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Deep Space Habitat Concept of Operations for Transit Mission Phases

August 2011

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Preface

This document describes a concept of operations (ConOps) for a habitat element to be used by human crews on future deep space missions; that is, missions well beyond the low Earth orbit of Space Shuttle and International Space Station missions of the past few decades.

As one facet of a number of studies conducted by NASA's Human Spaceflight Architecture Team to better understand possible implementations of what the U.S. Human Spaceflight Plans Committee (also known as the Augustine Committee) has named the "flexible path," a workshop was conducted to consider how best to define and quantify "habitable volume" for these future deep space missions. One conclusion reached during this workshop was the need for a description of the scope and scale of these missions and the resulting capabilities needed for a Deep Space Habitat (DSH) element. A group of workshop attendees was established to prepare a ConOps document to address this need. The ConOps, as developed by this group, was structured to identify and capture nominal activities and functions that were likely to occur on the DSH for a range of design reference missions that encompass the currently envisioned flexible path.

The group intended this ConOps to be used as an engineering/design tool to support more detailed systems engineering activities in the future, which provided guidance regarding the level of detail necessary for these descriptions. The document itself was originally structured as a set of briefing charts with facing page text providing additional detail where necessary. This document contains all of this information, but it has been reformatted to fit a "book" format. This report includes a page for each presentation page (with a title or caption for that page) and the associated facing page text (indicated with a "…(text)" in the title) if appropriate.

Acronyms and Nomenclature

AR&D	automated rendezvous and docking
AU	astronomical unit; the distance between the Earth and the Sun – approximately 150 million kilometers or 93 million miles
BME	biomedical engineer
CAD	computer aided design
C&DH	command & data handling
CMO	crew medical officer
CO2	carbon dioxide
CPS	cryogenic propulsion stage
DRM	design reference mission
DSH	Deep Space Habitat
ECLSS	environmental control and life support system
EDL	entry, descent, and landing
E-M L1	Earth-Moon Lagrange point 1 (between the Earth and the Moon)
EMR	electronic medical record
EPO	education and public outreach
EVA	extravehicular activity
FMEA	failure modes and effects analysis
FOV	field of view
FPR	flight performance reserve
GEO	geostationary Earth orbit
GNC	guidance, navigation, and control
HMO	high Mars orbit
HP-HEO	high periapse-high Earth orbit
IIMPDU	intelligent integrative medical data processing unit
ISRU	in-situ resource utilization

ISS	International Space Station
IVA	intravehicular activity
Kg	kilogram
LBO	low boil off
LEO	low Earth orbit
LSS	life support system
MCC	mission control center
MMSEV	multi-mission space exploration vehicle
MPCV	Multi Purpose Crew Vehicle
MRI	magnetic resonance imagery
MTV	Mars Transit Vehicle
NEA	Near Earth Asteroid
NTR	nuclear thermal rocket
PAO	public affairs office
PLSS	portable life support system
psi	pounds per square inch
RCA	Rapid Cycle Amine (a “swing bed” type of CO2 absorption technology for EVA suits)
RCS	reaction control system
RFID	radio frequency identification
SLS	Space Launch System
SEP	Solar Electric Propulsion
SEV	Space Exploration Vehicle
SM	service module
SM	solid (rocket) motor
SMEMCL	Space Medicine Exploration Medical Condition List
Sol	one Martian day (24hours 37minutes)
SWME	spacesuit water membrane evaporator

TBD	to be determined
TBR	to be reviewed
TMG	thermal management garment
VEI	velocity at entry interface
W	watts
ZBO	zero boil off

SECTION I
INTRODUCTION

Introduction (text)

The National Aeronautics and Space Administration (NASA) has begun evaluating various mission and system components of possible implementations of what the U.S. Human Spaceflight Plans Committee (also known as the Augustine Committee) has named the "flexible path" (Anon., 2009). As human spaceflight missions expand further into deep space, the duration of these missions increases to the point where a dedicated crew habitat element appears necessary. There are several destinations included in this "flexible path" – a near Earth asteroid (NEA) mission, a Phobos/Deimos (Ph/D) mission, and a Mars surface exploration mission – that all include at least a portion of the total mission in which the crew spends significant periods of time (measured in months) in the deep space environment and are thus candidates for a dedicated habitat element.

As one facet of a number of studies being conducted by the Human Spaceflight Architecture Team (HAT) a workshop was conducted to consider how best to define and quantify "habitable volume" for these future deep space missions. One conclusion reached during this workshop was the need for a description of the scope and scale of these missions and the intended uses of a habitat element. A group was set up to prepare a concept of operations document to address this need.

This document describes a concept of operations for a habitat element used for these deep space missions. Although it may eventually be determined that there is significant overlap with this concept of operations and that of a habitat destined for use on planetary surfaces, such as the Moon and Mars, no such presumption is made in this document.

Introduction

- NASA has begun evaluating human spaceflight missions into deep space
- These future missions are of a duration that may require a dedicated habitat for the crew
- The Human Spaceflight Architecture Team (HAT) asked that a workshop examine the definition and quantification of “habitable volume” for these missions
- One recommendation from this workshop was the development of a concept of operations document for a habitat element
- This document describes such a concept of operations (ConOps)

ConOps Major Assumptions (text)

This ConOps development was structured to identify and capture the nominal activities and functions that would occur on the Deep Space Habitat (DSH) for those design reference missions (DRMs) needing such a capability. Because the ConOps was describing functions and activities and not design solutions, there is an assumption that a cost-effective, technologically feasible design solution will be found to allow the crew to carry out these activities and functions. It was also assumed that this feasible design solution could be accommodated by the transportation system used by individual DRMs – whether it is the launch phase or any of the required deep space maneuvers. An eventual real-world design process may prove that certain constraints must be applied that would limit the identified activities and functions, but it would be impossible to identify which of these constraints should be imposed on the ConOps. When this ConOps is used for actual design studies, the design team will need to adjust this ConOps to fit their particular suite of constraints.

This ConOps also assessed only nominal activities and functions. There will be a range of contingencies that a specific DSH will need to accommodate once a specific design is considered. But as with the constraint situation just discussed, a design team will need to determine how their particular set of contingencies can be accommodated within this ConOps and what additional functions must be added.

Finally this ConOps assumes that the DSH will operate in a microgravity-only mode for the entire duration of each DRM; this ConOps did not consider what changes or additions would be needed for this DSH to operate in a gravity environment, whether an artificial gravity environment in space or for dual use as a planetary surface habitat. It may be that there are no differences at the functional or activity level used for this ConOps, but no specific effort was made to identify such differences if they do exist.

ConOps Major Assumptions

- No programmatic constraints imposed on this assessment
  - Assume funding, technology, etc., available to achieve the function or activity
  - Assume transportation system can accommodate this element
  - Recognize that real world will impose these types of constraint eventually, but not clear which constraints to impose now
- Assessing only nominal activities and functions; no contingencies included at this time
- Micro-gravity environment for the full mission duration

Document Scope (text)

This concept of operations is intended to be used as "…an engineering/design tool to support systems engineering activities (i.e., requirements definition and refinement, concept development and evaluation, trade study analysis, design, test and evaluation) by identifying significant design-driving operational elements [i.e., events or activities] and characterizing them to the level of detail necessary to assess design impact" (Lilly and Russell, 2003). This concept of operations is also intended to be an evolutionary document that can be revised "to tailor or modify the scenario and its components [or systems] over time in order to update prospective solutions" (Lilly and Russell, 2003).

This document will NOT attempt to design or size systems, other than to note items such as currently accepted or applicable "best practices," constraints, or lessons learned from relevant mission experience.

Document Scope

- An engineering/design tool to support systems engineering activities
- Identify significant design-driving operational events or activities
- Document will NOT attempt to design or size systems
- Intended to be an evolutionary document

Other Applicable Documents

- Anon. (October 2009). *Seeking a Human Spaceflight Program Worthy of a Great Nation*, Final report of the U.S. Human Spaceflight Plans Committee, Washington, DC.

- Drake, Bret G. (July 2009). *Human Exploration of Mars, Design Reference Architecture 5.0*, NASA/SP–2009–566, National Aeronautics and Space Administration, Washington, DC.

- Lilly, T. C., and Russell, B. R., (2003) "The Multi-Mission Maritime Aircraft Design Reference Mission," Johns Hopkins APL Technical Digest 24(3), 257–262

SECTION II
DESTINATIONS

Flexible Path Missions using a Deep Space Habitat

- Three missions currently included in the Flexible Path have an identified need for a Deep Space Habitat.
  - Near Earth Asteroid mission
    - 4 crew
    - Nominal time in deep space/micro gravity = 399 days (from the 34B reference case)
    - Radial distance from the Sun = no closer than the orbit of Venus; no farther than the orbit of Mars
  - Phobos/Deimos Exploration mission
    - 4 crew
    - Nominal time deep space/micro gravity = 550-700 days for the short stay option; 920-1040 days for the long stay option
    - Radial distance from the Sun = inside the orbit of Venus (short stay option), no closer than Earth (long stay option); no farther than Mars for both options
  - Mars Surface Exploration transit mission
    - 6 crew
    - Nominal time deep space/micro gravity = two 180 day transits separated by 18 months on the Martian surface; in a contingency (no Mars landing) 850-950 days
    - Radial distance from the Sun = no closer than Earth; no farther than Mars
- "Servicing and Deployment" missions have a likely need for this habitat function but analyses are still underway to define this need
  - Likely mission attributes leading to a defined habitat need:
    - Missions durations longer than 21 days
    - Missions conducted at Earth-Moon L1 (or other Lagrange points in cis-lunar space)
    - Missions conducted at the Sun-Earth L1 or L2 points

SECTION II: DESTINATIONS
NEAR EARTH ASTEROID MISSION

Near Earth Asteroid Mission: Transit and Destination Operations

- Begins upon the successful completion of the departure burn from the Earth-Moon L1 point
  - The DSH may have been on station for 250 – 300 days during stack buildup, depending on specific buildup scenario
- Outbound transits last approximately 170 days; Return transits last approximately 210 days; 14 or 30 days at NEA
- Activities:
  - System maintenance and repair (IVA and contingency EVA)
  - Training
    - Refresher training for any mission phase (systems, health/wellbeing)
    - Destination (IVA, virtual, and EVA)
    - Return (re-entry systems, other (TBD))
  - Crew wellbeing
    - Health and fitness schedules
    - Crew sleep rotation schedules
    - Physiological and psychological monitoring/testing
  - Opportunities for astronomical (deep space) observations, observation of other NEAs, or observations of other solar system objects or environment
  - Equipment preparation for NEA exploration (outbound); Sample testing and curation (inbound)
  - Education and Public Outreach (EPO) and Public Relations activities
  - Personal time and personal communications with Earth
  - Instrument testing
    - Destination NEA first look
    - Remote interaction with robotic precursor left at NEA as a beacon
    - Flight test experimental navigation and other space flight technologies
  - Successful approach to rendezvous with NEA
    - Course monitoring and corrections

DRM 34B Mission Description (text)

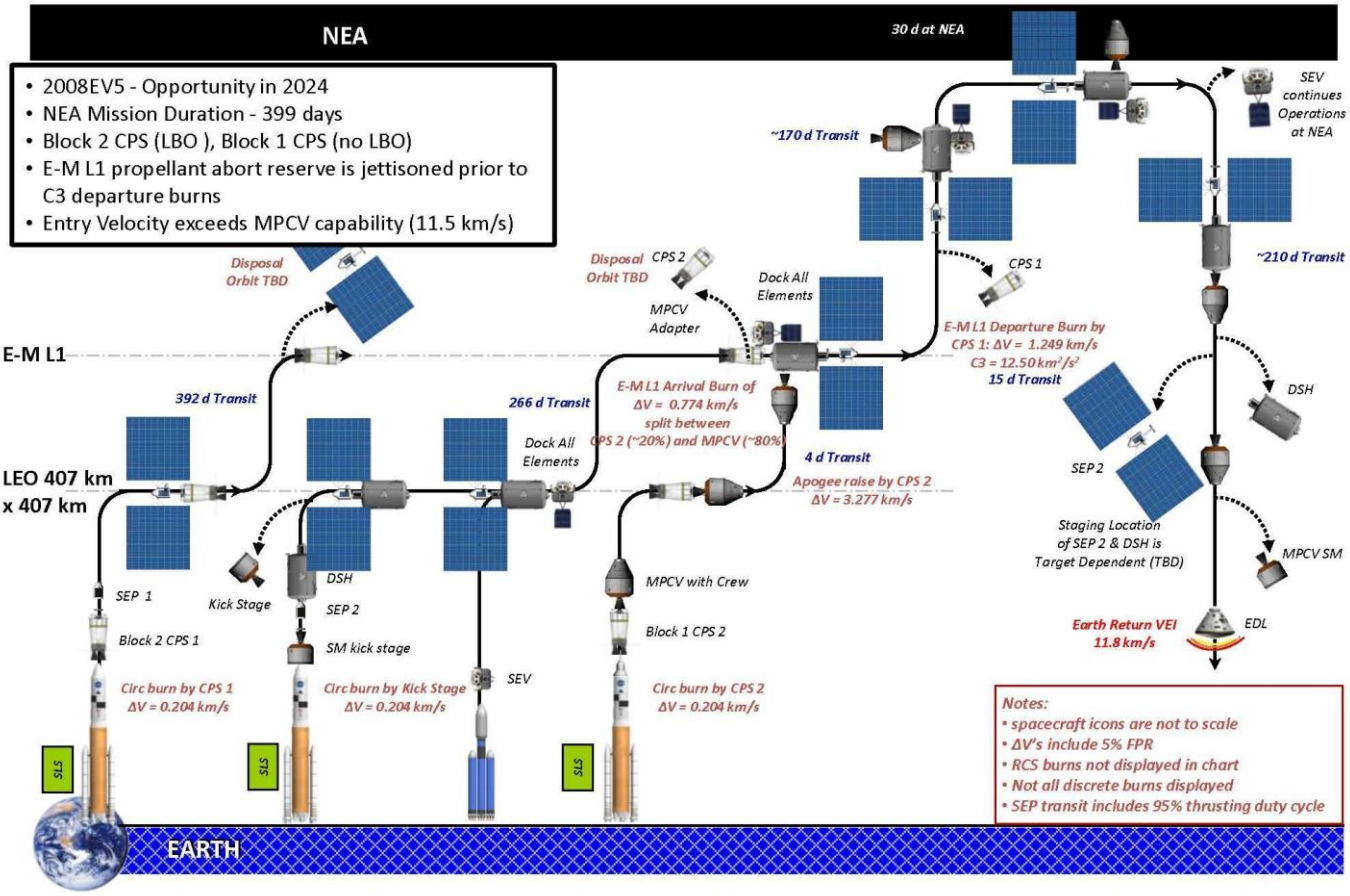
Near-Earth Asteroids (NEAs) missions can provide important scientific discoveries and vital operational experience for Mars missions and beyond, assist in the development of planetary defense approaches, and foster the future utilization of space resources. Longer NEA mission durations of a year or more are commensurate with the in-space transit segments for sending humans to Mars.

Long-duration interplanetary space missions, such as the 399-day NEA mission* described here, present unique challenges for the crew, spacecraft systems, and the mission control team. The cumulative experience and knowledgebase for human space missions beyond six months and an understanding of the risks to humans and human-rated vehicle systems outside of the Earth's protective magnetosphere is severely limited at this time. A variety of challenges exist, including:

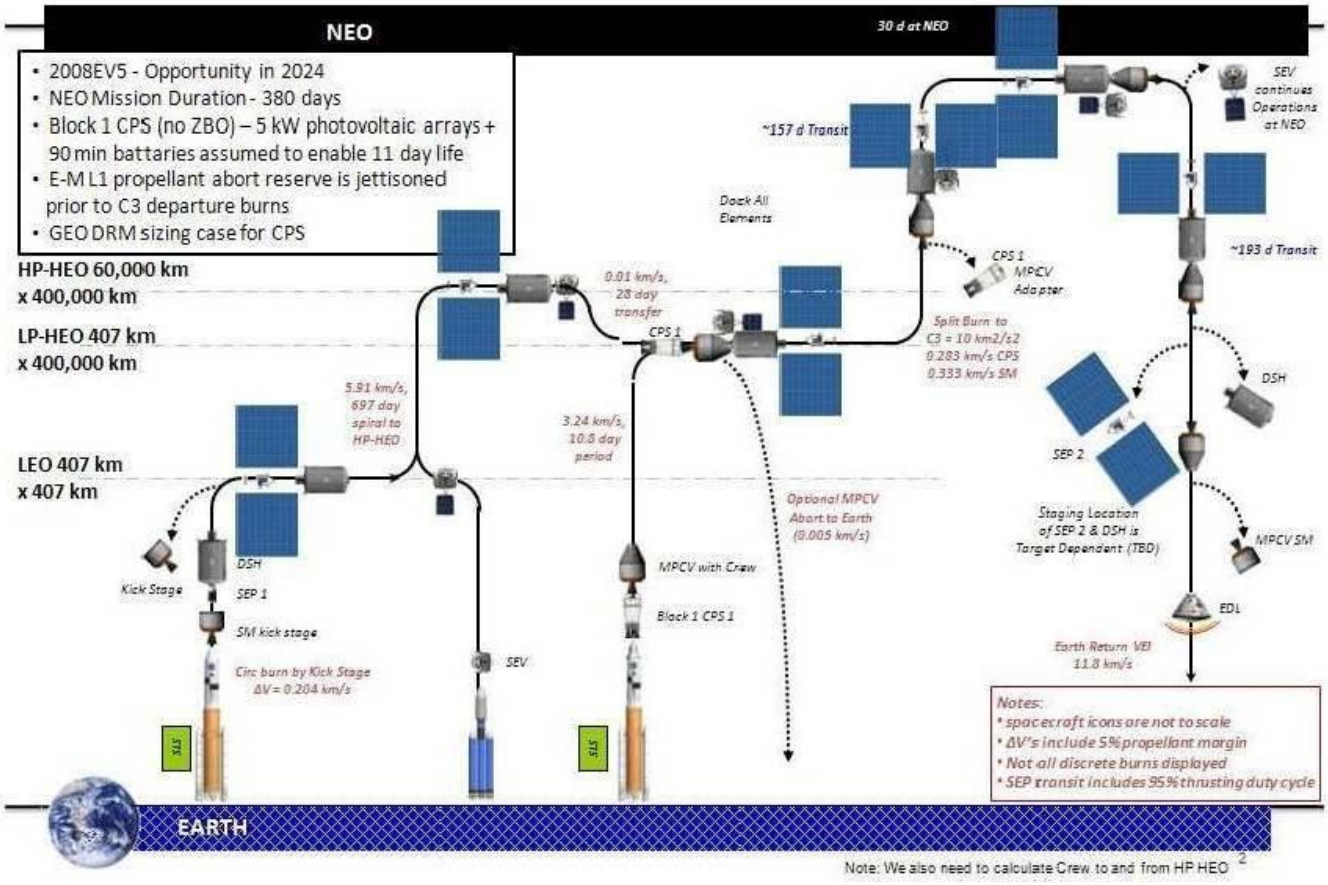
- radiation exposure (cumulative dosage and episodic risks)
- physiological effects
- psychological and social-psychological concerns
- habitability issues, including consumables and trash management
- system redundancy
- life support systems reliability
- missions contingencies, including abort scenarios
- communications light-time delays.

* Variations on this DRM, including short duration missions, are discussed in the full briefing of this reference mission.

Reference NEA Mission: DRM 34B (NEA 2008EV5 with SEP)



Alternate NEA Mission: “hybrid” mission

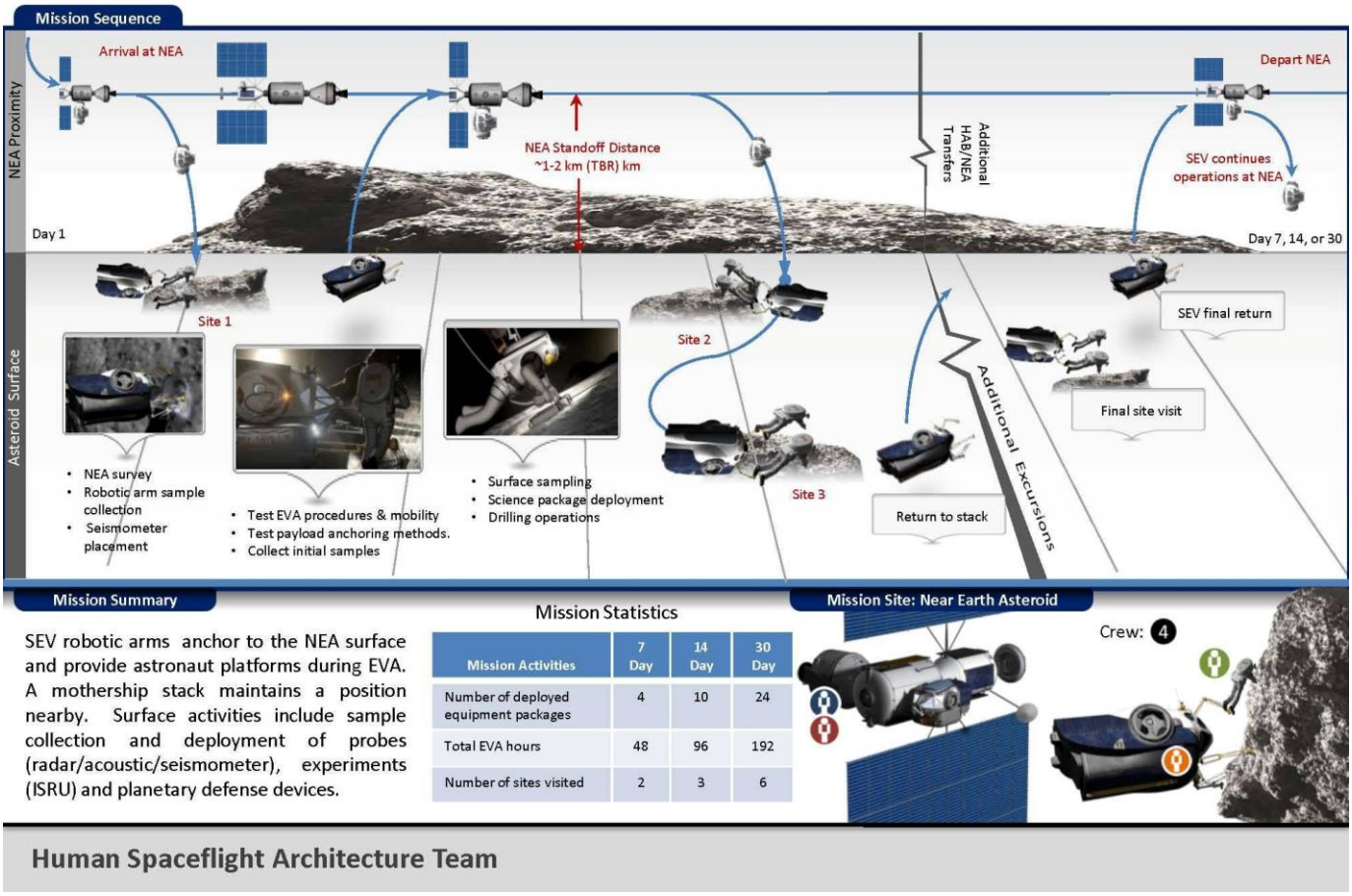


NEA Exploration – Street View Chart (text)

Since NEAs have very low surface gravity, the mission will not require a surface lander in the traditional sense. A significant challenge will be to station-keep alongside the NEA or "dock" and anchor to the NEA's surface. Asteroid spin rate and surface/internal structure are significant factors that influence this operational challenge and are significant factors in target qualification.

The ConOps for the 30 day stay, full capability NEA mission is designed to address the challenges listed above – in addition to adding to humankind's understanding of the origin and evolution of the solar system and other scientific investigations.

NEA Exploration with 1 SEV; 7, 14 or 30 days at NEA Street View Chart



Mission Activities	7 Day	14 Day	30 Day
Number of deployed equipment packages	4	10	24
Total EVA hours	48	96	192
Number of sites visited	2	3	6

SECTION II: DESTINATIONS
MARS MISSION CHARACTERISTICS

Mars Mission Modes (text)

Earth-Mars Mission Planning

Round-trip missions to Mars and back are, in effect, a double rendezvous problem. The outbound trajectory must be established while considering the position of Earth at the end of the mission. Upon arrival at Mars the Earth is in a relatively unfavorable alignment (phase angle) for an energy efficient return. This unfavorable alignment results in two distinct classes of round-trip Mars missions: Opposition class missions, which are also commonly referred to as short-stay missions, and Conjunction class missions, referred to as long-stay missions. Practical considerations, such as total propulsive requirements, mission duration, surface objectives, and human health considerations must be considered in the mission design process when choosing between these mission classes. The period of time necessary for the phase angle between Earth and Mars to repeat itself varies. This variation is referred to as the Synodic Cycle. The Synodic Cycle, or mission repetition rate for identical Earth-Mars phasing, and therefore launch opportunities for similar mission classes, is on the order of every 26 months. The mission characteristics such as mission duration, trip times, and propulsive requirements vary to due to the eccentricity of Mars' orbit.

Opposition Class: Short-Stay Missions

Short-stay missions consists of short stay-times (typically 30 sols) and round-trip mission times ranging from 550-660 days. This is often referred to as an opposition-class mission, although the exploration community has adopted the more descriptive terminology "short-stay" mission. Trajectory profiles for typical short-stay missions are shown. This class of mission has high propulsive requirements. Short-stay missions always have one short transit leg, either outbound or inbound, and one long transit leg, the latter requiring close passage by the sun (0.7 AU or less). After arrival at Mars, rather than waiting for a near-optimum return alignment, the spacecraft initiates the return after a brief stay and the return leg cuts well inside the orbit of the Earth to make up for the "negative" alignment of the planets that existed at Mars departure. Distinguishing characteristics of the short-stay mission are: 1) short-stay at Mars, 2) medium total mission duration, 3) perihelion passage inside the orbit of Venus on either the outbound or inbound legs, and 4) large total energy (propulsion) requirements.

Conjunction Class: Long Stay Missions

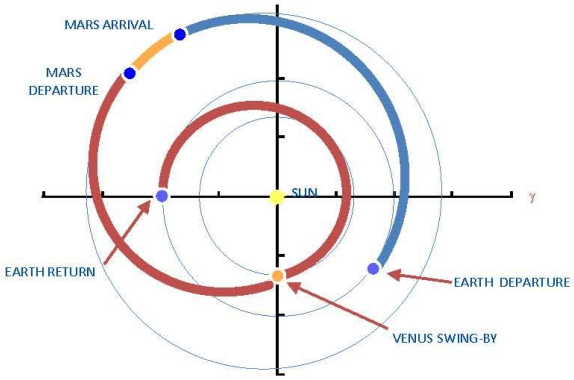
The second Mars mission class is typified by long-duration stay-times (as much as 550 sols) and long total round-trip times (approximately 900 days). This mission type is often referred to as conjunction-class, although the exploration community has adopted the more descriptive terminology "long-stay" mission. These missions represent the global minimum-energy solutions for a given launch opportunity. Unlike the short-stay mission approach, instead of departing Mars on a non-optimal return trajectory, time is spent at Mars waiting for more optimal alignment for lower energy return. Distinguishing characteristics of the long-stay mission include: 1) long total mission durations, 2) long-stays at Mars, 3) relatively little energy change between opportunities, 4) bounding of both transfer arcs by the orbits of Earth and Mars (closest perihelion passage of 1 AU), and 5) relatively short transits to and from Mars (less than 200 days).

Mars Mission Modes

- Round-trip human missions to Mars are double rendezvous problems
  - Relative phasing of Earth-Mars (outbound leg) must be considered along with the relative phasing Mars-Earth (return leg)
- This leads to two distinct mission classes

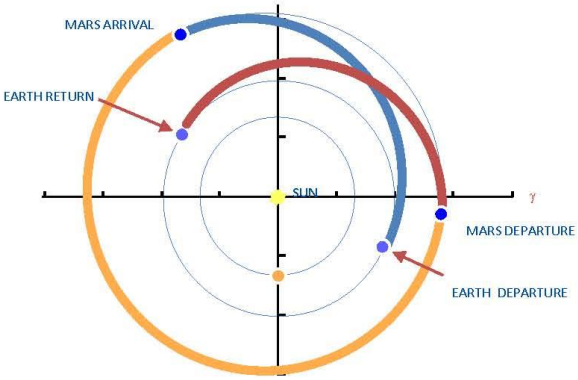
Short-Stay (Opposition Class)

- Variations of missions with short Mars surface stays and may include Venus swing-by
- Often referred to as Opposition Class missions



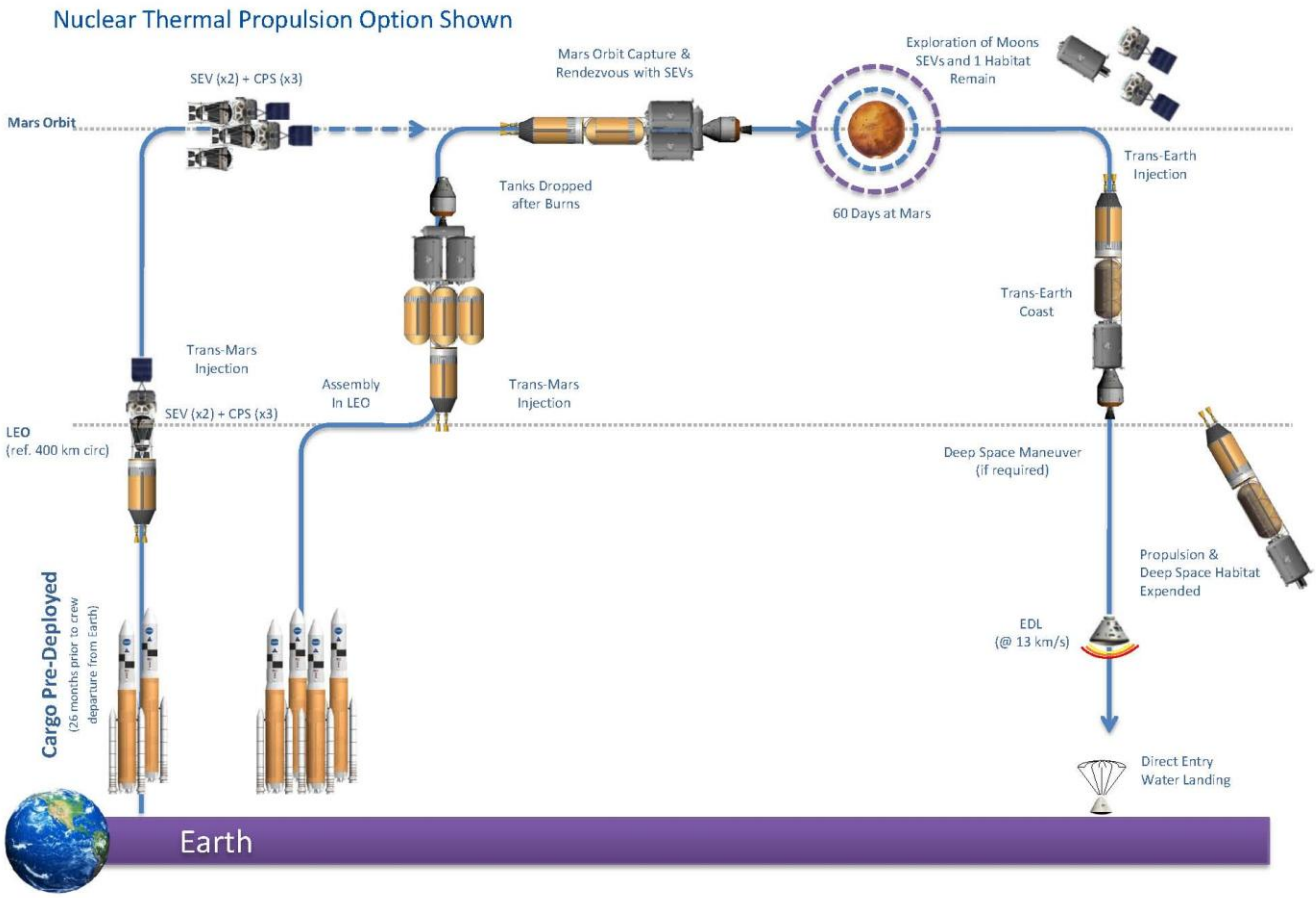
Long-Stay (Conjunction Class)

- Variations about the minimum energy mission
- Often referred to as Conjunction Class missions



SECTION II: DESTINATIONS
PHOBOS / DEIMOS EXPLORATION MISSION

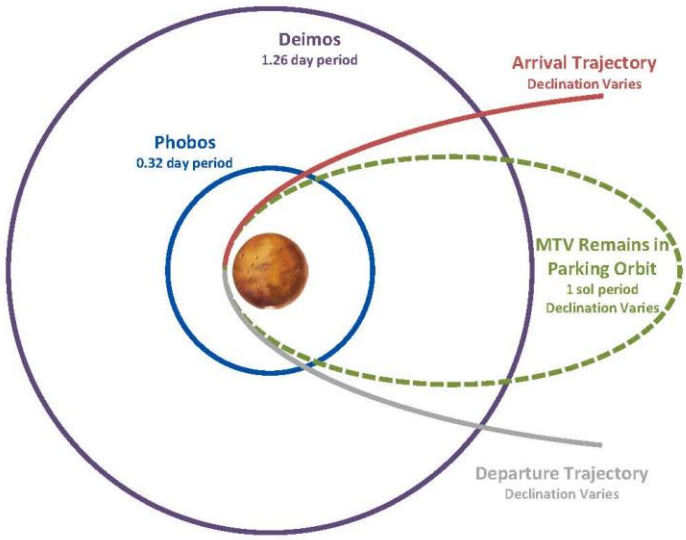
High Thrust (NTR) Short-Stay Mission Profile



Ph/D Short Stay Mission: Transit and Destination Operations

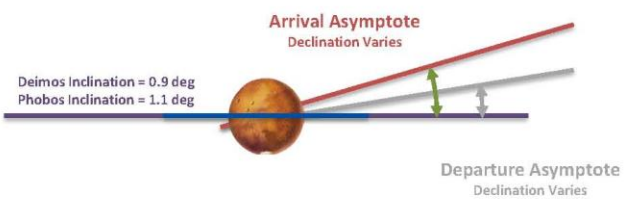
- Begins in LEO upon successful completion of MPCV docking and Mars departure burn
  - The DSH may have been on station for 30 – 120 days during stack buildup, depending on specific buildup scenario
- Outbound transits last between 170 and 370 days; Return transits last between 200 and 400 days (see opening slide for total flight time range)
- Activities:
  - System maintenance and repair (IVA and contingency EVA)
  - Training
    - Refresher training for any mission phase (systems, health/wellbeing)
    - Destination (IVA, virtual, and EVA)
    - Return (re-entry systems, other (TBD))
  - Crew wellbeing
    - Health and fitness schedules
    - Crew sleep rotation schedules
    - Physiological and psychological monitoring/testing
  - Opportunities for astronomical (deep space) observations, observation of NEAs, or observations of other solar system objects or environment
  - Education and Public Outreach (EPO) and Public Relations activities
  - Personal time and personal communications with Earth
  - Instrument testing
    - Phobos/Deimos first look
    - Remote interaction with robotic precursor left at Phobos and/or Deimos (if used)
    - Flight test experimental navigation and other space flight technologies
  - Successful approach to rendezvous with pre-deployed cargo followed by SEV deployments to Phobos and Deimos
    - Course monitoring and corrections

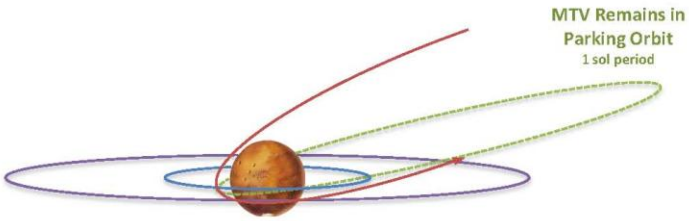
Short Stay Orbital Operations Concept
High Thrust Missions



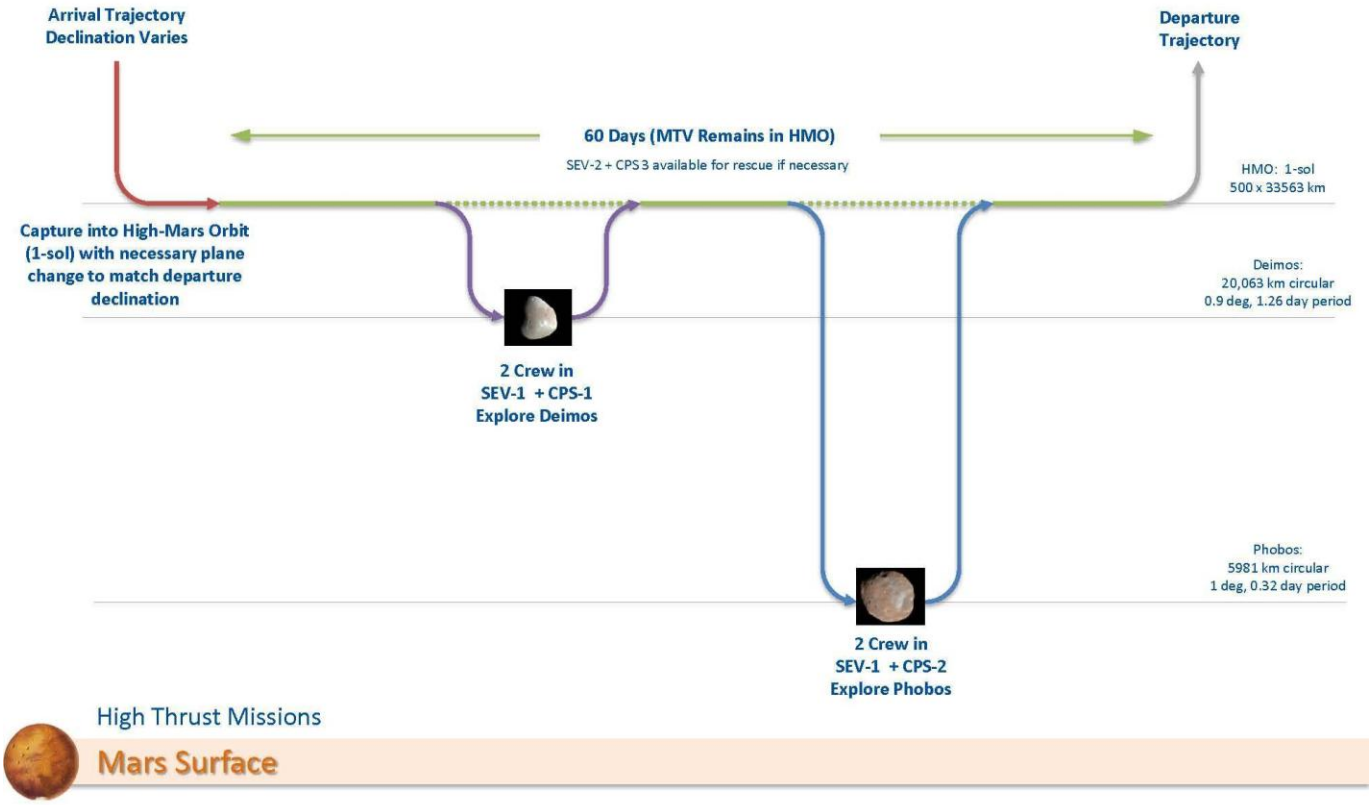
Assumed Mars Orbit Strategy

1. Capture into a 1-sol parking orbit (500 x 33,563 km) with proper plane change to match departure asymptote
2. Leave Mars Transfer Vehicle in 1-sol parking orbit
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Deimos for 14 days (1,300-1,600 m/s delta-v required)
5. Utilize SEV-2 to explore Phobos for 14 days (1,630-2,000 m/s delta-v required)
6. Prepare for Mars departure
7. Trans-Earth Injection





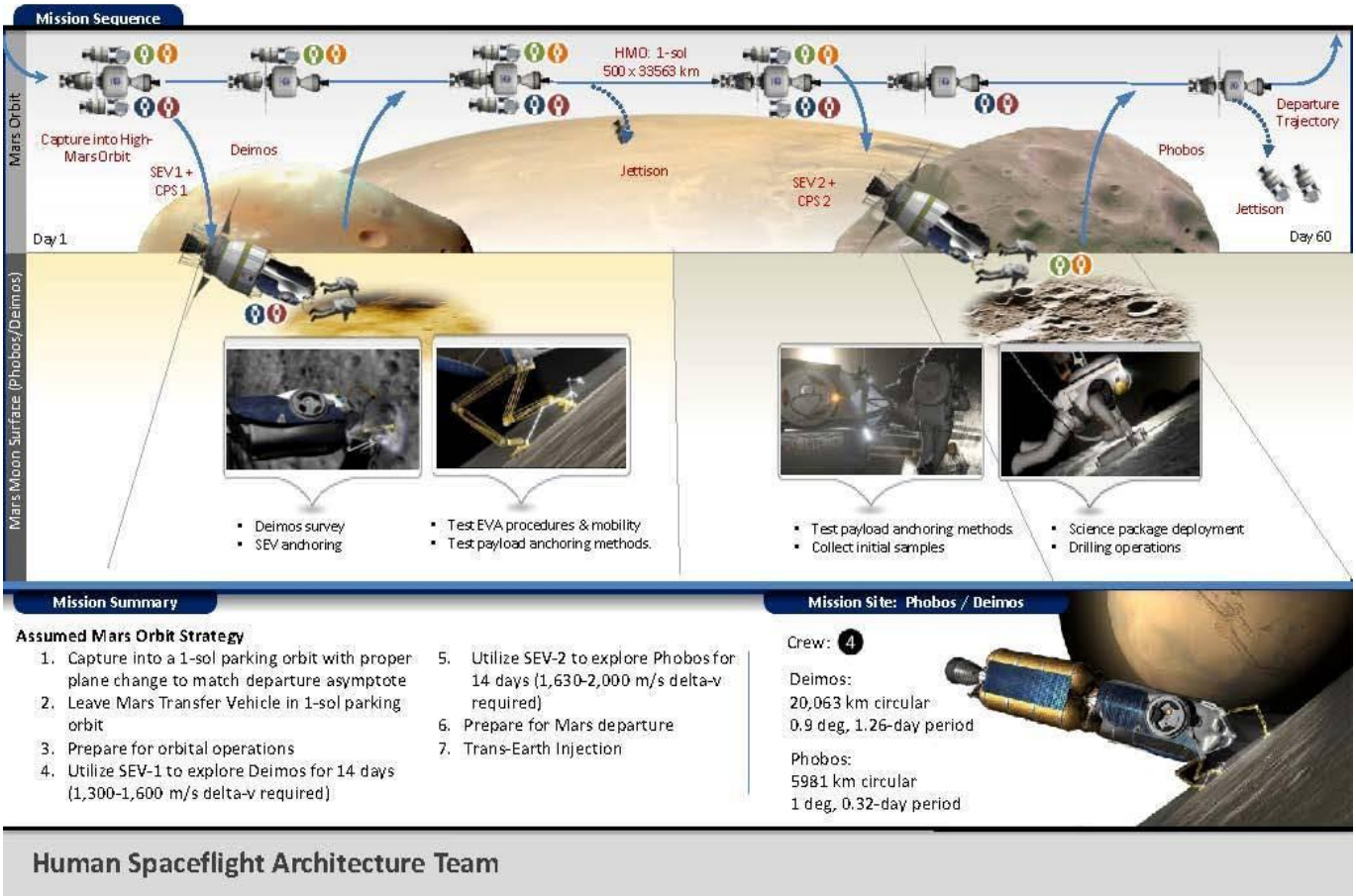
Short-Stay Mars Vicinity Operations



High Thrust Missions

Mars Surface

Short-Stay Mars Vicinity Operations



Mission Summary

Assumed Mars Orbit Strategy

1. Capture into a 1-sol parking orbit with proper plane change to match departure asymptote
2. Leave Mars Transfer Vehicle in 1-sol parking orbit
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Deimos for 14 days (1,300-1,600 m/s delta-v required)
5. Utilize SEV-2 to explore Phobos for 14 days (1,630-2,000 m/s delta-v required)
6. Prepare for Mars departure
7. Trans-Earth Injection

Mission Site: Phobos / Deimos

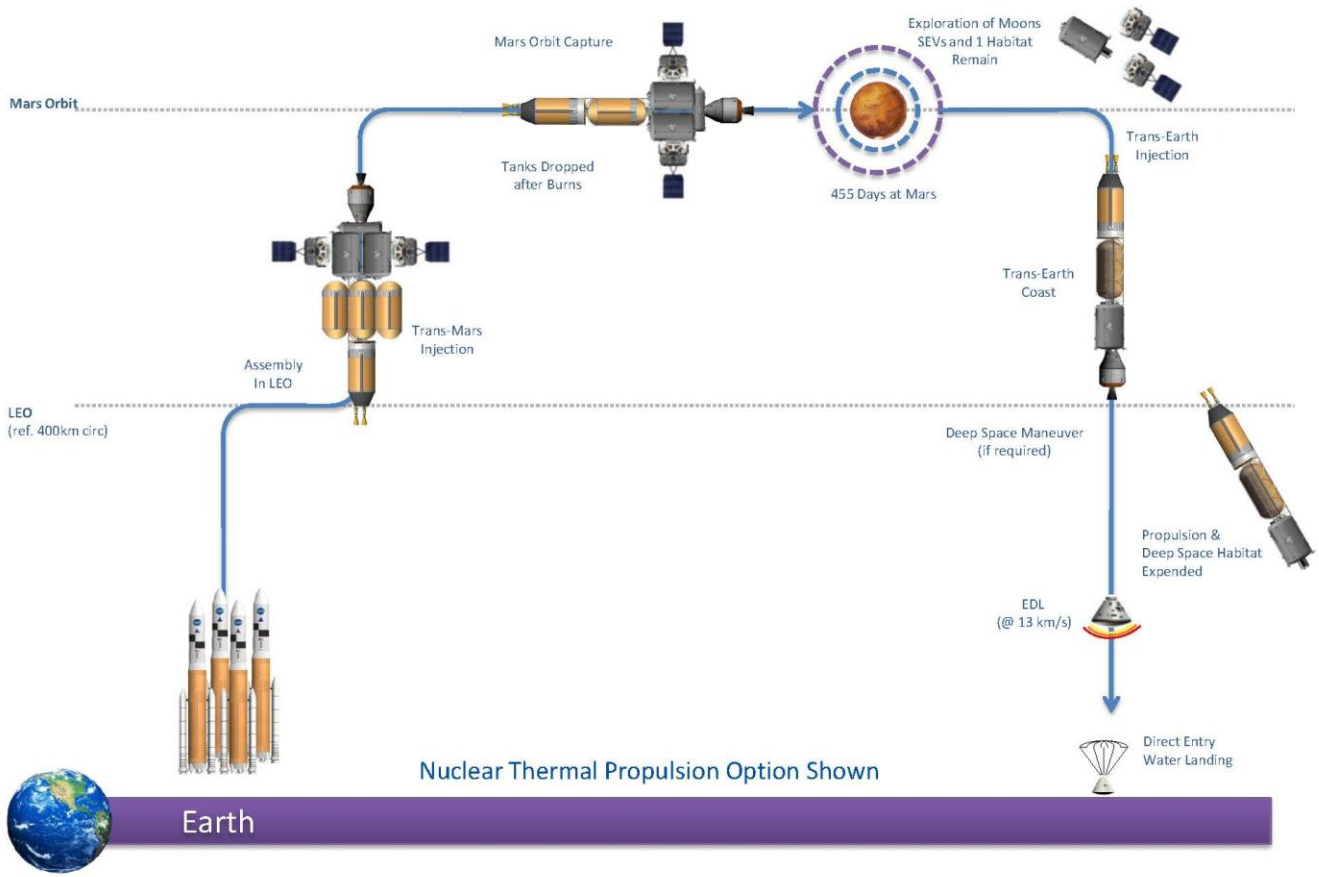
Crew: 4

Deimos:
20,063 km circular
0.9 deg, 1.26-day period

Phobos:
5981 km circular
1 deg, 0.32-day period

Human Spaceflight Architecture Team

High Thrust (NTR) Long-Stay Mission Profile

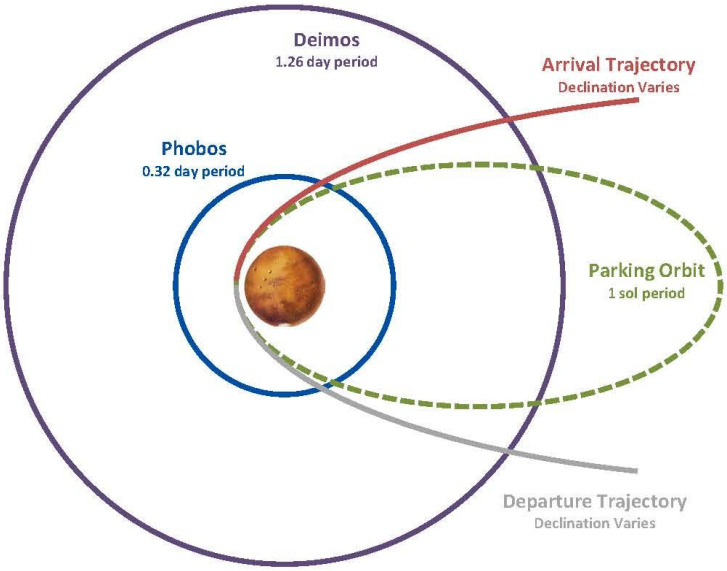


Ph/D Long Stay Mission: Transit and Destination Operations

- Begins in LEO upon successful completion of MPCV docking and Mars departure burn
  - The DSH may have been on station for 30 – 120 days during stack buildup, depending on specific buildup scenario
- Outbound transits last between 170 and 350 days; Return transits last between 200 and 330 days (see opening slide for total flight time range)
- Activities:
  - System maintenance and repair (IVA and contingency EVA)
  - Training
    - Refresher training for any mission phase (systems, health/wellbeing)
    - Destination (IVA, virtual, and EVA)
    - Return (re-entry systems, other (TBD))
  - Crew wellbeing
    - Health and fitness schedules
    - Crew sleep rotation schedules
    - Physiological and psychological monitoring/testing
  - Opportunities for astronomical (deep space) observations, observation of NEAs, or observations of other solar system objects or environment
  - Education and Public Outreach (EPO) and Public Relations activities
  - Personal time and personal communications with Earth
  - Instrument testing
    - Phobos/Deimos first look
    - Remote interaction with robotic precursor left at Phobos and/or Deimos (if used)
    - Flight test experimental navigation and other space flight technologies
  - Successful approach to rendezvous with Deimos and then Phobos
    - Course monitoring and corrections

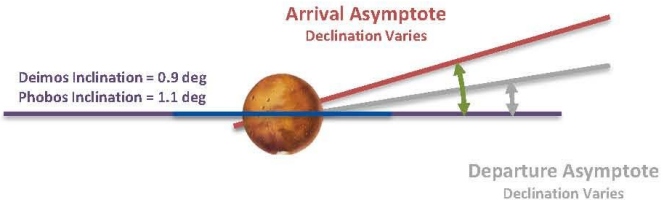
Long Stay Orbital Operations Concept

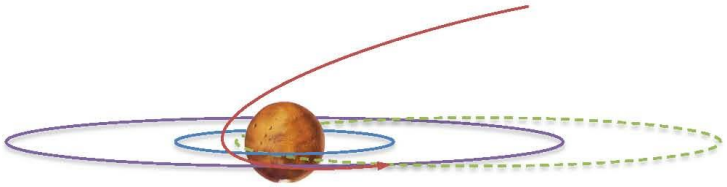
High Thrust Missions



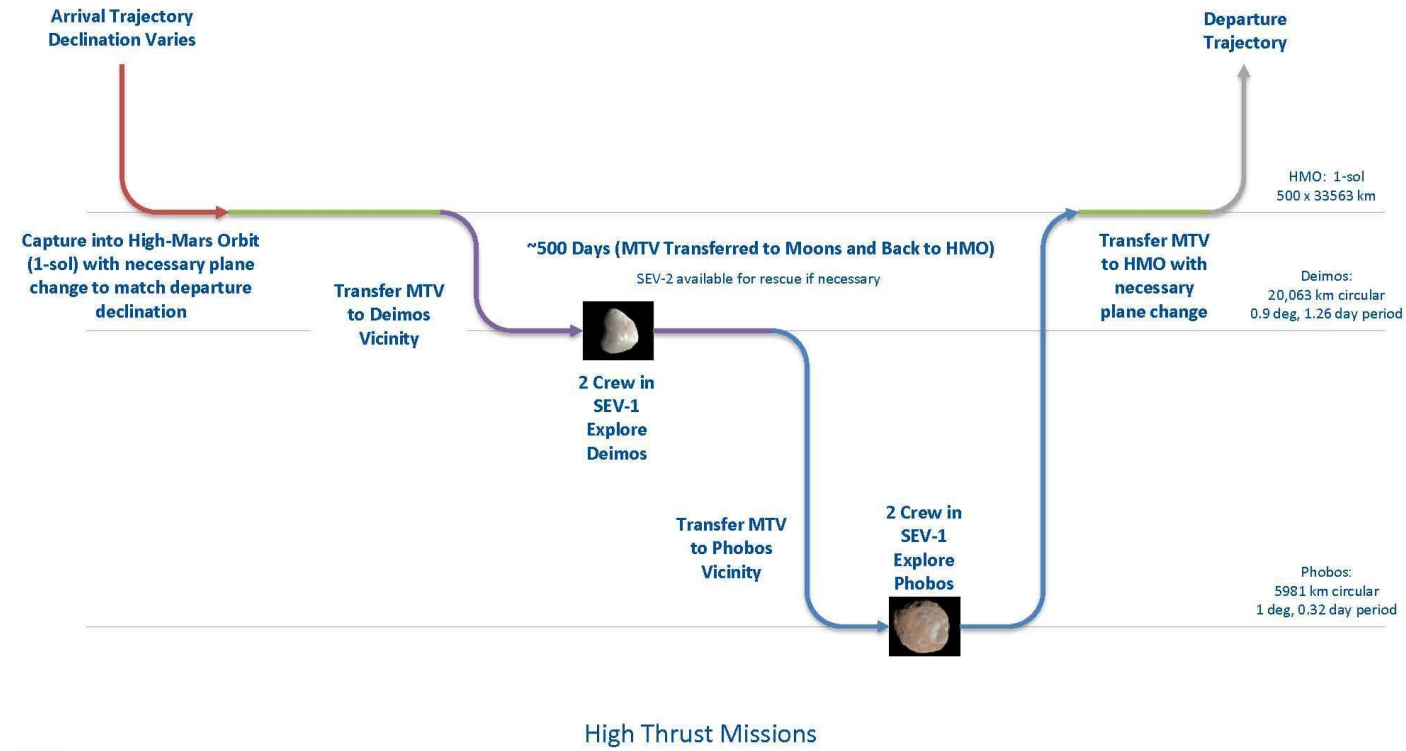
Assumed Mars Orbit Strategy

1. Capture into a 1-sol parking orbit (500 x 33,563 km) with proper plane change to Diemos inclination
2. Lower Mars Transfer Vehicle to Deimos orbit (653 m/s delta-v required)
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Deimos numerous times
5. Lower Mars Transfer Vehicle to Phobos orbit (784 m/s delta-v required)
6. Utilize SEV-2 to explore Phobos numerous times
7. Prepare for Mars departure including orbit and plane change
8. Trans-Earth Injection





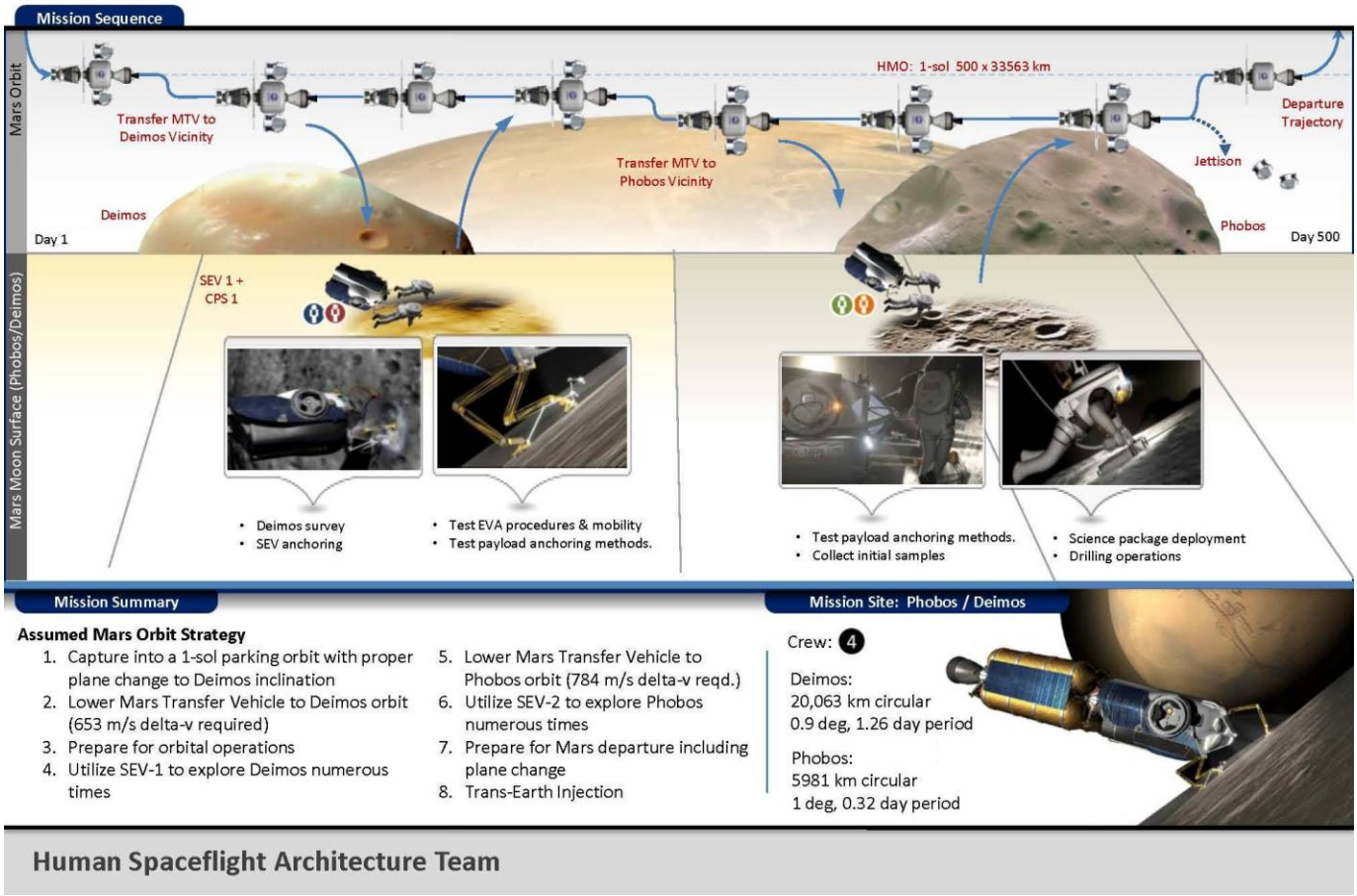
Long Stay Mars Vicinity Operations



High Thrust Missions

Mars Surface

Long Stay Mars Vicinity Operations



Mission Summary

Assumed Mars Orbit Strategy

1. Capture into a 1-sol parking orbit with proper plane change to Deimos inclination
2. Lower Mars Transfer Vehicle to Deimos orbit (653 m/s delta-v required)
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Deimos numerous times
5. Lower Mars Transfer Vehicle to Phobos orbit (784 m/s delta-v reqd.)
6. Utilize SEV-2 to explore Phobos numerous times
7. Prepare for Mars departure including plane change
8. Trans-Earth Injection

Mission Site: Phobos / Deimos

Crew: 4

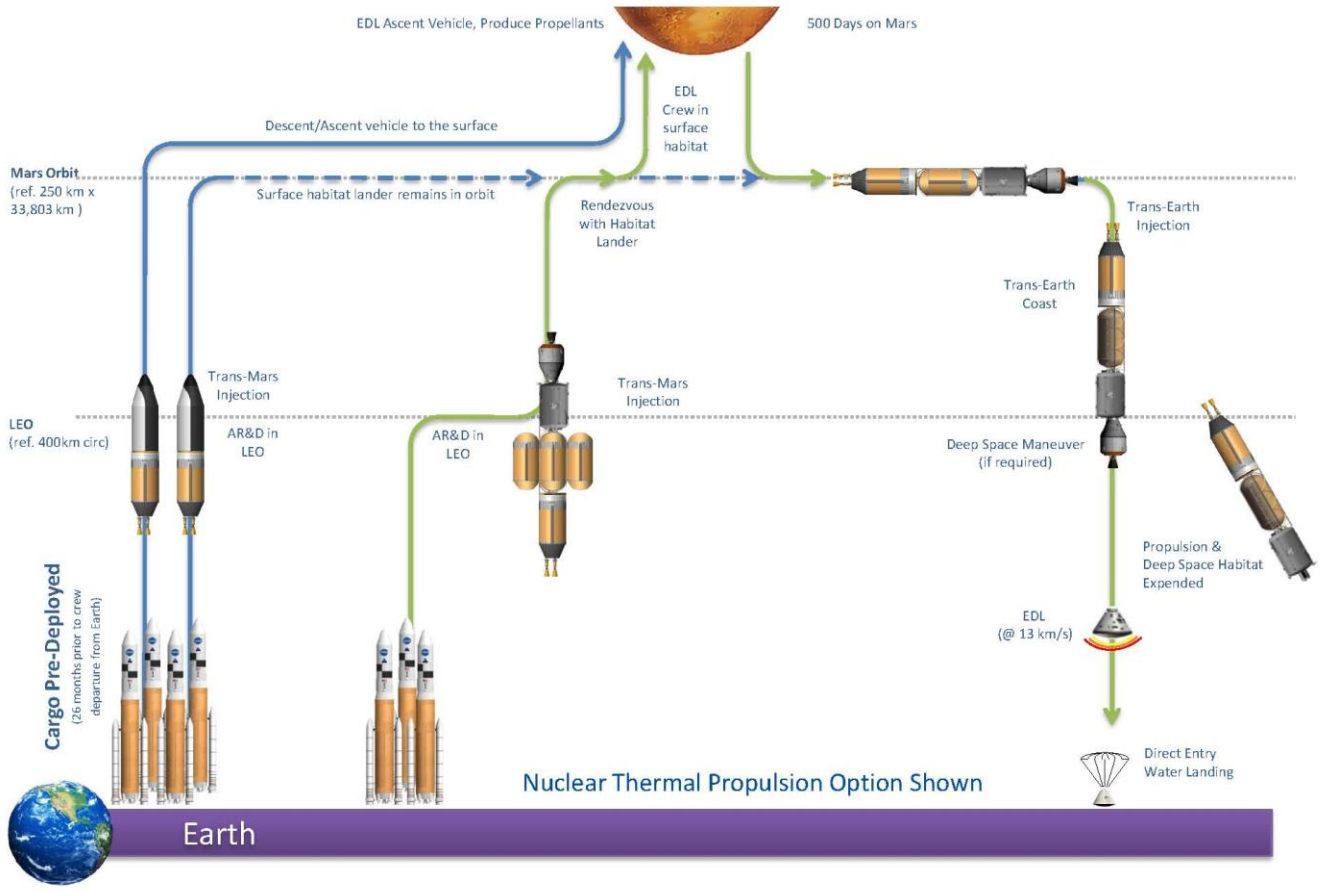
Deimos:
20,063 km circular
0.9 deg, 1.26 day period

Phobos:
5981 km circular
1 deg, 0.32 day period

Human Spaceflight Architecture Team

SECTION II: DESTINATIONS
MARS SURFACE EXPLORATION TRANSIT MISSION

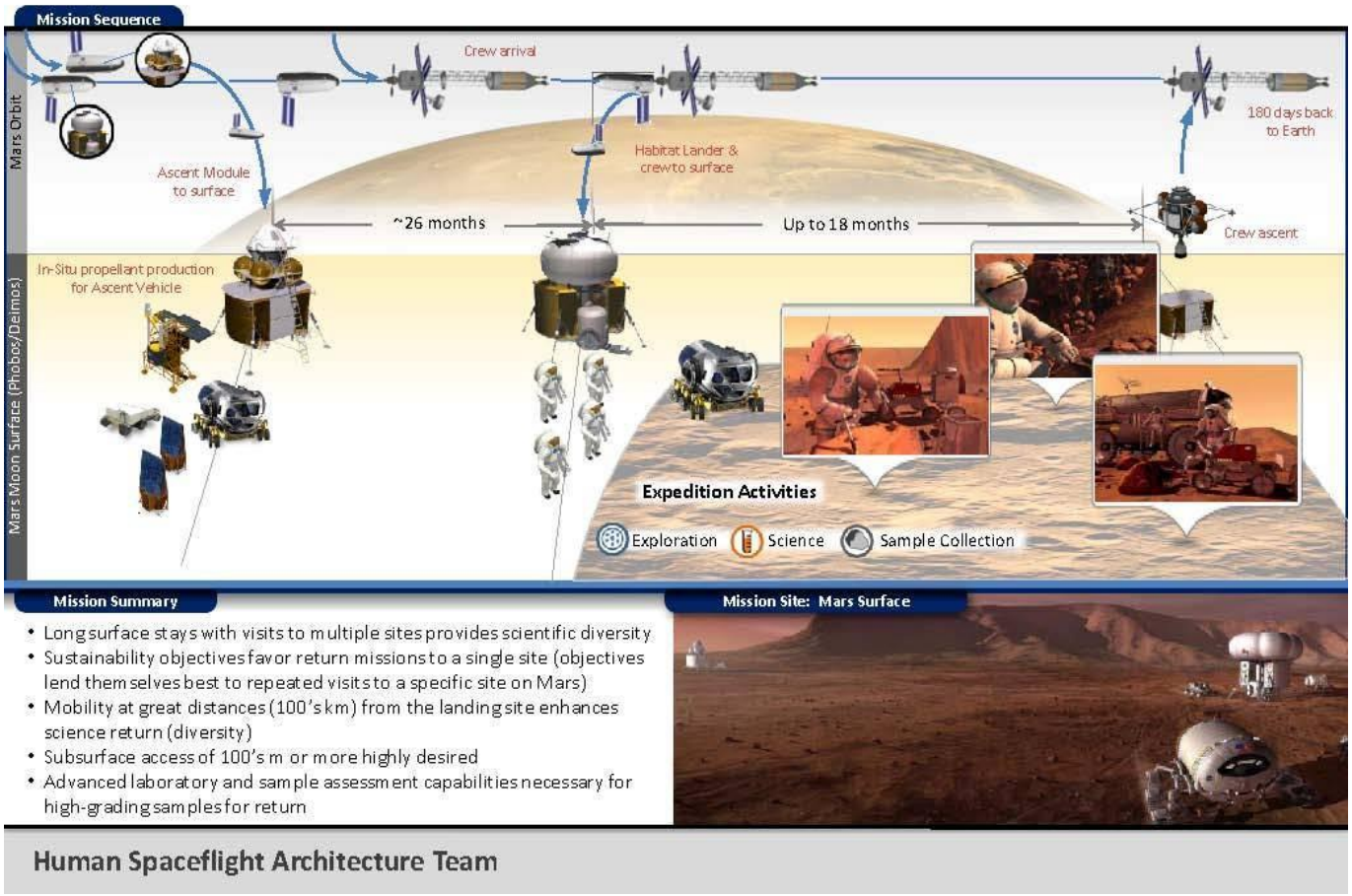
Long-Stay Mission Profile



Mars Surface Mission : Transit Operations

- Begins upon successful completion of MPCV docking and Earth departure burn
- Outbound and return transits last 180 days (in isolated cases during the synodic cycle, this could stretch to 200-220 days)
- Activities:
  - System maintenance and repair (IVA and contingency EVA)
  - Training
    - Refresher training for any mission phase (systems, health/wellbeing)
    - Destination (IVA, virtual, and EVA)
    - Return (re-entry systems, other (TBD))
  - Crew wellbeing
    - Health and fitness schedules
    - Crew sleep rotation schedules
    - Physiological and psychological monitoring/testing
  - Opportunities for astronomical (deep space) observations, observation of NEAs, or observations of other solar system objects or environment
  - Education and Public Outreach (EPO) and Public Relations activities
  - Personal time and personal communications with Earth
  - Mars approach
    - Phobos/Deimos remote observations
    - Remote interaction with precursor robotic and cargo elements previously deployed
  - On arrival: successful approach to rendezvous with orbiting cargo element (surface habitat and other systems)
    - Course monitoring and corrections
  - On departure: successful approach to rendezvous with transit vehicle and configure for Mars departure
    - Course monitoring and corrections

Mars Surface Operations



SECTION II: DESTINATIONS

SUMMARY OF DESTINATION MISSION CHARACTERISTICS

Summary of Destination Mission Characteristics

- Three mission currently included in the Flexible Path have an identified need for a Deep Space habitat.
  - Near Earth Asteroid mission
    - 4 crew
    - Nominal time in deep space/micro gravity = 399 days (from the 34B reference case)
    - Radial distance from the Sun = no closer than the orbit of Venus; no farther than the orbit of Mars
  - Phobos/Deimos Exploration mission
    - 4 crew
    - Nominal time deep space/micro gravity = 550-700 days for the short stay option; 920-1040 days for the long stay option
    - Radial distance from the Sun = inside the orbit of Venus (short stay option), no closer than Earth (long stay option); no farther than Mars for both options
  - Mars Surface Exploration transit mission
    - 6 crew
    - Nominal time deep space/micro gravity = two 180 day transits separated by 18 months on the Martian surface; in a contingency (no Mars landing) 850-950 days
    - Radial distance from the Sun = no closer than Earth; no farther than Mars
- The “Servicing and Deployment” mission (in cis-lunar space) has a likely need for this habitat function

Summary of Destination Mission Characteristics

	NEA	Ph/D (short stay)	Ph/D (long stay)	Mars Transit (long stay)
Number of Crew	4	4	4	6
Flight Time				
Min (days)	~399 (DRM 34B)	550	920	2 x 180
Max (days)	~399 (DRM 34B)	700	1040	850-950 (contingency)
Distance from Sun				
Min (AU) (average across multiple opportunities)	0.75	0.4	1.0	1.0
Max (AU) (average across multiple opportunities)	1.50	1.5	1.5	1.5

SECTION III
HABITAT FUNCTIONS AND ACTIVITIES

DSH ConOps Functions for Transit Mission Phases

1. Provide support systems
    - Communications
    - Thermal control (active and passive)
    - Power management
    - Environmental Protection
        - Radiation protection
        - Micro meteoroid/Orbital debris
    - ECLSS
2. Provide on-board subsystem monitoring and control (C&DH, Caution and Warning, "Crew autonomy" [e.g., diagnostics/prognostics], etc.)
3. Provide on-board piloting/proximity operations/navigation
4. Provide docking for one MPCV and up to two SEVs
5. Provide control of external devices (manipulators, robotic devices, etc.)
6. Provide external visibility (observation of target body, situational awareness during EVA and SEV flight operations)
7. Provide EVA egress and ingress (with airlock or suitport) for suited crew members and for EVA suits (for maintenance and repair)
8. Provide Stowage (food, personal hygiene, housekeeping, maintenance/tools, trash, waste, general, etc.)
9. Provide maintenance and repair
    - Electronic
    - Mechanical
    - Soft Goods (e.g., EVA garment)
10. Provide food preparation
11. Provide multipurpose gathering space (meals, crew meetings, individual work, recreation, etc.)
12. Provide crew personal accommodations (sleep, private space, etc.)
13. Provide crew hygiene
14. Provide crew exercise
15. Provide crew health/medical support
16. Provide mission specific on-board research
17. Provide crew safe haven (covered by environmental protection?)
18. Provide crew training

(*Note: the order of this list does not imply priority.*)

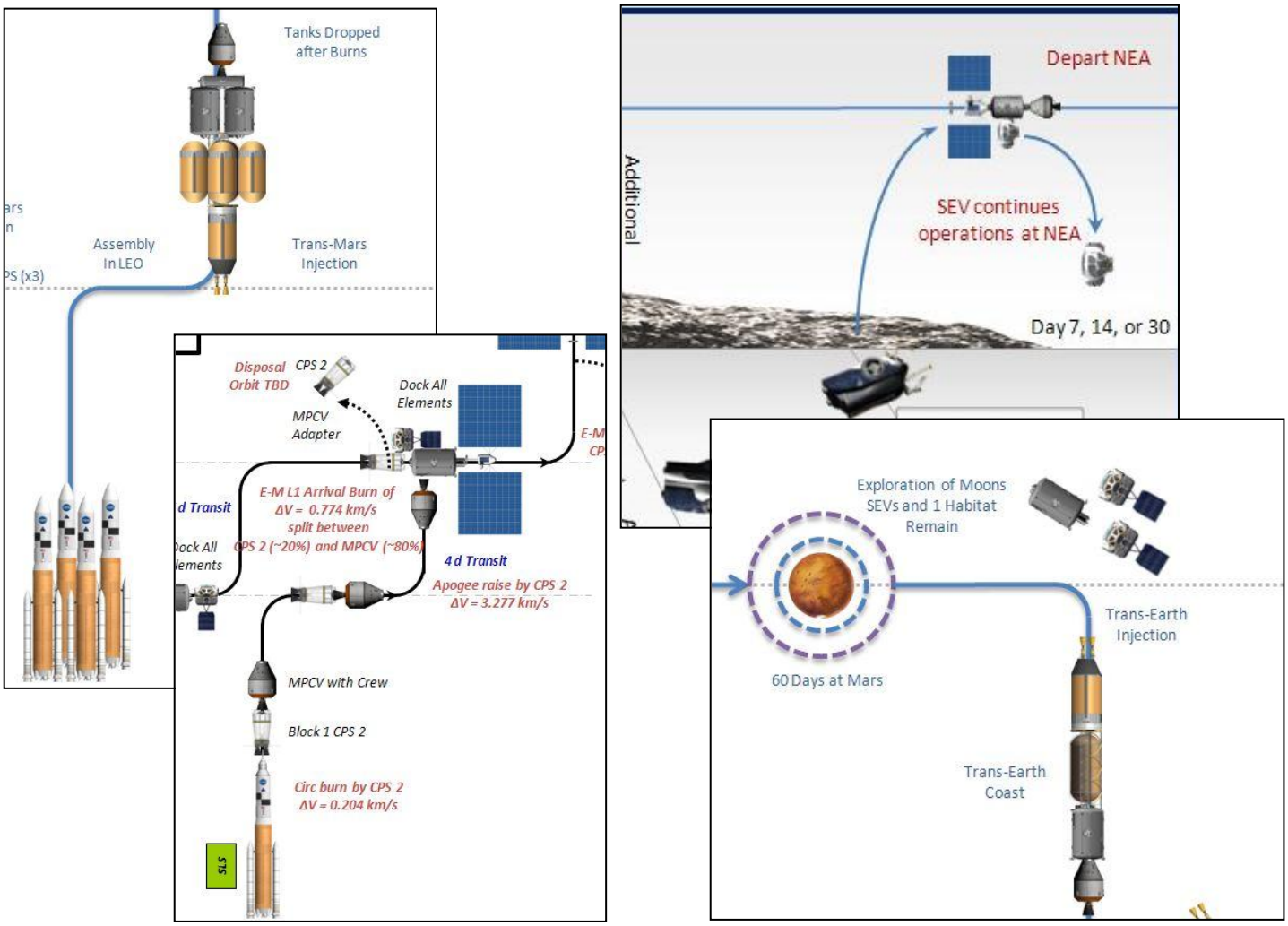
Departure Activities (text)

This section is a summary description of crew activities and habitat functions that the previous DRM descriptions indicate are likely to occur when departing from either Earth or the destination for a specific mission. Because these descriptions are crew and habitat focused, they do not cover the buildup of the vehicle stack that includes the Deep Space Habitat (DSH).

Earth Departure. This description begins with the rendezvous and docking of the crew in an MPCV vehicle. The vehicle stack that includes the DSH is likely to be the passive partner in this event, but most (all?) systems on board the habitat will have been functioning for some period of time in anticipation of the crew's arrival (e.g., power, ECLSS, thermal, communications, data, etc.). Once on board the habitat, the crew will activate any systems not already functioning and confirm the status of all systems. Any crew or personal gear arriving on the MPCV will be transferred and stowed. The crew will then configure all systems in the vehicle stack (which includes the habitat and the MPCV) for the departure delta-V maneuver. Once this departure maneuver has been completed, the crew will configure the stack for the cruise phase. The crew will then have the opportunity to observe the Earth and the Moon as the stack escapes Earth's gravitational influence.

Destination Departure. Several days before the window for departing the destination opens, the crew will gather trash and other equipment not required for the return to Earth and jettison these items. The vehicle stack is likely to have been moved some distance away from the destination object to avoid any of these jettisoned items from landing on the destination or from becoming a hazard to future visiting vehicles. The crew will then configure all systems in the vehicle stack for the departure delta-V maneuver. Once this departure maneuver has been completed, the crew will configure the stack for the cruise phase. These two "configuring" activities should be very similar, if not the same, as those performed at Earth departure. The crew will then have the opportunity to observe the destination object as the stack begins the return trajectory to Earth.

Departure Activities



On-board Piloting, Proximity Operations, & Navigation (text)

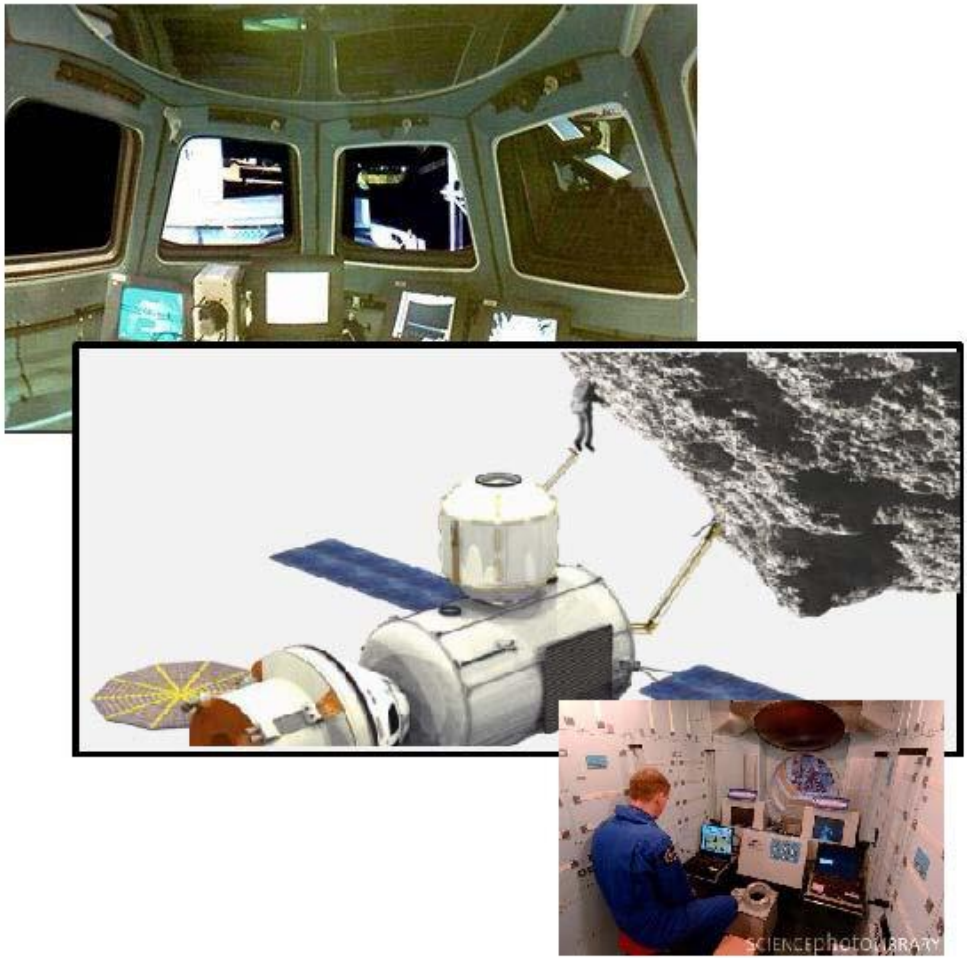
Introduction. The Deep Space Habitat will contain a work station from which the crew can navigate the vehicle, and plan and execute rotational and translational maneuvers for the entire integrated stack. Rotational maneuvering satisfies vehicle attitude requirements for sunlight on solar arrays, thermal conditioning, antenna pointing, camera and other remote sensor pointing, and orienting the field of view through windows. Control over the thrust magnitude and direction of long duration, low thrust translational maneuvers is needed during transit and for station keeping. If the habitat is ever in the rendezvous chaser role, it will need a means of performing impulsive maneuvers, perhaps through the propulsion systems of other docked vehicles.

Crew Activities. Mission operations centers on Earth will periodically update onboard navigation, and plans for course corrections during transit phases. The crew will also have key roles in spacecraft navigation and maneuvering during all mission phases. These roles become more critical as distance from Earth, and the communications delay caused by the finite speed of light, increase. The crew will evaluate data quality and perform maneuver execution procedures. They may also take optical sightings of stars and solar system objects to calibrate onboard navigational equipment, or to flight-test experimental navigation systems. When in the vicinity of an asteroid or free-flying spacecraft, the crew will acquire and process relative navigation data for station keeping or near-field rendezvous and proximity operations.

Habitat Design Impacts. Most translational maneuvers will be performed by a dedicated propulsion module. Options are currently being studied to determine whether a high thrust or a low thrust system is optimal. Regardless of the choice of primary propulsion a reaction control system (RCS) will be needed to maneuver the stack. This RCS could be part of the primary propulsion system module or could require assistance from the RCS of other docked vehicles, such as the Multi-Purpose Crew Vehicle Service Module (MPCV SM), or a Space Exploration Vehicle (SEV). This would require a command path to exist between the habitat and the propulsion systems of these vehicles. Guidance and control systems must be able to compensate for differences in mass and center of mass for any possible docked or undocked stack configuration, and to sense rotational and translational accelerations. The crew station control systems should enable direct piloting inputs by the crew, with intuitive displays of maneuver status, attitude and attitude rates, relative positions and rates with respect to other objects, and direct visual and/or camera views. Relative navigation sensors will also be controlled from the crew station. Sensors enable relative range, range rates, and angles to be determined between vehicles and other objects for near-field rendezvous and proximity operations. The guidance, navigation, and control (GNC) computer will maintain state vectors for the integrated stack, undocked vehicles, and other targets, such as an asteroid. Sensor, camera, and window placement should minimize blockage by other vehicle structures. GNC avionics must be shielded against radiation upsets.

Provide On-board Piloting/Proximity Operations/Navigation

- Crew workstation for:
  - Navigation
  - Plan and execute rotation and translation of entire stack
  - Proximity operations at destination
- Connectivity to other elements in stack
  - Distributed sensor data
  - Command path



Provide Mission Specific On-board Research (text)

Introduction. As one element of a deep space research vessel, the transit habitat will likely be configured to accommodate one or more types of scientific research. Mission-specific research could be associated with: the mission destination (before, during, and after the encounter), the environment through which the habitat is traveling, remote observations from the unique location of the habitat during transit, and observation of the crew as test subjects being exposed to this environment for these durations. Some examples include:

- Destination-specific research: long range and synoptic observations of the destination could be conducted before the encounter; these remote observations could continue in addition to direct observations by the crew on EVA or in the SEV; and, finally, on return to Earth preliminary examination of sensor data and gathered samples could be conducted by the crew.
- As this vehicle stack travels to and from the mission destination it will be traveling through different portions of the Solar System's interplanetary environment. This provides an opportunity for on-board sensors, and the crew itself, to make observations concurrent with similar observations made from Earth to help understand the 2D/3D structure and time-varying dynamics of the Solar System's interplanetary environment.
- In addition to observing the environment through which they are traveling, the out bound and return transits provide the crew with the opportunity to observe other Solar System objects as well as objects outside of the Solar System. One possibility is for concurrent observation (with similar sensors on Earth) of different hemispheres of the Sun or other planets. Another possibility is to shape the outbound and return trajectories to allow for fly-by's and remote observation of small bodies (asteroids or comets) that are not part of the primary mission
- Finally the crew themselves will be traveling to remote, planetary surfaces for extended duration, which will be unlike any other human spaceflight mission to date. As such detailed observations of the crew will help characterize the physiological, neurobehavioral and psychosocial adaptation to this environment and, in so doing, help improve habitat and mission design for future crews.

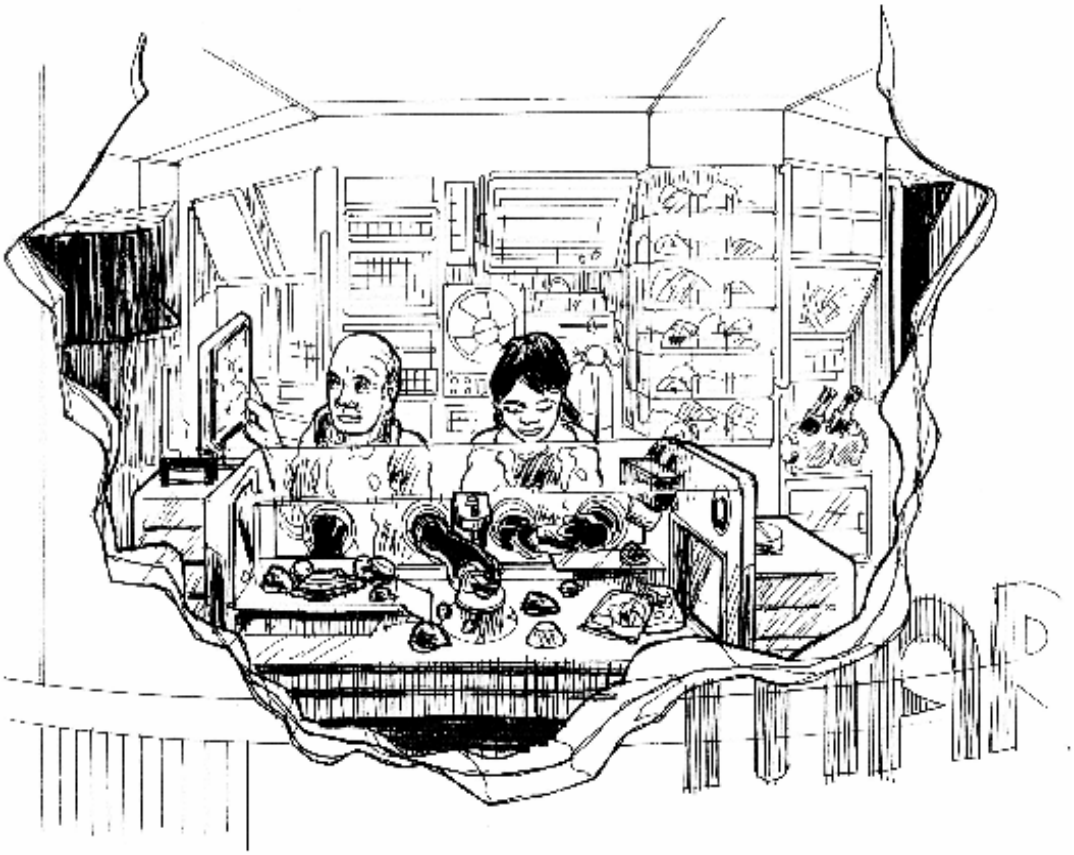
Provide Mission Specific On-board Research (text)
continued

Crew Activities. Evidence has shown that a salient aspect of long duration missions is ensuring meaningful work is available to each individual crew member; as a result, pre-flight, each crew member should identify their individual development plan, which outlines what constitutes meaningful work specifically for that individual. For some crewmembers, this may consist of heading up their own research objectives. The crew will be actively engaged in several aspects of each of the types of research just discussed. First, depending on the experimental apparatus and protocol are set up, the crew will be actively operating the experiment hardware or at least monitoring its operation while the experiment is underway. Before the experiment begins, the crew may be asked to set up or deploy some portion of the experiment hardware and ensure that it is functioning properly. This may include calibrating sensors. At the conclusion of the experiment, the crew may be asked to stow some portion of the experiment hardware and/or any physical samples collected during the experiment. At any point in the mission the crew may be tasked with conducting an analysis of some portion of the collected data or samples. Sample analysis may be required due to the volatility or perishable nature of the sample or due to the limited volume or mass available for returned samples.

Habitat Design Impacts. Until a specific mission, with associated research objectives, is defined it is not possible to specify the detailed habitat requirements to support research. However constraints or not-to-exceed limits on habitat resources (volume, power, data, etc.) may be defined a priori. Once a mission-specific suite of experiments has been selected, some portion of these experiments are likely to use externally mounted sensors and also likely to be steerable. Both sensors and humans will have unobstructed field of view (FOV) requirements that will result in habitat configuration constraints and trade-offs for other external systems (e.g., solar arrays, radiators, communication arrays, etc.). It may be that the habitat design will specify certain unobstructed FOV areas based on the best available estimate of general FOV requirements and mission-specific experiments will be required to work within these areas.

Provide Mission Specific On-board Research

- Research opportunities during transit
  - Destination-specific investigations
  - Observation of other solar system bodies (including NEAs during flybys)
  - Observation of the dynamic local environment
  - Physiological, neurobehavioral and psychosocial observations of the crew
- Dedicated volume, external FOV, and other resources required



Provide Control of External Devices (text)

Introduction. For the types of missions assumed to be supported by this habitat there are two general categories of "external devices" that could require control from within the habitat: devices permanently attached to the habitat and independent robots operating either in free space or on the surface of a planet or other small body. The permanently attached devices are typically one or more mechanical arms using a variety of end effectors (likely to be interchangeable). These arms are assumed to be part of the habitat capabilities when no smaller, independent SEV (or its functional equivalent) is included as one of the elements in the vehicle stack sent to explore a NEA or Phobos/Deimos. These arms could be used to interact directly with the NEA or Phobos/Deimos or they could be used to support an EVA astronaut that is interacting with these bodies. Independent robots could be part of a NEA mission but are more often discussed in association with Mars orbital missions, specifically as robots on the surface of Mars that are controlled by astronaut crews in orbit. In either case a workstation will be required on-board the habitat from which one or more crew members will direct these devices.

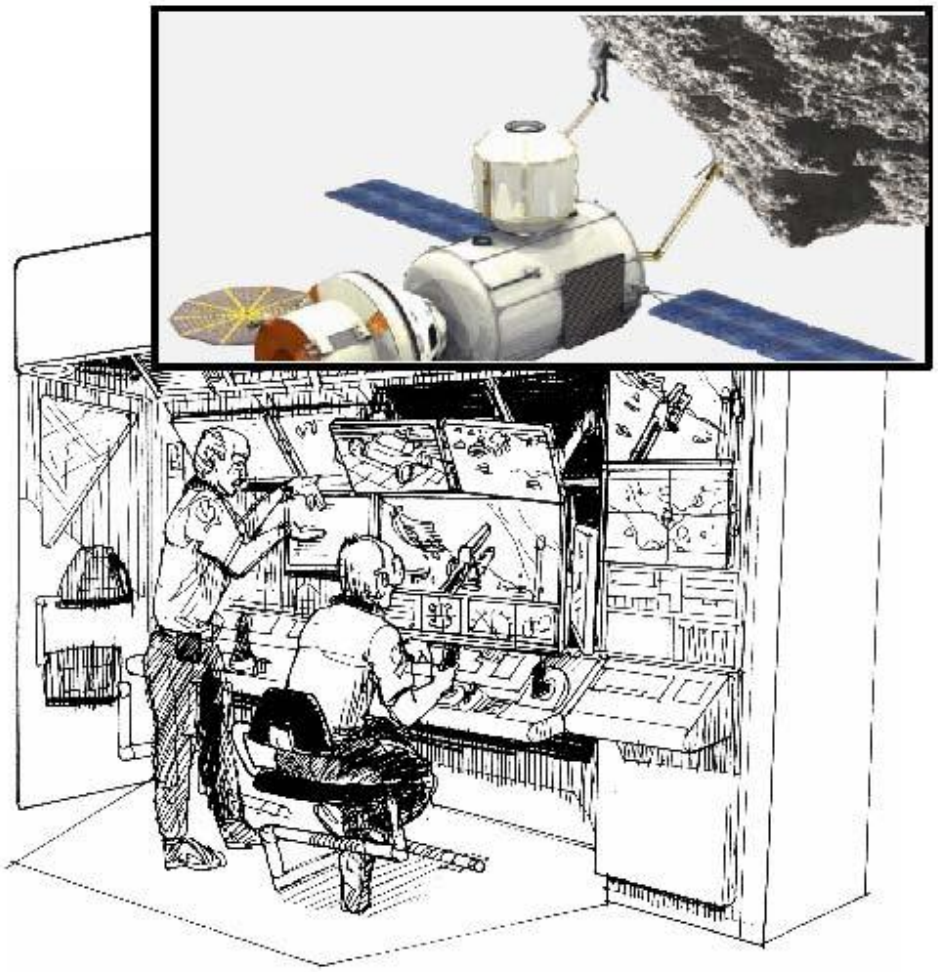
Crew Activities. During those phases of a mission when these external devices are being controlled by the crew, this activity will be a part of the daily assigned tasks for the crew. This implies that the crew will unstow workstation components (as required) prior to first usage and verify that all components are working properly. Assigned crew members will then activate and shut down the workstation on a periodic basis while the external devices are under active control of the habitat crew. Once the active phase of the mission has been completed and the return transit begins, the crew will stow workstation components.

Habitat Design Impacts. Use of attached devices or teleoperation of remote robots is likely to be a relatively small portion of the total mission duration, meaning that access to this workstation may not be required during the outbound and return transit phases of the mission. However during the mission phases at the destination, this workstation is likely to be in constant use. If this workstation is used to control attached manipulators then multiple views of the work area are likely to be required. This could include windows with line of sight viewing of the reach envelop of the mechanical arms.

Teleoperation is currently assumed to be an enhancing feature to speed up the activity of the robot and thus improve the effectiveness of both the crew and the robot. However, this conjecture needs to be tested through appropriate tests and simulations.

Provide Control of External Devices

- Two types of external devices considered possible
  - Attached devices (e.g., mechanical arms/manipulators
  - Free-flying robots
- Workstation for crew
  - Inputs from multiple cameras and other sensors
  - Possible direct visual observation for crew



Provide EVA Egress and Ingress

Introduction. The ability for the crew to repair external vehicle components and systems during a long duration flight is essential to mission success. During the weeks and months of transit to and from a NEA or Mars, the crew may indeed be required to leave the comfort of the pressurized vehicle to perform an external repair. This was seen during the early days of Skylab in the mid 1970's when the crew freed a stuck solar panel shortly after launch. On several occasions on ISS, repairs via EVA were required to bring critical systems to full functionality in order to meet mission objectives.

Assuming both DSH and MMSEV are part of the vehicle stack, MMSEV will serve as the nominal EVA platform. If needed, EVAs can be conducted from DSH, but primarily DSH will be used for suit maintenance and repair as well as for swapping out suits on MMSEV.

Crew activities. The first activity the crew will perform regarding EVA readiness will be to place the EVA suits into proper configuration following launch. If the suits are launched in MMSEV, the crew will unpack and don the suits inside MMSEV, isolate and depressurize MMSEV, and egress via MMSEV's side hatch. After translating the short distance from the side hatch to the aft bulkhead, the crew will install the suits on the MMSEV suitports and ingress MMSEV by doffing the suits via the backpack rear hatches.

If the space suits are launched in DSH, the crew has two options for transferring the suits to MMSEV. First, the crew can transfer the suits in the shirtsleeve environment of the vehicle stack from DSH to MMSEV, go EVA from MMSEV, then install the suits on MMSEV's suitport in the same manner as described above. Alternatively, the crew can egress DSH, translate to the MMSEV aft bulkhead, and install the suits on the MMSEV suit ports.

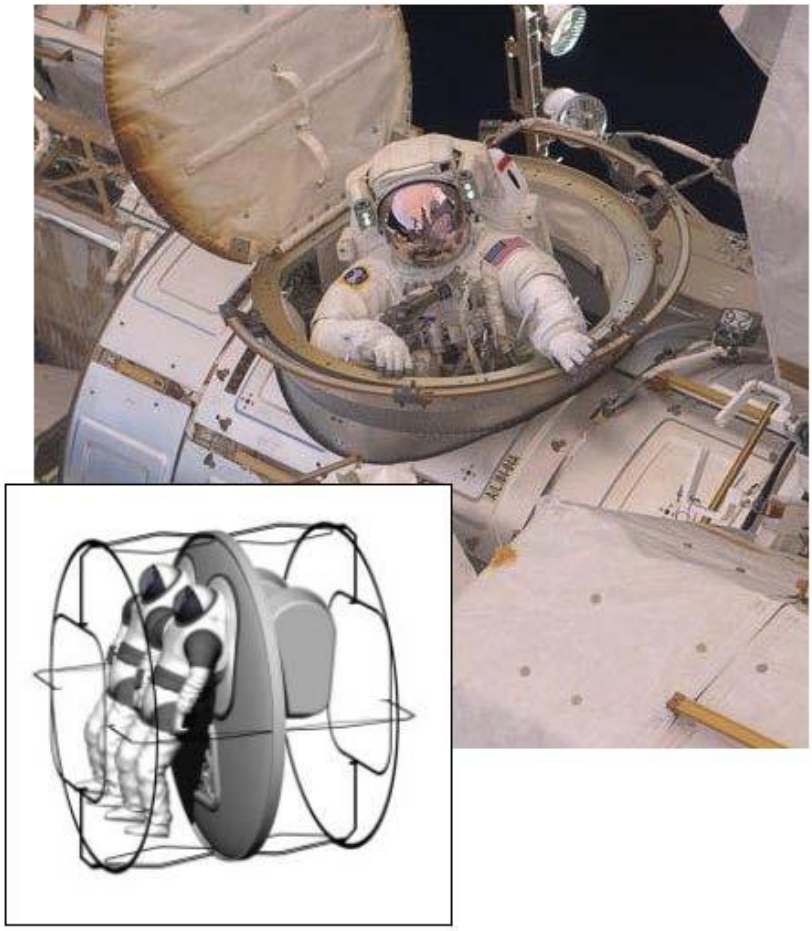
When suit maintenance or repair is required, the crew will transfer the suits from MMSEV to DSH by going EVA from the MMSEV suit port, translate to DSH, and ingress.

Habitat Design Impacts. Several factors should be taken into account to satisfy the requirements for EVA capability. A design that allows for rapid egress/ingress, containment of dust and other foreign contaminants, minimal loss of cabin air upon depressurization, and shirt sleeve maintenance and logistics should be considered.

Several options are possible for the vehicle architecture from which the crew will egress for EVA. DSH may employ a single chamber airlock - NASA's traditional approach. Isolation via hatch closure, depressurization, and crew egress will be performed in a similar manner as on Shuttle and ISS. Another option, is the suitport as is used on MMSEV. Suitports allow for rapid egress and ingress with very little loss of air during depressurization prior to egress. Alternatively, DSH may use a single- or dual-chamber suitlock. This will provide a volume for suit maintenance activities while keeping dust from a planetary surface or NEA out of DSH's main habitable volume.

Provide EVA Egress and Ingress

- EVA likely for destination exploration
- EVA for contingencies possible but infrequent
- Options still being considered
    - Airlock
    - Suitport
    - Egress/ingress via
        - Habitat
        - Attached vehicle (e.g., SEV)



Provide External Visibility (text)

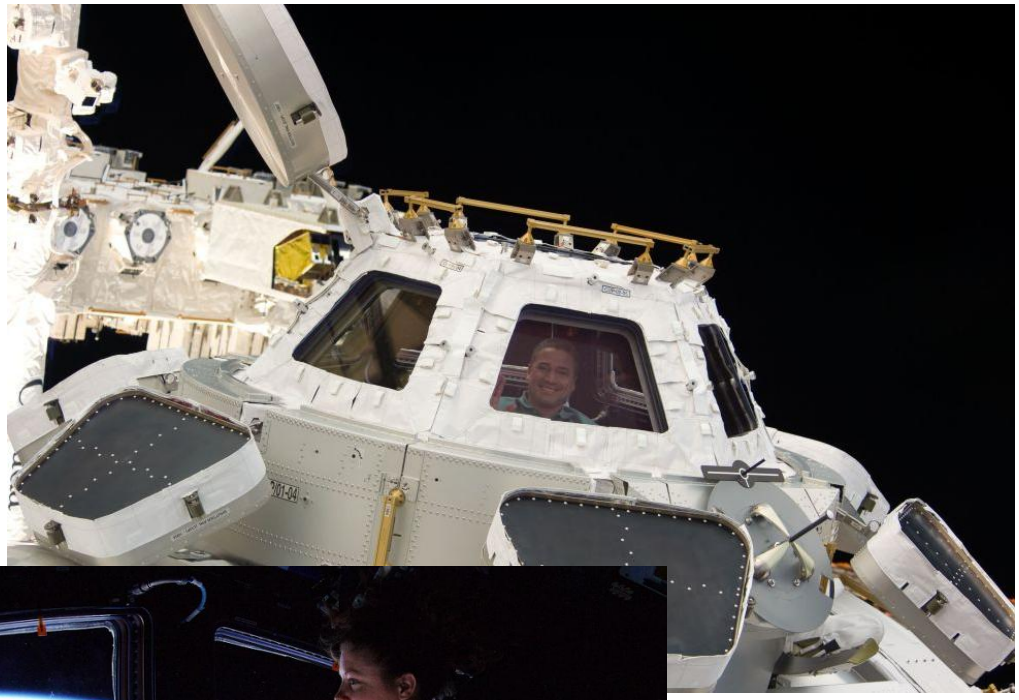
Introduction. External viewing from the Deep Space Habitat and/or other attached elements (e.g., the SEV) will be needed to provide the crew working from inside the habitat with a view of several different types of external activities. Examples associated with vehicle operations include: Extra Vehicular Activities (EVAs), approaching or departing elements during docking operations, and general observation of spacecraft conditions. Additionally, external viewing will allow crew observations of the destination target itself, allowing the recording of images/videos, scientific observations, public relations opportunities, etc. While at the destination target, line of sight viewing from command and control workstations will be needed by the crew to assist in the operation of remote manipulator systems (if included) during telerobotic operations and EVAs.

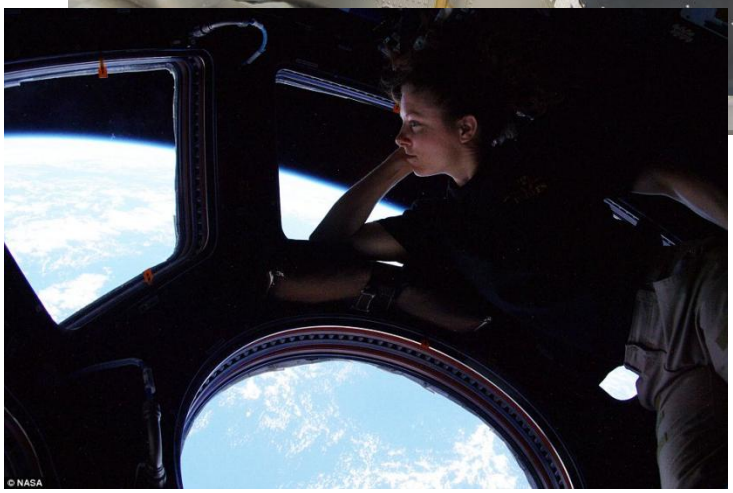
Crew Activities. If there are crew members on board the habitat during rendezvous and docking events, then these crew members will likely perform the role of "traffic control" for the approaching/departing vehicle(s). This implies that the crew has line of site visibility (either directly or via cameras) of the approaching or departing vehicles as well as access to other sensor data important for the docking/undocking event. During deep space mission transit periods when EVA support is not required (an EVA is likely only in a contingency situation), external viewing may not be as critical to completing mission objectives, but could still offer significant psychological benefits to the crew. As the vehicle approaches or departs the destination target, the crew will be interested in a synoptic view of the target. In the case of NEA missions, the crew will be interested in observing any smaller objects located in the vicinity of the target NEA. Observing these objects, if they exist, will be of both scientific interest as well as for situational awareness as the crew maneuvers the vehicle stack into close proximity with the primary NEA. While in the vicinity of the target, external viewing will also be important for both scientific observations as well as psychological benefits to the crew.

Habitat Design Impacts. External viewing can be accomplished directly through viewing portals and windows, through external cameras coupled with internal monitors, and via a telescope (including potential use of non-visible wavelengths and 3-D imaging). A combination of these approaches is likely. External cameras should not significantly impact the design of the habitat; these devices can be located at points where a particular view is needed or desired. Viewing portals and widows will require unobstructed access from inside the habitat and external appendages must be located so as not to obstruct the desired viewing angle from this portal or window.

Provide External Visibility

- External visibility needed for:
  - EVAs
  - Approaching or departing elements during docking operations
  - General observation of spacecraft conditions
  - Observations of the destination target
  - Teleoperations
- Function could be indirect (e.g., cameras) or direct (view ports/windows)





Provide Crew Health/Medical Support (text)

Introduction . The mission profiles included as elements of this ConOps are primarily ones of exploration. The crew will be actively involved with a variety of tasks, both internal and external to their pressurized habitat, designed to gain a better understand of these destinations and the solar system environment. Keeping the crew healthy and productive in this environment performing these tasks for mission durations varying in length from 18 to 35 months will undoubtedly involve some measure of medical care. Additionally, for long duration missions such as the NEA mission used in this study, the crew will not be able to make an early return to Earth in the unlikely event of a significant crew health issue. Medical care on these missions will be a continuum of prevention, countermeasures, and clinical treatment.

Crew Activities. Due to remoteness of crew and the associated communication time-lag for immediate support from Earth, it is assume that one crewmember is a trained physician. One aspect of "prevention" for crew health and medical support will require that crew members periodically (i.e., daily or weekly (TBR)) undergo a routine physical and psychological examinations by the physician.

Due to the limited payload capabilities for these long duration missions, the ability to deal with unforeseen illness and injury is very limited and, therefore, effective prevention and countermeasures are essential. However, prevention and countermeasures will not completely eliminate the possibility of events requiring the need for clinical care. With no opportunity to learn from other's experience (the first crews on these missions will by definition be the first humans to experience these environments) the medical equipment and crew medical training will be kept basic and general purpose to deal with a wide range of potential events. It is therefore assumed that entire crew is trained in first aid and routinely drills for emergencies associated with the illnesses or trauma described below. It is also assumed that a database of medical procedures with virtual training should be provided as increased crew autonomy is required.

Habitat Design Impacts. The facilities to care for the crew's medical needs will be concentrated in a single, dedicated location in the habitat, but with provisions for emergency care (e.g., first aid kits and telemetry stations) distributed throughout the rest of the habitat and with other systems if EVAs are implemented en route. The central medical facility should allow privacy for medical consultations and examinations. It should also contain most (all?) of the medical consumables and mass intensive medical equipment for these missions. These facilities should be able to deal with both routine and emergent medical problems, which can be reasonably expected given the mission profile (up to and including surgical procedures). These problems include :

Provide Crew Health/Medical Support (text)
continued

- Decompression sickness (associated with EVA)
- Radiation sickness
- Bone fractures
- Trauma
- Deconditioning
- Stress, depression, and other neurobehavioral outcomes
- Infection
- Dust and toxic exposures

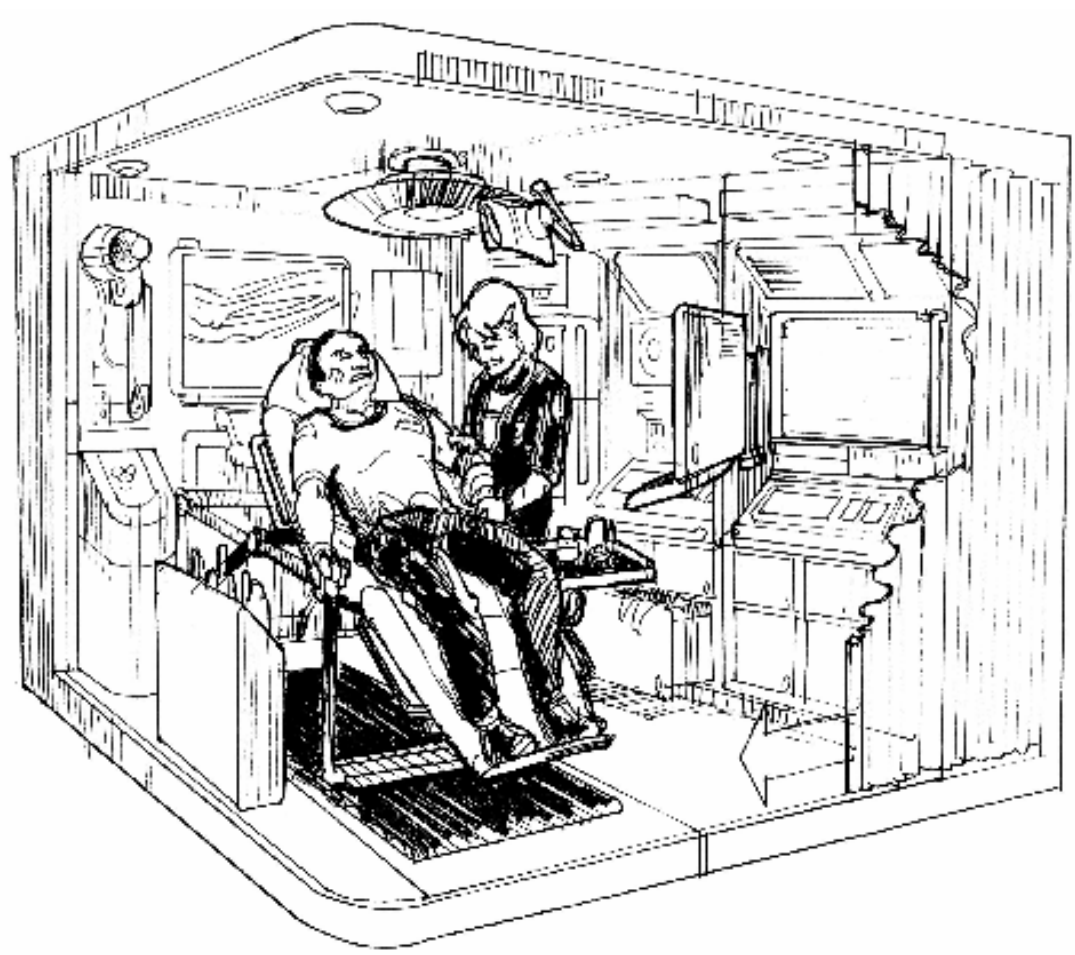
Crew recovery from serious illness or trauma is assumed to take place in their (dedicated) crew quarters where sensors will be capable of monitoring their condition.

Medical data for each crew routinely gathered and stored (e.g., vital signs, physical samples (TBR)). A decision must be made regarding whether these samples are to be stored for the duration of the mission or analyzed on board (implying analysis equipment).

Additional discussion of crew health and medical issues leading to this summary, along with proposed approaches to address these issues, can be found in Appendix A.

Provide Crew Health/Medical Support

- Single dedicated facility for primary functions
  - Privacy for consultations and examinations
  - Medical procedures (including surgery)
  - Biological sample analysis (TBR)
- Distributed equipment for first aid
- Crew recovery in crew quarters
- Physical stowage
  - Medical consumables
  - Collected biological samples (TBR)
- Electronic storage
  - Crew medical records
  - Procedures and tutorials



Provide Crew Exercise (text)

Introduction Astronauts en route to distant planetary surfaces will need to perform a variety of physical tasks (for example extravehicular activities, habitat assembly, etc.) to accomplish their missions. However, they may be physically unable to do these tasks if some of the health effects of space flight are not mitigated. Early medical data from International Space Station (ISS) astronauts have revealed adverse health outcomes after extended periods of micro-gravity exposure: loss of bone density, decreased muscle strength and endurance, sensory-motor function (i.e. balance), and reductions in aerobic capacity. These deconditioning effects, caused by the absence of Earth's gravity, over time can impair astronauts' performance or increase their risk of injury. Exercise will play an essential role in lowering the risks from these effects, increasing the probability of mission success for objectives when operating near a Near Earth Asteroid or landing on the Moon or Mars, and ensuring optimal recovery on return to Earth.

Crew Activities Each crew member will need to engage in daily protocols of exercise , including both aerobic and resistance exercise countermeasures. During current spaceflight, resistance exercise is completed by securing the astronaut to a strength device that imparts load on the body. Aerobic exercise is accomplished through daily use of the treadmill , where walking, running, and deep knee bends are completed. The treadmill is used to maintain bone mass, cardiovascular fitness, and muscle endurance. Cycle ergometer exercise also provides general aerobic and cardiovascular conditioning as well as improved muscular endurance. Evidence further indicates that exercise is an effective countermeasure that mitigates stress and supports behavioral health and well-being, serving another essential function over long duration missions.

Current exercise protocols require astronauts on six month ISS missions exercise two hours a day, every day. Time will also need to be allotted for exercise hardware maintenance and repair; semi-autonomous medical and physiological testing through current technologies (e.g. Ultrasound) and potential future technologies (e.g. MRI), metabolic gas analysis, strength and power testing, and blood and urine collection and lab analysis. Each crew member will have a scheduled time in the day for exercise, as opposed to a block exercise time for the whole crew, as there will be insufficient amounts of equipment to allow the entire crew to exercise simultaneously.

Habitat Design Impacts The next generation of exercise countermeasures being developed will play a key role in the resolution of deleterious effects of space exploration by building on the knowledge gained from previous space flight exercise equipment and protocols. These countermeasures are being developed with designers of exploration vehicles and habitats to determine the requirements that an exercise device must meet for use in distant planetary environments and in new transit vehicles. It is known that a variety of equipment should be developed, to maintain the whole body and, in part, to help minimize boredom.

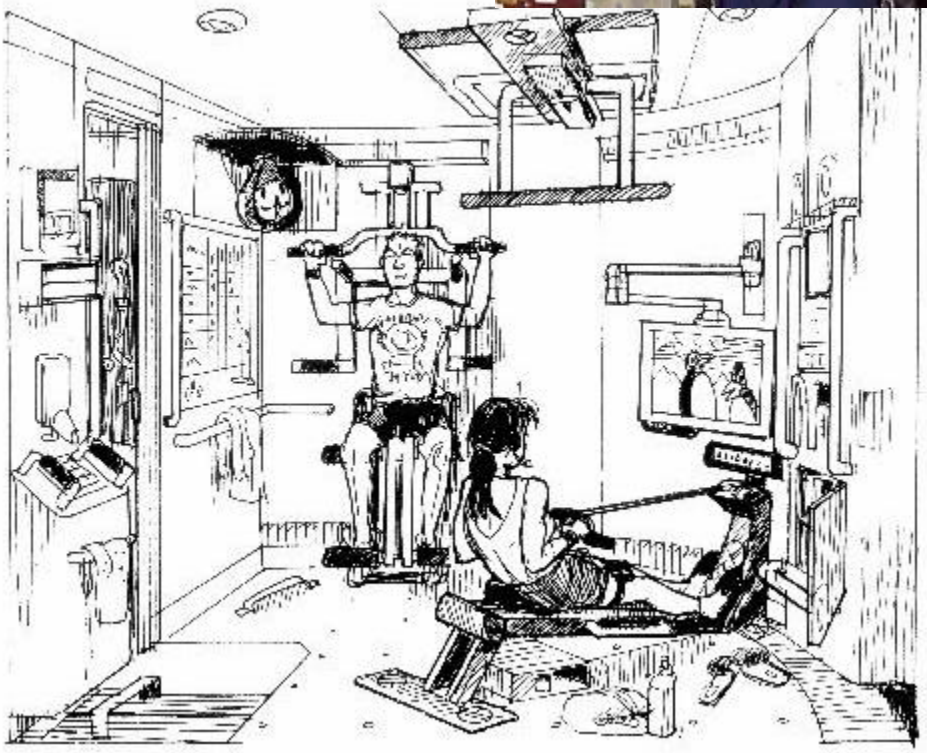
Provide Crew Exercise (text-continued)

To further enhance the utility of exercise as a behavioral countermeasure, equipment should be coupled with visual displays on or near equipment that show video scenes to simulate a Earth scenes, such as a run in the park or a bike ride through the mountains. Crew members could also listen to music using headphones. Displays could also show statistics about a crew member's performance such as distance, average speed, or time elapsed. Simulating olfactory senses (via inducing smells of the forest) could also add to this experience.

The location of exercise equipment within the habitat is another important factor. When in use, the exercise equipment should be mounted such that vibration loads are isolated from the remainder of the habitat. The gym area needs to have good air circulation. This circulation will cool crew members during their workout, as well as cool and dehumidify the area after its use. The collection of equipment needs to stay out of the way of general traffic, which may prompt the design of a dedicated fitness area. Another option is to stow all equipment out of sight, and only bring it out for periods of use. The problem with this is the time necessary for setting up the equipment, as well as finding suitable locations for storage and use. Efforts are needed to ensure minimal volume and time needed for storing and setting up the equipment.

Provide Crew Exercise

- Daily exercise for all crew
  - Two hours/day
  - Aerobic and resistance
- Periodic medical exams
- Habitat impacts
  - Vibration isolation
  - Good air circulation
  - Minimize interference with traffic patterns



Off-Duty and Recreation (text)

Introduction. This section describes a number of activities considered important for the wellbeing of the crew on missions of the length being considered here. These activities are not aligned with one specific location or function within the habitat but cut across several other locations and functions described in other sections; these will be noted accordingly.

Past experience with long-duration missions on Earth and the growing experience with extended missions in space indicate that the crew in transit to a remote destination will likely encounter two extremes in activity schedules: periods of time with too much to do and times with too little to do. Providing adequate recreation options for the entire crew therefore will help to minimize monotony and provide means through which to wind-down from high tempo activity, maintain behavioral health and well being, enhance performance, and promote cohesion amongst the crew. It is important to protect wind-down and off-duty times as much as possible even in conditions of high workload, as wind-down becomes increasingly important for mitigating stress and facilitating sleep (Whitmire et al., 2012). Stuster (2010) conducted a content analysis of journals written by astronauts during ISS expeditions. This analysis resulted in a rank-ordering of behavioral issues in terms of importance, based on the premise that the more salient a topic is, the more frequently it will be discussed. Findings indicate that "Work" was the most frequently discussed category and that "Recreation/Leisure" was the fifth most frequently discussed category. Evidence also indicates that leisure activities provide a coping mechanism for stress (Iwasaki and Schneider, 2003). Research examining the effects of "off-duty recovery" shows that social activity and recreation predicts well being and performance (Fritz & Sonnentag, 2006; Joudrey, 2009). Given that future long duration missions will be increasingly stressful (by virtue of the isolation, confinement, and time away from home) defining off-duty and recreation activities should play a prominent role in mission preparation.

Crew Activities. ISS crewmembers have expressed an appreciation for meaningful work conducted in flight (Stuster, 2010). Accommodations should be made, in both time and resources, to allow each crewmember to engage in creative mission-related work throughout the transit phases that align with their personal interests. Off-duty time (or, during scheduled work times) could also be devoted towards research and experiments that are meaningful for that individual crew member. For example, on the return portion of the trip the crewmember could draft the results of their experiments and their experiences at the destination, in preparation for a scientific publication.

There are several examples of group and individual entertainment and leisure activities likely to be part of the crew's routine. Several of group activities including meals, movie watching, external viewing, are discussed in other sections of this report. Individual free time activities may be more common than group off-duty activities. Additional details of these individual activities are discussed in the "Crew Accommodations" section.

Off-Duty and Recreation (text-continued)

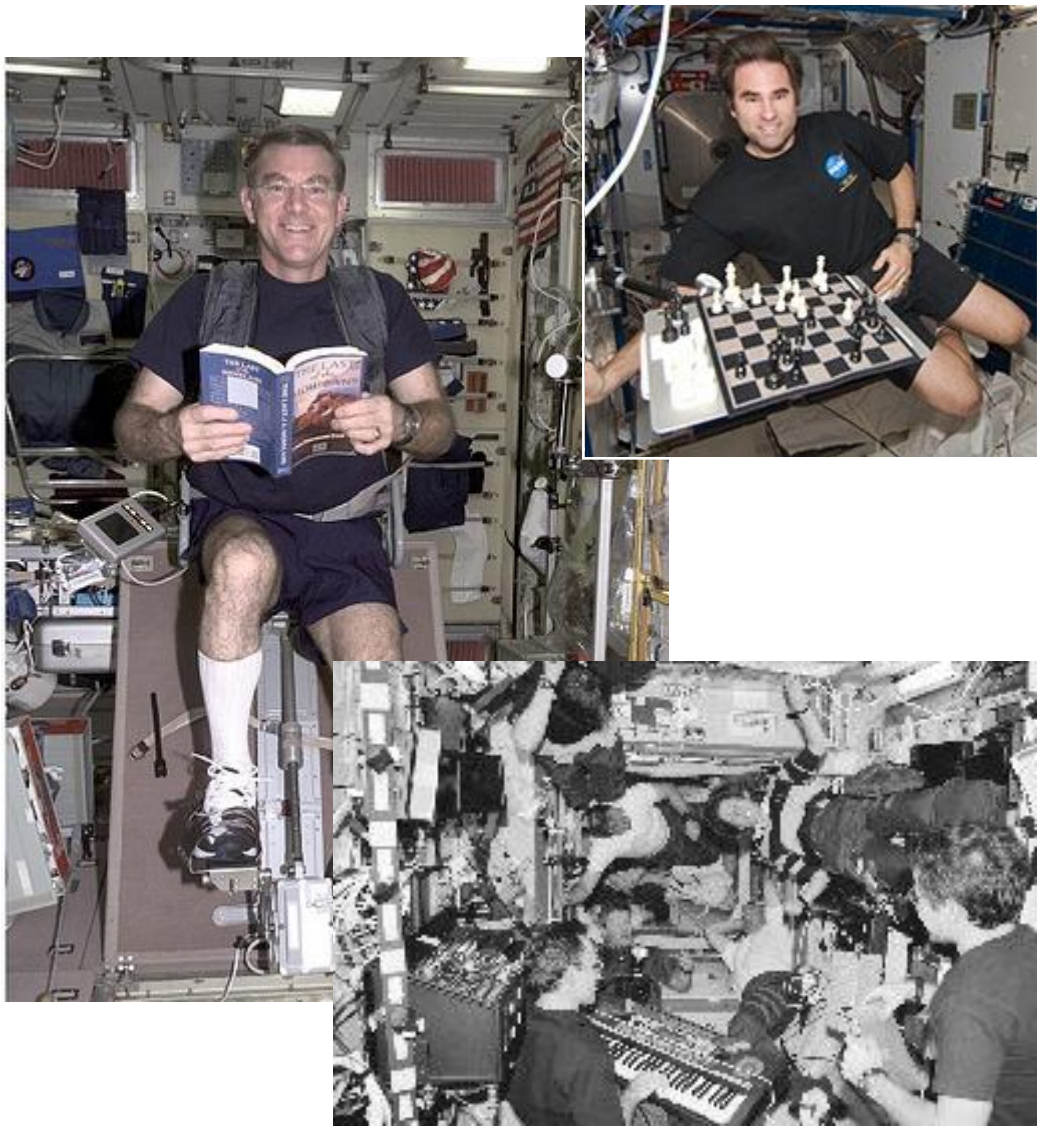
The amount of free time available for the crew and its placement in daily schedules is very important for productivity. Mission and schedule planners, as well as the crew itself, must develop a standard routine that balances free time with work. Also, most experts suggest that the establishment of a regular workweek will help crew members organize their time and stay on schedule. (see "Representative Daily/Weekly/Monthly Crew Time Allocations" section).

Habitat Design Impacts. The entire crew should be able to fit in a room for a group movie night, or an individual should have access to a platform on which to watch a movie or television show. Movies showing large, sweeping landscapes or outdoor scenes (which have been shown to be extremely popular with isolated crews in the past) should be included as these also address connections to home and sensory stimulation. Off-duty activities involving a majority of the crew will most likely take place in the multipurpose gathering area, since it can hold the entire group. Depending on the activity, private crew quarters might also be a place for two or three crew members to enjoy their off duty time. Anyone participating in free time activities must be considerate of noise levels, since not all crew members will be relaxing at the same time.

Data Mining. Determining how to schedule and plan for crewmembers to enjoy over an extended duration mission will provide a challenge for the planners of the Mars surface mission. Scheduling tools that predict optimal performance times based on sleep-wake data, workload, light exposure, etc. are encouraged for informing scheduling decisions. Past isolated missions such as the Skylab missions, Shuttle missions, Life Support System Integration Facility tests, and winters at South Pole bases however provide valuable insight into popular off-duty activities, the most effective scheduling methods, and estimations of off duty time for planners and crew members to make informed decision s in an increasingly autonomous environment.

Off-Duty and Recreation

- “Off-duty recovery” important to maintain crew productivity and individual well-being
- Both individual and group recreation options should be provided



Provide Food Preparation (text)

Introduction. Judging from past experience with orbital missions and comparable ground missions in isolated extreme environment the food preparation capability must be able to accommodate food preparation ranging from individual meals intended to be eaten "on the run" to group meals sized for the entire crew. Meals eaten "on the run" are likely to be common. Meals that are simple and require very little or no preparation will be especially useful in these situations. More elaborate meals will occur when the entire crew eats together. Most isolated crews try to maintain a common, mutually agreeable dinner time, no matter how hectic schedules become. Group meals provide necessary team bonding, as well as desired social interaction and organizational opportunities (Stuster, 1996). Due to the length of the mission being considered for this habitat, utensils that will be used for meal preparation and consumption are assumed to be reusable as opposed to disposable. This will help to conserve both mass and volume. However, this implies that cleaning facilities and supplies will be required to sanitize these utensils to avoid possible health risks to the crew. Each of the different types of meals will require different amounts of time, space and equipment to prepare. Those in the "on the run" category will obviously require the least amount of all of these resources; the evening meals for the entire crew will require the most resources and will define accommodations located in the food preparation area. These evening meals will typically involve heating some portion of the food.

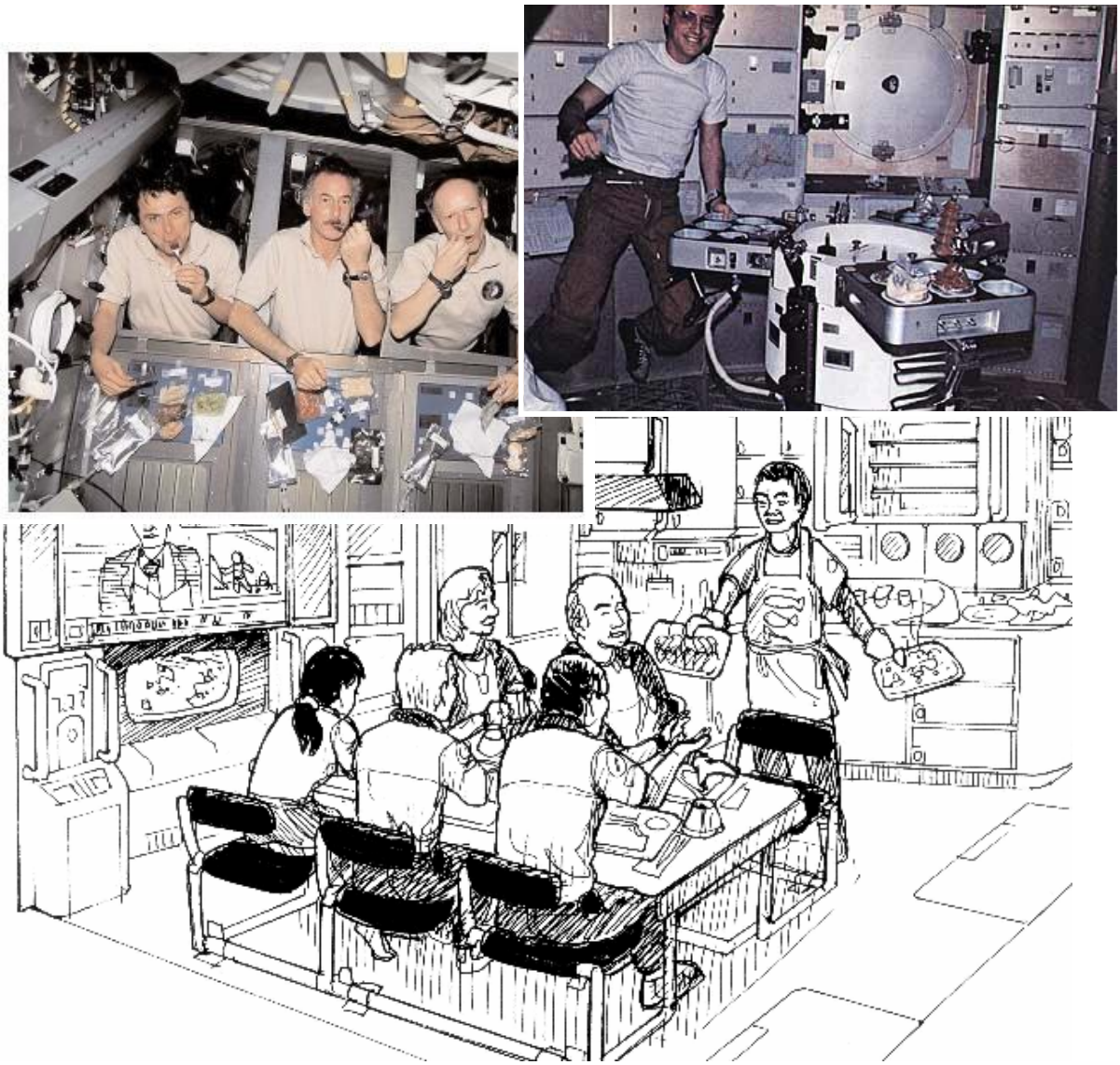
Crew Activities. Crew members should make every effort to plan for one group meal per day. Considering this, the process for one person to prepare dinner for the whole crew should ideally take no more than 30 minutes, except for special occasion meals that might be more elaborate. Responsibility for preparing group meals will rotate among the crew. Preparation times should be much faster for other meals. Each individual will prepare their own meal when crew members choose to eat separately. Each crew member will be responsible for cleaning up their own wastes after each meal. This will include finishing the entire portion of food served, compressing food packages, wiping clean all trays, utensils and food preparation areas used, and storing all equipment and wastes. The whole cleanup process should ideally take only about ten minutes.

Provide Food Preparation (text-continued)

Habitat Design Impacts. The food system must be considered from the beginning of the vehicle design, with implications for power, thermal, ECLS, stowage, and architectural layout. Given that any spacecraft faces thermal extremes on the sides facing the sun and away from the sun, it may be possible to tap into these thermal energies in support of food thermal conditioning. If plant growth is employed, there may need to be accommodations within the vehicle life support subsystem. It is also necessary for the life support subsystem to control the smells generated by the food system, including both preparation and waste. In addition to the space provided for large group meals and other group activities, the wardroom and food preparation areas should provide accommodations for some food storage space (several days to a week), storage for meal preparation as well as cleanup equipment and supplies, a meal preparation area, and facilities to clean the utensils used to prepare and consume meals. One or more devices to heat these meals should be provided in either the food preparation area or the multipurpose meeting space. These devices should be sized to heat food portions ranging in size from those for an individual to those for the entire crew. Food storage space will house food for use in the near future, while long term storage will be handled elsewhere in the habitat. Crew food may come from a variety of sources, including dehydrated, thermostabilized, shelf stable, in-situ grown (e.g. plants), fresh, and frozen/refrigerated. Specific vehicle designs may favor or exclude one or more of these sources. Additionally, one or more of these sources may only be available during limited portions of the mission (e.g. fresh meat available only the first few weeks or fresh fruits and vegetables within weeks of a plant harvesting cycle). One part of the cleanup process that needs major investigation, is the consolidation and storage of food packaging wastes. Dehydrated food packaging for Shuttle and ISS missions typically accounts for 40-50% of the total mass (Vodovotz, 1998). Large amounts of waste from food packaging materials is a problem on Shuttle flights, and will be a much greater obstacle during long duration missions.

Provide Food Preparation

- Prepare group or “on the go” meals
- Elaborate preparation for group meals
- Limit preparation time to 30 minutes
- Limit cleanup to 10 minutes
- Design impacts to ECLS, thermal, power, stowage, and architectural layout



Provide Multipurpose Gathering Space (text)

Introduction. Previous long duration, isolated missions have shown that a space large enough for the entire crew to assemble and interact as a group is a practical necessity as well as being beneficial for individual emotional and crew morale purposes (Stuster, 1996). This space is sometimes referred to as a wardroom, but because of its size and possibly central location, this space will be used for a range of activities that expand beyond the wardroom's traditional eating, relaxing, and socializing uses as discussed in the previous two sections.

Crew Activities. The previous two sections – food preparation and off-duty/recreation – are activities that could be undertaken individually or as a group. It is likely that one of the crew's daily meals will involve the entire crew. This has proven to be a useful means to build and maintain crew cohesiveness, particularly during isolated missions. Group entertainment/recreation events, such as a movie night, also help to build and maintain both individual and crew morale during the mission. In addition to these "traditional" uses for a large gathering space, the missions under consideration for this habitat are also likely to require a space where the crew can gather to plan the next day or week or extended period of work. As these work plans are being carried out, a space is likely to be needed for two or more of the crew to work on some aspects of their assigned tasks. PAO events will also be a frequent event for the types of missions envisioned for this habitat, pointing to the need for a space where some or all of the crew can gather to participate in this event. Although not driven by a particular requirement, having a space such as this becomes a logical assembly point in case of an emergency.

Habitat Design Impacts. Due to the wide range of uses for this space, it should be easily accessible from other sections of the habitat. Because it is likely to be used for both work tasks and off-duty activities, it is also likely that this space will be centrally located within the habitat. This could also be used advantageously as a buffer space between "work space" and "quiet space" (i.e., crew quarters). This space should be near the food preparation area and should include a table (or the micro-gravity equivalent) large enough to accommodate the entire crew. If there are physical windows in this habitat, this space is a location where one of them should be placed. A large, wall-mounted electronic display in this area would be useful for showing external camera view (particularly if there is not window), for movies, and for work-related tasks. If personal laptops (or their functional equivalents) are used by the crew, then this space must have power and data accessible by these devices.

Provide Multipurpose Gathering Space

- A single space needed to hold entire crew
- Activities in this space include:
  - Meals
  - Recreation (e.g., movie night)
  - Meetings
  - PAO events
- Potential buffer between “work space” and “quiet space”
- Locate near food preparation space
- Large, wall mounted display to support these activities

Provide Crew Personal Accommodations (text)

Introduction. To remain productive and proficient during a long duration mission crew members will need their habitat to possess certain characteristics, one of the most meaningful of which are facilities and equipment for ample sleep, privacy, and personal space. A habitat must contain crew accommodations and associated supplies to suitably accomplish these aspects of crew support. Mission planners and habitat designers frequently overlooked or dismissed the importance of these qualities and facilities in the past, to the later dismay of most crew members involved. The crew accommodations should be designed to provide both privacy for individual crew members and a means of mutual psychological and emotional support during the long mission. These accommodations should provide a place to sleep, relax, have private conversations with family back home, or work in private – simply closing a door or raising a partition should be sufficient to accomplish this, so long as other crew members recognize and respect these simple signs. However, it is important the door and/or partition provide not just visual privacy, but also auditory and olfactory privacy. If a crew member is excessively withdrawing into his or her room (a potential indication of depression; Stuster, 1996), others members of the crew should properly identify and address this potential problem, while recognizing that some withdrawal is normal.

Crew Activities. This habitat will be home for these crews for periods of many months or years. The duration of these missions is essentially equivalent to the crew members moving from their homes to this habitat. The crew will need to respect the personal space – physical, aural, visual, etc. – of individual members. For example, schedule "quiet hours" before major mission milestones to ensure the crew has adequate sleep and preparation time. But the crew also needs to provide mutual psychological and emotional support during these long missions and must be aware of the condition of other crew members, particular with respect to individual, personal accommodations.

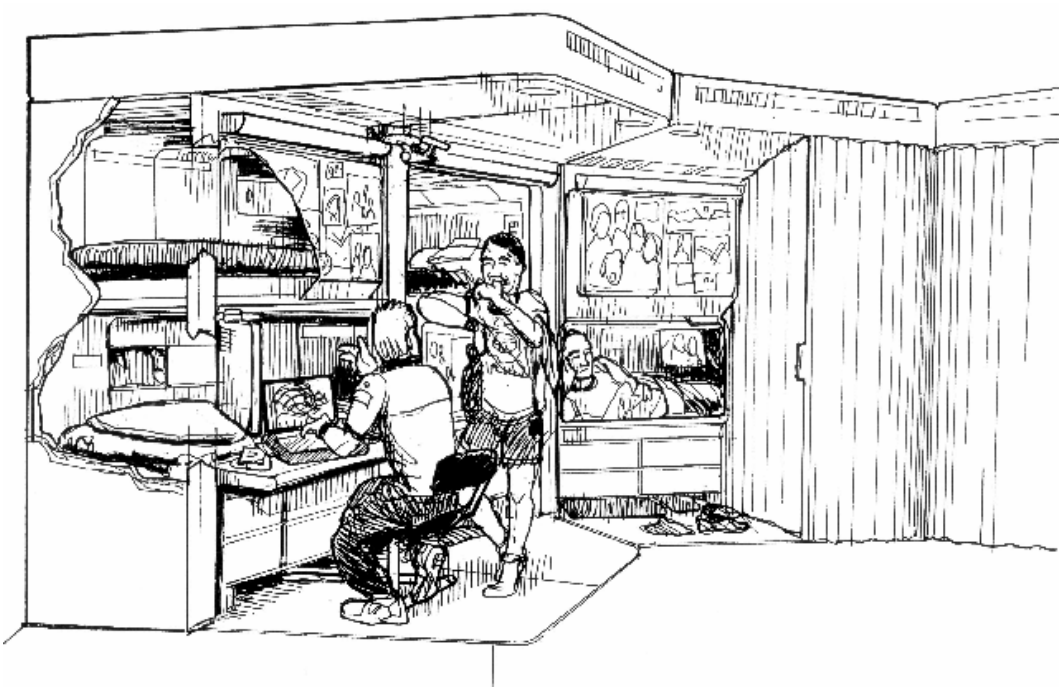
Habitat Design Impacts. Several design factors should be taken into account to satisfy the needs for quiet, privacy, and personal space. An important factor for good quality sleep is soundproofing or noise reduction for the walls. Skylab and ISS crew members complained that it was hard to sleep with only thin walls (or no walls) separating them from noisy equipment. Many other isolated crews on Earth had similar complaints. Positioning the crew quarters near the hygiene facilities will allow for easier access during the night, which is desirable. However, the hygiene facilities may also contain some loud equipment forcing habitat designers to include some noise reduction there as well. Privacy can be provided by breaking visual sight lines with other areas of the habitat. This could involve doors or partitions to separate personal space. Partitions will allow crew members to have privacy when the divider is up, or obtain more space if taken away. This variation in configurations is desirable for several reasons. Crew members will need a place to dress or think in private, and experts suggest that sleeping may be easier if crew members have their own rooms. However, additional space will help crew members avoid feeling claustrophobic that can be experienced by people in cramped remote habitats.

Provide Crew Personal Accommodations (text)
continued

Partitions should also allow crew members a limited ability to shape their rooms according to their own preferences. There should also be storage available for personal belongings inside the room that could be used for clothing, books, music, video recordings, supplies, or other personal items. Other habitat stowage should not be located in these rooms if at all possible. A flexible and automated light system that mimics the earth-day night cycle should be incorporated into crew quarters (and the rest of the habitat) to help maintain biological rhythms and promote optimal sleep-wake times. Individual lighting with several settings will be desirable so that crew members can adjust their personal space to their liking. Individual temperature control in these spaces is also a highly desirable feature mentioned by Space Shuttle and ISS crews for crew quarters. Crew members may conduct work in these spaces, particularly hobbies or independent research. This may require additional power, data, or thermal interfaces.

Provide Crew Personal Accommodations

- “Home” to crew during long duration mission
- Provide privacy and emotional/psychological support
- Allow crew members to reconfigure crew quarters based on their preferences
- Stowage in rooms should be limited to personal belongings



Provide Crew Hygiene (text)

Introduction. The human body must be understood as a system with input, output, and maintenance needs. Those needs not only include the physical facilities for accommodating the inputs and outputs, but also include a psychological factor as well, in the form of privacy, comfort, and ease of use. Even for missions as short as a few hours, crew members will need to have access to some sort of hygiene function. For longer duration missions hygiene becomes even more critical. Activities that relate to hygiene will allow crew members to feel healthy, clean, alert, and productive in their participation in critical mission operations. Hygiene functions will require partitioned volumes for privacy, to allow crew members to dress, undress, clean themselves, and perform other functions in the confined environment of the habitat without the stress of worrying whether those activities are transparent to other crew members. This is particularly important for crews with mixed gender, though all crew members deserve privacy regardless of crew gender mix or numbers. Crew hygiene can also sometimes include maintaining crew clothing and laundry, which will be covered in the General Housekeeping section.

Crew Activities. For very short durations (such as from a few hours), crew members should at least have access to some sort of personal cleaning, such as for hand washing, wiping, etc, and should also have the capacity to perform small hygiene functions such as relieve nasal congestion (using wipes, etc), and more complex functions should the need arise, such as urination. For longer duration missions, hygiene functions for full toilet uses should also be accommodated. In longer duration missions, crew members should have access to facilities for cleaning the entire body, brushing teeth, and taking care of grooming issues such as shaving, etc.

Habitat Design Impacts. Very short duration missions of just a few hours may only need a small dedicated station where wipes and disposal are available. Though urgent toilet needs have been met in the past by absorbent materials worn inside environmental suits, etc, it is recommended that, even on short duration missions, part of the habitation volume be dedicated, partitioned, or “borrowed” for such needs, allowing for privacy. Otherwise, the crew’s psychological health may be affected, and stress thereby influence that person’s productivity on critical mission operations. Longer duration missions need to have dedicated volume for toilet functions that provide for odor and sound control, and enough volume to allow the crew member to dress and undress as needed. Likewise, hygiene functions for cleaning the body must also allow enough volume to allow the crew member to dress and undress as needed, and must also provide for moisture control even if the cleaning activity uses only moist towels or wipes. In the hygiene facilities, the crew would need to have access to water, with moisture control, treatment, recycle, or disposal available nearby. Workstations and hardware should have access for maintenance and upgrade, preferably interfacing with modular infrastructure elements such as potable water, waste water, power, command & control, and various gas supplies. In summary, the following functions should be accommodated:

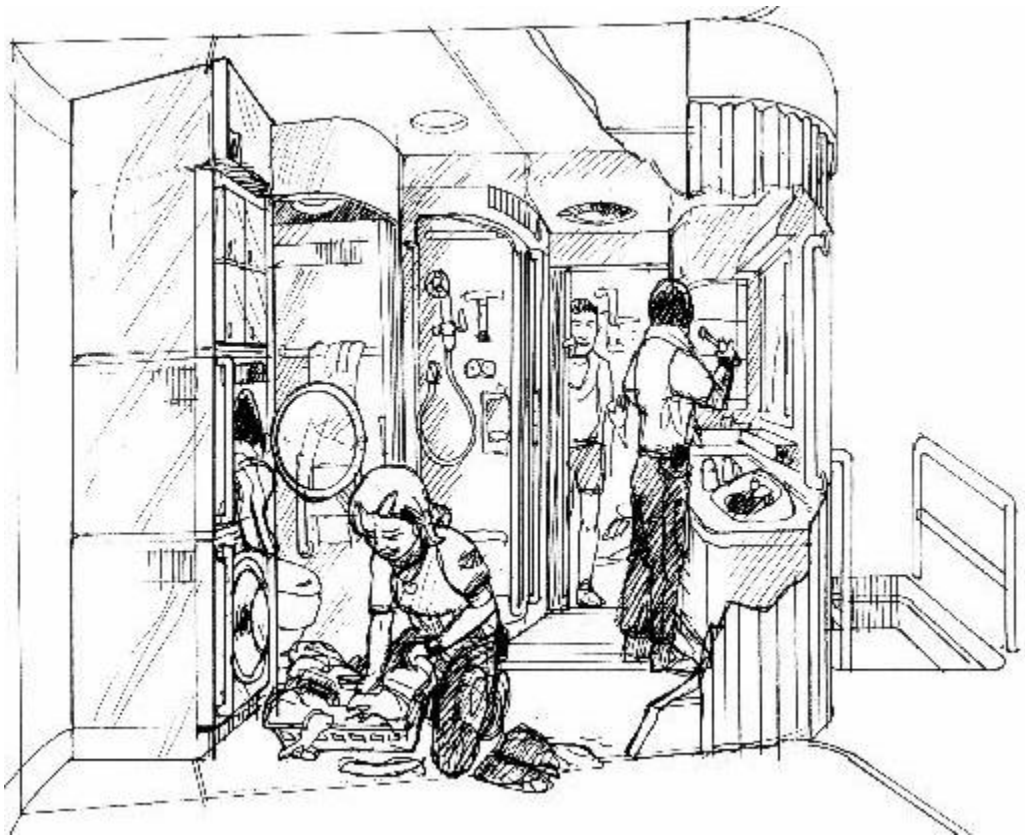
Provide Crew Hygiene (text)
continued

- Workstation for light personal cleaning (tissues, wipes, disposal, etc)
- Workstation for toilet functions (physical hardware for zero-g processing of bodily wastes, treatment, recycle, or disposal)
- Volume for toilet activities (spatial volume for crew member to dress, undress as needed – should provide for odor, sound, and visual privacy)
- Workstation for full body cleansing functions (water dispensing, moisture control, wipes, disposal, etc)
- Volume for body cleansing activities (spatial volume sufficient for crew member to dress, undress as needed – should provide visual privacy and moisture control)
- Workstation for water access (include moisture control, treatment, recycle, etc)

It should be noted that volume for toilet and full body cleansing activities could be dual use and need not be permanently dedicated or partitioned off from the habitation volume, but depending on the design, can be deployable as needed over the workstation. However, such "borrowing" of volume assumes that other functions might use that volume when the hygiene functions are not needed, so the designer must consider whether those other functions could be halted upon urgent need to allow for the hygiene volume to be deployed. A better design would be to provide dedicated volume for the hygiene functions that does not need to compete with volume required for other functions. This is particularly true for larger and larger crews who will need to take turns using hygiene facilities. Additionally, the location of the hygiene area should consider traffic patterns and be readily accessible at all times, not blocked by other long duration task volumes. Finally, if the habitat has a dedicated radiation safe haven, some type of hygiene facility must be accessible from this location.

Provide Crew Hygiene

- Functions included:
  - Workstation for light personal cleaning
  - Volume for toilet functions and related activities
    - Spatial volume to dress, undress as needed – should provide for odor, sound, and visual privacy
  - Volume for full body cleansing and related activities
    - Spatial volume sufficient to dress, undress as needed – should provide visual privacy and moisture control
  - Workstation for water access



Provide General Housekeeping (text)

Introduction. General housekeeping is needed for all missions, but the scope is smaller or greater depending on the duration of the mission. General housekeeping includes keeping the habitat interior clean, maintained, management of trash and waste, and in adequate working order, and also may include maintaining crew clothing in good condition (clothing and laundry issues may optionally be included under "hygiene"). The consideration of general housekeeping is important for crew productivity because a disorderly environment of the habitat might interfere with the ability of the crew to quickly find necessary tools and other needed items.

Crew Activities. Crews will be required to take time to clean surfaces, monitor and maintain subsystems, organize equipment and supplies that aren't included under logistics, make minor repairs, and maintain clothing orderliness and cleanliness. Tasks may include vacuuming, wiping surfaces, disposing of dirtied wipes, organizing small items on walls or in lockers, using tools to make minor repairs, material handling of small or bulky objects, checking on subsystems, and performing laundry of clothing or towels. Automation may be able to eventually take care of many general housekeeping tasks, depending on clever design, budget, operating system, and hardware concepts. These automated functions can include monitoring various subsystems, using automated means for cleaning surfaces and collecting foreign particles, cleaning clothes versus disposable clothes, and automated material handling. Trash management may include pyrolysis, trash compaction, etc.

Habitat Design Impacts. Beyond needs providing for vacuum cleaner, trash management, and laundry, general housekeeping functions will not require large volume allocations, but may influence the design in subtle ways, such as design for cleanliness, moisture control, organizers, and provision for storage in odd-shaped corners to maximize space use. Workstations and hardware should have access for maintenance and upgrade, preferably interfacing with modular infrastructure elements such as potable water, waste water, power, command & control, and various gas supplies. Major impacts to habitat design include:

- Vacuum cleaner / cleaning tools stowage volume
- Workstation for laundry functions
- Volume for tools and maintenance equipment
- Volume for material handling tools to assist in relocation and organization of bulk items
- Volume for trash management, compaction, pyrolysis, etc (including odor control, outgassing control, etc)

General Housekeeping

- Required for crew productivity
- Functions include
  - Cleaning habitat interior
    - Vacuuming
    - Wipes
  - Maintaining equipment organization
  - Trash/waste management
  - Clothing maintenance and laundry

Training (text)

Introduction. The mission profiles included as elements of this ConOps are primarily ones of exploration that are characterized by extended periods of routine, low tempo activity while enroute to and returning from the primary destination for a particular mission. During these extended periods of time, varying in length from six to 12 months (one way) the crew must maintain certain high priority skills (e.g., piloting the SEV), learn new skills discussed only briefly before departure (e.g., repairing a hardware item with a low probability of failure), or practice contingency skills (e.g., fire drills). Provisions must be available on board the habitat to accommodate these different training needs.

Crew Activities. Crew training activities may include:

- Mission training: Piloting operations (departure, arrival, rendezvous & proximity, descent/ascent, re-entry, aborts, etc.) and destination operations (EVA, IVA, SEV ops, surface ops, science ops, on-board observations, robotic/teleoperation, payload deployment, etc.)
- Crew health & safety training: Emergency and routine medical procedures, emergency safety operations (fire control, high energy particle/radiation event countermeasures, rapid de-pressurization/leak repair, etc.)
- Team training such as Spaceflight Resource Management, to help promote team cohesion and performance
- Stress management training, including virtual tools that provide cognitive behavioral therapy
- Spacecraft maintenance & repair training

Types of training activities will generally fall into three categories, each with certain training methods:

- Knowledge based: Training may consist of refresher courses, cross-training, learning new fields/subjects (such as earning certification or degree in a new field of study), games, quizzes, reading, etc.
- Physical response based: Training is intended to keep crew member responses sharp for time critical and/or emergency scenarios that require immediate, reflexive reaction, and may consist of periodically scheduled procedure reviews and team discussion, followed by exercises to perform the operations to the extent practical.
- Skills based: This training is intended primarily to practice activities that involve dynamic operations that require the crew member to have a “feel” for manipulating/controlling systems. In general, this will involve use of hardware such as hand controllers with simulated (likely) end items and mission scenarios (e.g., rendezvous, docking, track and capture, descent, etc.).

Training (text)
continued

Habitat Design Impacts. The goal will be to avoid impacts to the habitat design through use of functions required for other mission aspects to meet training needs, although some amount of dedicated training hardware should be anticipated. Some considerations that may require further evaluation as to DSH design impacts are as follows:

- Real time ground control of flight elements (e.g., ISS) will be limited due to time delay; a method/system will be required for rapidly delivering (or possibly storing onboard) video instruction or CAD animations to resolve anomalies or perform specific servicing activities.
- The extent and frequency of in-situ training required to maintain crew proficiency in critical skills and quick responses for long duration missions needs to be understood.
- The desired level of autonomy of DSH systems may drive training requirements. Training for non-time critical activities may be more capability-focused rather than task-focused to better prepare the crew for any number of flight system anomaly resolution scenarios.
- The extent of training deferred to in-situ to take advantage of performing in micro-gravity/with flight systems needs to be evaluated.
- Mass/volume impacts of dedicated training equipment/consumables must be accounted for.
- Cycling of flight hardware during training exercises needs to be factored into the design.

Training

- Mission duration indicates in-flight crew training for:
  - Maintaining critical skills
  - Learning new skills for specific tasks
  - Contingency training (e.g., fire drills)
- Three categories of training:
  - Knowledge based
  - Physical response based
  - Skills based

Provide Crew Safe Haven (text)

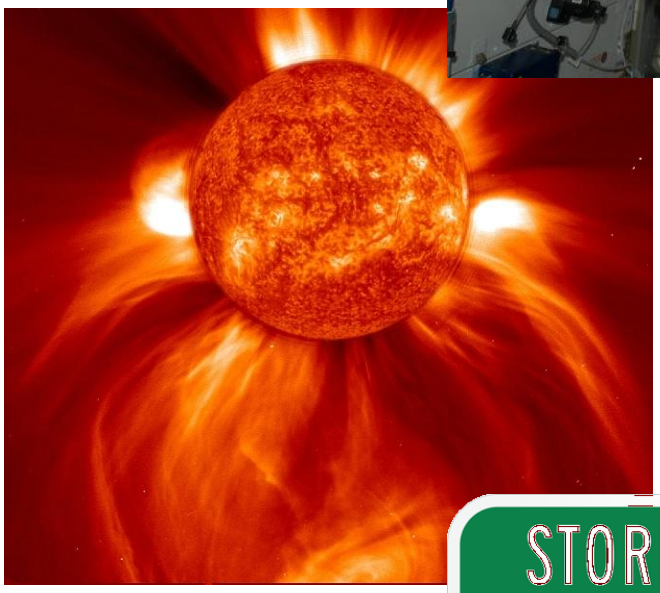
Introduction. There are various risks associated with maintaining a large pressurized volume that might result in life-threatening conditions for the crew. These risks include exposure to solar proton events, cosmic radiation, micrometeoroid impact, collisions with other vehicles, Environmental Control Life Support System (ECLSS) failure, loss of pressure, fire, and fungal growth among others. Though much attention has been given to the yet unsolved issues surrounding space radiation protection, where suggestions range from providing a protected compartment to waterwall barrier. However, safe haven from other catastrophic events also needs to be included, to allow crew members a minimally functioning habitat / refuge where they can survive for longer periods of time than would be possible in a compromised habitat system.

Crew Activities. Critical supplies and functionality (including power, communications, ECLSS, propulsion, thermal management, etc) need to be maintained in a distributed manner throughout the habitat. The crew must ensure that egress routes and safety hardware remain functional at all times during the mission. Crew members will need to check equipment and vehicles periodically to make sure they are in good working order.

Habitat Design Impacts. The various minimal habitat functionality must be distributed among several independent elements in a vehicle stack configured for a specific mission. For example, functioning SEVs, Multi Purpose Crew Vehicle (MPCV), Deep Space Habitat (DSH), environmental suits, etc may all contain varying degrees of ECLSS functionality, and can serve as an independent refuge should adverse conditions fall on one of the other elements. Habitat design for crew safe haven would then demand redundant functionality for all the essential elements of life support in each one of these vehicles.

Provide Crew Safe Haven

- Certain life-threatening risks will be faced by the crew
  - Loss of pressure
  - Fire
  - Radiation
- Distributed supplies and functionality among independent elements
- Redundant (dis-similar?) functionality for all essential elements of life support
  - ECLSS
  - Power
  - Communication
  - Thermal management



Provide Support Systems (text)

Introduction. In addition to support systems explicitly described in other sections of this ConOps there are a number of Deep Space Habitat support systems that will be essential for crew survival/safety, crew interaction with systems, and for successful completion of mission objectives. These additional systems include:

- ECLSS
- Power management
- Thermal management
- Communications and commanding
- Data processing (Computational and data storage)
- Navigation and attitude determination/control
- Environmental protection

Each of these systems will have unique requirements for volume both inside and outside of the habitat pressure vessel as well as interface requirements with the crew and with other systems. Additionally, the interface requirements includes a connection to the on-board system monitoring and control system described elsewhere in this ConOps. These habitat systems will typically operate with a high degree of autonomy with respect to crew interaction. Due to the extended duration of the missions for which this habitat will be used, some periodic maintenance and repair will be performed by the crew.

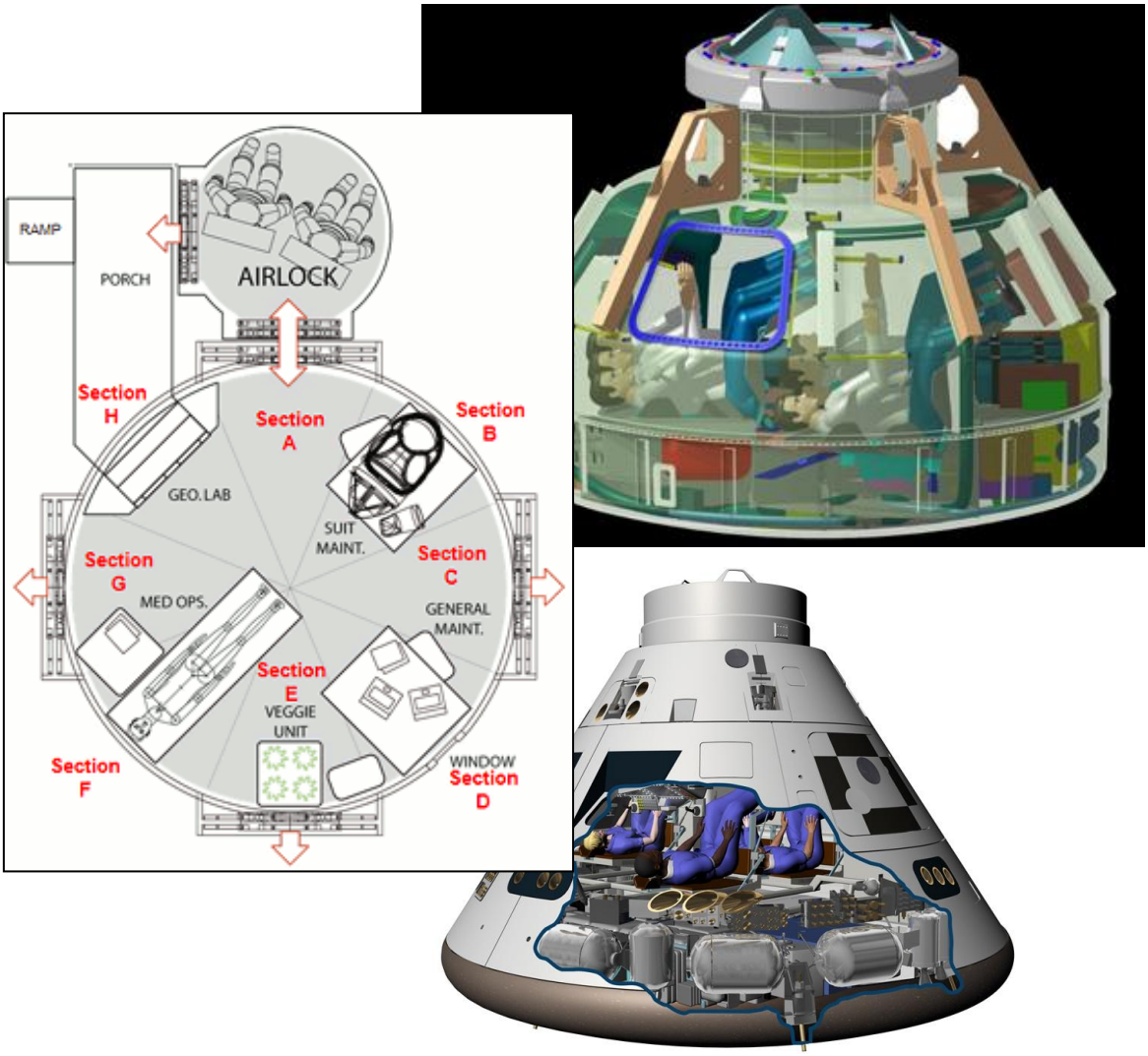
Crew Activities. The extended distances between deep space destinations and the Earth add a layer of complexity to manned spaceflight and to the execution of mission operations due to the increased communications time delay. Because of this, system reliability, and system/crew autonomy is critically important in ensuring mission success and crew safety. Crew interaction with various vehicle systems should only be required when the systems cannot determine or execute the necessary corrective action(s) to safe the system(s). These instances of crew intervention can be caused by conditions and/or failures that are considered to be outside the models limitations/scope or because physical interaction with a component is required for repair or replacement. Some examples of events requiring crew interaction include: a task that is the result of a failure and necessitates crew resolution/repair, routine equipment maintenance (e.g., an expected filter replacement), or when a multi-system, cascading failure occurs and the system autonomy cannot determine the necessary actions. The crew will also interact with the various vehicle systems whenever they wish to check the vehicle and systems health.

Provide Support Systems (text)
continued

Habitat Design Impacts. Vehicle and systems design and development should be performed with operability and systems modeling in mind. Even though autonomy is required for deep space missions, ultimately a crewmember will need to operate the systems and perhaps make real-time repairs during a mission. System components with known periodic maintenance should be readily accessible by the crew. Repair is considered a more infrequent activity but still likely and should be considered when designing the vehicle. Mission aborts or early mission termination due to a system failure are typically not possible, the crew must be given the capability to attempt a system repair. Thus the crew must not be precluded from accessing any of these on-board systems during the mission, including EVA to repair something outside the habitable volume. Conducting systems modeling in parallel to the systems design process allows for systems to be designed efficiently and with automation in mind (i.e. make decisions on system design and redundancy as well as optimum sensor placement for diagnostics/prognostics) and creates systems models that can be reused for various purposes (i.e. the model can be reused as part of vehicle diagnostics, training facilities, etc). Up front identification of products needed for all aspects of planning, training, and in the execution of mission operations is important in realizing substantial long term cost savings and enablement of deep space missions.

Provide Support Systems

- Provide volume and interfaces both inside and outside pressure vessel
  - ECLSS
  - Thermal management
  - Data processing
  - Environmental protection
  - Power management
  - Communications
  - Navigation & attitude determination/control
- Simple access to systems with known maintenance requirements
- Mission duration indicates some repair is likely for all systems
  - Access should not be precluded to any system



Provide On-board Subsystem Monitoring and Control (text)

Introduction. Monitoring and control of systems and subsystems is a critical function to insure safety of the crew and the mission. Monitoring and control systems must operate with a high degree of autonomy with respect to the crew and only involve the crew when necessary. Approaches must include an extensive network of sensors and monitoring devices which provide data to model-based control algorithms which allow for adjustments of systems by the control algorithms to maintain a safe vehicle and human environment and only involve the crew when necessary. This must be accomplished throughout all mission phases and operations including off-nominal situations.

Crew Activities. As a result of the long distances between the Deep Space Habitat and Earth, reliance on ground control must be minimized. Autonomy with respect to the on-board systems is very important. Crew-ground interactions should only be required when the systems cannot take corrective action and need a crew decision (such as outside model limits). Examples of events requiring crew-ground interaction include a failure which necessitates crew resolution, routine equipment maintenance is required (e.g., an expected filter replacement), or when crew wish to check the vehicle and systems health. Operations during mission phases such as EVA events and other vehicles docking or departing the Habitat must also be monitored to insure nominal safe operations.

The monitoring and control system will have to interface with the crew health/medical support equipment to provide data to crew members and medical personnel. Monitoring tools should include those that detect changes in cognition, stress and affect, sleep, team cohesion and communication, etc. Medical systems can integrate these data points into a single dashboard that allows crewmembers to track their physiological and psychological well-being in context of mission stressors.

The monitoring and control system should also have the capability to visualize the exterior of the spacecraft stack to assess status/potential damage in the event some system issue arises that challenges the overall confidence of the spacecraft stack systems as a whole.

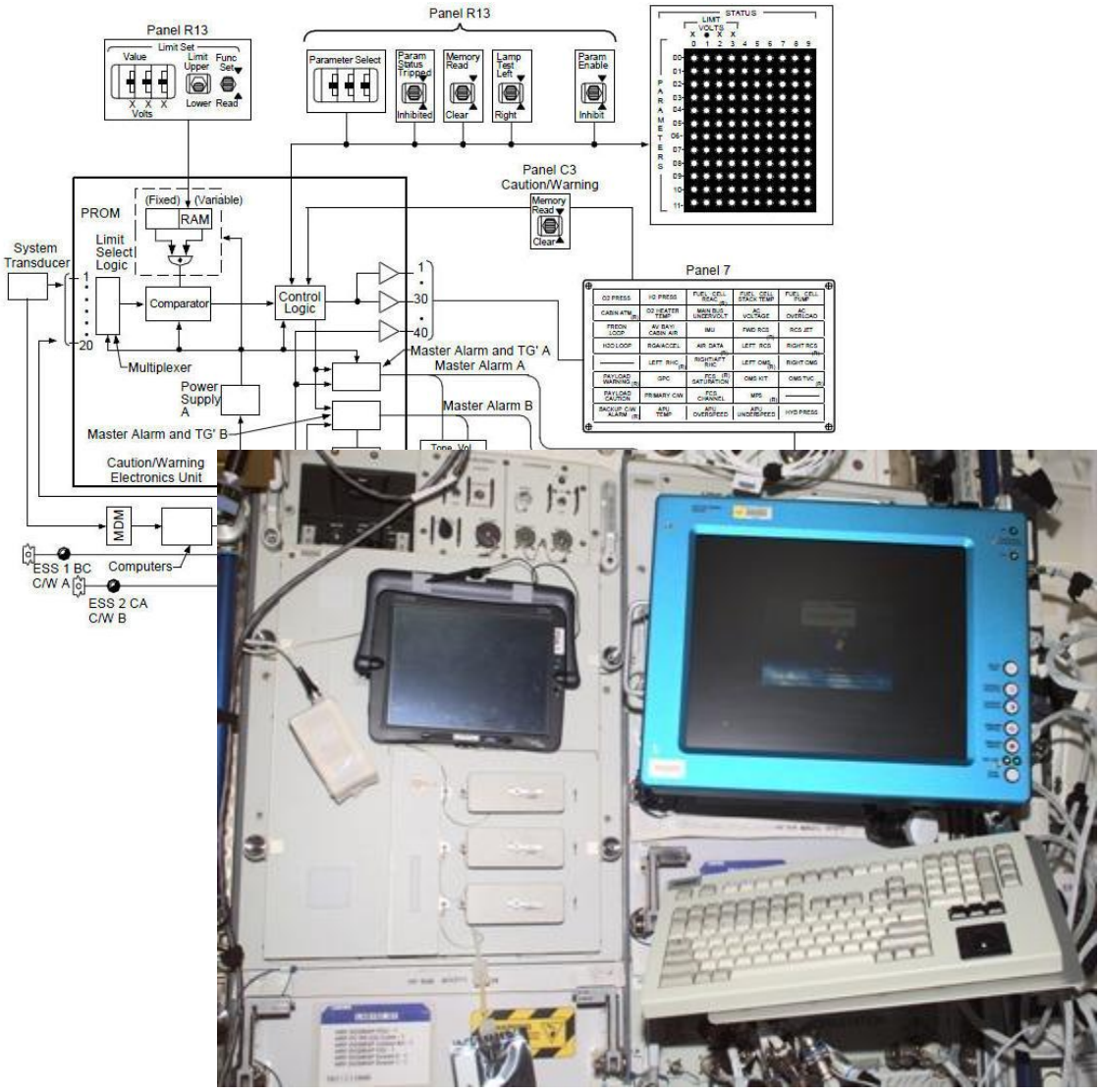
Provide On-board Subsystem Monitoring and Control (text)
continued

Habitat Design Impacts. The habitat systems must be instrumented to provide all necessary data required by the control system at the correct locations and frequency dictated by the models actively tracking vehicle performance. Models to actively assess vehicle systems status and health must provide a predictive capability to assess a future state and take action to avoid an undesirable future state. The monitoring and control system must be able to access data archives that include information such as wiring diagrams, equipment drawings, repair procedures, etc. when crew members are resolving a contingency. The habitat monitoring and control system must interface with other mission elements such as EVA suits, suit ports and air locks, other vehicles that are docked or arriving/departing, external antennas and radiators, etc. This is necessary to acquire interface data with which to monitor these habitat-external systems during passive and active operations.

The monitoring and control system must interface with the communications system for ground control and in-space communications of voice and data. The monitoring and control system must provide a caution and warning subsystem to alert the crew to events or trends requiring their immediate attention.

Provide On-board Subsystem Monitoring and Control

- Critical to safety of the crew and mission
- Increased importance due to time lag with ground support teams
  - Immediate alerts (e.g., on-board fire)
  - Monitor trends
- Interfaces with:
  - Support subsystems (e.g., ECLSS, power, thermal, etc.)
  - Crew health/medical support
  - Other docked elements



Provide Pressurized and Unpressurized Docking Accommodations (text)

Introduction. The range of missions under consideration for this habitat indicate that there will be at least one pressurized and one unpressurized docking accommodations required. The one pressurized docking accommodation is required for an MPCV-like crew capsule used to initially deliver the crew and for the crew to return to Earth. The unpressurized docking accommodation is required for the primary propulsion module. One or two additional docking accommodations could be required for small exploration vehicles (i.e., the SEV) but the use of these vehicles as part of the destination exploration strategy is still part of on-going trade studies.

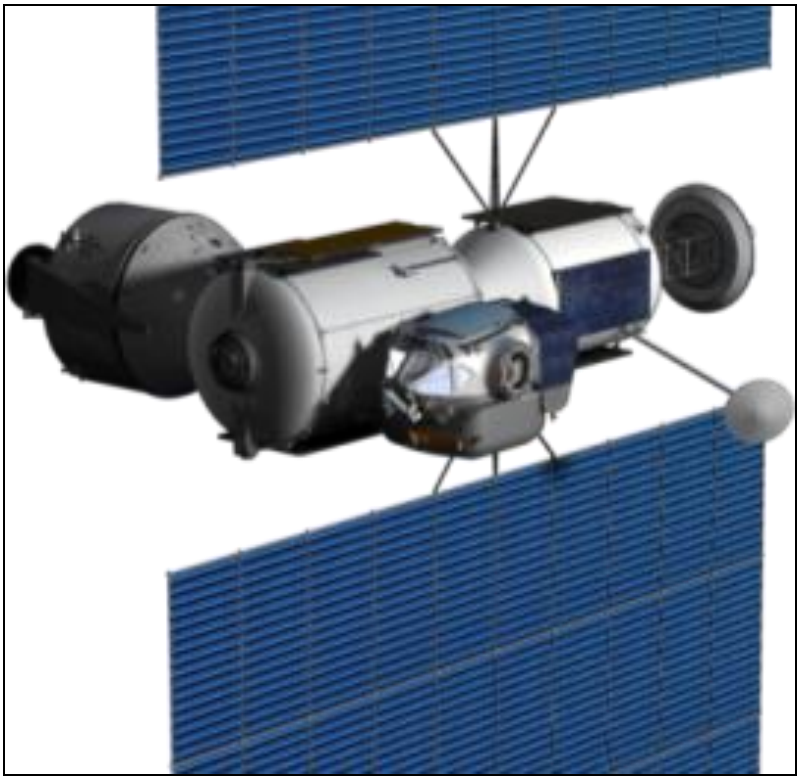
Crew Activities. If there are crew members on board the habitat during rendezvous and docking events, then these crew members will likely perform the role of "traffic control" for the approaching/departing vehicle(s). This assumes that the habitat is the passive element of the rendezvous and docking/undocking event. This also implies that the crew has line of site visibility (either directly or via cameras) with the approaching or departing vehicles as well as access to other sensor data important for the docking/undocking event.

Habitat Design Impacts. Based on the missions under consideration and the previous discussion, there is a requirement for the habitat to allocate "real estate" for at least one pressurized and one unpressurized docking system. Pending the outcome of mission trade studies, there could be a requirement for one or two additional pressurized docking ports. The external approaches to these docking ports must be clear of protrusions that could interfere with the approaching or departing vehicles.

Questions to be resolved. There are several issues that will need to be resolved for the eventual design of the habitat that are at least peripherally associated with the Concept of Operations. The first is the question of what services (e.g., communications, data, thermal management, etc.) and commodities (e.g., power, air, etc.) are provided by the habitat for these docked vehicles. The second is the question of whether the docked vehicles spend the majority of their docked time in a powered-up/active mode or are they powered-down/passive. Last is the question of what are the emergency access requirements for these docked vehicles (e.g., does the hatch for each of the docking ports need to be free and clear at all times while the vehicle is docked).

Provide Pressurized and Unpressurized Docking Accommodations

- Pressurized docking accommodations
  - One crew capsule (e.g., MPCV)
  - Zero, one or two small pressurized exploration vehicles (e.g., SEV)
- Unpressurized docking accommodations
  - Propulsion module (chemical or SEP)
- Crew in DSH perform “traffic control” function
- Open questions:
  - What services and commodities cross the docking interface
  - Are the docked vehicles primarily active or dormant
  - What are the crew emergency access requirements



Provide Stowage (text)

Introduction. One of the most critical volumes that need to be accounted for in space habitat design is stowage volume, which is often underestimated or overlooked. Since it will be unlikely that resupply for a deep space habitat will be possible (except through advance caching), all the needed supplies must be provided at the beginning of the mission. Stowed items cannot be packed solid in a volume on the assumption that items can be accessed sequentially, but must be stowed for random access. This means that access space adjacent to all stowage units must be maintained in order to ensure the safety of the crew. Stowage volume must not only take into account logistics packaging containing items in current use, but must also accommodate used items, discarded items, trash, unused equipment, and spares.

Crew Activities. Though logistics are inventoried and assigned stowage space, contents are sometimes rearranged for various reasons during the mission. Crew members will be involved with random access to logistics containers, and will move items from place to place as part of organizing tasks and general housekeeping.

Habitat Design Impacts. The consideration of logistics systems in parallel with equipment, pressure hull design, modularity, circulation routes, and mission design is crucial in order to optimize stowage volume for the needs required. A poorly designed logistics and stowage concept could result in significant mass penalty, whereas well-designed systems will concentrate on dual-use (or multi-use) and leveraging of other subsystems, volumes, internal outfitting, and access for a reduction of mass. For every volume of space that is dedicated for stowage, an appropriate amount of open circulation space must be added to allow random access of the items placed in that storage space. The circulation space can be shared between blocks of stowage or other temporary functions, as long as the other temporary functions can easily be taken out of the way when access to the storage space is needed. Other impacts to habitat design include allowance for mounting points, restraint systems, and organizers for items of various sizes. Tracking systems and inventory tracking can also be implemented, which require detectors at strategic locations in the habitat to sense the movement of Radio Frequency Identification (RFID) tags (or their functional equivalent) associated with various items of stowage. In summary, stowage systems will require:

- Adequate volume for logistics required for the entire planned mission, or until a resupply can be made (if applicable)
- Extra volume to accommodate discarded items, spares, unused equipment, and crew belongings
- Additional volume for each block of stowage space to be used for circulation and random access
- Volume for inventory tracking systems (e.g., RFID detectors, etc.)

Provide Stowage (text)
continued

- Advanced planning for stowage systems, with parallel design of modularity, interfaces, equipment, logistics systems, etc
- Design for attachment points, restraints, organizers, etc

Questions to be resolved. For manned vehicles, there have been challenging requirements for the stowage of goods to prevent shifting which could endanger crew during launch or contingency events. Additional information is needed to ensure that unmanned designs are not designed to these overly conservative constraints.

Provide Stowage

- Adequate volume is needed for logistics to support the entire mission
  - Consumables
  - Crew gear
  - Spares
  - Unused equipment
  - Discarded items and trash
- Stowage volume should be planned for random access not maximum density
  - Extra volume for crew access and temporary removal of some items to locate needed items
- RFID technology for tracking and inventory

Provide Maintenance and Repair (text)

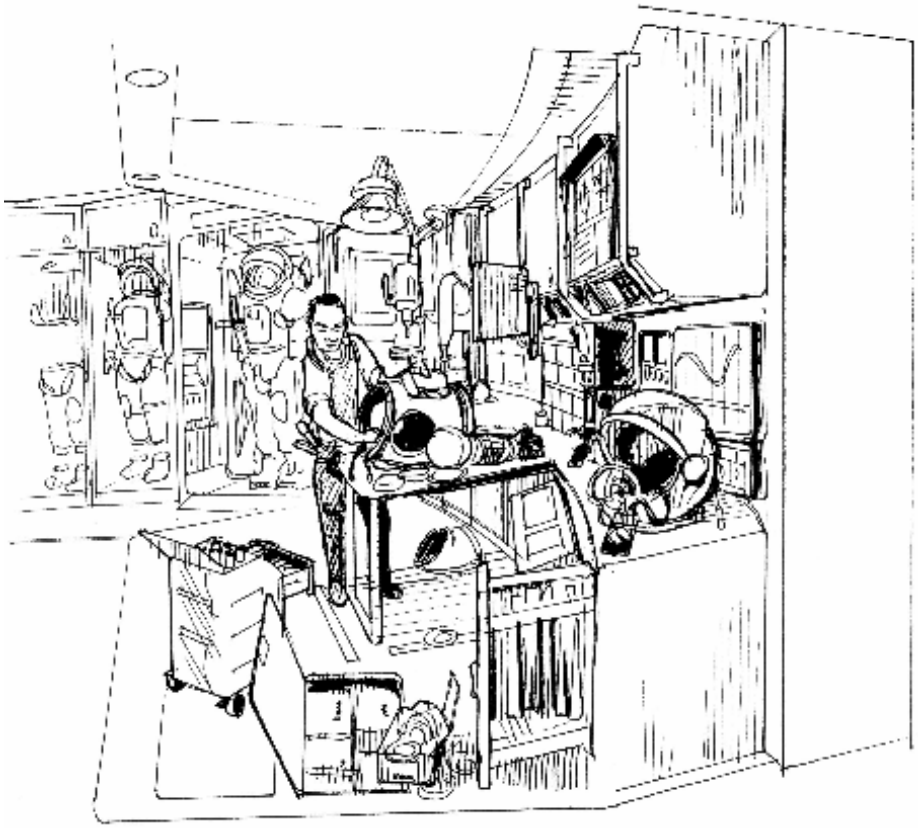
Introduction. Extended duration deep space missions that cannot be resupplied coupled with ever-present pressure to minimize system mass and volume will make the maintenance and repair needs of the Deep Space Habitat (DSH) unlike any other spacecraft designed thus far. Lacking any opportunity, once the vehicle has escaped from Earth, to provide the crew with unanticipated spare/replacement parts or consumables means that the approach to a DSH design will require a multi-part approach emphasizing increased system reliability, a more complete understanding of possible failure modes, increased utilization of common subsystems and components, and possibly an increased reliance on techniques infrequently used on piloted spacecraft: repair instead of replacement or reliance on 3-D fabrication of replacement parts and unique tooling using on-board feed stock.

Crew Activities. Crew should be trained to perform a range of repair and replacement procedures using standardized tool kits and techniques building upon capabilities developed for the ISS and augmented by selected capabilities typically performed on the ground for the ISS. Such capabilities may include circuit board level repair, standard removal and replacement of systems with common interfaces, and 3-D fabrication of replacement parts or unique tooling using on-board feed stock or re-cycled from on-board supplies. Crew capabilities should be enhanced by pre-flight or in-flight training with maintenance and repair kits and procedures. To minimize waste, crew will have to sort and separate materials for recycling, repurposing, or cleaning for additional usage.

Habitat Design Impacts. The first tier of an improved maintenance and repair capability for the DSH is to use design approaches and systems/subsystems that have a demonstrated high level of reliability. Gathering and analyzing failure data from the ISS and other relevant spacecraft can be used to identify those designs or systems that should be used or emulated. Ensuring that failure modes and effects analyses (FMEA) and related analyses are used during the design process will help improve overall reliability and thus reduce the need for maintenance or repair. The second tier of an improved maintenance and repair capability will also occur during the design phase by emphasizing the use of common (or at least a small number of alternative) subsystems and components to drive down quantities and types of replacement parts. This must be balanced with another design approach that can improve probability of success by using dissimilar redundancy to avoid loss of functionality due to common cause failure. With these features incorporated into the DSH design, the habitat must then accommodate the numbers of spares estimated for the duration of the mission. Tools needed for these replacement parts must also be accommodated. If the DSH design approach places an increased reliance on repair instead of or in addition to replacement, then appropriate tools and work space must be provided for these repair activities. Similarly, space must be provided for a 3-D fabrication machine and feed stock if this capability is part of the overall approach to maintenance and repair. Finally, reducing the amount of time and labor the crew must spend on maintenance is a desirable goal. At the system and sub-system level, incorporating enhanced capabilities (e.g. self-diagnostics, self-healing wiring and materials, autonomous control, etc.) will help achieve reduced maintenance times and efforts required from the crew.

Provide Maintenance and Repair

- DRMs have no opportunity for unanticipated replacement parts or consumables
- Multi-part approach to maintenance and repair
  - Increased reliability
  - Better understanding of failure modes
  - Increased reliance on repair
  - Possible use of 3-D fabrication
- Crew trained on use of common tool kits and repair/replacement techniques
- Incorporate enhanced capabilities to help reduce maintenance/repair time
  - Self diagnostics
  - Self healing wiring and structures
  - Autonomous control



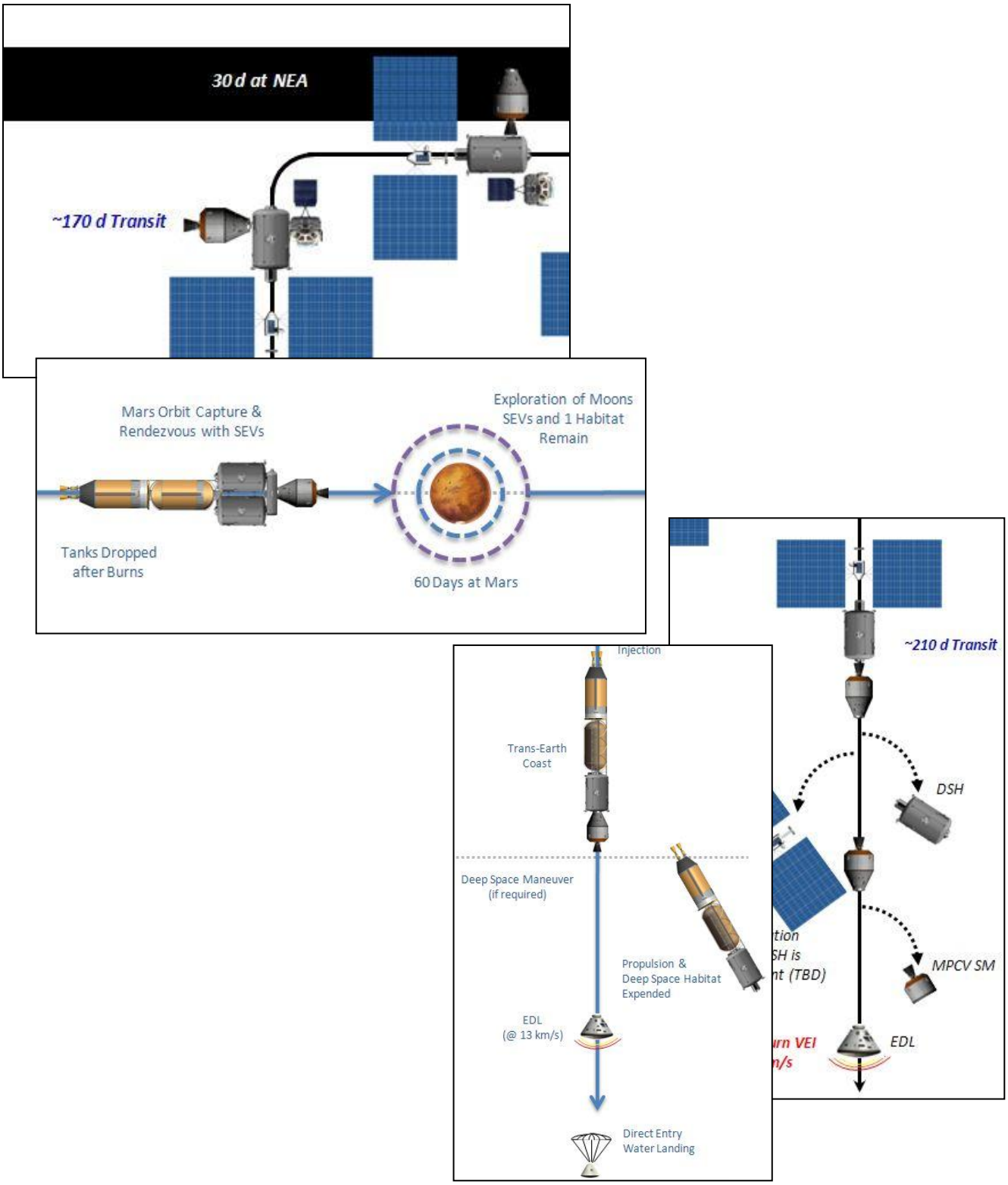
Arrival Preparations (text)

This section is a summary description of crew activities and habitat functions that the previous DRM descriptions indicate are likely to occur when arriving at either the destination for a specific mission or the Earth at the completion of the mission.

Destination Arrival. This description begins with the approach of the vehicle stack to the vicinity of the destination object. The crew will have the opportunity of conducting long range observations of the destination to look for any changes in the destination since the time when the data set used for planning was obtained. The crew will resume (or increase the frequency of) proficiency training for destination activities, such as EVA, sensor operations, proximity operations by and around the vehicle stack, SEV operations, etc. The crew will then configure all systems in the vehicle stack for the arrival delta-V maneuver. The crew will then maneuver the vehicle stack to the operational location chosen for this mission. The crew will compare what they can observe of the destination and the surrounding environment with information sent by any precursor missions and those data obtained from long range observations to confirm that this location still satisfies scientific interests and is safe for the vehicle stack. The crew will then configure the vehicle stack (including the habitat) for their primary mission operations.

Earth Arrival. Several days prior to arrival at Earth the crew will activate the MPCV and confirm its readiness for returning the crew to the Earth's surface. The crew will transfer and stow samples, data (if stored on physical media), and personal items in the MPCV. The crew will then begin to shut down unessential system in the habitat and configure the vehicle stack for the departure of the MPCV. At the appropriate time, the crew will transfer to the MPCV and undock from the stack. The habitat and remaining vehicle stack will then likely make a deflection maneuver to avoid the stack re-entering the Earth's atmosphere. The MPCV will then maneuver for the Earth entry conditions.

Arrival Preparations



Representative Daily/Weekly/Monthly Crew Time Allocations (text)

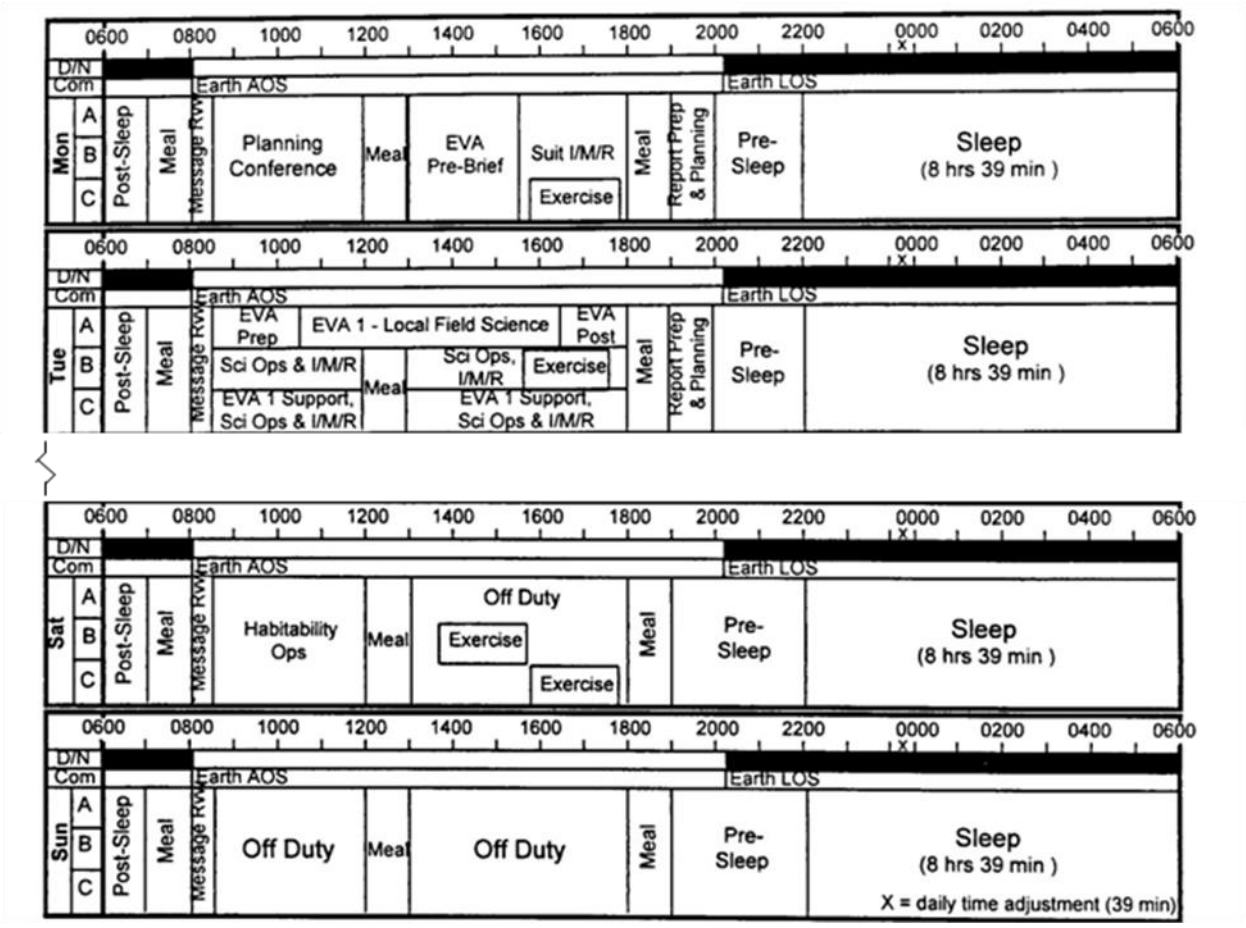
Introduction. The transit missions that are the focus of this Concept of Operations are characterized by many months of relatively low tempo and routine activity. A basic timeline that captures the range of activities, their frequency and pattern can help guide the allocation of habitat volume and other resources.

Crew Activities. The facing page illustrates many of the individual activities that must be planned by the crew (with support from the ground) on a regular basis (note: this graphic is for illustration only – it does not reflect a specific timeline for any of the missions currently under study). Because this transit phase is made up of mostly routine activities, it is likely that the crew activity timeline would be updated periodically (weekly?) but as deltas to a baseline timeline.

Habitat Design Impacts. An assessment of the pattern of concurrent activities captured in a typical crew timeline will help designers decide the number and placement of work spaces, along with access to or through these spaces, that must be accommodated concurrently within the habitat. This also implies that non-concurrent activities offer an opportunity where volume and access could be shared by several different activities.

Questions to be resolved. One item that should be developed for future work on this Concept of Operations is a basic crew timeline for the transit phase of the mission that could be applied to all of the missions considering the use of this habitat as part of the mission elements. A few of the questions that will arise as this timeline is developed include: How many shifts on board the habitat will the crew support? Regardless of the number of shifts and recognizing that with a significant time delay moving the crew towards more autonomy and less reliance on the ground support, should there be at least one crew member on watch at all times during the mission?

Representative Daily/Weekly/Monthly Crew Time Allocations

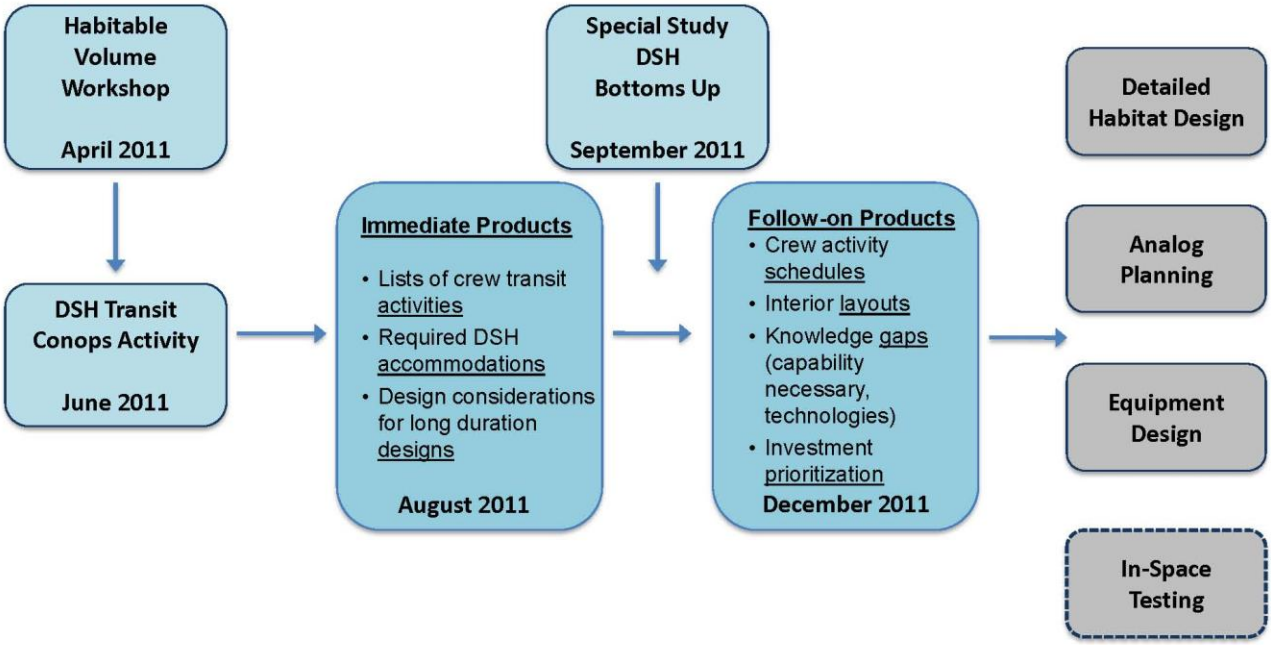


SECTION IV
ANALYSES AND RECOMMENDATIONS

What We've Learned

- Identified functions apply across all DRMs
  - Indicates a common approach can work across this DRM set
- Identified our level of understanding of each function (i.e. knowledge gaps)
- Identified potential habitat design implications of functions
- Differences in crew size and mission duration are significant for a DSH design
  - A single integrated/monolithic DSH design is probably not realistic
  - A modular approach could accommodate differences but raises other issues
  - This team will gather some additional relevant data but will not resolve this item
    - See Forward Work section

Uses of Study Results



Recommended Follow-on Work

- Crew-activity schedules
  - A basic set of activities have been identified
  - Will contact ISS crew planners to discuss preparing a “typical” crew week based on ISS experience and identified DSH activities/functions
- “Concurrent use” assessment
  - Using “typical” crew week, determine which functions are likely to occur concurrently
  - May offer insight into how much volume is needed based on the number and type of concurrent uses
- Interior layouts
  - Based on “concurrent use” and other functional constraints, prepare interior layout recommendations/guidelines
- Knowledge gaps
  - Using the identified functions and use patterns, begin identifying the next level of design details
    - What equipment is required?
    - How much crew time is required?
    - What level of capability is necessary for this activity?
    - Etc.
  - Capture other key questions regarding the habitat and is functions
    - See examples in backup
- “Understanding” scale
  - It would be useful to have a rating scale similar to Technology Readiness Level that rated our understanding of a particular activity or function
  - One possible example:

    0 - Not understood at all

    1 - Partially understood, would require significant terrestrial/orbital testing to understand

    2 - Pretty well understood, but would require adjustments for long duration transit

    3 - Well understood and similar to existing on a long duration transit
- Investment prioritization and analog tests
  - Once activities and functions are assigned a rating, use these values to guide technology investments or analog tests

Example Key DSH Questions

DSH Architecture Traceability Matrix Ref #	**Key Habitat Questions: Deep Space Hab (as defined by mission architecture scenarios)** *(not in priority order)*
DSH-1	**EVA Operations:** Will the capability of an integrated Airlock, Suitlock, or Suitport enable efficient EVAs for NEO exploration?
DSH-2	**Autonomous Hab Operations:** Will the capability of an autonomously-intelligent habitat management operating system enable efficient operations of a DSH saving mass and power, and increasing crew/mission safety and productivity?
DSH-3	**Logistics, Maintenance and Spares Operations:** Will the capability to in-situ manufacture of parts, perform remote repairs, and automated maintenance (such as self-healing or self repairing systems) enable efficient operations of a DSH saving mass and power, and increasing crew/mission safety and productivity?
DSH-4	**Habitable Volume:** Does the DSH provide sufficient long-duration mission functionality and habitable volume to enable efficient operations of increasing crew/mission safety, physiology, psychology, and productivity?
DSH-5	**Crew Operations:** Will the capability to provide more habitable volume using inflatable modules or appendages enable efficient operations of a DSH saving mass, launch volume, and increasing crew/mission productivity?
DSH-6	**Mission Operations:** Will the capability of providing tele-robotic workstation, EVA workstation, and maintenance workstation enable efficient operations of a long-duration mission DSH saving mass and power, and increasing crew/mission safety and productivity?
DSH-7	**Medical Operations:** Will the capability of providing a medical workstation enable efficient operations of a DSH increasing crew/mission safety and productivity?
DSH-8	**GeoScience Operations:** Will the capability to perform glovebox in-situ sample analysis enable efficient EVA and geological science operations for NEO exploration? Planetary Protection sample handling, procedures, practices, and operations.
DSH-9	**Life Support Closure:** Will the capability to "close" the life support system for a long-duration mission enable efficient operations of a DSH saving mass and power, and increasing crew/mission safety and productivity?
DSH-10	**Sufficient Stowage Volume:** Does the DSH provide sufficient stowage volume and accessibility to enable crew activity, MMSEV resupply, maintenance and housekeeping operations, and conduct overall mission operations for a long-duration mission?
DSH-11	**Radiation Protection:** Does the DSH provide sufficient long-duration mission radiation protection (SPE and GCR) to enable efficient operations of a DSH increasing crew/mission safety, physiology, psychology, and productivity?
DSH-12	**Life Sciences Research:** Does the DSH provide the capability for human and other biological life sciences research, inclusive of plant and animal research, necessary to understand the effect of the NEO environment on life processes and crew operations necessary to sustain plant food growth?
DSH-13	**Light Weight Structures:** Does the use of light weight composite structures (hard and flexible) provide sufficient pressure vessel protection in composite shell while being lighter weight than conventional ISS shell systems?
DSH-14	**Power Management & Distribution:** Does using smart grid and autonomous control technologies provide more efficient resource utilization and thus lower power operations?
DSH-15	**Environmental Protection:** Does using a "smart" skin multi-functional multi-layers self-healing pressure shell provide sufficient space environmental protection?

SECTION V
APPENDICES

Appendix A: NEA Medical Operations

Timely contingency return to Earth will not be possible following departure from low Earth orbit (LEO). Delays in communication with Earth will vary with distance but are expected to be 0 to 24 seconds in each direction. Depending on the communications infrastructure, periodic communication blackouts may occur. Thus, the crew will require autonomous medical capability, supported by the ground medical team acting as remote consultants via asynchronous telemedicine technologies.

The crew will consist of four crewmembers. A minimum of two crewmembers will be trained as crew medical officers (CMOs), who will assist each other and provide backup if one CMO becomes incapacitated. The primary CMO will be a physician astronaut, with training and experience in primary care, acute care, surgical skills, space medicine, and care in remote environments with limited medical resources (e.g., Antarctica). The deputy CMO will be an experienced mid-level provider. The primary CMO will provide medical care to the crew in coordination with the ground medical team and manage medical data onboard. The deputy CMO will assist the primary CMO in fulfilling his/her responsibilities. Training to the level of a physician and/or mid-level provider (physician assistant, nurse practitioner, or equivalent) will be necessary for the CMOs, since they may have to respond to medical contingencies without real-time support from the ground.

The ground medical team will consist of flight surgeons and biomedical engineers (BMEs) serving as flight controllers in the Mission Control Center (MCC), the crew surgeon and deputy crew surgeon as the primary physicians for the assigned crewmembers.

Crew selection criteria and preflight medical and psychological screening will be in place to minimize the range of medical contingencies that might occur during a NEA mission. Existing medical standards for Space Shuttle and International Space Station (ISS) crewmembers will likely be augmented by additional standards based on the NEA mission's objectives and duration.

In addition to primary prevention strategies implemented prior to crew selection to a mission and engineering controls against known hazards, secondary and tertiary prevention will be employed in flight to prevent illness and injury, reduce the severity of illness and injury, and minimize complications of and disability from injury or illness. The medical system for a NEA mission will address the conditions of concern on the Space Medicine Exploration Medical Condition List (SMEMCL). As a secondary prevention strategy, aerobic exercise and strength conditioning will be commenced as early as possible during a NEA mission and continued throughout transit.

NEA Medical Operations
continued

The telemedicine system will electronically capture and transmit data related to these conditions to the flight surgeon and consulting specialists via the MMC. Lack of real-time communications will require planning for three distinct modalities based on communication latency: synchronous, store-and-forward, and just-in-time telemedicine. Ideally, to minimize mass, volume, and power demands, medical devices will have multiple applications. For example, an ultrasound can be used for both diagnosis and treatment, a cardiac monitor can be used for both diagnosis and monitoring, and a fiber optic scope can be used for multiple anatomical sites.

The electronic medical record (EMR) system will provide a user interface to the telemedicine system and a repository for medical documentation, containing patient history, physical examination findings, laboratory and imaging results, clinical impressions, treatment plans, medications, and progress notes. The full EMR will be available to the ground medical team.

The onboard intelligent integrative medical data processing unit (IIMDPU) will analyze incoming diagnostic data (i.e., abnormal laboratory or imaging results) and recommend treatment options. It may also prompt the CMOs to adjust treatments based on ongoing treatment data (e.g., IV rates and antibiotic delivery) and patient monitoring data (e.g., vital signs, heart rhythm, and fluid balance). Such a system is not intended to replace the CMOs, but rather to enhance capability, suggest diagnostic and treatment options not considered, and ease the work load of the CMOs especially in high acuity cases. Collectively, the Intelligent Clinical Care System consisting of the EMR and IIMDPU will be linked with the MMC. New data added to a crewmember's EMR or any adjustments to patient parameters will be automatically downlinked to a mirror EMR and visible to the flight surgeons and consulting specialists in the MMC. An exploration medical laboratory (EML) will consist of one or more instruments that will analyze biological samples (i.e., blood, urine, saliva, sweat, and stool). Assays will include: measurement of dissolved gases, solutes, and biomolecules; identification of cells and cellular organisms in bodily fluids; and microscopic visualization of specimens. Treatment and intervention capability will be defined by the SMEMCL. Necessary medical equipment and consumables will be accessible from the patient area. A consumables and inventory tracking system in the EMR will record medication type, dose, amount, and date dispensed by the CMO.

NEA Medical Operations
concluded

Countermeasure monitoring will also fall under ambulatory care. It will be necessary to monitor countermeasure adherence and crewmember progress to ensure that each crewmember maintains functional status for mission and exploration activities. Acute medical care will encompass all care delivered to immediately stabilize severe illness or injury that would typically require hospitalization to prevent loss of life or limb. Examples include burns, trauma, and cardiac arrest. Acute care capabilities will be defined by the SMEMCL.

This will include advanced cardiac life support and limited advanced trauma life support. All required medical equipment and consumables for acute care will be located within the patient area. For surgical conditions that cannot be converted to medical ones, limited surgical capability guided by the SMEMCL will be available, with an emphasis on minimally invasive procedures Medical care during intravehicular activity (IVA) will be administered by the CMO and the deputy CMO. IVA medical care will occur in a manner consistent with acute care during NEA transit/Earth transit. During EVA, physiological monitoring of the EVA crewmembers will be conducted by the onboard CMO. Vital signs, heart rhythm, metabolic rate, oxygen consumption, and carbon dioxide (CO2) production will be monitored to not only ensure that physiological limits are not exceeded, but also detect early off-nominal events so that a proper response is executed, such as termination of the EVA. All physiological data collected during EVA will be entered into the crewmembers' EMR. A standard EVA medical kit will be deployed with the two-person EVA team so that basic care may be administered in the event of a medical emergency during an EVA. However, the standard operating procedure in such a scenario will be to abort the EVA and evacuate the crewmember to the MMSEV/DSH immediately.

Deep Space Suit – Baseball Card

Description:

The EVA Suit will be used to allow crew to perform autonomous and robotically assisted exploration and extravehicular servicing and repair operations in various environments. The suit provides life support, environmental protection and communications capability to the EVA crewmember while allowing them sufficient mobility to perform dexterous EVA tasks in conjunction with the capability of the telerobotics systems.

Design Constraints/Parameters

EVA Duration	Up to 8 hours
Operational Life w/o Maintenance	
Pressure Garment	25 EVA
Avionics / LSS	50 EVA
Vehicle Interfaces / Consumables	
O2 Usage per EVA	0.7 kg
High Pressure O2 Recharge	3000 psi
Water Usage per EVA	2.6 kg (SWME)
Water Recharge	4-25 psi
Estimated Power – IVA	145W
ECLSS	
Operating Pressure Range	0 – 9 psi
Nominal Operating Pressure	4.3 psi
CO2/Humidity Control	RCA
Back-Up Oxygen	30 minutes
Heat Rejection	SWME
Power and Avionics	
Total Battery Energy Storage	1155 kW-h
Network compatible radio w/ HD video capability	10 Mbps
Pressure Garment	
Touch Temperature Range	TBS
Entry Method	Rear
Insulation	Multi – layer TMG
Mobility	
Microgravity (Block 1)	Minimal Lower Torso Mobility
Surface (Block 2 & 3)	Maximum Lower Torso Mobility

Suit Configurations

Block 1	Microgravity [ISS, NEA, GEO]
Block 2	Surface w/ hard vacuum, partial gravity [Moon]
Block 3	Surface w/ CO2 atmosphere, partial gravity [Mars]

Category	Mass, kg
Pressure Garment	58.6
PLSS / Avionics	58.1
Suit Port Interface Plate	7.0
Recharge Umbilical	5.0
Growth	42.8
Unit Dry Mass Subtotal	182.3
Spares for 7 EVA	12.8
Repair Kit	2.3
Consumables	
WMS for 7 EVA	1.5
Unit Inert Mass Subtotal	198.9
Non-Propellant (as launched)	
Oxygen	TBS
Water	TBS
Propellant	N/A
Total Unit Wet Mass	TBD
Total Wet Mass (3 suits)	TBD

SECTION VI
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13. ABSTRACT *(Maximum 200 words)*
This document describes a concept of operations (ConOps) for a habitat element to be used by human crews on future deep space missions; that is, missions well beyond the low Earth orbit of Space Shuttle and International Space Station missions of the past few decades. As one facet of a number of studies conducted by NASA's Human Spaceflight Architecture Team to better understand possible implementations of what the U.S. Human Spaceflight Plans Committee (also known as the Augustine Committee) has named the "flexible path," a workshop was conducted to consider how best to define and quantify "habitable volume" for these future deep space missions. One conclusion reached during this workshop was the need for a description of the scope and scale of these missions and the resulting capabilities needed for a Deep Space Habitat (DSH) element. A group of workshop attendees was established to prepare a ConOps document to address this need. The ConOps, as developed by this group, was structured to identify and capture nominal activities and functions that were likely to occur on the DSH for a range of design reference missions that encompass the currently envisioned flexible path.

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