NASA's Moon to Mars (M2M) Transit Habitat Refinement Point of Departure Design

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***Abstract*— As NASA prepares for the next human footsteps on the lunar surface, the Agency is already looking ahead to systems that will enable a sustained human presence on the lunar surface and mission to Mars, including a lunar Surface Habitat (SH) and Mars Transit Habitat (TH). This paper describes the latest NASA government reference design for the TH and how it will support NASA's Moon to Mars human exploration architecture. First, it will serve as a test and demonstration platform in lunar orbit, demonstrating capabilities required for long-duration microgravity human spaceflight as part of the lunar-Mars analog missions. Then, the TH will serve as a major Mars exploration element to support crew habitation during their transit from the Earth's orbit to Mars and returning safely before TH's return to a lunar orbit. This paper will cover several considerations contributing to the latest habitat design refinement, including the TH's concept of operations, system functional definition, subsystem assumptions, notional interior layouts, a detailed mass and volume breakdown, and identify future trade studies and analyses required to close identified technology/ development/architecture gaps.**

In addition to a technical description of the TH, this paper describes how the current TH government reference design will achieve many of the current lunar and Mars mission goals. Additionally, there are many assumed technological advances needed to support the prescribed mission phases leading up to the crewed mission to Mars in the late 2030s. The paper will describe many of the TH systems requiring further technology development and identify architectural solutions to achieve these mass, reliability, autonomy, and crew health targets.

As a whole, the data shows the government reference TH design meeting the 26.4 metric ton launch /trans-Mars injection burn control mass limit outlined within NASA's Moon to Mars Campaign. This is achievable near the desired timeframe with moderate strategic investments including maintainable life support systems, innovative structures configuration and materials, and system/ logistics packaging.

The resulting design detail and data contained in this paper are intended to help teams across NASA and potential commercial, academic, or international partners understand the current performance targets of the Transit Habitat and vehicle interface considerations imposed by the latest Moon to Mars mission scope.

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1. INTRODUCTION

NASA's Exploration Systems Development Mission Directorate (ESDMD) is developing a strategy for sending humans to the Moon and Mars vicinity, known broadly as the Moon to Mars (M2M) Campaign [1]. Within this effort, the M2M Architecture Development Office (ADO) has been tasked to perform trade analyses and define the capabilities and elements necessary to sustainably expand human presence from low-Earth orbit (LEO) into deep space, the lunar surface, and Mars. The Transit Habitat (TH) plays a critical role in the M2M campaign due to its ability to support the crew during analog missions in cis-lunar orbit and then serve as the primary habitation system for the journey to and from Mars.

A critical part of the M2M campaign is the development of in-space habitation systems capable of substantially extending the human presence beyond LEO. An extensive list of functional vehicle and crew system capabilities is required to support crewed deep-space exploration. The M2M campaign leverages missions in lunar orbit and on the lunar

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surface to ready crew and supporting technologies for its Mars mission.

NASA's Mars missions feature an in-space TH capable of independently supporting four crew on long-duration missions of up to 1,200-days, which includes transit to and from Mars and time in Mars orbit. The TH is a complex element which must keep its crew healthy and productive. Primary challenges for development of TH systems include the deep-space environment with limited resupply, no short-duration abort opportunities, and significant communication delays. These challenges are present alongside the traditional spacecraft constraints: mass, volume, and power. The TH needs to provide habitable volume for four crew to adequately live and perform their duties while also accommodating the extensive amount of equipment (including spares) and food/consumables necessary for a long-duration mission. The TH systems must provide a reliable atmosphere, clean water supply/processing, nutrient rich food, sleeping quarters, exercise equipment, and sufficient workstations to support crew tasking.

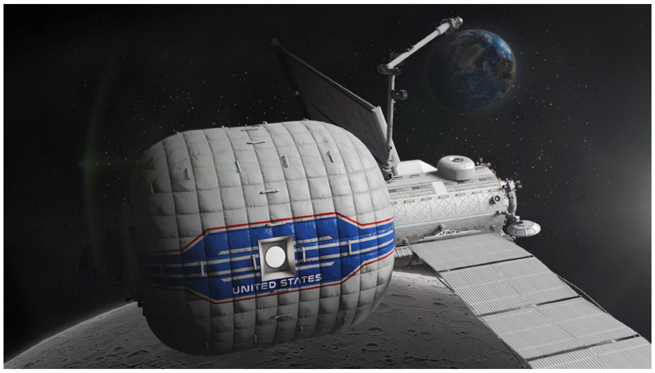


Figure 1: TH Free-Flying in Cis-lunar Space

In addition to supporting the Mars transit mission, the TH will be utilized in cis-lunar space to augment NASA's Gateway, a multi-purpose outpost stationed in lunar orbit. TH will extend Gateway's crewed duration capability and support lunar-Mars analog missions which will demonstrate integrated operation of long-duration habitation subsystems prior to Mars departure. Analogs will simulate crew and system operational scenarios planned for the Mars mission. These simulated Mars transit analogs will occur while TH is docked to Gateway and involve crewed missions to the lunar surface and return via the Human Landing System (HLS) to Gateway. These missions allow integrated testing of systems and operations in a relevant spaceflight environment, for representative durations, without taking on the risk of 'no abort' trajectories common in Mars missions. These early shakedown missions also allow corrective actions such as subsystem replacement or upgrades if a problem is found.

A government reference conceptual TH design has been developed and refined by the NASA Habitation Systems Development Office. It reflects the latest M2M architecture and establishes a technical basis for a future TH acquisition. It is important to note that since the TH will be acquired commercially, the design of the 'as-built' hardware will vary from the design presented in this paper. The Concept of Operations (CONOPS) presented in this paper are notional and subject to change as architectural trades and assessments continue within the M2M campaign. The purpose of this paper is to document the latest conceptual design for reference by internal NASA programs and projects looking to better understand the assumptions, performance, operations, interface, and capability needs of the TH within the M2M Campaign.

2. MISSION ARCHITECTURE CONTEXT

NASA's Artemis program seeks to return humans to the moon and enable sustainable exploration of the lunar surface, with the additional goal of using the moon to develop and advance technologies to support eventual Mars exploration. The TH will be launched and become part of the M2M architecture in the early 2030s. At this point in time, the Lunar Gateway will be well established as an orbiting platform in a lunar Near-Rectilinear Halo Orbit (NRHO) and supporting crewed surface missions via the HLS. Gateway also supports lunar surface systems to enable a sustained lunar presence.

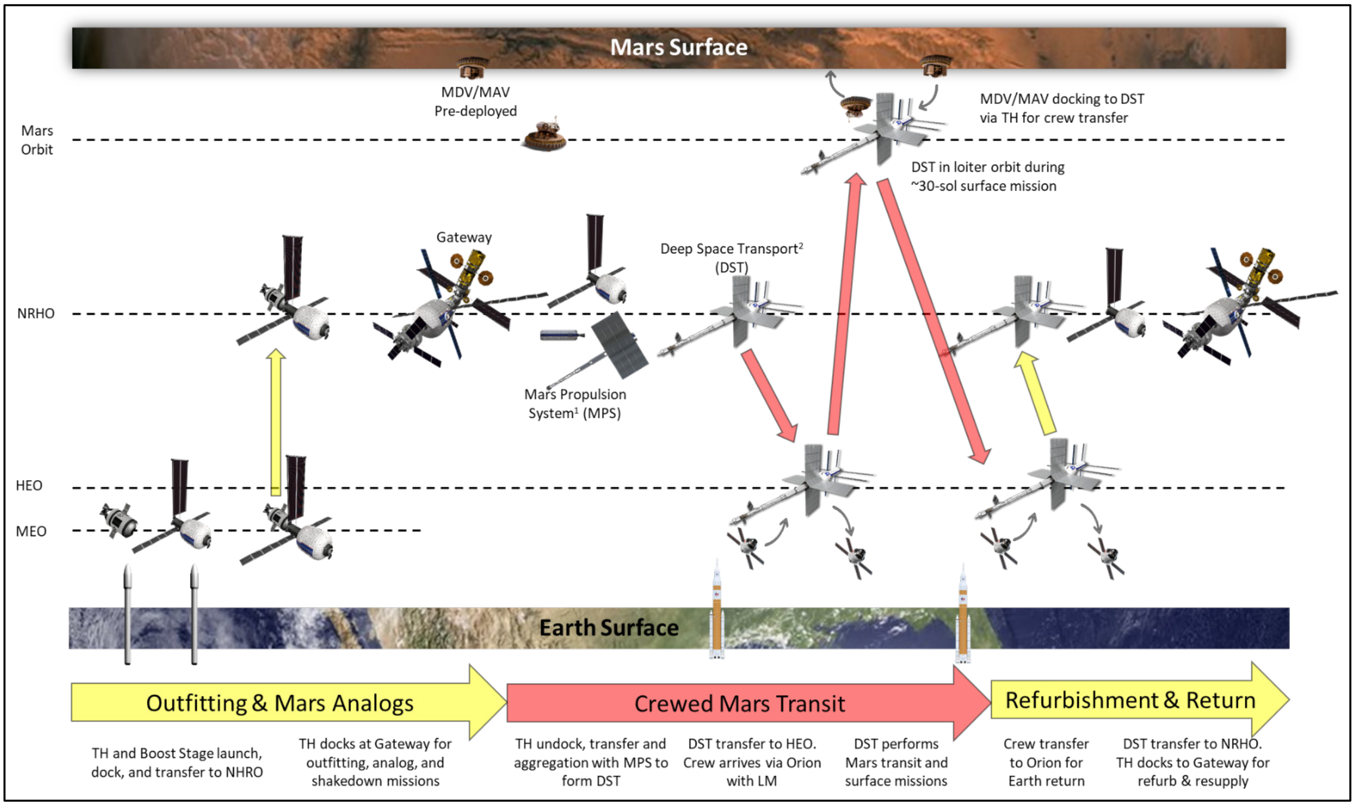
While TH is docked at Gateway and undergoing its full deployment and outfitting, numerous logistic modules (LM) will be launched as part of Gateway Logistics Services (GLS). These LMs will supply the TH logistics outfitting effort alongside on-going Gateway and lunar surface analog missions. In parallel, several Mars-focused elements will be launched in preparation for the Mars surface missions [9]. In the mid/late-2030s, the Mars Propulsion System (MPS) elements will launch and aggregate in NRHO before docking with TH to form the Deep Space Transport (DST) crewed variant. Cargo variants of the DST will pre-deploy several elements to Mars. The Mars Descent Vehicle (MDV) will be delivered to Mars orbit and later dock with TH for the crew-to-surface transfer. The Mars Ascent Vehicle (MAV) and supporting Mars surface systems will pre-deploy to a pre-determined surface location. At the end of a crewed surface stay, the MAV will launch to Mars orbit and dock with the DST via TH, which will begin the crew's return transit to Earth.

3. MISSION PHASES

The primary objective of the TH is to support a crewed mission to Mars, and it will go through three key phases throughout its 15-year operational life.

1. Outfitting and Mars Analogs
2. Crewed Mars Transit
3. Refurbishment and Return Readiness

These three phases within the TH mission objective can be further divided into seven operation activities.



[1] MPS notionally shown as NEP/Chem. SEP/Chem, NTP, all-Chem also in trade space

[2] DST shown as notional MPS/TH configuration

Figure 2: TH Mission Phases & Activities

Deployment and Activation

The TH and a boost stage will launch via separate Commercial Launch Vehicles (CLV) to Medium Earth Orbit (MEO) (200x20,082 km). The TH will autonomously deploy and function independently prior to docking with the boost stage and initiating the requisite trans-lunar injection (TLI) burn to NRHO and subsequent Gateway docking. The boost stage will be disposed after transferring the TH to NRHO, but before TH docks with Gateway.

Initial Gateway Crewed Mission

TH will dock with Gateway while both vehicles are un-crewed. TH acts as the chasing vehicle and must comply with Gateway's Rendezvous, Proximity Operations and Docking/Undocking (RPOD/U) Targets. The TH Reaction Control System (RCS) will be used to control the TH during RPOD. Once TH docks to Gateway, it will extend Gateway's habitable duration beyond 60 days. The initial crewed mission will include sub-system and logistics outfitting activities and system check-out operations. This activity is fundamentally different from the subsequent analog missions where the TH will operate as independently as possible from Gateway while remaining docked.

Lunar-Mars Analog Missions

While docked at Gateway, TH will be utilized to simulate Mars transit and surface missions. Crewed missions include a simulated Mars transit in the isolated TH (while remaining docked to Gateway) and a simulated Mars surface mission using HLS to transport crew to/from the lunar surface.

The analog missions will occur routinely and vary in duration. The objectives of these analog missions include:

- Research, demonstrate, and test human performance for incrementally longer durations in deep space
- Test and demonstrate TH sub-systems operation and performance to increase confidence in long-duration crewed operational periods and un-crewed dormancy periods
- Refine planned maintenance and sparing needs
- Aggregate logistics for first Mars Mission
- Gradually deploy logistics using GLS

To meet these objectives, TH will be required to operate as independently as possible during the attached shakedown and analog missions.

Missions include a simulated four crew transit followed by a simulated Mars surface mission on the lunar surface. All lunar surface missions are planned to include four-crew, however only two crew are planned for the Mars surface mission [10].

Logistics Buildup for Mars Missions

The systematic buildup of logistics and equipment is needed for the TH Mars mission. A massive amount of logistics (i.e.

food, equipment/spares, consumables, etc.) is required for the Mars mission. This buildup of logistics will occur gradually by utilizing GLS missions. It is anticipated that the delivered logistics will be stored in TH, however there may be potential to utilize free space within Gateway modules on a temporary basis.

Deep-Space Transport Aggregation

Prior to aggregation of the DST vehicle, the TH and MPS will both have undergone their respective shakedown operations. The uncrewed TH will undock with Gateway and, under its own propulsion, transfer to and dock with the MPS in NRHO. TH will be capable of receiving power from the MPS in addition to sharing thermal fluids across the docking adapter. Data will be shared between the DST elements, with the TH facilitating the crew's nominal control of the integrated vehicle. The RCS on the MPS will be utilized for primary vehicle control, with the TH RCS available to assist with orientation control in a contingency. Communications will be routed through the TH, however the MPS will provide primary communications hardware.

Mars Transit Mission

After successful aggregation and autonomous/remote system checkout and shakedown, the DST will transfer to HEO orbit and dock with the SLS launched Orion and co-manifested LM. Orion and the LM will dock with the DST via the TH radial docking port. Final logistics and all four crew will transfer to TH and then Orion with the LM will un-dock.

The crewed DST will initiate the Trans Mars Injection (TMI) maneuvers, marking the start of the transit mission from Earth to Mars orbit. Transit duration is largely a product of the final MPS design and departure mass. Multiple MPS options and trajectories are being traded within the M2M architecture. MPS is responsible to perform the necessary burn maneuvers and course corrections. Trash will be jettisoned regularly throughout the transit phase to reduce overall TH mass. The TH will be reliant on supplemental power from the DST, as its solar arrays are sized for use at 0.6-1.6 astronomical unit (AU) [2].

The MDV will dock via the TH radial docking port and the crew will transfer to the Mars surface and conduct a planned 30-sol mission [10]. Following the surface mission, the crew will utilize the MAV for their return and transfer to the TH after docking. The MAV will undock with the TH and the DST initiates return transit propulsion maneuvers. The DST will return to HEO and dock with the Orion capsule for final crew transfer and return to Earth's surface. Once crew transfer is complete, the DST will autonomously return to NRHO.

Refurbishment for Second Mars Mission

Following completion of the first Mars mission and return to NRHO, the TH will autonomously undock from the DST and return as a visiting vehicle to Gateway. Subsequent Mars missions will require that the TH undergo refurbishment and resupply activities including various vehicle and system-level inspections and replacement of system hardware. This would involve a series of crewed and uncrewed missions. Additional activities may also permit and extend the TH service life beyond 15 years.

Logistics for the refurbishment mission(s) and subsequent Mars mission will be delivered via GLS to Gateway. It is anticipated that this logistics build-up will be occurring while the first Mars mission is in progress. Depending on the LM and GLS capabilities, multiple deliveries may be required to resupply the TH and dispose of remaining waste goods and spent equipment.

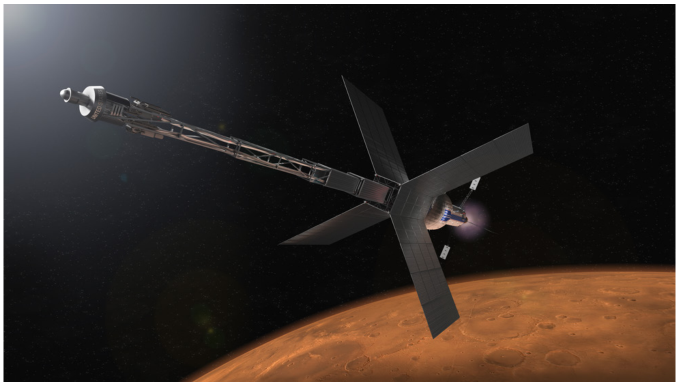


Figure 3: Notional DST using NEP/Chem MPS variant

4. CHALLENGES

TH is a complex element within the M2M architecture as it must complete several critical mission phases and maintain crew health and safety across the unforgiving deep-space operating environment. Deep-space exploration has inherent physical, crew-health, and operational challenges which require unique system design criteria to address limited resupply opportunities, significant communication delays and interference, increased radiation exposure and solar particle events (SPE), and no short-duration mission abort opportunities. A multi-day safe-haven configuration must be considered in the design in order to provide a means for crew to recover the TH following a major habitation system failure. The capability has the potential to significantly reduce risk to crew safety.

In addition to the environmental challenges, the TH also must interface with several architectural elements throughout its design life. Each element interface requires both physical and functional definition for the distinctive role in the M2M campaign. Therefore, the TH must be designed to operate independently as a free-flying vehicle. To accommodate the challenges of each distinct mission phase, the TH integrates and relies on other elements within the M2M architecture.

Each mission phase and subsequent activity presents its own unique challenges:

- The initial phase of the overall TH mission prepares it for the subsequent primary goal of reaching Mars. The TH will spend several years at Gateway which requires thorough design and operation integration consideration. Coordination between TH and Gateway is required for control of the integrated vehicle (including impacts from HLS, Orion, and LMs simultaneously docked at Gateway), communications, power, etc.

- Fully outfitting and testing TH sub-systems while simultaneously loading the substantial logistics manifest for its Mars transit mission will be a delicate operational balance for the crew. TH design considerations must consider parallel Mars-focused analog missions and Mars transit preparation.

- The crewed Mars transit mission provides an unforgiving operational challenge for the TH, its crew, and systems. The TH must be able to support a point of departure mission lasting up to 1200-days without resupply chains or short-term mission abort capability. It must also be designed or configured to mitigate the increased radiation and MMOD exposure (including GCR, SPE events). TH will dock with multiple pre-deployed Mars architectural elements (MDV, MAV, etc.) and must fully integrate physically and operationally to ensure crew safety and mission success.

- Refurbishment of the TH at Gateway following the initial Mars mission presents an opportunity to retrofit and/or replace specific system hardware, but this must be a design consideration for the initial configuration. The timeline between Mars missions is TBD at this time, however the TH must have the flexibility to adjust and comply to be retrofitted and resupplied in a timely manner.

Before the TH can address the M2M exploration mission complexities, several system technology and development gaps must be addressed. Advancements in existing habitation/vehicle systems must be leveraged to ensure the TH can successfully carry out all mission phases and objectives. Advanced food storage (low mass/power freezers), regenerative Environmental Control and Life Support Systems (ECLSS) with advanced O2 recovery, and crew health/performance systems will be required to monitor and keep the crew healthy. Thermal, power, and communication systems must be sufficiently designed for radiation exposure operation.

The TH must also account for a variety of contingency operations in the deep-space environment. Solutions and emergency operations currently used on heritage crew rated systems may not carry over for the TH Mars mission. The TH must also withstand an extended quiescent period of up to 3 years which may drive hardware selection and need for further system autonomy.

5. GROUND RULES AND ASSUMPTIONS

To help scope the design needs and constraints for the TH, a set of ground rules and assumptions (GR&A) has been developed which also acts as notional design requirements. A NASA technical memo [2] was published in 2022 to outline the GR&As and system level capabilities for the TH design. These GR&As have helped to refine the NASA government reference design and to assist in the verification of initial requirements. They are also a means of communicating constraints and capabilities to agency leaders and commercial partners. This ensures that the TH as envisioned and designed is in concert with agency priorities and exploration objectives. A functional assessment of the TH within the latest M2M architecture GR&As has also been considered and implemented in the latest TH definition.

Refer to Reference [2] for a complete set TH GR&As and functional capabilities.

6. TH DESIGN DESCRIPTION

The government reference TH conceptual design has been considerably modified since the previously published configuration in Reference [8]. This refined configuration reflects changes to functional requirements driven by the evolving M2M architecture and a shift in the TH primary structure. The TH outer mold line (OML) now reflects a hybrid structure consisting of two compartments: one a 3-meter diameter metallic cylinder and the other a large, 8-meter diameter softgoods inflatable. The internal and external configurations have been updated to reflect the latest TH, Lunar and Mars Architecture GR&As. Due to the fact that TH is planned to be acquired commercially, and the M2M architecture may change due to continued trade studies and assessments, the TH design characteristics described herein will vary from future 'as-built' hardware.

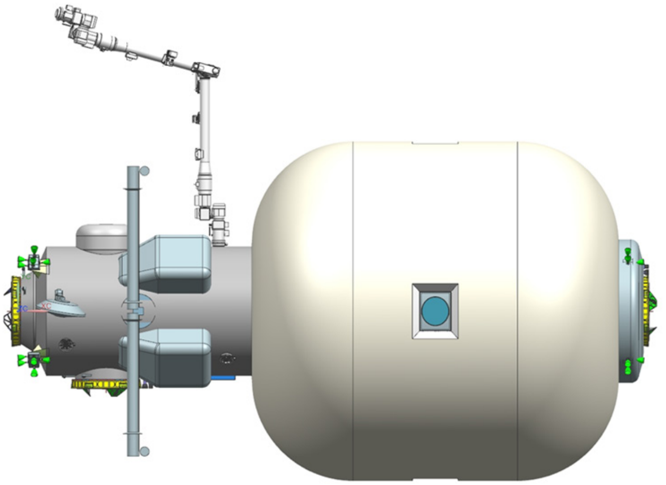


Figure 4: TH Outer Mold Line

External Features

For the NASA reference design configuration, a hybrid configuration with both inflatable and metallic sections was selected. Much of the habitable volume is provided by the inflatable section, while the metallic section accommodates the radial docking port, EVA hatch, solar array, radiators, and propulsion components. To support the inflatable compartment, there are a six longerons and shear panels within the pressurized volume. Additional cross-members are included as needed between the longerons for subsystem pallet support. There are no plans to mount hardware externally to the softgoods structure.

The inflatable portion has a total OML volume of approximately 360 m^3 while the metallic portions have a total OML volume of 40 m^3. The TH therefore contains approximately 400 m^3 of pressurized volume. The nominal operating pressure of the habitat is 14.7 psia (101.3 kPa), with a Maximum Design Pressure of 15.2 psia (104.8 kPa) and the ability to operate at 10.2 psia (70.3 kPa) when docked (open hatch) with Gateway.

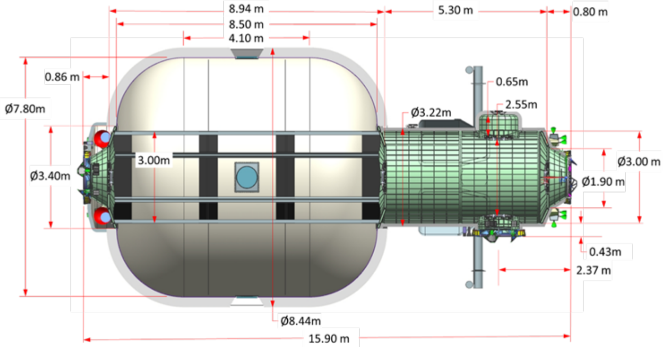


Figure 5: TH External Dimensions

The TH requirements for large habitable volume with an overall architecture sensitivity to mass provide a challenge for primary structure design. Metallic designs that fit within available CLV payload fairings, such as ones based on heritage metallic International Space Station (ISS) modules, have high mass due to inherent size inefficiencies and the need to include multiple separate modules. Larger diameter designs utilizing lightweight metallic materials and advanced manufacturing processes may be able to achieve the volume/mass needs but would have limited launch vehicle options.

Inflatable softgoods structures have the ability to provide the needed volume/mass efficiency within a smaller launch diameter, thus maximizing launch vehicle options. Design factors of safety, material qualification and loads assessment criteria are specified in "Certification Guidelines for Crewed Inflatable Softgoods Structures" [6]. Incorporation of external load-carrying components into the softgoods primary structures (i.e. docking/EVA ports, solar arrays, radiators, propulsion) adds complexity to certification testing. Since softgoods structures are launched in a deflated state, deployment (pressurization), system location and outfitting configuration must be considered in the design.

The NASA reference TH design provides ample pressurized volume via the softgoods compartment while accommodating the necessary external system hardware mounting real estate via the metallic portion.

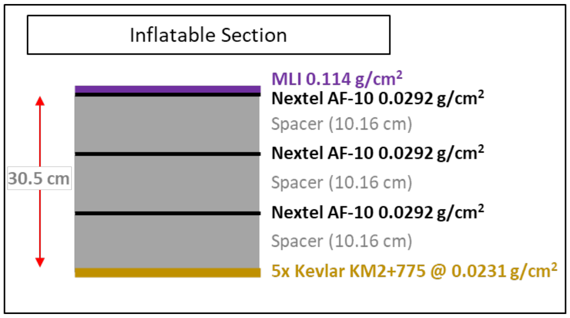


Figure 6: Softgoods Cross Section Configuration

The inflatable section of the habitat consists of the softgoods and the internal core structure. Figure 6 provides a notional cross section of the softgoods composite makeup. A bi-directional weave of hoop straps and axial straps makes up the primary structure restraint layer of the inflatable softgoods, which connects to clevises at the end bulkheads shown in Figure 7. Beneath the restraint layer is the air barrier, which is made up of three layers of air barriers sandwiched between four layers of Kevlar felt with a Nomex scuff layer.

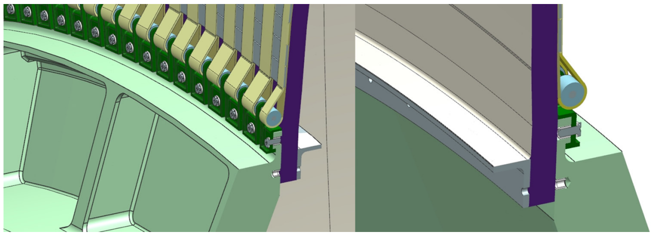


Figure 7: Softgoods to Bulkhead Interface

In addition to these layers, the softgoods can be modified to include window(s) based on a patented NASA design. Each window consists of an Al-Li 2050 frame with clevises for the restraint layer and can be placed anywhere in the cylindrical section with a minimum of 10 hoop straps between the end of the toroid tangency and the window frame. The TH design has four windows implemented in the center of the inflatable barrel area.

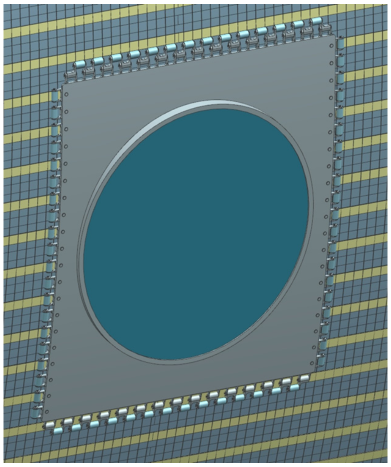


Figure 8: Integrated Window Frame

The TH core structure consists of Al-Li 2050 single piece end bulkheads, six longerons, and shear panels. Each bulkhead features a 0.95 m square intra-vehicular activity (IVA) hatch opening. The graphite-epoxy sandwich shear panels attach to the longerons to distribute the loads along core interface of the bulkheads. An additional six shear panels are included in the middle of the core to add resistance to torsion and buckling of the longerons.

The metallic sections of the TH are designed from Al-Li 2050. Four 90-degree barrel panels are joined to one of the inflatable section bulkheads to form the 3.0 m diameter long compartment. These panels have an internal ortho-grid and smooth OML. Two of the panels include welded bulkheads to support the EVA hatch and the radial docking port vestibule. The ends of the barrel panels are welded to a bulkhead containing a 0.95 m square IVA hatch opening. At both ends of the TH, a docking port vestibule is bolted to the corresponding bulkhead.

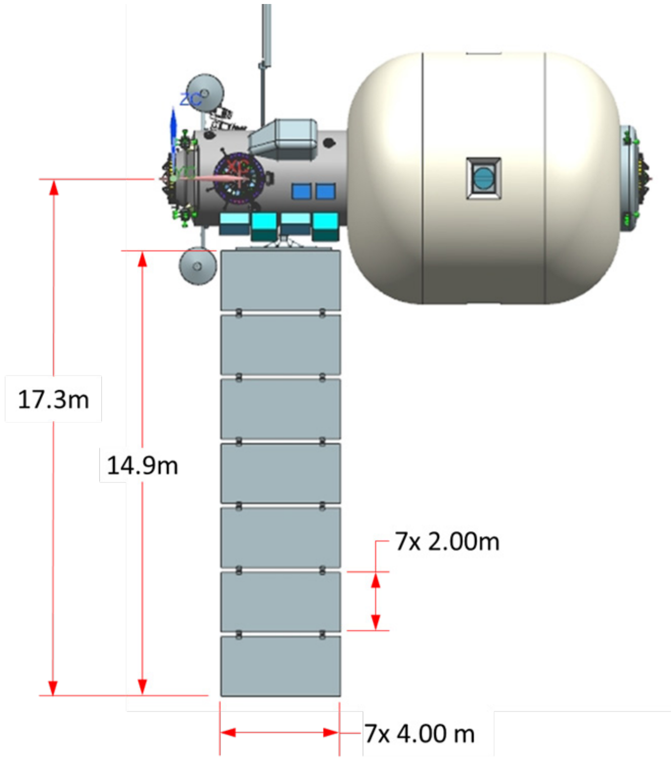


Figure 9: TH with Fully Deployed Radiator Panels

The TH includes three docking systems that meet Gateway Docking Subsystem requirements. The inflatable axial port is an active system, the metallic axial port is a passive system, and the radial docking port is androgynous. A fourth external hatch exists opposite to the radial docking port for contingency EVAs and trash jettison.

Due to the nature of the softgoods inflatable structure, externally mounted hardware is located primarily on the metallic compartment. The TH power system uses a single Roll-Out Solar Array (ROSA) which is clocked 90 degrees to the radial airlock and 180 degrees to a single Thermal control system (TCS) collapsible radiator panel. TCS pump packages, cold plates, heat exchangers, communication antennas, and an external robotic arm comprise the significant hardware mounted to the metallic compartment OML. To accommodate contingency EVAs, grapple fixtures and handrails will be notionally positioned. RCS nozzles and propellant/pressurizer tanks are externally mounted to both the metallic compartment and to the softgoods axial bulkhead port. There is no planned external stowage for the TH. An ISS derived Bishop Airlock is planned for use on the radial contingency EVA radial hatch for trash jettison.

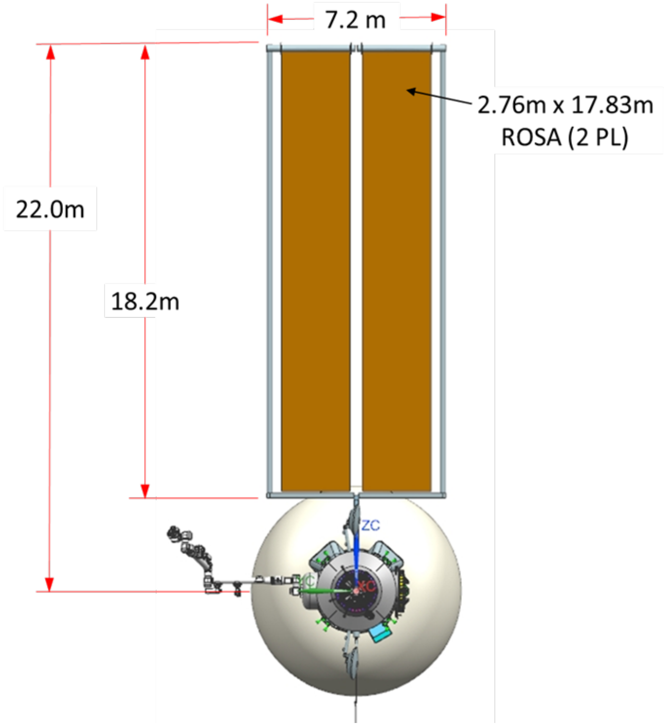


Figure 10: TH with Fully Deployed Solar Array

Internal Layout

Interior outfitting of inflatable structures is complicated by the need to deploy or manually place components after inflation that cannot be accommodated within rigid core structures. Therefore, the as-launched configuration of the TH will need some degree of final outfitting before becoming formally operational. All primary system hardware and internal structure is planned to be configured for launch and deployed autonomously or by crew after TH docks at Gateway.

The notional internal TH layout uses dimensions from the external OML and representative system hardware dimensions. The inflatable portion of the TH was the main focus of the notional layout since this will be the primary habitable volume. The layout's required functionality, minimal net habitable volume, and minimal functional dimensions are derived from the "Human Integration Design

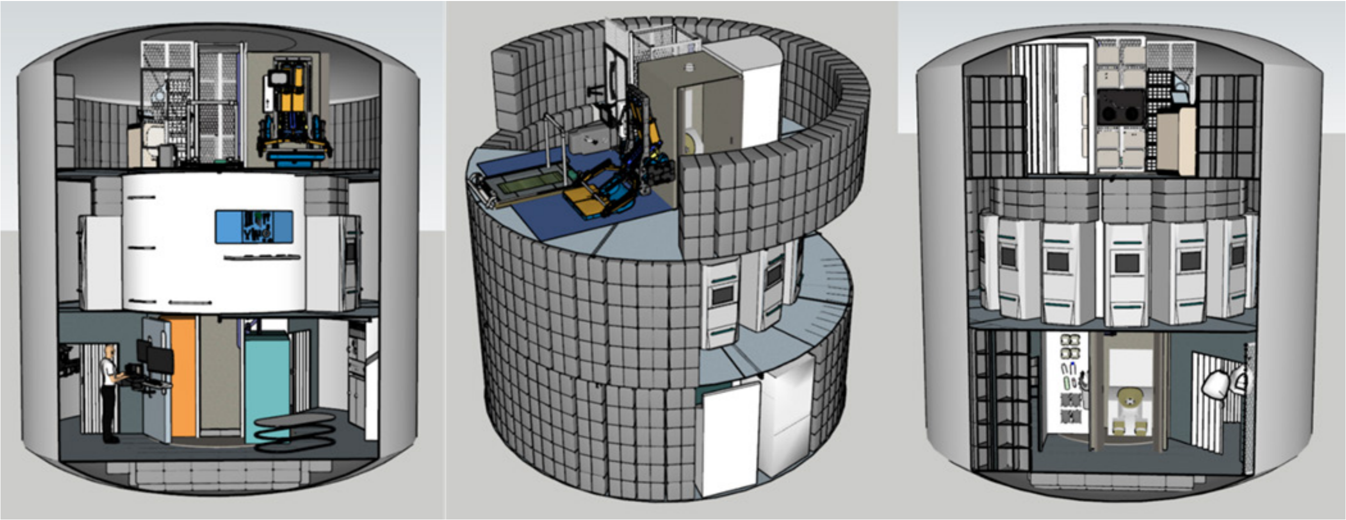


Figure 11: TH Inflatable Compartment Cross Sections

Handbook" [7]. The process used to define these recommendations is described in "Defining the Required Net Habitable Volume for Long-Duration Exploration Missions" [5].

The TH inflatable interior is approximately 7.8 m in diameter and 8.5 m long with a 3 m inner core diameter. This portion of the TH encloses approximately 342 m^3 of pressurized volume with 55 m^3 allocated to stowage, 30 m^3 for vehicle systems equipment, 22 m^3 in voids and unused space, and approximately 235 m^3 habitable volume at the start of the Mars transit mission. For four crew, this is nearly 59 m^3 per crew member, and increases during the Mars transit mission after logistics have been consumed and jettisoned.

There are three separate levels in the inflatable portion of the habitat. Each level is accessed by a translation path through the inner core and through gaps in the floors between levels. Logistics are stowed on board and stowage is dispersed throughout the habitat, lining the outer edges of the habitable areas to simplify logistics access and allow logistics mass to perform double duty as crew radiation protection. The first level is adjacent to the metallic airlock compartment and includes the galley, medical and washing station, one of two Universal Waste Management Systems (UWMS), trash management, and a command & control station. Additional volume is allocated on the first level for sub-systems dedicated to power, avionics, food processing, and thermal systems. The second level provides space for the crew quarters, sub-system racks and maintenance stations. The layout includes locations for 10 universal pallets dedicated to ECLSS on the second level. The third level includes the second UWMS, multiple exercise equipment units, a hygiene station and additional stowage.

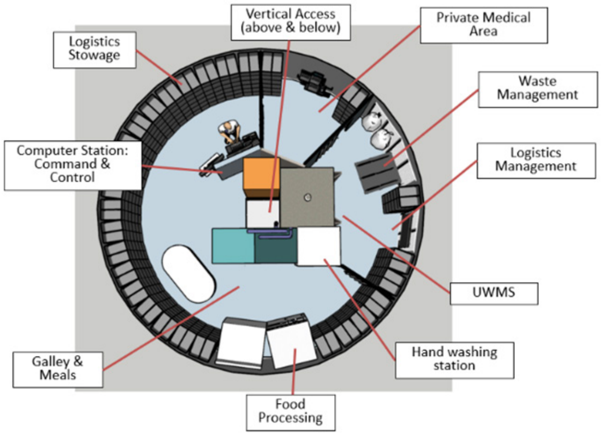


Figure 12: First Level of TH

The first level functionality is allocated to a large, open area with a galley, open space for recreation and a command & control station with access to monitors. The first level also contains a private medical station with a computer station and access to a medical stretcher. There are also two workstations for waste management and logistics management, a UWMS, and a small hygiene station dedicated to hand washing.

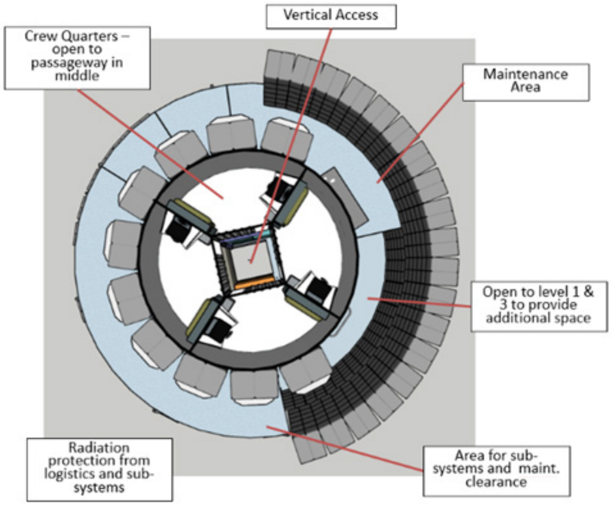


Figure 13: Second Level of TH

The second level contains four crew quarters of equal size and functional space for the ECLSS and sub-system access. There is also a maintenance workstation located adjacent to the systems for ease of access, repair, and routine maintenance.

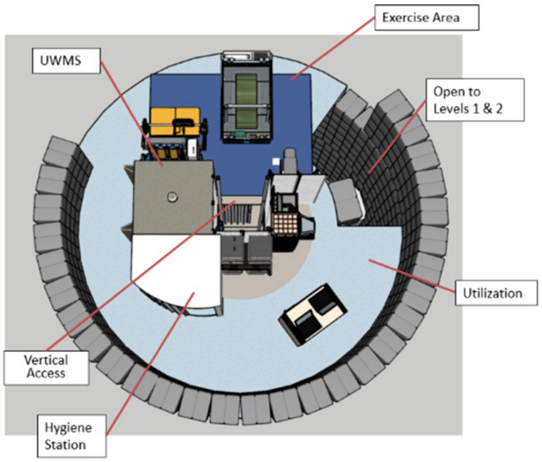
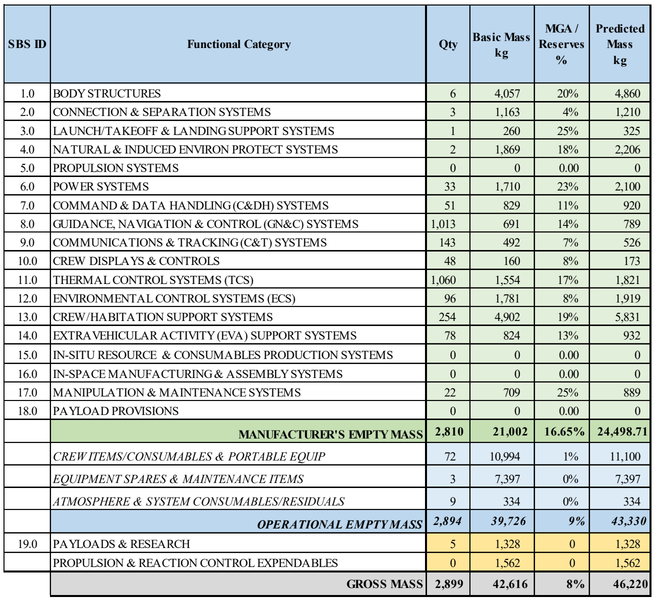


Figure 14: Third Level of TH

The third level provides space for a full exercise station with a treadmill, resistance system, and a resistive/aerobic device. It hosts a large area for utilization with three science workstations. There is one UWMS and one large hygiene station. Storage lines the walls.

7. MASS OVERVIEW

The TH mass is separated into categories to best manage within the M2M architecture. The "dry" or control mass is the metric used to convey the basic TH configuration primarily for use by CLV providers and the MPS. The "wet" or total mass metric reflects the TH mass configuration just prior to is long-duration Mars transit mission. The control mass for the TH is 26.4 metric tons. The fully loaded, Point of Departure (PoD) TH mass configuration varies greatly on the Mars transit mission duration. This is due in part to the variability of food storage needs, system spares and maintenance items, and additional crew systems and consumables. The variable TH PoD mass also includes the crew members, RCS propellant and 1000 kg allocated to science/utilization. Altogether, the wet mass can be nearly double the control mass as shown in Figure 15.



SBS ID	Functional Category	Qty	Basic Mass kg	MGA / Reserves %	Predicted Mass kg
1.0	BODY STRUCTURES	6	4,057	20%	4,860
2.0	CONNECTION & SEPARATION SYSTEMS	3	1,163	4%	1,210
3.0	LAUNCH/TAKEOFF & LANDING SUPPORT SYSTEMS	1	260	25%	325
4.0	NATURAL & INDUCED ENVIRON PROTECT SYSTEMS	2	1,869	18%	2,206
5.0	PROPULSION SYSTEMS	0	0	0.00	0
6.0	POWER SYSTEMS	33	1,710	23%	2,100
7.0	COMMAND & DATA HANDLING (C&DH) SYSTEMS	51	829	11%	920
8.0	GUIDANCE, NAVIGATION & CONTROL (GN&C) SYSTEMS	1,013	691	14%	789
9.0	COMMUNICATIONS & TRACKING (C&T) SYSTEMS	143	492	7%	526
10.0	CREW DISPLAYS & CONTROLS	48	160	8%	173
11.0	THERMAL CONTROL SYSTEMS (TCS)	1,060	1,554	17%	1,821
12.0	ENVIRONMENTAL CONTROL SYSTEMS (ECS)	96	1,781	8%	1,919
13.0	CREW/HABITATION SUPPORT SYSTEMS	254	4,902	19%	5,831
14.0	EXTRAVEHICULAR ACTIVITY (EVA) SUPPORT SYSTEMS	78	824	13%	932
15.0	IN-SITU RESOURCE & CONSUMABLES PRODUCTION SYSTEMS	0	0	0.00	0
16.0	IN-SPACE MANUFACTURING & ASSEMBLY SYSTEMS	0	0	0.00	0
17.0	MANIPULATION & MAINTENANCE SYSTEMS	22	709	25%	889
18.0	PAYLOAD PROVISIONS	0	0	0.00	0
	MANUFACTURER'S EMPTY MASS	**2,810**	**21,002**	**16.65%**	**24,498.71**
	CREW ITEMS/CONSUMABLES & PORTABLE EQUIP	72	10,994	1%	11,100
	EQUIPMENT SPARES & MAINTENANCE ITEMS	3	7,397	0%	7,397
	ATMOSPHERE & SYSTEM CONSUMABLES/RESIDUALS	9	334	0%	334
	OPERATIONAL EMPTY MASS	***2,894***	***39,726***	***9%***	***43,330***
19.0	PAYLOADS & RESEARCH	5	1,328	0	1,328
	PROPULSION & REACTION CONTROL EXPENDABLES	0	1,562	0	1,562
	GROSS MASS	**2,899**	**42,616**	**8%**	**46,220**

Figure 15: TH Mass Summary

Significant attention has been given to the Master Equipment List (MEL) provided in Appendix A as it captures the detailed mass breakdown across each of the TH systems. The MEL is organized by function rather than discipline. A similar MEL was provided in the 2017 TH Design Refinement paper [8] and can be used as a basis to compare. As the TH CONOPS has continued to change and each sub-systems' architecture has matured around the GR&As, the MEL is revised. Each system owner applies a Mass Growth Allowance (MGA) for their system components which reflects the current technical maturity. While not shared within this paper, additional system margin and Program Manager's Reserve (PMR) is carried against the TH MEL to be used while integrating within the architecture modeling and launch/MPS integration levels.

The TH control mass has grown since the publication of Reference [8]. This is largely due in part to overall system and CONOPS maturation which now leverages more TH-specific designs. Additional GR&A criteria were introduced, such as Safe Haven capability which drives the duplication of some system level hardware and sparing postures. While there have been increases to several systems, the TH structural design has decreased due to improvements in how to model and integrate the softgoods and its internal structural requirement with the adjacent metallic compartment.

8. SUMMARY AND FUTURE WORK

The TH is a complex vehicle and is vital to the M2M architecture. It will be the first vehicle of its kind to travel to deep-space and transport humans to Mars. The time spent on potential free-flying missions and while docked to Gateway in cis-lunar space before transiting to Mars will be instrumental in proving new technologies critical for a successful Mars mission. Continuing to mitigate the risks will be key to enabling a human Mars mission in the late 2030s.

The NASA TH reference design reflects a significant update based on the impacts from across the M2M campaign. Mission objective and element interface details have emerged driving the need for optimized capability and margin. The subsequent mass has reflected this situation. As the TH design concept definition matures existing vehicle and broader architecture GR&As will need to be continually challenged to understand impacts and necessary system modifications.

Additional studies will be required to continually refine the TH concept design and how it integrates with the major M2M elements. Mainly, the TH must continue working to define the integrated CONOPS when docked at Gateway and later aggregated with the MPS to form the DST. Detailed system interface and operational capability assessments are critical for much of the TH life spent docked to Gateway or the DST. These details and assessments are on-going and impact all TH systems.

By representing the NASA TH design as a hybrid softgoods/metallic structure, the TH team will continue to pursue this unprecedented approach for long-duration and deep-space habitation system. Continued efforts to define specific outfitting constraints and considerations is required, especially within the designated TH CONOPS. These constraints may drive further need for autonomous systems operation and overall vehicle management.

In conjunction with the NASA Crew Health and Performance teams, the TH design must continue to reflect systems and capabilities supporting the long-duration mission impacts to crew health and well-being. This on-going assessment influences design decisions and requirements related to interior layout, on-board crew support systems, and ECLSS capability.

The TH design will be further influenced by the abovementioned studies and assessments in addition to possible changes to the planned M2M architecture. Control mass and outfitting strategy alongside TH's integration development with Gateway and MPS options will remain primary focus items for continued TH design options. Finally, the on-going effort to assess known habitation system capability gaps and the planned paths to close these gaps through testing and technology maturation are documented in Reference [11].

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BIOGRAPHY

Andrew Choate *leads the Mars Transit Habitat concept design team within the NASA Habitation Systems Development Office at the Marshall Space Flight Center. He obtained a B.S. in Mechanical Engineering from Carnegie Mellon University in 2008 and a M.S. in Systems Engineering from Worcester Polytechnic Institute in 2013. Prior to joining the NASA team in 2020 as a support contractor with the Jacobs Space Exploration Group, Andrew worked in the private sector on commercial jet engine and Orion ECLSS hardware development.*

Paul Kessler *received a Bachelor's in Biology and an M.S. in Aerospace Engineering from the University of Colorado in 2005 and has worked for DoD since 2006 and NASA since 2008 as both a contractor and civil servant. He currently works in the Habitation Systems Development Office at MSFC as the lead architect for the Lunar Surface Habitat (SH). Prior to MSFC he worked at NASA Langley Research Center as a systems analyst for human exploration of space and the Science Mission Directorate. He also worked as the lead analyst for the Committee on Earth Observation Satellites (CEOS) System Engineering Office (SEO) at Langley Research Center.*

Tiffany Nickens *serves as the Systems Engineering & Integration (SE&I) Lead for NASA's Habitation Formulation Team supporting the Exploration Systems Development Mission Directorate (ESDMD). In this role, Nickens supports technical and programmatic integration of habitation government reference architectures as well as engagement with commercial partners. She previously supported Avionics/Flight Software design and development on the Space Launch System (SLS) program. Prior to joining NASA in 2017, Nickens worked in the private sector on primary flight displays for rotorcraft and fixed-wing aircraft. She received a bachelor's in human factors and a master's in human factors and systems engineering from Embry-Riddle Aeronautical University.*

Matthew Simon *is the Capability Integration Deputy for the Exploration Systems Development Mission Directorate responsible for characterizing and assessing the capability gaps required to achieve future human exploration missions. He has previously served as the Mars TH Lead designing space habitat and mission concepts for NASA's Moon to Mars architecture. In addition to these roles, Dr. Simon supports multiple other NASA projects on spacecraft design, habitation, medical capability development, strategic decision analysis, and technology portfolio characterization. He received his Ph. D. in Aerospace Engineering from Georgia Tech in May 2016 with his thesis on automated spacecraft interior layout evaluation and design.*

Danny Harris *is the NASA Marshall Space Flight Center Manager for Habitation Systems Development. In addition, Mr. Harris also serves as the NASA Human Exploration and Operations Mission Directorate Strategy and Architecture Lead for Habitation and manager for the Next Space Technologies for Exploration Partnerships (NextSTEP) Habitation Systems, a program which uses public-private partnerships to enable commercial development of deep-space exploration habitats. Prior to this work, Mr. Harris held a variety of program/project management and engineering leadership positions including serving as the NASA Headquarters Space Technology Mission Directorate (STMD) Deputy Chief Engineer, the Science Mission Directorate Deputy Chief Engineer, overseeing the implementation of the STMD Technology Demonstration Missions program portfolio of technology projects, as well as work on the Lunar Atmosphere and Dust Environment Explorer (LADEE) and Lunar Crater Observation and Sensing Satellite (LCROSS) missions, International Space Station (ISS) Environmental Control and Life Support Systems (ECLSS), and ISS flight element development. Before joining NASA, Mr. Harris worked for McDonnell Douglas and The Boeing Company, following the merger of the two companies, as a Thermal Control and ECLSS engineer on the Spacelab and International Space Station programs.*

APPENDIX A: MASTER EQUIPMENT LIST

SBS ID	COMMON FUNCTIONAL CATEGORY (TIER 1) COMMON EQUIPMENT GROUP (TIER 2) UNIQUE COMPONENT/SUB-ASSEMBLY (TIER 3)	Qty	Unit Mass (kg)	Basic Mass (kg)	Applied MGA (%)	MGA (kg)	Predicted Empty Mass (kg)	Predicted Total Ops Mass (kg)	Predicted Total Tier 1 Mass (kg)
1.0.0	BODY STRUCTURES	6	-	4,056.55	0.0%	803.70	4,860.25	0.00	4,860.25
1.1.0	PRIMARY STRUCTURE - PRESSURIZED	4	-	3,006.31	0.0%	541.14	3,547.45	-	-
1.1.1	Inflatable Restraint Layer & Air Barrier	1	810.51	810.51	18.0%	145.89	956.40	-	-
1.1.2	Inflatable Core End Bulkheads	1	268.86	268.86	18.0%	48.39	317.25	-	-
1.1.3	Inflatable Core Tunnel	1	720.34	720.34	18.0%	129.66	850.00	-	-
1.1.4	Metallic Structures	1	1,206.61	1,206.61	18.0%	217.19	1,423.80	-	-
1.2.0	PRIMARY STRUCTURE - UNPRESSURIZED	0	-	0.00	0.0%	0.00	0.00	-	-
1.3.0	SECONDARY STRUCTURE - INTERNAL	0	-	0.00	0.0%	0.00	0.00	-	-
1.4.0	SECONDARY STRUCTURE - EXTERNAL	2	-	1,050.24	0.0%	262.56	1,312.80	-	-
1.4.1	Inflatable Module Secondary Structures	1	594.62	594.62	25.0%	148.66	743.28	-	-
1.4.2	Metallic Module Secondary Structures	1	455.62	455.62	25.0%	113.90	569.52	-	-
2.0.0	CONNECTION & SEPARATION SYSTEMS	3	-	1,163.00	0.0%	46.52	1,209.52	0.00	1,209.52
2.1.0	MATING INTERFACE MECHANISMS	3	-	1,163.00	0.0%	46.52	1,209.52	-	-
2.1.1	Axial Active NASA Docking System (NDS) w/Thermal Cover	1	465.00	465.00	4.0%	18.60	483.60	-	-
2.1.2	Axial Passive NDS w/Thermal Cover	1	233.00	233.00	4.0%	9.32	242.32	-	-
2.1.3	Radial Androgynous NDS w/Thermal Cover	1	465.00	465.00	4.0%	18.60	483.60	-	-
2.2.0	SEPARATION EQUIP	0	-	0.00	0.0%	0.00	0.00	-	-
2.9.0	CONNECTION & SEP SYS MOUNTING/INSTALL H/W	0	-	0.00	0.0%	0.00	0.00	-	-
3.0.0	LAUNCH/TAKEOFF & LANDING SUPPORT SYSTEMS	1	-	260.00	0.0%	65.00	325.00	0.00	325.00
3.1.0	LAUNCH SUPPORT EQUIP	1	-	260.00	0.0%	65.00	325.00	-	-
3.1.1	Launch Vehicle Adapters	1	260.00	260.00	25.0%	65.00	325.00	-	-
4.0.0	NATURAL & INDUCED ENVIRON PROTECT SYSTEMS	2	-	1,869.15	0.0%	336.45	2,205.60	0.00	2,205.60
4.1.0	RADIATION PROTECTION EQUIP	0	-	0.00	0.0%	0.00	0.00	-	-
4.2.0	MMOD PROTECTION EQUIP	2	-	1,869.15	0.0%	336.45	2,205.60	-	-
4.2.1	MMOD/MLI, Inflatable	1	1,621.02	1,621.02	18.0%	291.78	1,912.80	-	-
4.2.2	MMOD/MLI, Metallics	1	248.14	248.14	18.0%	44.66	292.80	-	-
4.3.0	THERMAL PROTECTION EQUIP	0	-	0.00	0.0%	0.00	0.00	-	-
4.4.0	VIBRO-ACOUSTIC PROTECTION EQUIP	0	-	0.00	0.0%	0.00	0.00	-	-
5.0.0	PROPULSION SYSTEMS	0	-	0.00	0.0%	0.00	0.00	0.00	0.00
6.0.0	POWER SYSTEMS	33	-	1,710.20	0.0%	390.20	2,100.40	0.00	2,100.40
6.1.0	MAIN POWER GENERATION EQUIP	16	-	1,080.20	0.0%	209.30	1,289.50	-	-
6.1.1	Solar Array Wing	2	151.00	302.00	24.0%	72.48	374.48	-	-
6.1.2	Array Regulation Unit	1	59.80	59.80	20.0%	11.96	71.76	-	-
6.1.3	Battery Charge Discharge Unit (BCDU) [6KW]	0	30.00	0.00	20.0%	0.00	0.00	-	-
6.1.4	Battery (134 Ah)	4	158.60	634.40	15.0%	95.16	729.56	-	-
6.1.5	Hinge/Gimbal	2	10.00	20.00	35.0%	7.00	27.00		
6.1.6	Motor + Drivetrain + Controller	2	5.00	10.00	35.0%	3.50	13.50		
6.1.7	Structure + Boom	2	25.00	50.00	35.0%	17.50	67.50		
6.1.8	Locking Mechanism	2	1.00	2.00	50.0%	1.00	3.00		
6.1.9	Slip Ring	1	2.00	2.00	35.0%	0.70	2.70		
6.2.0	MAIN POWER MGMT & DISTRIB SYS	17	-	630.00	0.0%	180.90	810.90	-	-
6.2.1	16 kW Spacecraft Pwr Dist-Distributers	4	22.00	88.00	20.0%	17.60	105.60	-	-
6.2.2	16 kW Spacecraft Pwr Dist-Wiring	4	12.00	48.00	35.0%	16.80	64.80	-	-
6.2.3	20 kW NEP Pwr Dist-Distributers	4	22.00	88.00	20.0%	17.60	105.60	-	-
6.2.4	20 kW NEP Pwr Dist-Charge Controllers	4	22.00	88.00	20.0%	17.60	105.60	-	-
6.2.5	EI Cabling for Spacecraft	1	318.00	318.00	35.0%	111.30	429.30	-	-
6.2.6	DDCU (12KW DC To DC Converter Unit)	0	51.00	0.00	20.0%	0.00	0.00	-	-
6.2.7	Main Bus Switching Unit (MBSU) - Primary	0	34.00	0.00	20.0%	0.00	0.00	-	-
6.2.8	MBSU - Secondary	0	15.00	0.00	20.0%	0.00	0.00	-	-
6.2.9	PDU - Internal	0	26.00	0.00	20.0%	0.00	0.00	-	-
6.2.10	Portable Utility Panel (PUP)	0	7.00	0.00	20.0%	0.00	0.00	-	-
6.2.11	Spacecraft Bus Harness Power	0	154.00	0.00	50.0%	0.00	0.00	-	-
6.3.0	AUX POWER GENERATION EQUIP	0	-	0.00	0.0%	0.00	0.00	-	-
6.4.0	AUX POWER MGMT & DISTRIB SYS	0	-	0.00	0.0%	0.00	0.00	-	-
7.0.0	COMMAND & DATA HANDLING (C&DH) SYSTEMS	51	-	829.23	0.0%	90.60	919.82	0.00	919.82
7.1.0	COMMAND PROCESSING EQUIP	49	-	529.23	0.0%	30.60	559.82	-	-
7.1.1	Vehicle Management Computer	4	23.75	95.00	5.0%	4.75	99.75	-	-
7.1.2	Vehicle Management Computer (Alternate)	2	10.20	20.40	5.0%	1.02	21.42	-	-
7.1.3	Wireless Hub	3	2.00	6.00	10.0%	0.60	6.60	-	-
7.1.4	RIU-Data Acquisition Unit	4	2.68	10.70	10.0%	1.07	11.77	-	-
7.1.5	Data Recorder	3	20.00	60.00	3.0%	1.80	61.80	-	-
7.1.6	Data Acquisition Unit (DACU) (PDU-C3)	16	14.20	227.12	5.0%	11.36	238.48	-	-
7.1.7	MPS Controller	2	10.00	20.00	10.0%	2.00	22.00	-	-
7.1.8	RCS Controller	4	10.00	40.00	10.0%	4.00	44.00	-	-
7.1.9	Avionics Thermal Controller (Heaters & Pumps)	3	10.00	30.00	10.0%	3.00	33.00	-	-
7.1.10	Pyrotechnic Arm/Safe units	4	2.00	8.00	5.0%	0.40	8.40	-	-
7.1.11	Deployment Controller	4	3.00	12.00	5.0%	0.60	12.60	-	-
7.2.0	OPERATIONAL INSTRUMENTATION EQUIP	1	-	100.00	0.0%	20.00	120.00	-	-
7.2.1	Instrumentation, Sensors, ISH&M	1	100.00	100.00	20.0%	20.00	120.00	-	-
7.3.0	DEVELOPMENTAL & TEST INSTRUMENTATION EQUIP	0	-	0.00	0.0%	0.00	0.00	-	-
7.4.0	C&DH CABLES/DATA DISTRIB EQUIP	1	-	200.00	0.0%	40.00	240.00	-	-
7.4.1	Cabling	1	200.00	200.00	20.0%	40.00	240.00	-	-
8.0.0	GUIDANCE, NAVIGATION & CONTROL (GN&C) SYSTEMS	1,021	-	691.36	0.0%	98.02	789.39	263.51	2,614.89
8.1.0	DEDICATED GN&C COMPUTERS/PROCESSORS	0	-	0.00	0.0%	0.00	0.00	-	-
8.2.0	NAVIGATIONAL AIDS & CONTROL SENSORS	77	-	162.26	0.0%	11.00	173.27	-	-
8.2.1	Sun Sensors	16	0.03	0.54	3.0%	0.02	0.56	-	-
8.2.2	Sun Sensor Electronics	8	0.50	4.00	3.0%	0.12	4.12	-	-
8.2.3	Star Tracker	3	1.66	4.98	3.0%	0.15	5.13	-	-
8.2.4	IMU	3	0.75	2.25	3.0%	0.07	2.32	-	-
8.2.5	LIDAR	4	12.00	48.00	5.0%	2.40	50.40	-	-
8.2.6	LIDAR Reflectors	12	0.84	10.08	10.0%	1.01	11.09	-	-
8.2.7	Optical Navigation Camera	8	0.77	6.16	10.0%	0.62	6.78	-	-
8.2.8	Optical Navigation Target	5	0.45	2.25	10.0%	0.23	2.48	-	-
8.2.9	AR&D Computer Processer	4	10.00	40.00	5.0%	2.00	42.00	-	-
8.2.10	Rendezvous Lights	8	4.00	32.00	10.0%	3.20	35.20	-	-
8.2.11	Docking Lights	6	2.00	12.00	10.0%	1.20	13.20	-	-
8.3.0	ATTITUDE CONTROL SYSTEMS	550	-	529.10	0.0%	87.02	616.12	-	-
8.3.1	FORWARD ATTITUDE CONTROL SYSTEM (METALLIC SI	293		289.69	0.0%	47.08	336.76		
8.3.1.1	THRUST GENERATION EQUIPMENT	20		68.00	0.0%	6.80	74.80	-	-

SBS ID	COMMON FUNCTIONAL CATEGORY (TIER 1) COMMON EQUIPMENT GROUP (TIER 2) UNIQUE COMPONENT/SUB-ASSEMBLY (TIER 3)	Qty	Unit Mass (kg)	Basic Mass (kg)	Applied MGA (%)	MGA (kg)	Predicted Empty Mass (kg)	Predicted Total Ops Mass (kg)	Predicted Total Tier 1 Mass (kg)
8.3.1.1.1	Thruster (445 N, 110 lbf)	20	3.40	68.00	10.0%	6.80	74.80		
8.3.1.2	**PROPELLANT MGMT & DISTRIB SYSTEM**	**141**		**61.95**	**0.0%**	**9.03**	**70.98**		
8.3.1.2.1	Fill/Drain Valve	4	0.21	0.83	5.0%	0.04	0.88	-	-
8.3.1.2.2	Pryo Valve	6	0.31	1.88	5.0%	0.09	1.97	-	-
8.3.1.2.3	Propellant Latch valve	2	1.70	3.40	5.0%	0.17	3.57	-	-
8.3.1.2.4	Solenoid Iso-Valve with Back-Relief	28	0.73	20.32	5.0%	1.02	21.34	-	-
8.3.1.2.5	Propellant Filter	4	0.30	1.20	5.0%	0.06	1.26	-	-
8.3.1.2.6	Propellant Test port	28	0.09	2.52	15.0%	0.38	2.90	-	-
8.3.1.2.7	Propellant Feed Lines	1	25.00	25.00	25.0%	6.25	31.25	-	-
8.3.1.2.8	Pressure Transducers	40	0.10	4.00	15.0%	0.60	4.60	-	-
8.3.1.2.9	Temperature Sensors	28	0.10	2.80	15.0%	0.42	3.22	-	-
8.3.1.3	**PROPELLANT ACQUISITION & STORAGE SYSTEMS**	**20**		**44.50**	**0.0%**	**8.84**	**53.34**	**-**	**-**
8.3.1.3.1	Fuel (MMH) Tanks	4	5.41	21.65	20.0%	4.33	25.98	-	-
8.3.1.3.2	Oxidizer (NTO) Tanks	4	5.41	21.65	20.0%	4.33	25.98	-	-
8.3.1.3.3	Pressure Transducers	0	0.10	0.00	15.0%	0.00	0.00	-	-
8.3.1.3.4	Temperature Sensors	12	0.10	1.20	15.0%	0.18	1.38	-	-
8.3.1.4	**PROPELLANT RESUPPLY EQUIPMENT**	**25**		**20.10**	**0.0%**	**1.98**	**22.08**		
8.3.1.4.1	Propellant Latch valve	8	1.70	13.60	5.0%	0.68	14.28	-	-
8.3.1.4.2	Propellant Filter	4	0.30	1.20	5.0%	0.06	1.26	-	-
8.3.1.4.3	Propellant Resupply Coupling Connector With Self-Sealing	4	0.50	2.00	25.0%	0.50	2.50	-	-
8.3.1.4.4	Propellant Feed Lines	1	2.50	2.50	25.0%	0.63	3.13	-	-
8.3.1.4.5	Pressure Transducers	4	0.10	0.40	15.0%	0.06	0.46	-	-
8.3.1.4.6	Temperature Sensors	4	0.10	0.40	15.0%	0.06	0.46	-	-
8.3.1.5	**PRESSURANT MGMT & DISTRIB SYSTEM**	**59**		**28.08**	**0.0%**	**5.10**	**33.18**		
8.3.1.5.1	Pressurant Fill/Drain Valve	2	0.11	0.23	5.0%	0.01	0.24	-	-
8.3.1.5.2	Pryo Valve	2	0.31	0.63	5.0%	0.03	0.66	-	-
8.3.1.5.3	Pressurant Latch valve	14	0.34	4.76	5.0%	0.24	5.00	-	-
8.3.1.5.4	Check Valve	2	0.11	0.23	10.0%	0.02	0.25	-	-
8.3.1.5.5	Burst Disc/Relief Valve	2	0.68	1.36	25.0%	0.34	1.70	-	-
8.3.1.5.6	Regulator	3	0.68	2.04	10.0%	0.20	2.25	-	-
8.3.1.5.7	Pressurant Filter	4	0.25	1.00	5.0%	0.05	1.05	-	-
8.3.1.5.8	Pressurant Test port	6	0.09	0.54	20.0%	0.11	0.65	-	-
8.3.1.5.9	Presssurant Feed Lines	1	15.00	15.00	25.0%	3.75	18.75	-	-
8.3.1.5.10	Pressure Transducer, High Pressure Gas	9	0.10	0.90	15.0%	0.14	1.04	-	-
8.3.1.5.11	Pressure Transducer, Low Pressure Gas	14	0.10	1.40	15.0%	0.21	1.61	-	-
8.3.1.5.12	Temperature Sensor	0	0.10	0.00	15.0%	0.00	0.00	-	-
8.3.1.6	**PRESSURANT ACQUISITION & STORAGE SYSTEMS**	**8**	**-**	**14.96**	**0.0%**	**2.96**	**17.92**	**-**	**-**
8.3.1.6.1	Pressurant Tanks	2	7.18	14.36	20.0%	2.87	17.23	-	-
8.3.1.6.2	Pressure Transducer, High Pressure Gas	0	0.10	0.00	15.0%	0.00	0.00	-	-
8.3.1.6.3	Temperature Sensor	6	0.10	0.60	15.0%	0.09	0.69	-	-
8.3.1.7	**PRESSURANT RESUPPLY EQUIPMENT**	**15**	**-**	**5.92**	**0.0%**	**0.82**	**6.74**	**-**	**-**
8.3.1.7.1	Pressurant Latch valve	8	0.34	2.72	5.0%	0.14	2.86	-	-
8.3.1.7.2	Pressurant Filter	2	0.25	0.50	5.0%	0.02	0.52	-	-
8.3.1.7.3	Pressurant Resupply Coupling Connector With Self-Sealing	2	0.50	1.00	25.0%	0.25	1.25	-	-
8.3.1.7.4	Pressurant Feed Lines	1	1.50	1.50	25.0%	0.38	1.88	-	-
8.3.1.7.5	Pressure Transducer, High Pressure Gas	2	0.10	0.20	15.0%	0.03	0.23	-	-
8.3.1.7.6	Temperature Sensor	0	0.10	0.00	15.0%	0.00	0.00	-	-
8.3.1.8	**MOUNTING EQUIPMENT**	**5**	**-**	**46.18**	**0.0%**	**11.54**	**57.72**	**-**	**-**
8.3.1.8.1	Thruster Pod Structure	4	8.50	34.00	25.0%	8.50	42.50	-	-
8.3.1.8.2	Component Mounting Hardware	1	12.18	12.18	25.0%	3.04	15.22	-	-
8.3.2	**AFT ATTITUDE CONTROL SYSTEM (INJFLATIBLE SIDE)**	**257**	**-**	**239.41**	**0.0%**	**39.94**	**279.36**	**-**	**-**
8.3.2.1	**THRUST GENERATION EQUIPMENT**	**12**		**40.80**	**0.0%**	**4.08**	**44.88**	**-**	**-**
8.3.2.1.1	Thruster (445 N, 110 lbf)	12	3.40	40.80	10.0%	4.08	44.88		
8.3.2.2	**PROPELLANT MGMT & DISTRIB SYSTEM**	**109**		**53.82**	**0.0%**	**8.39**	**62.22**		
8.3.2.2.1	Fill/Drain Valve	4	0.21	0.83	5.0%	0.04	0.88	-	-
8.3.2.2.2	Pryo Valve	6	0.31	1.88	5.0%	0.09	1.97	-	-
8.3.2.2.3	Propellant Latch valve	2	1.70	3.40	5.0%	0.17	3.57	-	-
8.3.2.2.4	Solenoid Iso-Valve with Back-Relief	20	0.73	14.51	5.0%	0.73	15.24	-	-
8.3.2.2.5	Propellant Filter	4	0.30	1.20	5.0%	0.06	1.26	-	-
8.3.2.2.6	Propellant Test port	20	0.09	1.80	15.0%	0.27	2.07	-	-
8.3.2.2.7	Propellant Feed Lines	1	25.00	25.00	25.0%	6.25	31.25	-	-
8.3.2.2.8	Pressure Transducers	32	0.10	3.20	15.0%	0.48	3.68	-	-
8.3.2.2.9	Temperature Sensors	20	0.10	2.00	15.0%	0.30	2.30	-	-
8.3.2.3	**PROPELLANT ACQUISITION & STORAGE SYSTEMS**	**20**		**44.50**	**0.0%**	**8.84**	**53.34**	**-**	**-**
8.3.2.3.1	Fuel (MMH) Tanks	4	5.41	21.65	20.0%	4.33	25.98	-	-
8.3.2.3.2	Oxidizer (NTO) Tanks	4	5.41	21.65	20.0%	4.33	25.98	-	-
8.3.2.3.3	Pressure Transducers	0	0.10	0.00	15.0%	0.00	0.00	-	-
8.3.2.3.4	Temperature Sensors	12	0.10	1.20	15.0%	0.18	1.38	-	-
8.3.2.4	**PROPELLANT RESUPPLY EQUIPMENT**	**25**		**20.10**	**0.0%**	**1.98**	**22.08**		
8.3.2.4.1	Propellant Latch valve	8	1.70	13.60	5.0%	0.68	14.28	-	-
8.3.2.4.2	Propellant Filter	4	0.30	1.20	5.0%	0.06	1.26	-	-
8.3.2.4.3	Propellant Resupply Coupling Connector With Self-Sealing	4	0.50	2.00	25.0%	0.50	2.50	-	-
8.3.2.4.4	Propellant Feed Lines	1	2.50	2.50	25.0%	0.63	3.13	-	-
8.3.2.4.5	Pressure Transducers	4	0.10	0.40	15.0%	0.06	0.46	-	-
8.3.2.4.6	Temperature Sensors	4	0.10	0.40	15.0%	0.06	0.46	-	-
8.3.2.5	**PRESSURANT MGMT & DISTRIB SYSTEM**	**63**		**28.48**	**0.0%**	**5.16**	**33.64**		
8.3.2.5.1	Pressurant Fill/Drain Valve	2	0.11	0.23	5.0%	0.01	0.24	-	-
8.3.2.5.2	Pryo Valve	2	0.31	0.63	5.0%	0.03	0.66	-	-
8.3.2.5.3	Pressurant Latch valve	14	0.34	4.76	5.0%	0.24	5.00	-	-
8.3.2.5.4	Check Valve	2	0.11	0.23	10.0%	0.02	0.25	-	-
8.3.2.5.5	Burst Disc/Relief Valve	2	0.68	1.36	25.0%	0.34	1.70	-	-
8.3.2.5.6	Regulator	3	0.68	2.04	10.0%	0.20	2.25	-	-
8.3.2.5.7	Pressurant Filter	4	0.25	1.00	5.0%	0.05	1.05	-	-
8.3.2.5.8	Pressurant Test port	6	0.09	0.54	20.0%	0.11	0.65	-	-
8.3.2.5.9	Presssurant Feed Lines	1	15.00	15.00	25.0%	3.75	18.75	-	-
8.3.2.5.10	Pressure Transducer, High Pressure Gas	9	0.10	0.90	15.0%	0.14	1.04	-	-
8.3.2.5.11	Pressure Transducer, Low Pressure Gas	14	0.10	1.40	15.0%	0.21	1.61	-	-
8.3.2.5.12	Temperature Sensor	4	0.10	0.40	15.0%	0.06	0.46	-	-
8.3.2.6	**PRESSURANT ACQUISITION & STORAGE SYSTEMS**	**8**	**-**	**14.96**	**0.0%**	**2.96**	**17.92**	**-**	**-**

SBS ID	COMMON FUNCTIONAL CATEGORY (TIER 1) COMMON EQUIPMENT GROUP (TIER 2) UNIQUE COMPONENT/SUB-ASSEMBLY (TIER 3)	Qty	Unit Mass (kg)	Basic Mass (kg)	Applied MGA (%)	MGA (kg)	Predicted Empty Mass (kg)	Predicted Total Ops Mass (kg)	Predicted Total Tier 1 Mass (kg)
8.3.2.6.1	Pressurant Tanks	2	7.18	14.36	20.0%	2.87	17.23	-	-
8.3.2.6.2	Pressure Transducer, High Pressure Gas	0	0.10	0.00	15.0%	0.00	0.00	-	-
8.3.2.6.3	Temperature Sensor	6	0.10	0.60	15.0%	0.09	0.69	-	-
8.3.2.7	**PRESSURANT RESUPPLY EQUIPMENT**	**15**	**-**	**5.92**	**0.0%**	**0.82**	**6.74**	**-**	**-**
8.3.2.7.1	Pressurant Latch valve	8	0.34	2.72	5.0%	0.14	2.86	-	-
8.3.2.7.2	Pressurant Filter	2	0.25	0.50	5.0%	0.02	0.52	-	-
8.3.2.7.3	Pressurant Resupply Coupling Connector With Self-Sealing	2	0.50	1.00	25.0%	0.25	1.25	-	-
8.3.2.7.4	Pressurant Feed Lines	1	1.50	1.50	25.0%	0.38	1.88	-	-
8.3.2.7.5	Pressure Transducer, High Pressure Gas	2	0.10	0.20	15.0%	0.03	0.23	-	-
8.3.2.7.6	Temperature Sensor	0	0.10	0.00	15.0%	0.00	0.00	-	-
8.3.2.8	**MOUNTING EQUIPMENT**	**5**	**-**	**30.83**	**0.0%**	**7.71**	**38.54**	**-**	**-**
8.3.2.8.1	Thruster Pod Structure	4	5.10	20.40	25.0%	5.10	25.50	-	-
8.3.2.8.2	Component Mounting Hardware	1	10.43	10.43	25.0%	2.61	13.04	-	-
8.4.0	**GN&C SYS MOUNTING/INSTALL H/W**	**0**	**-**	**0.00**	**0.0%**	**0.00**	**0.00**	**-**	**-**
8.L.0	***CONTROL SYSTEM RESIDUALS***	***8***	**-**	***263.51***	***0.0%***	***0.00***	**-**	**263.51**	**-**
8.L.1	**FORWARD ACS (METALLIC SIDE) RESIDUALS**	***4***	**-**	***131.75***	***0.0%***	***0.00***	**-**	**131.75**	**-**
8.L.1.1	*Residual Oxidizer (NTO) Mass*	*1*	*66.31*	*66.31*	*0.0%*	*0.00*	-	66.31	-
8.L.1.2	*Residual Fuel (MMH) Mass*	*1*	*40.19*	*40.19*	*0.0%*	*0.00*	-	40.19	-
8.L.1.3	*Fuel Bias (MMH)*	*1*	*2.68*	*2.68*	*0.0%*	*0.00*	-	2.68	-
8.L.1.4	*Pressurant Mass (N2)*	*1*	*22.57*	*22.57*	*0.0%*	*0.00*	-	22.57	-
8.L.2	**AFT ACS (INFLATABLE SIDE) RESIDUALS**	***4***	**-**	***131.75***	***0.0%***	***0.00***	**-**	**131.75**	**-**
8.L.2.1	*Residual Oxidizer (NTO) Mass*	*1*	*66.31*	*66.31*	*0.0%*	*0.00*	-	66.31	-
8.L.2.2	*Residual Fuel (MMH) Mass*	*1*	*40.19*	*40.19*	*0.0%*	*0.00*	-	40.19	-
8.L.2.3	*Fuel Bias (MMH)*	*1*	*2.68*	*2.68*	*0.0%*	*0.00*	-	2.68	-
8.L.2.4	*Pressurant Mass (N2)*	*1*	*22.57*	*22.57*	*0.0%*	*0.00*	-	22.57	-
8.Q.0	**FORWARD ACS (METALLIC SIDE) USEABLE PROPELLANT**	***4***	**-**	***781.00***	***0.0%***	***0.00***	**-**	**781.00**	**-**
8.Q.1	*Useable Oxidizer (NTO) Mass*	*1*	*442.08*	*442.08*	*0.0%*	*0.00*	-	442.08	-
8.Q.2	*Useable Fuel (MMH) Mass*	*1*	*267.92*	*267.92*	*0.0%*	*0.00*	-	267.92	-
8.Q.3	*Reserve Oxidizer (NTO) Mass*	*1*	*44.21*	*44.21*	*0.0%*	*0.00*	-	44.21	-
8.Q.4	*Reserve Fuel (MMH) Mass*	*1*	*26.79*	*26.79*	*0.0%*	*0.00*	-	26.79	-
8.R.0	**AFT ACS (INFLATABLE SIDE) USEABLE PROPELLANT**	***4***	**-**	***781.00***	***0.0%***	***0.00***	**-**	**781.00**	**-**
8.R.1	*Useable Oxidizer (NTO) Mass*	*1*	*442.08*	*442.08*	*0.0%*	*0.00*	-	442.08	-
8.R.2	*Useable Fuel (MMH) Mass*	*1*	*267.92*	*267.92*	*0.0%*	*0.00*	-	267.92	-
8.R.3	*Reserve Oxidizer (NTO) Mass*	*1*	*44.21*	*44.21*	*0.0%*	*0.00*	-	44.21	-
8.R.4	*Reserve Fuel (MMH) Mass*	*1*	*26.79*	*26.79*	*0.0%*	*0.00*	-	26.79	-
9.0.0	**COMMUNICATIONS & TRACKING (C&T) SYSTEMS**	**143**	**-**	**491.86**	**0.0%**	**33.68**	**525.54**	**0.00**	**525.54**
9.1.0	**SHORT RANGE/PROXIMITY RF COMM EQUIP**	**60**	**-**	**104.63**	**0.0%**	**8.68**	**113.31**	**-**	**-**
9.1.1	S-band P/A (3x3) antenna	8	6.85	54.78	10.0%	5.48	60.26	-	-
9.1.2	Thermal Spreader Plate	8	0.37	2.94	10.0%	0.29	3.23	-	-
9.1.3	RF Switch Mattrix	3	1.92	5.77	3.0%	0.17	5.94	-	-
9.1.4	S-band Test Coupler	8	0.23	1.81	3.0%	0.05	1.87	-	-
9.1.5	S-band Transponder	2	4.31	8.62	3.0%	0.26	8.88	-	-
9.1.6	S-band Baseband Processor	2	3.31	6.61	10.0%	0.66	7.27	-	-
9.1.7	S-band LGA antenna	8	0.73	5.80	10.0%	0.58	6.39	-	-
9.1.8	Surge Protector	8	0.14	1.09	3.0%	0.03	1.12	-	-
9.1.9	S-band Radio with A&DI	2	4.99	9.98	5.0%	0.50	10.48	-	-
9.1.10	Aux Hybrid Coupler	1	0.11	0.11	10.0%	0.01	0.12	-	-
9.1.11	UHF Surge Protector	2	0.32	0.63	3.0%	0.02	0.65	-	-
9.1.12	UHF/VHF Antenna	4	0.91	3.63	10.0%	0.36	3.99	-	-
9.1.13	VHF Surge Protector	2	0.24	0.47	3.0%	0.01	0.49	-	-
9.1.14	UHF/VHF Voice Radio	2	1.19	2.38	10.0%	0.24	2.61	-	-
9.2.0	**LONG RANGE/DEEP SPACE COMM EQUIP**	**34**	**-**	**105.69**	**0.0%**	**8.18**	**113.86**	**-**	**-**
9.2.1	Ka/X-band antenna	1	25.00	25.00	10.0%	2.50	27.50	-	-
9.2.2	Gimbal platfrom	1	5.50	5.50	10.0%	0.55	6.05	-	-
9.2.3	Gimbal Control Unit	2	5.00	10.00	10.0%	1.00	11.00	-	-
9.2.4	X-band Waveguide assy	1	2.59	2.59	5.0%	0.13	2.71	-	-
9.2.5	Ka-band Waveguide assy	1	2.59	2.59	5.0%	0.13	2.71	-	-
9.2.6	X-band filter	2	0.23	0.45	5.0%	0.02	0.48	-	-
9.2.7	Ka-band filter	2	0.23	0.45	5.0%	0.02	0.48	-	-
9.2.8	Ka/X-band Converter	2	0.79	1.59	5.0%	0.08	1.67	-	-
9.2.9	X-band Diplexer	2	0.80	1.60	5.0%	0.08	1.68	-	-
9.2.10	Ka-band Diplexer	2	0.80	1.60	5.0%	0.08	1.68	-	-
9.2.11	X-band Amplifier (TWTA)	2	2.70	5.40	5.0%	0.27	5.67	-	-
9.2.12	X-band TWT power conditioner	2	1.30	2.60	5.0%	0.13	2.73	-	-
9.2.13	Ka-band Amplifier (TWTA)	2	4.40	8.80	5.0%	0.44	9.24	-	-
9.2.14	Ka-band TWT power conditioner	2	4.60	9.20	5.0%	0.46	9.66	-	-
9.2.15	X-band Transponder	2	3.20	6.40	5.0%	0.32	6.72	-	-
9.2.16	Ka-band Transmitter	2	2.30	4.60	5.0%	0.23	4.83	-	-
9.2.17	Ka-band Reciever	2	2.05	4.10	10.0%	0.41	4.51	-	-
9.2.18	X Baseband Processor	2	3.31	6.61	10.0%	0.66	7.27	-	-
9.2.19	Ka Baseband Processor	2	3.31	6.61	10.0%	0.66	7.27	-	-
9.3.0	**TIMING EQUIP**	**1**	**-**	**17.00**	**0.0%**	**0.85**	**17.85**	**-**	**-**
9.3.1	Deep space atomic clock	1	17	17.00	5.0%	0.85	17.85	-	-
9.4.0	**COMM POINTING AIDS**	**0**	**-**	**0.00**	**0.0%**	**0.00**	**0.00**	**-**	**-**
9.5.0	**COMM SECURITY (COMSEC) EQUIP**	**0**	**-**	**0.00**	**0.0%**	**0.00**	**0.00**	**-**	**-**
9.6.0	**AUDIO-VISUAL EQUIP**	**46**	**-**	**104.54**	**0.0%**	**7.98**	**112.52**	**-**	**-**
9.6.1	Audio Headset w/Microphone	4	0.21	0.83	10.0%	0.08	0.92	-	-
9.6.2	Audio interface Unit	7	0.22	1.56	10.0%	0.16	1.71	-	-
9.6.3	Audio Control Unit	3	4.19	12.57	10.0%	1.26	13.83	-	-
9.6.4	Speaker Unit	4	1.98	7.93	10.0%	0.79	8.72	-	-
9.6.5	Area Microphone	5	0.06	0.32	10.0%	0.03	0.35	-	-
9.6.6	Portable Microphone	2	0.06	0.13	10.0%	0.01	0.14	-	-
9.6.7	Digital Video Recorder (DVR)	2	4.54	9.07	10.0%	0.91	9.98	-	-
9.6.8	Video Processing unit (VPU)	2	11.34	22.68	10.0%	2.27	24.94	-	-
9.6.9	External PAN/TILT/ZOOM CAMERA	4	2.04	8.16	5.0%	0.41	8.57	-	-
9.6.10	External 360 VIDEO CAMERA	4	4.50	18.00	5.0%	0.90	18.90	-	-
9.6.11	Internal 360 VIDEO CAMERA	5	4.50	22.50	5.0%	1.13	23.63	-	-
9.6.12	Internal CREW CAMERAS	4	0.20	0.80	5.0%	0.04	0.84	-	-
9.7.0	**COMM CABLES AND RF INTERCONNECTIONS**	**1**	**-**	**110.00**	**0.0%**	**5.50**	**115.50**	**-**	**-**

SBS ID	COMMON FUNCTIONAL CATEGORY (TIER 1) COMMON EQUIPMENT GROUP (TIER 2) UNIQUE COMPONENT/SUB-ASSEMBLY (TIER 3)	Qty	Unit Mass (kg)	Basic Mass (kg)	Applied MGA (%)	MGA (kg)	Predicted Empty Mass (kg)	Predicted Total Ops Mass (kg)	Predicted Total Tier 1 Mass (kg)
9.7.1	Avionics Cabling	1	110.00	110.00	5.0%	5.50	115.50	-	-
9.8.0	**TRACKING EQUIP**	**1**	**-**	**50.00**	**0.0%**	**2.50**	**52.50**	**-**	**-**
9.8.1	Instrumentation	1	50.00	50.00	5.0%	2.50	52.50	-	-
9.9.0	**C&T SYS MOUNTING/INSTALL H/W**	**0**	**-**	**0.00**	**0.0%**	**0.00**	**0.00**	**-**	**-**
10.0.0	**CREW DISPLAYS & CONTROLS**	**48**	**-**	**160.37**	**0.0%**	**12.29**	**172.66**	**21.28**	**193.94**
10.1.0	**VISUAL DISPLAY DEVICES (E.G., MONITORS, INDICATORS**	**5**	**-**	**62.36**	**0.0%**	**6.24**	**68.59**	**-**	**-**
10.1.1	Display	5	12.47	62.36	10.0%	6.24	68.59	-	-
10.2.0	**TOUCH, MOTION & VOICE CONTROL DEVICES**	**10**	**-**	**20.12**	**0.0%**	**2.01**	**22.13**	**-**	**-**
10.2.1	Hand Controller w/mount	2	3.49	6.98	10.0%	0.70	7.68	-	-
10.2.2	Curser Control Device	2	0.95	1.90	10.0%	0.19	2.10	-	-
10.2.3	Keypad	2	1.10	2.20	10.0%	0.22	2.41	-	-
10.2.4	Hand Controller w/mount (Robotic Arm)	2	3.49	6.98	10.0%	0.70	7.68	-	-
10.2.5	Curser Control Device (Robotic Arm)	1	0.95	0.95	10.0%	0.10	1.05	-	-
10.2.6	Keypad (Robotic Arm)	1	1.10	1.10	10.0%	0.11	1.21	-	-
10.3.0	**CAUTION & WARNING ELECTRONICS**	**8**	**-**	**40.39**	**0.0%**	**4.04**	**44.43**	**-**	**-**
10.3.1	Console Panel U1	1	5.32	2.66	10.0%	0.27	2.93	-	-
10.3.2	Console Panel F1	1	2.73	1.37	10.0%	0.14	1.50	-	-
10.3.3	Console Panel F2	1	2.35	1.18	10.0%	0.12	1.29	-	-
10.3.4	Console Panel F3	1	1.85	0.93	10.0%	0.09	1.02	-	-
10.3.5	Console Panel F4	1	3.62	1.81	10.0%	0.18	1.99	-	-
10.3.6	Console Panel F5	1	1.51	0.76	10.0%	0.08	0.83	-	-
10.3.7	Console Panel U1 (Robotic Arm)	1	5.32	5.32	10.0%	0.53	5.85	-	-
10.3.8	Console Panel F2 (Robotic Arm)	1	2.35	2.35	10.0%	0.24	2.59	-	-
10.3.9	Console Panel F4 (Robotic Arm)	1	3.62	3.62	10.0%	0.36	3.99	-	-
10.3.10	Computer (Robotic Arm)	2	10.20	20.40	10.0%	2.04	22.44	-	-
10.9.0	**CREW DISPLAYS & CONTROLS MOUNTING/INSTALL H/W**	**25**	**-**	**37.50**	**0.0%**	**0.00**	**37.50**	**-**	**-**
10.9.1	Miscellaneous (brackets, spacers, washers)	25	1.50	37.50	0.0%	0.00	37.50	-	-
10.B.0	***CREW DISP & CTLS MOBILE DEVICES***	***17***	**-**	***20.24***	***0.0%***	***1.04***	**-**	**21.28**	**-**
10.B.1	*Display*	*1*	*12.47*	*6.24*	*10.0%*	*0.62*	-	6.86	-
10.B.2	*Crew Tablet*	*4*	*0.50*	*2.00*	*3.0%*	*0.06*	-	2.06	-
10.B.3	*Spacecraft Laptop*	*4*	*1.00*	*4.00*	*3.0%*	*0.12*	-	4.12	-
10.B.4	*Payloads Laptop*	*4*	*1.00*	*4.00*	*3.0%*	*0.12*	-	4.12	-
10.B.5	*Crew Laptop*	*4*	*1.00*	*4.00*	*3.0%*	*0.12*	-	4.12	-
10.J.0	***SPARE CREW DISP & CTLS EQUIP & MAINT ITEMS***	***0***	**-**	***0.00***	***0.0%***	***0.00***	**-**	**0.00**	**-**
11.0.0	**THERMAL CONTROL SYSTEMS (TCS)**	**1,060**	**-**	**1,554.02**	**0.0%**	**267.12**	**1,821.14**	**0.00**	**1,821.14**
11.1.0	**ACTIVE HEAT COLLECTION AND TRANSPORT EQUIP**	**135**	**-**	**888.16**	**0.0%**	**163.00**	**1,051.16**	**-**	**-**
11.1.1	Water/PG Coolant Pumps	2	15.00	30.00	25.0%	7.50	37.50	-	-
11.1.2	Water/PG Accumulators (with coolant)	2	25.00	50.00	25.0%	12.50	62.50	-	-
11.1.3	Water/PG Lines (with coolant)	1	83.00	83.00	20.0%	16.60	99.60	-	-
11.1.4	Flow Control Valve	2	6.00	12.00	25.0%	3.00	15.00	-	-
11.1.5	Coldplates - BCDU, BDDCU, DDCU, PDU	8	3.60	28.80	10.0%	2.88	31.68	-	-
11.1.6	Coldplates - DDCU (12kW), MBSU2, FCM, CMU	5	4.20	21.00	10.0%	2.10	23.10	-	-
11.1.7	Coldplates - MBSU Primary, TTE Switches	4	5.30	21.20	10.0%	2.12	23.32	-	-
11.1.8	Coldplates - Avionics (100+ Units)	1	173.18	173.18	10.0%	17.32	190.50	-	-
11.1.9	Coldplates - Payloads	4	8.60	34.40	20.0%	6.88	41.28	-	-
11.1.10	Temperature Sensors	7	0.10	0.70	25.0%	0.18	0.88	-	-
11.1.11	Flow Meter	2	1.00	2.00	25.0%	0.50	2.50	-	-
11.1.12	Liquid Level Sensors (2 for each accumulator)	4	0.25	1.00	25.0%	0.25	1.25	-	-
11.1.13	Pressure Sensors (2 for each accumulator, 3 in the loop)	7	0.10	0.70	25.0%	0.18	0.88	-	-
11.1.14	Filters (1 for each pump)	2	0.40	0.80	25.0%	0.20	1.00	-	-
11.1.15	Interloop Heat Exchanger	1	8.00	8.00	25.0%	2.00	10.00	-	-
11.1.16	Isolation or Shut Off Valves	8	1.73	13.84	25.0%	3.46	17.30	-	-
11.1.17	Check Valves	2	0.24	0.48	25.0%	0.12	0.60	-	-
11.1.18	Fill Ports	2	0.60	1.20	25.0%	0.30	1.50	-	-
11.1.19	Avionics Fan	2	2.00	4.00	25.0%	1.00	5.00	-	-
11.1.20	Avionics Heat Exchanger	2	11.00	22.00	25.0%	5.50	27.50	-	-
11.1.21	Internal Loop Jumpers	2	12.50	25.00	25.0%	6.25	31.25	-	-
11.1.22	HFE 7200 Coolant Pumps	2	15.00	30.00	20.0%	6.00	36.00	-	-
11.1.23	HFE 7200 Primary Accumulator (with coolant)	2	34.00	68.00	20.0%	13.60	81.60	-	-
11.1.24	HFE 7200 External Tank (with residual coolant)	1	68.00	68.00	20.0%	13.60	81.60	-	-
11.1.25	HFE 7200 Lines (with coolant)	1	96.00	96.00	20.0%	19.20	115.20	-	-
11.1.26	Coldplates - Batteries	2	8.60	17.20	15.0%	2.58	19.78	-	-
11.1.27	Coldplates - BDCU	2	8.60	17.20	15.0%	2.58	19.78	-	-
11.1.28	Temperature Sensors	12	0.10	1.20	25.0%	0.30	1.50	-	-
11.1.29	Flow Meter (as per internal loop)	2	1.00	2.00	25.0%	0.50	2.50	-	-
11.1.30	Liquid Level Sensors (2 for each accumulator)	4	0.30	1.20	25.0%	0.30	1.50	-	-
11.1.31	Pressure Sensors (2 for each accumulator, 3 in the loop)	7	0.10	0.70	25.0%	0.18	0.88	-	-
11.1.32	Filters (1 for each pump)	2	0.40	0.80	25.0%	0.20	1.00	-	-
11.1.33	Regenerator	1	6.75	6.75	25.0%	1.69	8.44	-	-
11.1.34	Radiator Flow Split Valve	1	2.00	2.00	25.0%	0.50	2.50	-	-
11.1.35	Regenerator Flow Control Valve	2	6.00	12.00	25.0%	3.00	15.00	-	-
11.1.36	Isolation or Shut Off Valves	17	1.73	29.41	25.0%	7.35	36.76	-	-
11.1.37	Check Valves (1 for each pump) +4 (one for each radiator)	5	0.24	1.20	25.0%	0.30	1.50	-	-
11.1.38	Fill Ports	2	0.60	1.20	25.0%	0.30	1.50	-	-
11.2.0	**ACTIVE TCS WORKING FLUIDS (CLOSED LOOP)**	**0**	**0.00**	**0.00**	**0.0%**	**0.00**	**0.00**	**-**	**-**
11.3.0	**ACTIVE HEAT GENERATION (HEATERS) EQUIP**	**760**	**-**	**22.80**	**0.0%**	**5.34**	**28.14**	**-**	**-**
11.3.1	Wall Heaters (MAIN+REDUNDANT+3rd LEG)	360	0.03	10.80	25.0%	2.70	13.50	-	-
11.3.2	Hatch Heater (MAIN+REDUNDANT+3rd LEG)	240	0.03	7.20	25.0%	1.80	9.00	-	-
11.3.3	Gas Sys Mgmt Heaters (2 lines + 2 redundant)	40	0.03	1.20	25.0%	0.30	1.50	-	-
11.3.4	RCS Heaters	120	0.03	3.60	15.0%	0.54	4.14	-	-
11.4.0	**ACTIVE HEAT REJECTION EQUIP**	**5**	**-**	**618.30**	**0.0%**	**92.75**	**711.05**	**-**	**-**
11.4.1	Radiator System (@52 m2)	1	464.00	464.00	15.0%	69.60	533.60	-	-
11.4.2	Interface Heat Exchanger	1	39.40	39.40	15.0%	5.91	45.31	-	-
11.4.3	Pump	1	3.70	3.70	15.0%	0.56	4.26	-	-
11.4.4	Lines	1	91.10	91.10	15.0%	13.67	104.77	-	-
11.4.5	Instrumentation/sensors	1	20.10	20.10	15.0%	3.02	23.12	-	-
11.5.0	**PASSIVE HEAT COLLECTION, TRANSPORT, AND REJECTI**	**1**	**-**	**20.00**	**0.0%**	**5.00**	**25.00**	**-**	**-**
11.5.1	MLI Blankets - no High temperature or Internal MLI	0	1.50	0.00	15.0%	0.00	0.00	-	-

SBS ID	COMMON FUNCTIONAL CATEGORY (TIER 1) COMMON EQUIPMENT GROUP (TIER 2) UNIQUE COMPONENT/SUB-ASSEMBLY (TIER 3)	Qty	Unit Mass (kg)	Basic Mass (kg)	Applied MGA (%)	MGA (kg)	Predicted Empty Mass (kg)	Predicted Total Ops Mass (kg)	Predicted Total Tier 1 Mass (kg)
11.5.2	Armaflex for isolation (cold ATCS piping\valves, water delivery syst	1	20.00	20.00	25.0%	5.00	25.00	-	-
11.6.0	**INTERNAL THERMAL INSULATING EQUIP**	**2**	**-**	**0.20**	**0.0%**	**0.05**	**0.25**	**-**	**-**
11.6.1	Solid Thermal Filler (2 square meters assumed)	2	0.10	0.20	25.0%	0.05	0.25	-	-
11.7.0	**TCS MANAGEMENT SYS**	**156**	**-**	**1.56**	**0.0%**	**0.23**	**1.79**	**-**	**-**
11.7.1	Thermistors (Heater lines command 104 + monitoring 16)	120	0.01	1.20	15.0%	0.18	1.38	-	-
11.7.2	Thermostats	36	0.01	0.36	15.0%	0.05	0.41	-	-
12.0.0	**ENVIRONMENTAL CONTROL SYSTEMS (ECS)**	**96**	**-**	**1,781.35**	**0.0%**	**137.49**	**1,918.84**	**70.00**	**1,988.84**
12.1.0	**ENVIRONMENTAL MONITORING & PROTECTION EQUIP**	**1**	**-**	**14.00**	**0.0%**	**2.80**	**16.80**	**-**	**-**
12.1.1	Spacecraft Atmosphere Monitor and dist pump	0	12.50	0.00	20.0%	0.00	0.00	-	-
12.1.2	Combustion Products Monitor/ smoke detector	1	2.40	2.40	20.0%	0.48	2.88	-	-
12.1.3	Acoustic Monitor	1	1.10	1.10	20.0%	0.22	1.32	-	-
12.1.4	Trace Contaminate Monitor	1	10.50	10.50	20.0%	2.10	12.60	-	-
12.2.0	**PRESSURE CONTROL SYSTEM**	**26**	**-**	**315.18**	**0.0%**	**15.76**	**330.94**	**-**	**-**
12.2.1	Pressure Control Panel (Main)	1	5.00	5.00	5.0%	0.25	5.25	-	-
12.2.2	N2 Supply Tank	3	53.67	161.01	5.0%	8.05	169.06		
12.2.3	N2 Tank Regulator	1	13.10	13.10	5.0%	0.66	13.76		
12.2.4	O2 Supply Tank	1	53.67	53.67	5.0%	2.68	56.35		
12.2.5	O2 Tank Regulator	1	13.10	13.10	5.0%	0.66	13.76		
12.2.6	Total Press Sensor (Main)	1	0.40	0.40	5.0%	0.02	0.42		
12.2.7	Manual Pressure Equilization Valve (Main)	2	1.10	2.20	5.0%	0.11	2.31	-	-
12.2.8	SAM w/ dist pump (Main)	1	12.50	12.50	5.0%	0.63	13.13	-	-
12.2.9	Overpress Relief Assembly (main)	1	1.45	1.45	5.0%	0.07	1.52		
12.2.10	Pressure Control Panel (Safe Haven)	1	5.00	5.00	5.0%	0.25	5.25		
12.2.11	Total Press Sensor Safe Haven	1	0.40	0.40	5.0%	0.02	0.42		
12.2.12	Manual Pressure Equilization Valve (Safe H)	2	1.10	2.20	5.0%	0.11	2.31	-	-
12.2.13	Vent Relief Valve Air Lock (Depress)	4	5.70	22.80	5.0%	1.14	23.94	-	-
12.2.14	Non Propulsive Vent (Depressurization)	4	2.10	8.40	5.0%	0.42	8.82	-	-
12.2.15	SAM w/ dist pump (safe haven)	1	12.50	12.50	5.0%	0.63	13.13		
12.2.16	Overpress Relief Assembly	1	1.45	1.45	5.0%	0.07	1.52		
12.3.0	**ATMOSPHERE REVITALIZATION SYS**	**10**	**-**	**1,157.42**	**0.0%**	**90.12**	**1,247.54**	**-**	**-**
12.3.1	CO2 Removal (CDRA in Main)	1	200.00	200.00	5.0%	10.00	210.00	-	-
12.3.2	CO2 Reduction and Resource Recovery /Sabatier (Main)	1	205.00	205.00	5.0%	10.25	215.25	-	-
12.3.3	CO2 Reduction and Resource Recovery Post Processor (PPA) (Main	1	75.00	75.00	20.0%	15.00	90.00	-	-
12.3.4	O2 Generation	1	458.00	458.00	5.0%	22.90	480.90	-	-
12.3.5	High Pressure O2 and Delivery (Compressor + delivery) (main)	1	75.00	75.00	20.0%	15.00	90.00	-	-
12.3.6	Trace Contaminant Control Subassembly (TCCS)	1	79.40	79.40	5.0%	3.97	83.37	-	-
12.3.7	Amine Swingbed CO2 removal (Safe H)	2	29.51	59.02	20.0%	11.80	70.82	-	-
12.3.8	TCCS media filter cartridge (Safe H)	2	3.00	6.00	20.0%	1.20	7.20	-	-
12.4.0	**THC (HePA Filters, Ducting, CCAAs)**	**59**	**-**	**294.75**	**0.0%**	**28.81**	**323.56**	**-**	**-**
12.4.1	Common Cabin Air Assemblies (CCAAS)	2	89.98	179.95	5.0%	9.00	188.95	-	-
12.4.1.1	Inlet Cabin Air Fan ORU	0	25.31	0.00	0.0%	0.00	0.00	-	-
12.4.1.2	Water Separator ORU	0	11.93	0.00	0.0%	0.00	0.00	-	-
12.4.1.3	Heat Exchanger ORU	0	52.24	0.00	0.0%	0.00	0.00	-	-
12.4.1.4	Sensor, Liquid, Heat Exchanger	0	0.50	0.00	0.0%	0.00	0.00	-	-
12.4.2	HEPA Filter and screens (atmosphere particulate and and microbial c	6	2.10	12.60	20.0%	2.52	15.12	-	-
12.4.3	Air Dirculation Ducting (main)	18	1.00	18.00	20.0%	3.60	21.60	-	-
12.4.4	Plenum and Air Supply Registers (Main)	14	1.00	14.00	20.0%	2.80	16.80	-	-
12.4.5	Air Dirculation Ducting (safe H)	8	1.00	8.00	20.0%	1.60	9.60	-	-
12.4.6	Plenum and Air Supply Registers (Safe H)	4	1.00	4.00	20.0%	0.80	4.80	-	-
12.4.7	IMV Fan (Main)	2	5.00	10.00	5.0%	0.50	10.50	-	-
12.4.8	IMV Valve (main)	2	5.50	11.00	5.0%	0.55	11.55	-	-
12.4.9	Avionics Air Assembly (2 in main)	3	12.40	37.20	20.0%	7.44	44.64		
12.K.0	***ECS ATMOSPHERE & CONSUMABLES***	***1***	***-***	***70.00***	***0.0%***	***0.00***	***-***	***70.00***	***-***
12.K.1	*LiOH Canisters*	*1*	*70.00*	*70.00*	*0.0%*	*0.00*	*-*	*70.00*	*-*
13.0.0	**CREW/HABITATION SUPPORT SYSTEMS**	**254**	**-**	**4,902.39**	**0.0%**	**928.52**	**5,830.91**	**17,805.54**	**23,636.44**
13.1.0	**LIVING & WORKSPACE ACCOMMODATIONS**	**129**	**-**	**690.08**	**0.0%**	**129.34**	**819.42**	**-**	**-**
13.1.1	HANDRAILS AND WORK INTERFACE FIXTURES (FCDT ASS	1	52.00	52.00	11.0%	5.72	57.72	-	-
13.1.2	Restraints	1	50.00	50.00	20.0%	10.00	60.00	-	-
13.1.3	MAINTENANCE WORKSTATION STRUCTURES AND PARTI	2	85.00	170.00	20.0%	34.00	204.00	-	-
13.1.4	General Light	40	1.00	40.00	20.0%	8.00	48.00	-	-
13.1.5	Task Light	40	0.50	20.00	20.0%	4.00	24.00	-	-
13.1.6	MANUAL LIGHTING CONTROL	8	0.01	0.08	20.0%	0.02	0.10	-	-
13.1.7	WORK SURFACES	1	40.00	40.00	10.0%	4.00	44.00	-	-
13.1.8	CLOSEOUT PANELS (GALLEY)	3	6.00	18.00	20.0%	3.60	21.60	-	-
13.1.9	CQ - CREW WORK DESK	4	3.00	12.00	20.0%	2.40	14.40	-	-
13.1.10	CQ - Crew Compartment Enclosure (placeholder)	4	25.00	100.00	20.0%	20.00	120.00	-	-
13.1.11	CQ - Bunk/Sleep Restraints	8	2.00	16.00	20.0%	3.20	19.20	-	-
13.1.12	CQ - Mirror	4	1.00	4.00	20.0%	0.80	4.80	-	-
13.1.13	Hygiene - Crew Restraint	3	11.00	33.00	20.0%	6.60	39.60	-	-
13.1.14	Hygiene Compartment Enclosure (Placeholder)	2	20.00	40.00	20.0%	8.00	48.00	-	-
13.1.15	Hygiene - Facial Mirror	2	1.00	2.00	20.0%	0.40	2.40	-	-
13.1.16	Private Waste Management Enclosure (Placeholder)	3	20.00	60.00	20.0%	12.00	72.00	-	-
13.1.17	Private Waste Management Enclosure - Crew Restraint	3	11.00	33.00	20.0%	6.60	39.60	-	-
13.2.0	**WATER RECOVERY & MGMT SYS**	**15**	**-**	**1,232.76**	**0.0%**	**190.70**	**1,423.46**	**-**	**-**
13.2.1	H2O/O2 TANKS	2	33.54	67.08	15.0%	10.06	77.14	-	-
13.2.2	Urine Processing (UPA)	1	350.00	350.00	5.0%	17.50	367.50	-	-
13.2.3	Brine Processing	1	65.30	65.30	20.0%	13.06	78.36	-	-
13.2.4	Water Processing (WPA)	1	518.00	518.00	20.0%	103.60	621.60	-	-
13.2.5	Process Controller	1	36.91	36.91	20.0%	7.38	44.29	-	-
13.2.6	Water Recovery System (WRS) with Tank	1	47.72	47.72	20.0%	9.54	57.26	-	-
13.2.7	Microbial Check	1	1.84	1.84	20.0%	0.37	2.21	-	-

SBS ID	COMMON FUNCTIONAL CATEGORY (TIER 1) COMMON EQUIPMENT GROUP (TIER 2) UNIQUE COMPONENT/SUB-ASSEMBLY (TIER 3)	Qty	Unit Mass (kg)	Basic Mass (kg)	Applied MGA (%)	MGA (kg)	Predicted Empty Mass (kg)	Predicted Total Ops Mass (kg)	Predicted Total Tier 1 Mass (kg)
13.2.8	Water Quality Monitoring	1	34.10	34.10	20.0%	6.82	40.92	-	-
13.2.9	Water Delivery System	2	20.65	41.31	20.0%	8.26	49.57	-	-
13.2.10	Sink, Spigot for Hydration of Food and Drinking Water	2	27.25	54.50	20.0%	10.90	65.40	-	-
13.2.11	Handwash/Mouthwash Faucet	2	8.00	16.00	20.0%	3.20	19.20	-	-
13.3.0	**FOOD MGMT SYS**	**3**	-	**891.70**	**0.0%**	**255.89**	**1,147.59**	-	-
13.3.1	Food Warmers	2	58.10	116.20	20.0%	23.24	139.44	-	-
13.3.2	Cold Stowage	1	775.50	775.50	30.0%	232.65	1,008.15	-	-
13.4.0	**WASTE COLLECTION & MGMT SYS**	**8**	-	**703.50**	**0.0%**	**140.70**	**844.20**	-	-
13.4.1	URINE COLLECTION SYSSTEM	2	4.55	9.10	20.0%	1.82	10.92	-	-
13.4.2	SOLID WASTE COLLECTION	2	58.40	116.80	20.0%	23.36	140.16	-	-
13.4.3	SOLID WASTE BULK COMPACTOR/STORAGE	2	8.80	17.60	20.0%	3.52	21.12	-	-
13.4.4	TRASH COMPACTOR W/ WATER RECOVERY	1	120.00	120.00	20.0%	24.00	144.00	-	-
13.4.5	TRASH AIRLOCK	1	440.00	440.00	20.0%	88.00	528.00	-	-
13.5.0	**EXERCISE SYS**	**6**	-	**1,090.00**	**0.0%**	**208.20**	**1,298.20**	-	-
13.5.1	TREADMILL	1	150.00	150.00	3.0%	4.50	154.50	-	-
13.5.2	TREADMILL VIBRATION ISOLATION	1	300.00	300.00	30.0%	90.00	390.00	-	-
13.5.3	RESISTANCE SYSTEM	1	165.00	165.00	3.0%	4.95	169.95	-	-
13.5.4	RESISTANCE VIBRATION ISOLATION	1	50.00	50.00	30.0%	15.00	65.00	-	-
13.5.5	Resistance and Aerobic Exercise Device	1	125.00	125.00	3.0%	3.75	128.75		
13.5.6	Resistance and Aerobic Exercise Device Vibraton Isolation	1	300.00	300.00	30.0%	90.00	390.00		
13.6.0	**MEDICAL SYS**	**1**	-	**259.54**	**0.0%**	**0.00**	**259.54**	-	-
13.6.1	MISCELLANEOUS LONG DURATION MEDICAL DEVICES	1	259.54	259.54	0.0%	0.00	259.54	-	-
13.7.0	**FIXED CREW EMERGENCY EQUIP**	**92**	-	**34.81**	**0.0%**	**3.69**	**38.51**	-	-
13.7.1	EMERGENCY LIGHT	8	0.05	0.40	20.0%	0.08	0.48	-	-
13.7.2	EMERGENCY LIGHTING MARKERS	72	0.00	0.07	20.0%	0.01	0.09	-	-
13.7.3	EMERGENCY O2 MASKS/FILTERING RESPIRATOR	8	2.25	18.00	20.0%	3.60	21.60	-	-
13.7.4	FIRE EXTINGUISHER	2	4.54	9.08	0.0%	0.00	9.08	-	-
13.7.5	POST-FIRE CLEANUP CANISTER	2	3.63	7.26	0.0%	0.00	7.26	-	-
13.8.0	**HYGIENE FACILITIES**	**0**	-	**0.00**	**0.0%**	**0.00**	**0.00**	-	-
13.9.0	**CREW/HAB SPT SYS MOUNTING/INSTALL H/W**	**0**	-	**0.00**	**0.0%**	**0.00**	**0.00**	-	-
13.A.0	***LIVING SPACE ITEMS***	***3***	-	***258.42***	***0.0%***	***1.73***	-	**260.15**	-
13.A.1	*RECREATION & PERSONAL STOWAGE*	*1*	*200.00*	*200.00*	*0.0%*	*0.00*	-	200.00	-
13.A.2	*VACUUM (PRIME + 2 SPARES)*	*1*	*8.67*	*8.67*	*20.0%*	*1.73*	-	10.40	-
13.A.3	*Consumables CTB Liners*	*1*	*49.75*	*49.75*	*0.0%*	*0.00*	-	49.75	-
13.B.0	***WORK SUPPORT ITEMS***	***1***	-	***100.00***	***0.0%***	***0.00***	-	**100.00**	-
13.B.1	*OPERATIONAL SUPPLIES*	*1*	*100.00*	*100.00*	*0.0%*	*0.00*	-	100.00	-
13.D.0	***MEDICAL ITEMS***	***22***	-	***175.33***	***0.0%***	***0.00***	-	**175.33**	-
13.D.1	*FIRST AID KIT*	*2*	*9.10*	*18.20*	*0.0%*	*0.00*	-	18.20	-
13.D.2	*CONVENIENCE MEDICATION PACK*	*1*	*2.81*	*2.81*	*0.0%*	*0.00*	-	2.81	-
13.D.3	*IV SUPPLY PACK*	*1*	*6.17*	*6.17*	*0.0%*	*0.00*	-	6.17	-
13.D.4	*MEDICAL DIAGNOSTIC PACK*	*1*	*4.04*	*4.04*	*0.0%*	*0.00*	-	4.04	-
13.D.5	*MEDICAL SUPPLY PACK*	*1*	*2.92*	*2.92*	*0.0%*	*0.00*	-	2.92	-
13.D.6	*MINOR TREATMENT PACK*	*1*	*3.88*	*3.88*	*0.0%*	*0.00*	-	3.88	-
13.D.7	*ORAL MEDICATION PACK*	*1*	*2.67*	*2.67*	*0.0%*	*0.00*	-	2.67	-
13.D.8	*PHYSICIAN EQUIPMENT PACK*	*1*	*2.54*	*2.54*	*0.0%*	*0.00*	-	2.54	-
13.D.9	*TOPICAL & INJECTABLE PACK*	*1*	*3.37*	*3.37*	*0.0%*	*0.00*	-	3.37	-
13.D.10	*AED*	*1*	*3.73*	*3.73*	*0.0%*	*0.00*	-	3.73	-
13.D.11	*ECG*	*1*	*8.50*	*8.50*	*0.0%*	*0.00*	-	8.50	-
13.D.12	*ULTRASOUND*	*1*	*3.70*	*3.70*	*0.0%*	*0.00*	-	3.70	-
13.D.13	*PATIENT RESTRAINT SYSTEM*	*2*	*18.20*	*36.40*	*0.0%*	*0.00*	-	36.40	-
13.D.14	*MEDICAL WORKSTATION STRUCTURE*	*2*	*18.20*	*36.40*	*0.0%*	*0.00*	-	36.40	-
13.D.15	*PRIVACY CURTAIN*	*5*	*8.00*	*40.00*	*0.0%*	*0.00*	-	40.00	-
13.D.16	*MISCELLANEOUS LONG DURATION MEDICAL DEVICES*	*0*	*259.54*	*0.00*	*0.0%*	*0.00*	-	0.00	-
13.E.0	***EMERGENCY ITEMS***	***2***	-	***28.81***	***0.0%***	***5.76***	-	**34.57**	-
13.E.1	*EMERGENCY MEDICAL TREATMENT PACK*	*1*	*2.81*	*2.81*	*20.0%*	*0.56*	-	3.37	-
13.E.2	*LIGHTWEIGHT TRAUMA MODULE*	*1*	*26.00*	*26.00*	*20.0%*	*5.20*	-	31.20	-
13.F.0	***FOOD, WATER & WASTE MGMT ITEMS***	*7*	-	***7,880.49***	***0.0%***	***1.60***	-	**7,882.09**	-
13.F.1	*FOOD*	*1*	*6,298.10*	*6,298.10*	*0.0%*	*0.00*	-	6,298.10	-
13.F.2	*H20 & GASSES*	*1*	*640.87*	*640.87*	*0.0%*	*0.00*	-	640.87	-
13.F.3	*COOKING/EATING SUPPLIES*	*1*	*8.00*	*8.00*	*20.0%*	*1.60*	-	9.60	-
13.F.4	*WASTE COLLECTION - FECAL CANISTERS*	*1*	*708.40*	*708.40*	*0.0%*	*0.00*	-	708.40	-
13.F.5	*WASTE COLLECTION - URINE PREFILTER*	*1*	*123.20*	*123.20*	*0.0%*	*0.00*	-	123.20	-
13.F.6	*FECAL/URINE COLLECTION BAGS (CONTINGENCY)*	*1*	*9.52*	*9.52*	*0.0%*	*0.00*	-	9.52	-
13.F.7	*TRASH BAGS*	*1*	*92.40*	*92.40*	*0.0%*	*0.00*	-	92.40	-
13.G.0	***PERSONAL,WEARABLE/LAUNDRY, HYGIENE ITEMS***	***12***	-	***1,947.90***	***0.0%***	***8.33***	-	**1,956.24**	-
13.G.1	*EVA MAGs*	*1*	*1.04*	*1.04*	*0.0%*	*0.00*	-	1.04	-
13.G.2	*Wipes and Gloves*	*1*	*616.00*	*616.00*	*0.0%*	*0.00*	-	616.00	-
13.G.3	*OCSS SUITS AND 2 SHORT UMBILICALS*	*0*	*21.25*	*0.00*	*11.0%*	*0.00*	-	0.00	-
13.G.4	*OCSS SUIT KITS (ARCM SERVICING AND SUIT KITS FOR ...)*	*0*	*265.00*	*0.00*	*11.0%*	*0.00*	-	0.00	-
13.G.5	*CLOTHING*	*1*	*541.19*	*541.19*	*0.0%*	*0.00*	-	541.19	-
13.G.6	*PERSONAL HYGIENE KIT*	*1*	*118.80*	*118.80*	*0.0%*	*0.00*	-	118.80	-
13.G.7	*HYGIENE CONSUMABLES / WCS WIPES*	*0*	*984.00*	*0.00*	*3.0%*	*0.00*	-	0.00	-
13.G.8	*TOWELS*	*1*	*393.07*	*393.07*	*0.0%*	*0.00*	-	393.07	-
13.G.9	*COMMUNITY HYGIENE KIT*	*0*	*4.72*	*0.00*	*20.0%*	*0.00*	-	0.00	-
13.G.10	*HEALTHCARE CONSUMABLES*	*1*	*277.20*	*277.20*	*3.0%*	*8.32*	-	285.52	-
13.G.11	*WIPES (HOUSEKEEPING)*	*0*	*198.88*	*0.00*	*3.0%*	*0.00*	-	0.00	-
13.G.12	*Clothesline*	*6*	*0.10*	*0.60*	*3.0%*	*0.02*	-	0.62	-
13.J.0	***SPARE CREW/HAB SPT SYS EQUIP & MAINT ITEMS***	***3***	-	***7,397.15***	***0.0%***	***0.00***	-	**7,397.15**	-
13.J.1	*SPARES TOTAL*	*1*	*7,261.00*	*7,261.00*	*0.0%*	*0.00*	-	7,261.00	-
13.J.2	*MAINTENANCE TOTAL*	*1*	*110.00*	*110.00*	*0.0%*	*0.00*	-	110.00	-
13.J.3	*WHC Plumbing to UPA*	*0*	*16.30*	*0.00*	*3.0%*	*0.00*	-	0.00	-
13.J.4	*Fan Control Panel Assembly*	*0*	*22.70*	*0.00*	*3.0%*	*0.00*	-	0.00	-
13.J.5	*Spares and Maint CTB Liners*	*1*	*26.15*	*26.15*	*0.0%*	*0.00*	-	26.15	-
14.0.0	**EXTRAVEHICULAR ACTIVITY (EVA) SUPPORT SYSTEMS**	**78**	-	**823.62**	**0.0%**	**107.93**	**931.55**	**670.79**	**1,602.34**
14.1.0	**EVA EQUIP AND SERVICE INTERFACES**	**72**	-	**315.76**	**0.0%**	**39.49**	**355.25**	-	-
14.1.1	EVA PATH LIGHTING	8	1.00	8.00	18.0%	1.44	9.44	-	-
14.1.2	PERMANENT HARDWARE (DON/DOFF STAND, UMBILICAL	2	105.00	210.00	13.0%	27.30	237.30	-	-
14.1.3	LARGE HABITAT COMMUNICATION (ARCM COMM. KITS)	4	11.50	46.00	11.0%	5.06	51.06	-	-
14.1.4	HANDRAILS (TBD FOR HAB AND TWO C/L)	45	0.70	31.50	11.0%	3.47	34.97	-	-

SBS ID	COMMON FUNCTIONAL CATEGORY (TIER 1) COMMON EQUIPMENT GROUP (TIER 2) UNIQUE COMPONENT/SUB-ASSEMBLY (TIER 3)	Qty	Unit Mass (kg)	Basic Mass (kg)	Applied MGA (%)	MGA (kg)	Predicted Empty Mass (kg)	Predicted Total Ops Mass (kg)	Predicted Total Tier 1 Mass (kg)
14.1.5	WIF (TBD)	12	0.73	8.76	11.0%	0.96	9.72	-	-
14.1.6	APFR	1	11.50	11.50	11.0%	1.27	12.77	-	-
14.2.0	**INTERNAL AIRLOCK EQUIP**	**4**	**-**	**352.30**	**0.0%**	**68.44**	**420.74**	**-**	**-**
14.2.1	AIRLOCK CO2 REMOVAL	1	181.30	181.30	20.0%	36.26	217.56	-	-
14.2.2	DEPRESSURIZATION PUMP & SUPPORT	1	98.00	98.00	18.0%	17.64	115.64	-	-
14.2.3	AIRLOCK RECYCLE PUMP	1	70.00	70.00	20.0%	14.00	84.00	-	-
14.2.4	AUDIO SYSTEM (AIRLOCK)	1	3.00	3.00	18.0%	0.54	3.54	-	-
14.3.0	**EVA SYS FIXED STORAGE SPACE**	**0**	**-**	**0.00**	**0.0%**	**0.00**	**0.00**	**-**	**-**
14.4.0	**IVA SUIT LOOP**	**1**	**-**	**100.00**	**0.0%**	**0.00**	**100.00**	**-**	**-**
14.4.1	IVA SUIT LOOP HARDWARE	1	100.00	100.00	0.0%	0.00	100.00	-	-
14.9.0	**EVA SPT SYS MOUNTING/INSTALL H/W**	**1**	**-**	**55.56**	**0.0%**	**0.00**	**55.56**	**-**	**-**
14.9.1	Installation	1	55.56	55.56	0.0%	0.00	55.56	-	-
14.H.0	***EVA SUITS & PACKAGING***	***8***	**-**	***582.90***	***0.0%***	***87.89***	**-**	**670.79**	**-**
14.H.1	*M-EMU (MARS SURFACE SUITS) - SIZING COMPONENTS ONL*	*2*	*54.17*	*108.34*	*20.0%*	*21.67*	-	130.01	-
14.H.2	*LEA SUITS AND SHORT UMBILICALS*	*4*	*29.84*	*119.36*	*15.9%*	*18.98*	-	138.34	-
14.H.3	*OCSS SUIT KITS (ARCM SERVICING AND SUIT KITS FOR ...)*	*0*	*265.00*	*0.00*	*11.0%*	*0.00*	-	0.00	-
14.H.4	*xEMU-SP + xPLSS*	*2*	*177.60*	*355.20*	*13.3%*	*47.24*	-	402.44	-
15.0.0	**IN-SITU RESOURCE ACQUISITION & CONSUMABLES PRODU**	**0**	**-**	**0.00**	**0.0%**	**0.00**	**0.00**	**0.00**	**0.00**
16.0.0	**IN-SPACE MANUFACTURING & ASSEMBLY SYSTEMS**	**0**	**-**	**0.00**	**0.0%**	**0.00**	**0.00**	**0.00**	**0.00**
17.0.0	**MANIPULATION & MAINTENANCE SYSTEMS**	**22**	**-**	**709.00**	**0.0%**	**179.58**	**888.58**	**0.00**	**888.58**
17.1.0	**ROBOTIC & HANDLING EQUIP**	**22**	**-**	**709.00**	**0.0%**	**179.58**	**888.58**	**-**	**-**
17.1.1	External - Payload Avionics	1	83.00	83.00	30.0%	24.90	107.90	-	-
17.1.2	External - Robotics (Payload Manipulation)	1	600.00	600.00	25.0%	150.00	750.00	-	-
17.1.3	Exterior - Robotic Area Lighting	8	1.00	8.00	18.0%	1.44	9.44	-	-
17.1.4	Exterior - Survelliance Lighting	12	1.50	18.00	18.0%	3.24	21.24	-	-
18.0.0	**PAYLOAD PROVISIONS**	**0**	**-**	**0.00**	**0.0%**	**0.00**	**0.00**	**0.00**	**0.00**
	MANUFACTURER'S EMPTY MASS	2,818	-	21,002.10	0.0%	3,497.10	**24,499.20**		
	TOTALS								
	OPERATIONAL ITEMS SUMMARY	**84**	**-**	**18,724.75**	**0.0%**	**106.36**	**-**	**18,831.11**	
	CREW ITEMS/CONSUMABLES & PORTABLE EQUIP	***72***	**-**	***10,994.09***	***0.0%***	***106.36***	**-**	**11,100.45**	**-**
	EQUIPMENT SPARES & MAINTENANCE ITEMS	***3***	**-**	***7,397.15***	***0.0%***	***0.00***	**-**	**7,397.15**	**-**
	ATMOSPHERE & SYSTEM CONSUMABLES/RESIDUALS	***9***	**-**	***333.51***	***0.0%***	***0.00***	**-**	**333.51**	**-**
	CLOSED SYSTEM FLUIDS (FIELD-LOADED/SERVICED)	***0***	**-**	***0.00***	***0.0%***	***0.00***	**-**	**0.00**	**-**
	PYROTECHNIC/ORDNANCE ITEMS & BALLAST	***0***	**-**	***0.00***	***0.0%***	***0.00***	**-**	**0.00**	**-**
	GENERAL PURPOSE CONTAINERS & CARRIERS	***0***	**-**	***0.00***	***0.0%***	***0.00***	**-**	**0.00**	**-**
	OPERATIONAL ITEMS - CREW	-	-	-	-	-	-	-	-
	OPERATIONAL EMPTY MASS	2,902	-	39,726.85	0.0%	3,603.46	-	-	**43,330.31**
19.0.0	**PAYLOADS & RESEARCH**	**5**	**-**	**1,328.00**	**0.0%**	**0.00**	**-**	**-**	**1,328.00**
19.1.0	***CARGO***	***5***	**-**	***1,328.00***	***0.0%***	***0.00***	**-**	**-**	**1,328.00**
19.1.1	*CREW MEMEBERS (4 Crew)*	*4*	*82.00*	*328.00*	*0.0%*	*0.00*	-	-	328.00
19.1.2	*Payload Utilization*	*1*	*1,000.00*	*1,000.00*	*0.0%*	*0.00*	-	-	1,000.00
	PROPULSION & REACTION CONTROL EXPENDABLES	**0**	**-**	**1,562.00**	**0.0%**	**0.00**	**-**	**-**	**1,562.00**
	GROSS ITEM CONTRIBUTIONS	5	-	**2,890.00**	**0.0%**	**0.00**	-	-	**2,890.00**
	GROSS MASS TOTALS	**2,907**	**-**	**42,616.85**	**0.0%**	**3,603.46**	**24,499.20**	**43,330.31**	**46,220.31**