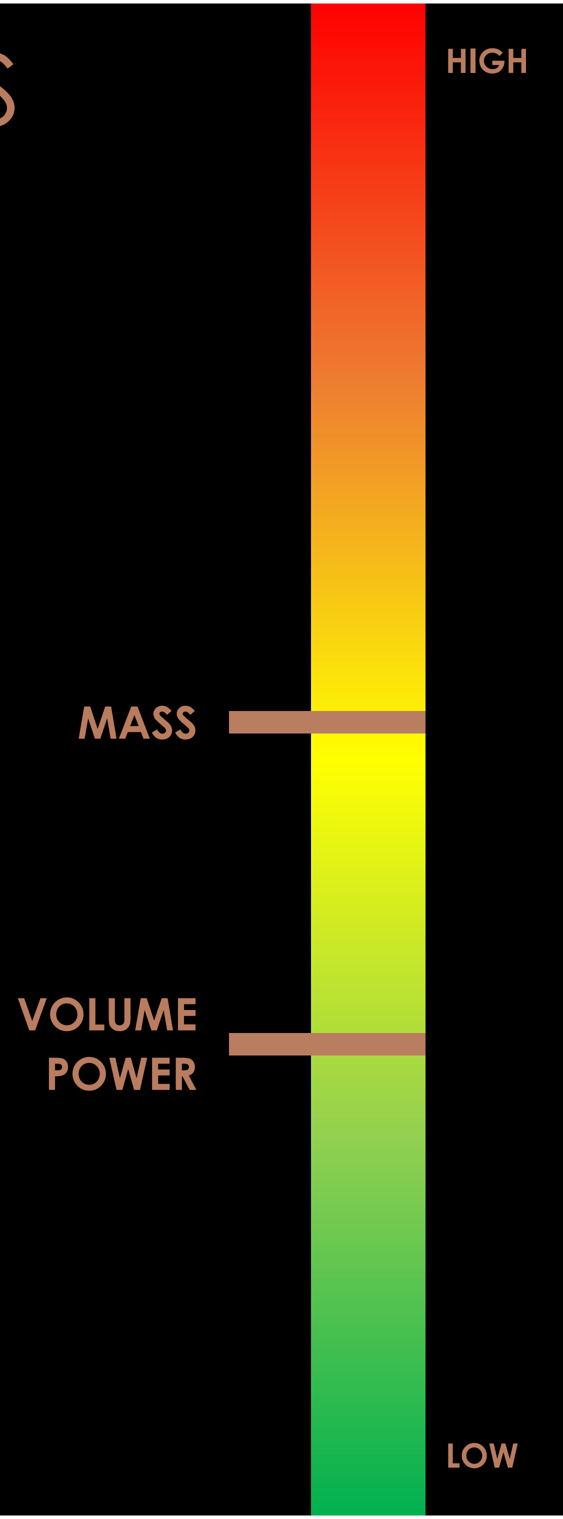
The logistics module mass is moderate as a Class 2 module with contents being loaded after landing and set up

VOLUME

The logistics module will provide lower volume because of their smaller size, but will provide additional volume per mass as a Class 2 module

POWER

The logistics module requires fairly low power as it will serve primarily as stowage capacity



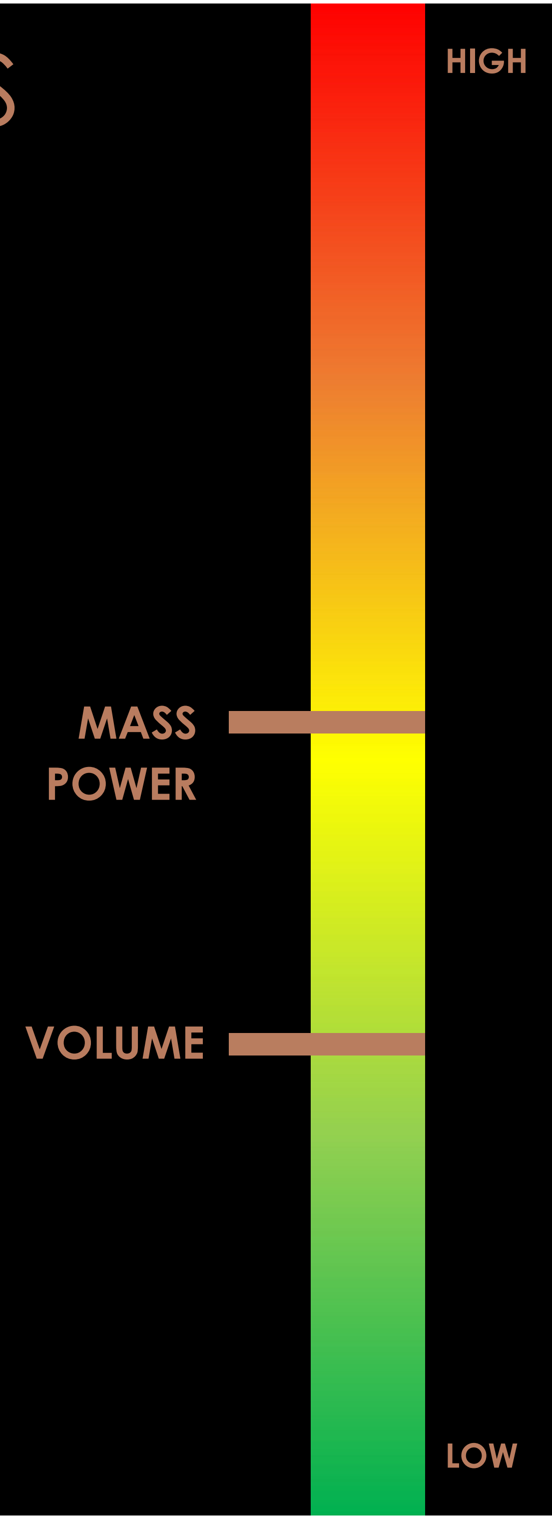
*Space Station Usage Rates "Balancing" Around a Person Philistine et al, SAE ICES 2006-01-2094
*Build Planning Rates for New Designs And Other Crew Equipment Anderson & Stambaugh, ICES-2015-235
*Space Architecture Technical Committee Brand Norman Griffin
*"NASA Fact Sheet" NASA, FS-2006-10-130-LaRC

TRANSITIONAL NEEDS/REQUIREMENTS

CREW	MASS	VOLUME	POWER
6	<13t	≈100 cu m	<11KW

LOGISTICS MODULE 2
- Class 2 Pre-fabricated module
- Minimum 2 connection ports
- Site leveling pre installation
- 8t food + 8t water + 2t expendables/spares = 18t consumables*
- 5t waste*
- Cold + dry + dirty stowage

MASS
The second logistics module mass will also be moderate
VOLUME
The second logistics module will also provide lower volume adapting to the increased storage needed for accumulating waste and consumables needed to support a larger crew size
POWER
The second logistics module will have a moderate power consumption as it will likely provide increased cold stowage capacity



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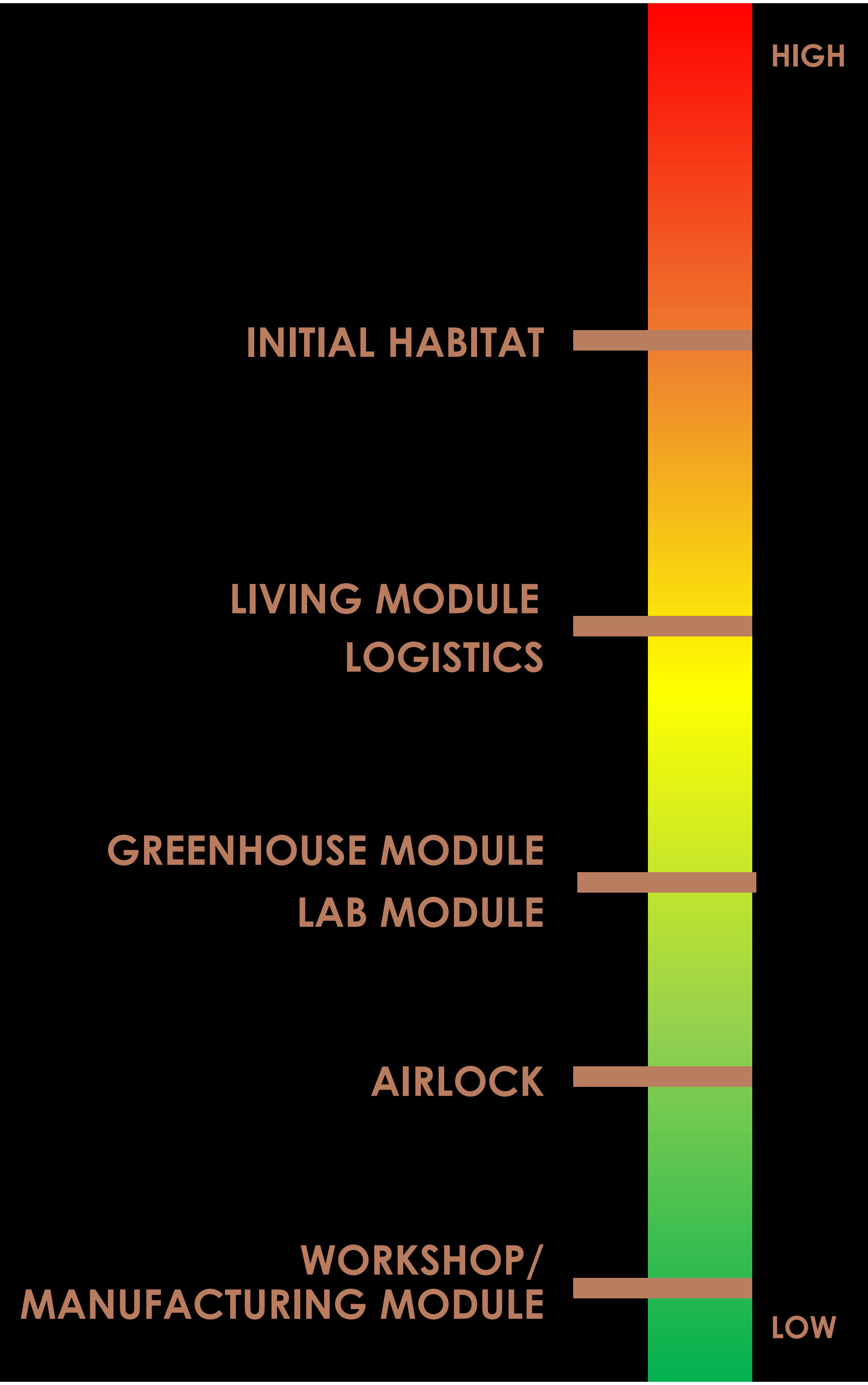
MASS COMPARISON

Airlock Module	6t CLASS 1 Pre-integrated Module
Initial Habitat Module	16.5t CLASS 1 Pre-integrated Module
Logistics Module	CLASS 2 hybrid inflatable module
Lab Module	CLASS 2 inflatable lab
Living Module	CLASS 2 hybrid inflatable module
Greenhouse Module	CLASS 2 inflatable greenhouse
Workshop/Manufacturing	CLASS 3 ISRU 3D printed module

INSIGHTS OF MASS TRANSITONAL REQUIREMENTS

- Initial mass will be higher as modules need to arrive ready to use requiring modules to be pre-integrated hard-shells
- Following modules will likely use inflatable and hybrid module technology as they provide reduced mass with higher volume and the initial habitat will support the crew while the newer modules are set up
- As 3D printing technology improves, future modules can be made from Martian resources requiring much lower mass imported



VOLUME COMPARISON

Airlock Module	6t CLASS 1 Pre-integrated Module
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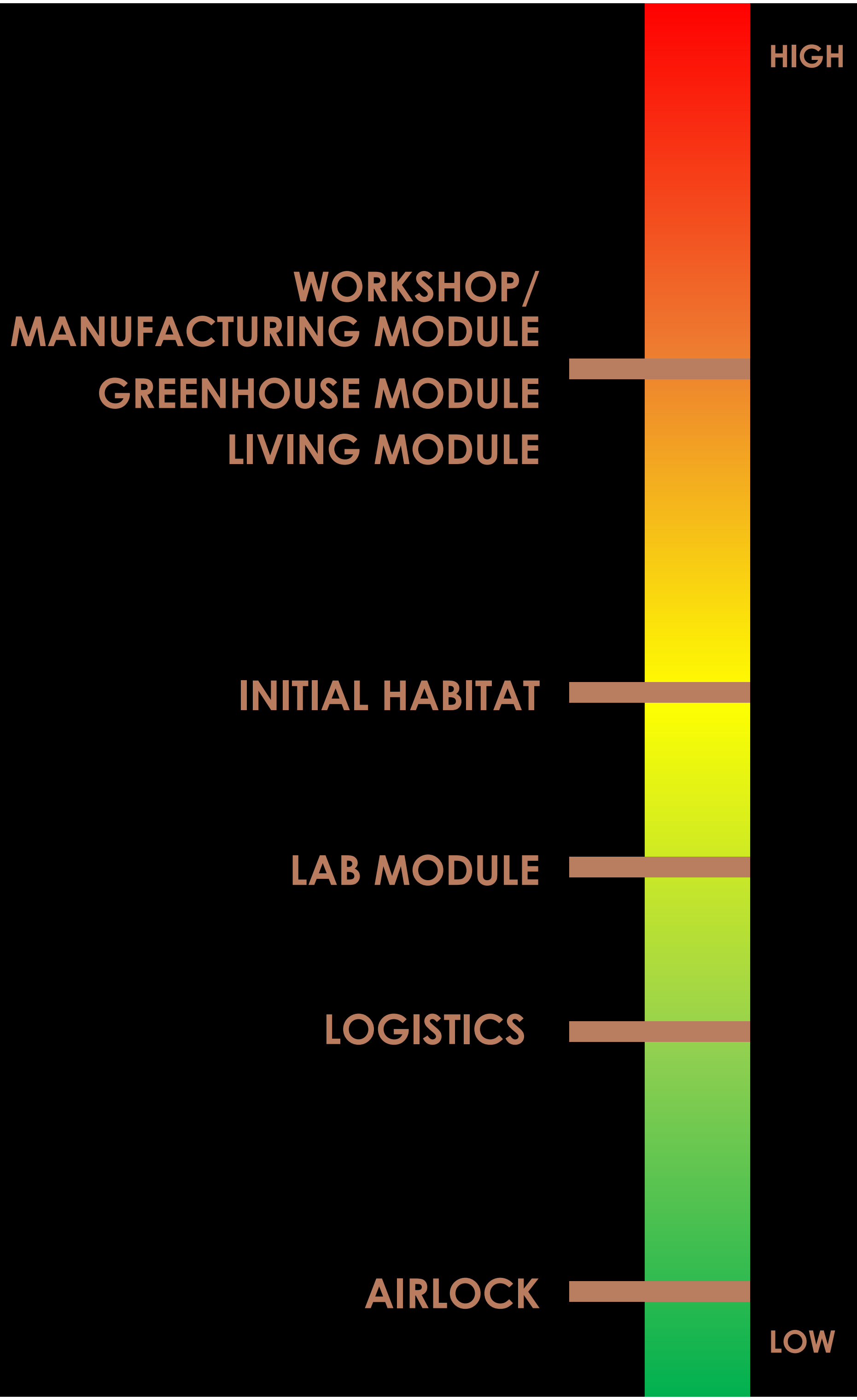
Workshop/Manufacturing	CLASS 3 ISRU 3D printed module

INSIGHTS OF VOLUME TRANSITONAL REQUIREMENTS

- Initial volume will be moderate as hard-shell modules will be restricted by the transit vehicle payload diameter
- Following modules using inflatable and hybrid module technology will allow modules to be compact during transit and provide a higher volume
- Logistic volume will be necessary to support additional modules
- As future modules become 3D printed, modules will no longer be restricted by transit payload limitations allowing for the maximum volume



POWER COMPARISON

Airlock Module	6t CLASS 1 Pre-integrated Module
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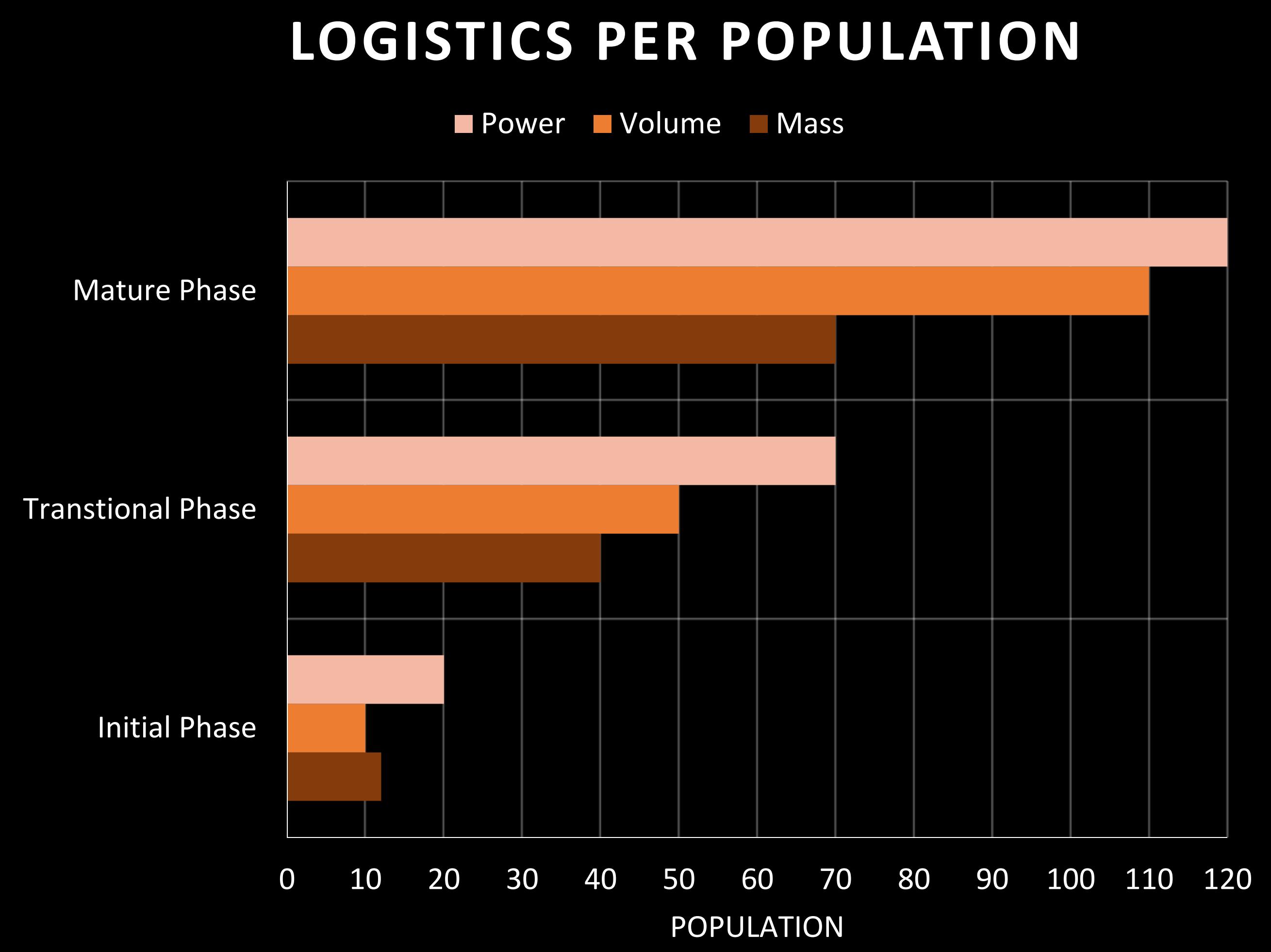
INSIGHTS OF POWER TRANSITONAL REQUIREMENTS

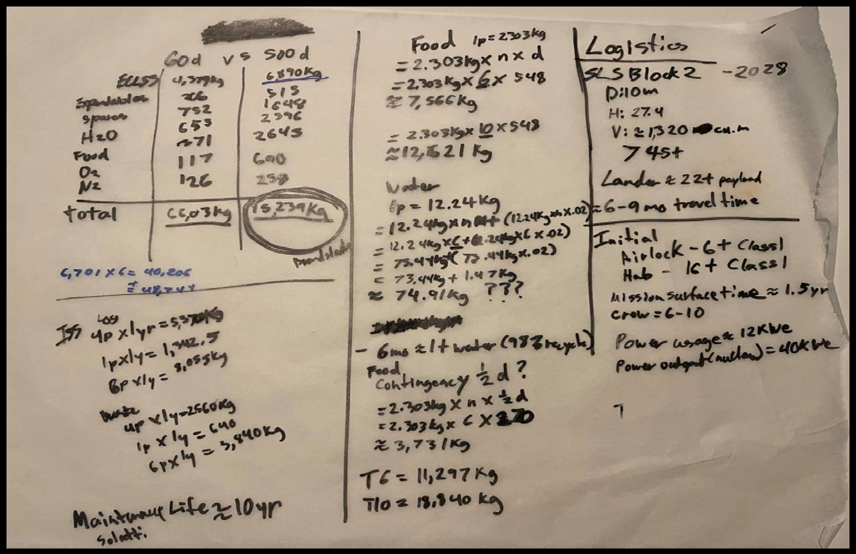
- Initial power will be moderate as functions and capabilities will be limited
- Following logistics modules will have a relatively low power consumption
- Larger modules with more functions and capabilities will have a higher power consumption
- Modules for living functions having moderate power consumption
- Modules used for production having the highest power consumption

LOGISTICS OVER TIME



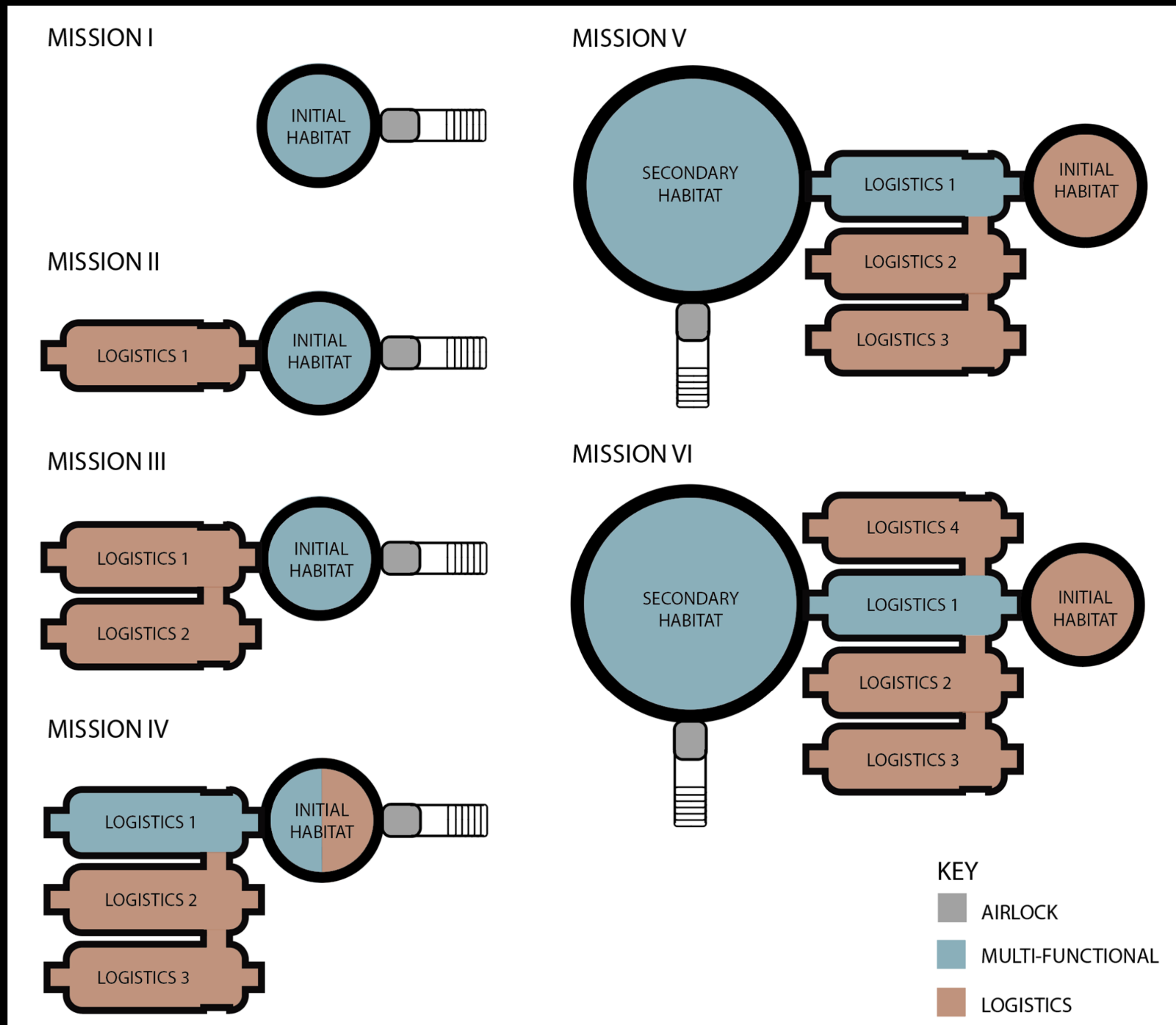
INSIGHTS

- The minimum crew for a sustainable station is 110 people
- Power capabilities will increase in jumps to support new growth
- Volume will incrementally increase to along with population increase
- Logistical mass of modules + consumables will decrease as station approaches self-sufficiency

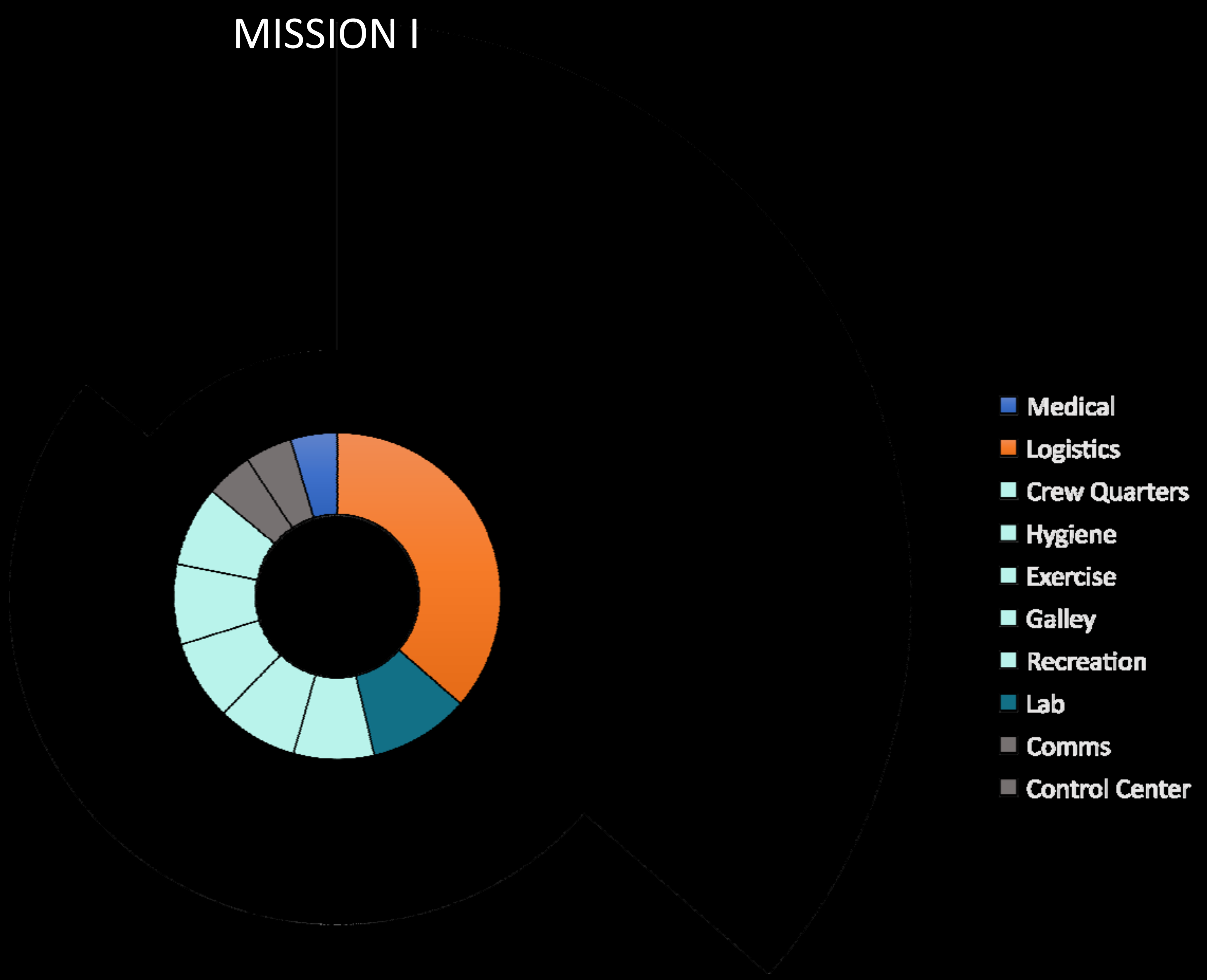


***Minimum Number of Settlers for Survival on Another Planet** Salotti

LOGISTICAL SEQUENCE



FUNCTIONAL SEQUENCE



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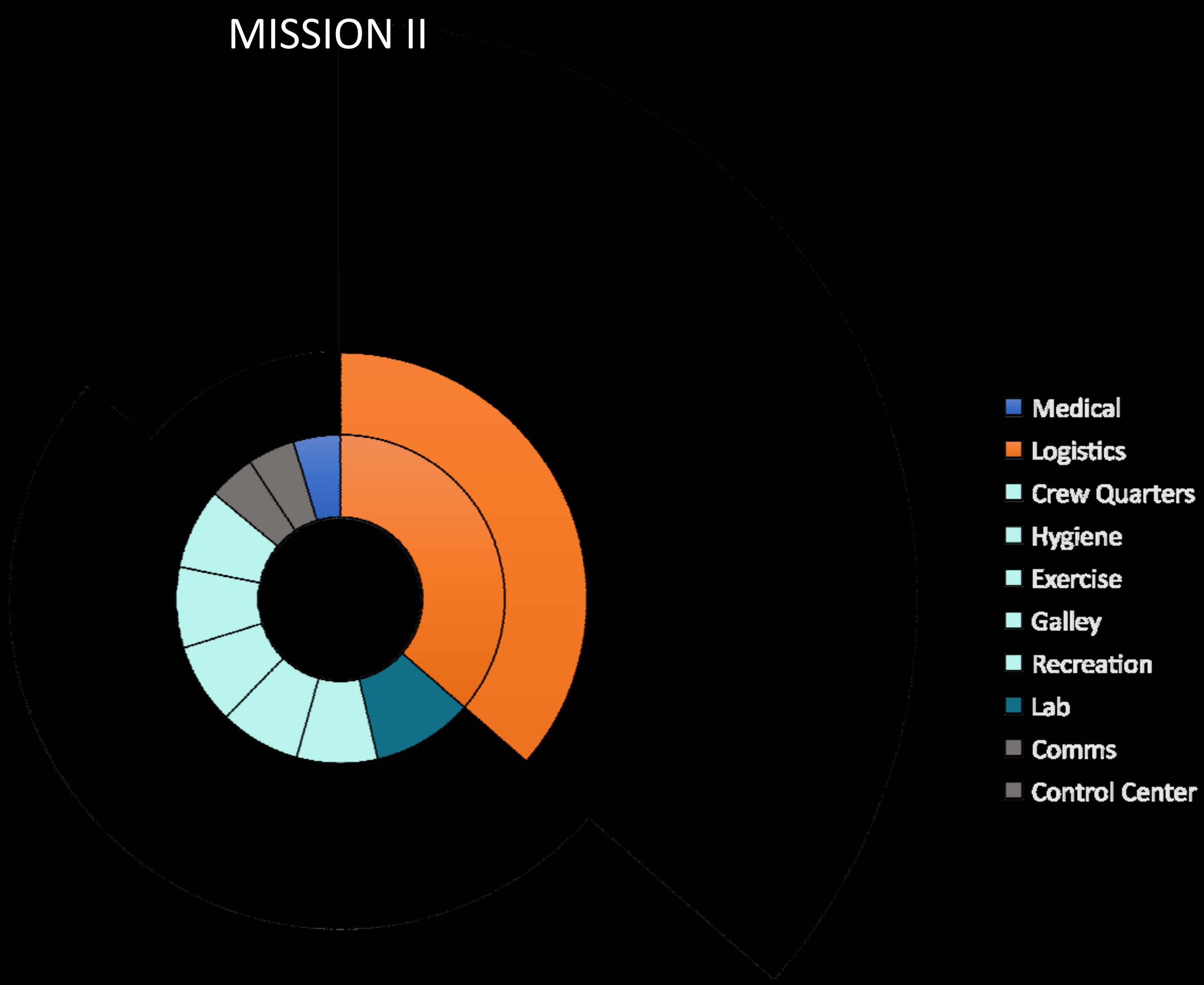

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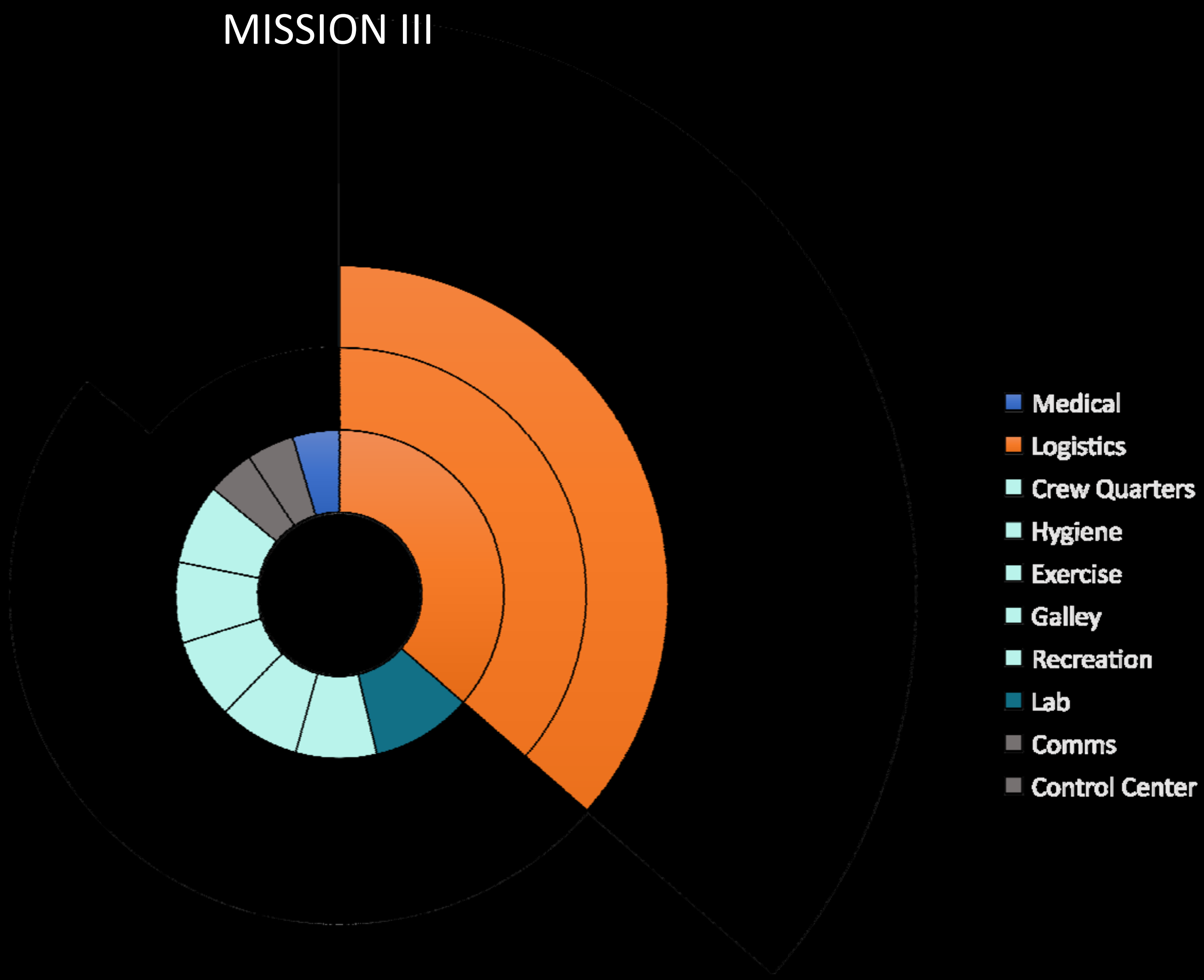

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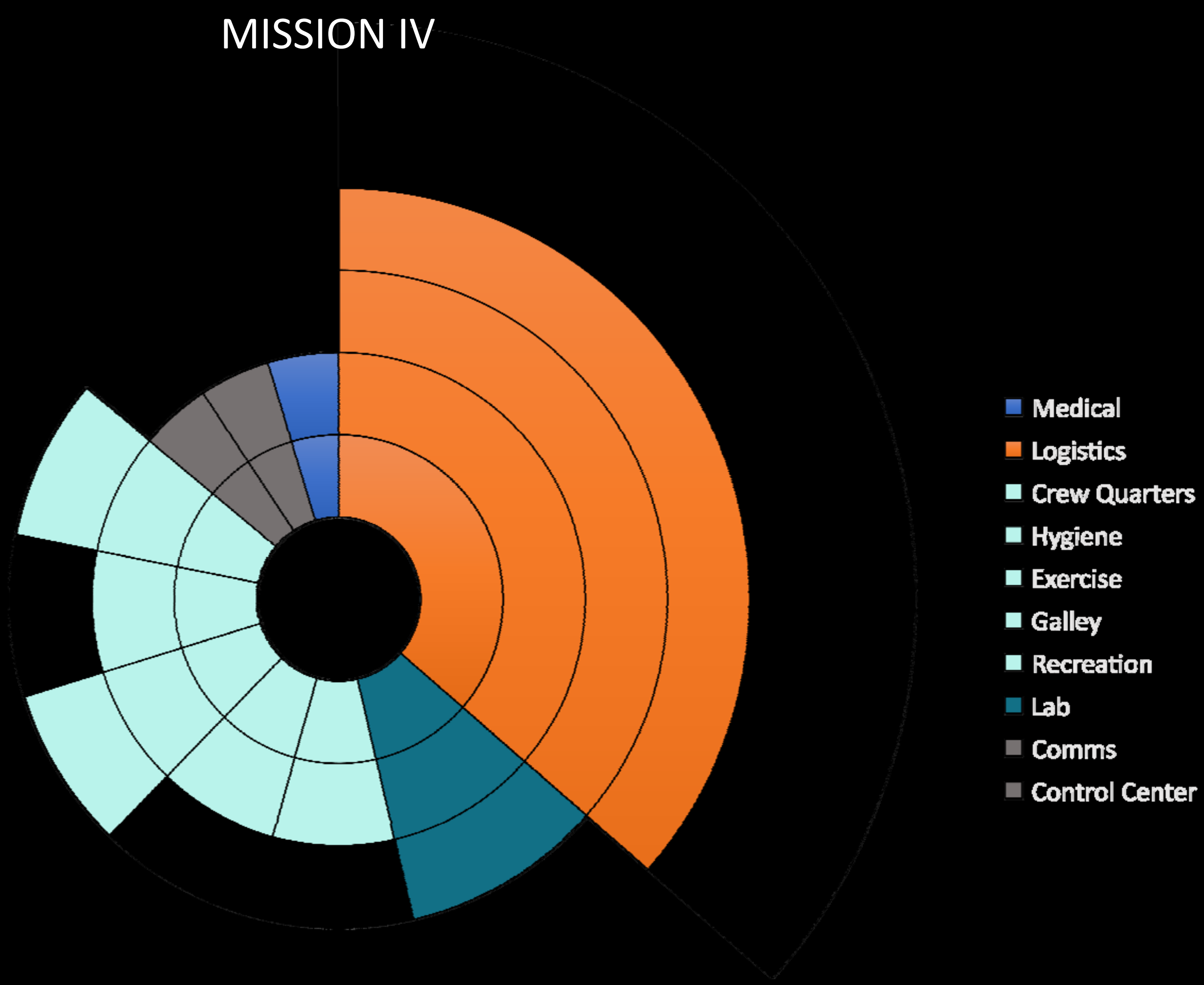

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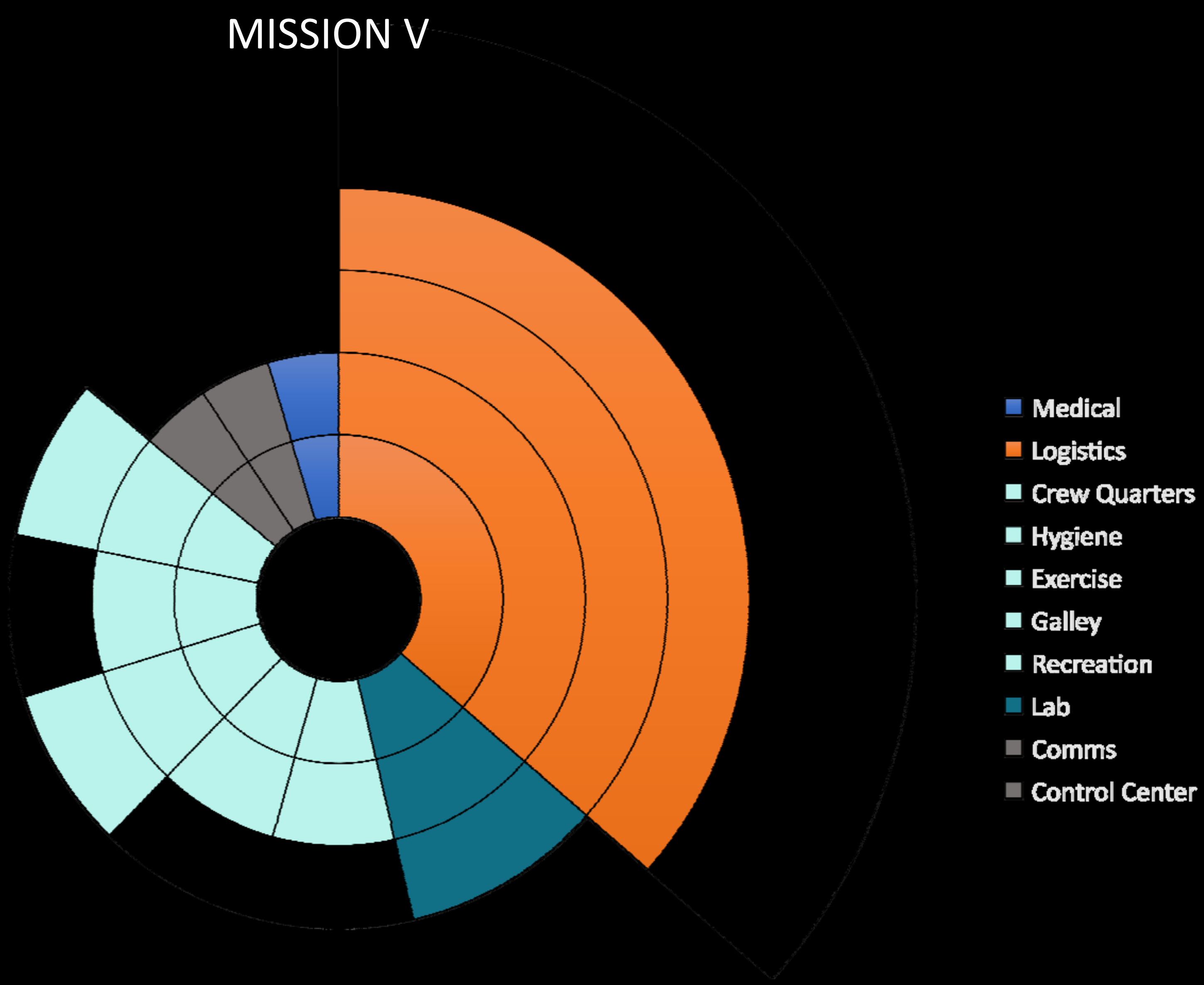

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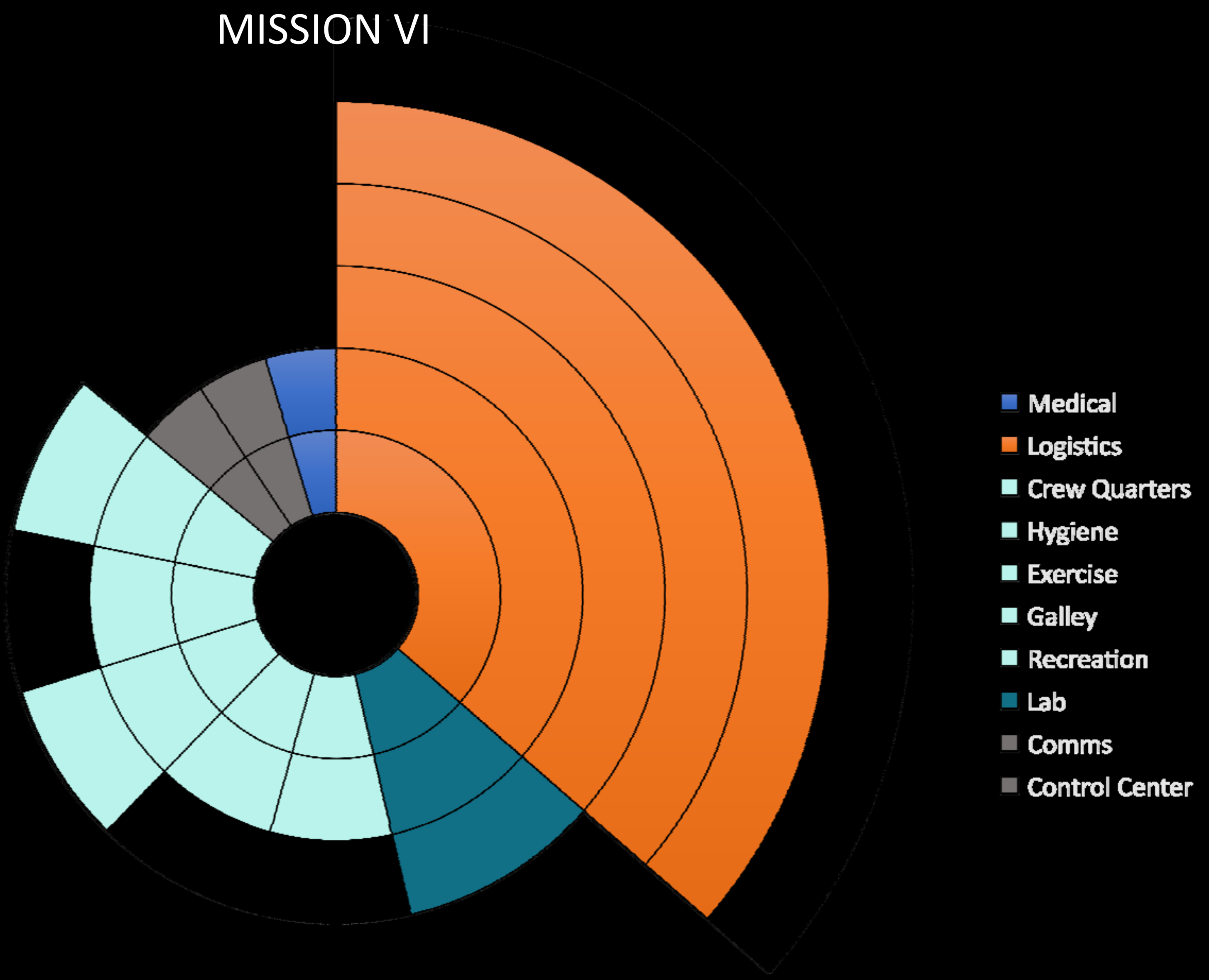
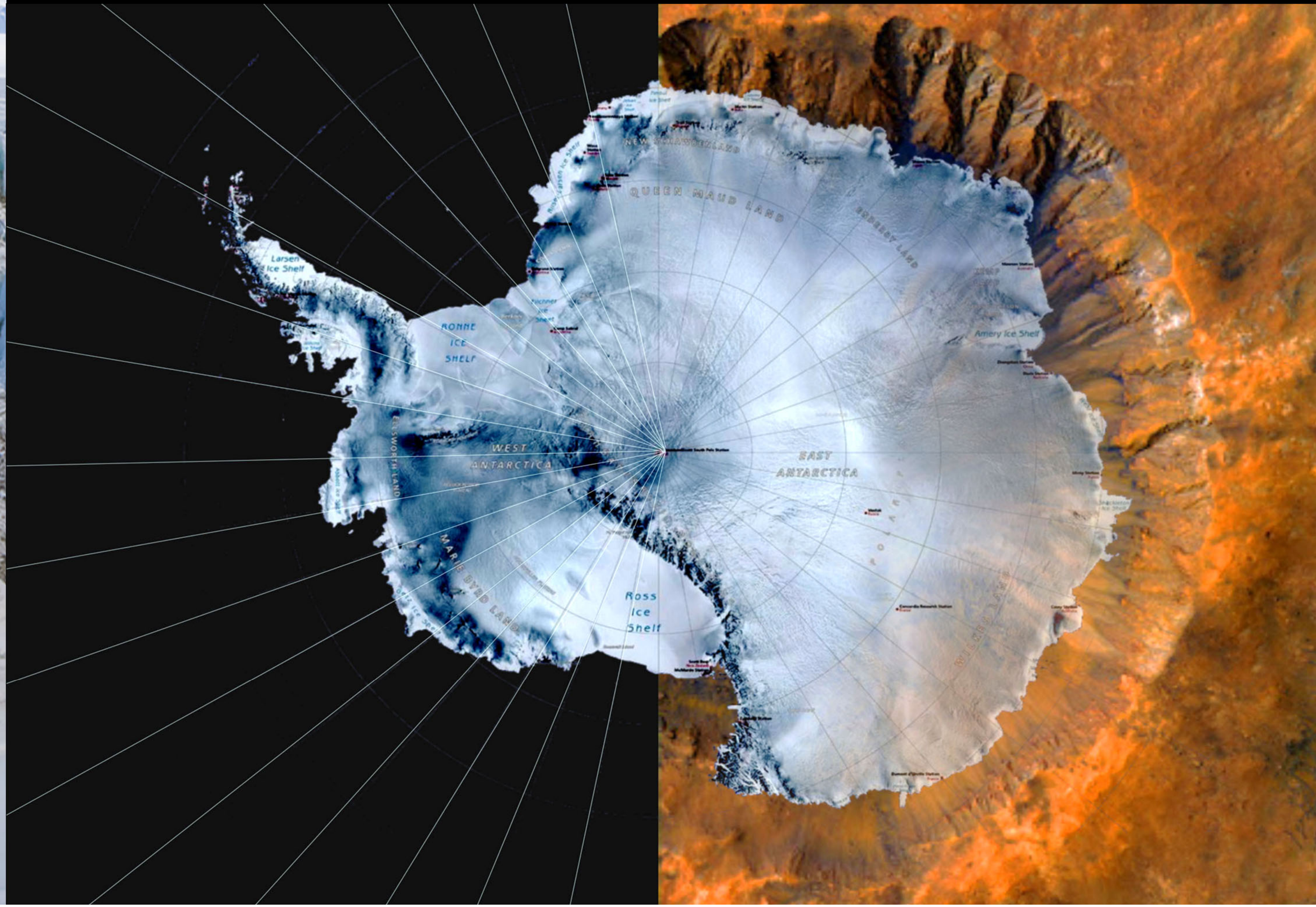


CONCLUSIONS + FUTURE WORK



LESSONS APPLIED

- Unlike Antarctica where each station iteration is built new, Martian station must build on earlier modules and incorporate their life cycle into the design
- Logistic capabilities are the backbone of station operations and essential to enabling sustainable growth
- Logistic mass, volume, and power needs/requirements affect when station and population growth occurs and changes as the station transitions
- Station design must be able to adapt functionally to reuse spaces for changing needs over time
- Unknown factors will always exist and design must be able to adapt to them

FUTURE WORK

- Further analysis of mass, volume, power needs/requirements for advanced transitional phase
- Impact of ISRU production + manufacturing on long-term logistical requirements
- Logistical comparison of needs/requirements of different mature station types
- Design parameters to allow functional repurposing the modules over time


THANK YOU
QUESTIONS?
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Center for Space Architecture