Workstation Designs for a Cis-lunar Deep Space Habitat

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Using the International Standard Payload Rack (ISPR) system, a suite of workstations required for deep space missions have been proposed to fill out habitation functions in an International Space Station (ISS) derived Cis-lunar Deep Space Habitat. This paper introduces the functional layout of the Cis-lunar habitat design, and describes conceptual designs for modular deployable work surfaces, General Maintenance Workstation (GMWS), In-Space Manufacturing Workstation (ISMW), Intra-Vehicular Activity Telerobotics Work Station (IVA-TRWS), and Galley / Wardroom.

Nomenclature

AES	=	NASA Advanced Exploration Systems project
ATHLETE	=	All-Terrain Hex-Limbed Extra-Terrestrial Explorer robotic mobility system
CTB	=	Cargo Transfer Bag
D-RATS	=	NASA Desert Research and Technology Studies
DSH	=	Deep Space Habitat
EAM	=	Exploration Augmentation Module
EXPRESS	=	EXpedite the PRocessing of Experiments for Space Station
GMWS	=	General Maintenance Work Station
HDU	=	Habitat Demonstration Unit
HERA	=	Human Exploration Research Analog
ISMW	=	In-Space Manufacturing Work Station
ISPR	=	International Standard Payload Rack
ISIS	=	International Subrack Interface Standard
ISS	=	International Space Station
IVA	=	Intravehicular Activity
MPCV	=	Multi-Purpose Crew Vehicle
MPLM	=	Multi-Purpose Logistics Module
PLSS	=	Personal Life Support System
RAF	=	Random Access Frames
TRWS	=	Telerobotics Work Station

I. Introduction

THE International Space Station (ISS) uses a modular layout standard called the International Standard Payload Rack (ISPR), that consists of refrigerator-sized identical cabinets to organize avionics, stowage, workstations, lockers, life-support hardware, payloads, and experiments. The ISPR system was conceived by space architects (Jones 2009) as a means to organize infrastructure, equipment, payloads, science experiments, stowage, logistics, and internal outfitting using swappable rack modules delivered by the Space Shuttle. Since the ISS was permanently located in Low Earth Orbit (LEO), frequent visits by the Shuttle allowed for frequent resupply and swapping in and out of payloads and experiments. However, with the end of the Shuttle program, the ability to deliver rack-sized modules was reduced to infrequent visits by the Japanese- and European-built supply vessels, which themselves were on their way out. The question remained, could the ISPR heritage systems continue to be used, even if the original requirements for swap-out, frequent resupply, and replaceable payloads no longer apply? We reported on the overall ISS-derived Cis-lunar layout studies previously (Griffin, Smitherman, Howe 2013). For this research, it was decided to support a proposed transition from LEO to deep space human presence by using rack-based heritage

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for internal layout, to explore how the ISS-derived modular system could be adapted for use in a Deep Space Habitat.

II. ISPR System

The ISPR system consists of two main components – refrigerator-sized rack modules that plug into standoff structures containing infrastructure elements. Figure 1 (left) shows a cross-section of four ISPR rack modules (green) installed between four standoff frames (gray), defining a square volume corridor for crew occupancy. Racks are removed or installed by tipping the unit into the central corridor, and floating it through the end hatch of the module (Figure 1, right).

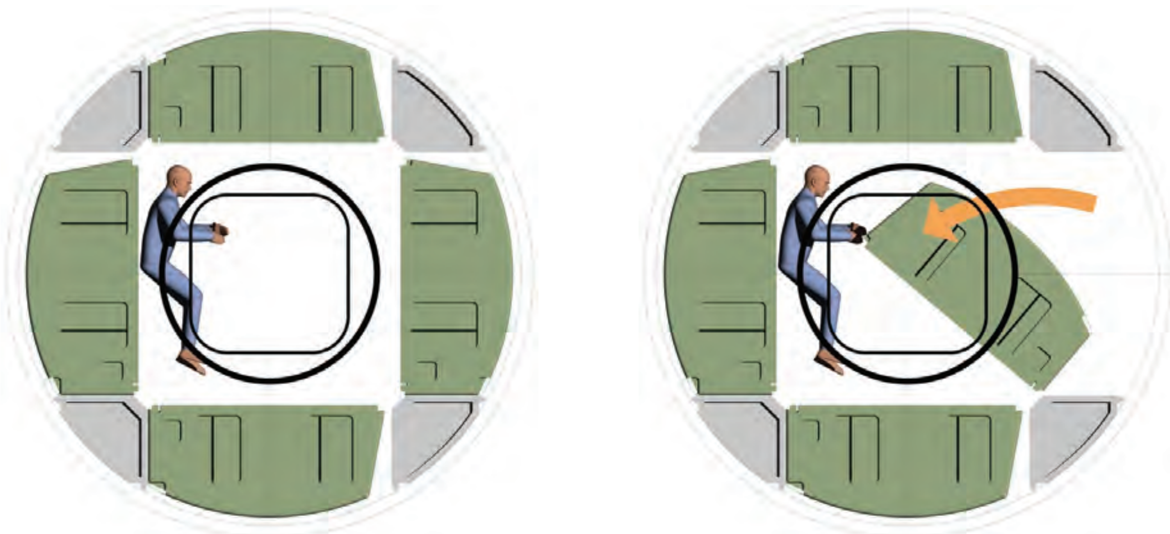

Figure 1: Cross-section of ISS modules showing the International Standard Payload Rack (ISPR) method of organizing equipment and logistics (left, shown as green modules attached to gray standoff structure) – rack modules can be swapped in and out with frequent resupply (right)

The ISPR system has standard interfaces for power, data, thermal, fluid, gases, fire suppression, and other subsystems that each rack can plug into on basis of need. In actuality, though some racks were indeed swapped in and out, many of the racks were permanently installed and the most convenient swappability occurred on a smaller level by means of the "EXpedite the PRocessing of Experiments for Space Station" (EXPRESS) payloads, Shuttle middeck lockers, equipment, and avionics based on the International Subrack Interface Standard (ISIS).

Modular systems are generally compromises that may be suboptimal in any particular instance, but through efficient management of interfaces, standards, and identical parts are able to address a wide number of situations that custom solutions cannot. This compromised modularity penalty pays for itself in the manufacture or mass-production of many parts, and in the need to keep products from multiple destinations and vendors consistent and integrated with each other. The strict modularity of the ISPR system, with its standard disconnects and interfaces, contributed additional mass to the system, but the Space Shuttle was more than equipped to accommodate such additional masses and complexity.

III. ISS-derived Cis-Lunar Habitat

With the move from LEO to deep space and the retirement of the Shuttle, there is more and more a need to optimize mass that will need to be carried to distant destinations. Ideally, one would start anew and design a vehicle more appropriate for the new destination. However, with the ISS being a currently maintained live aboard space facility with known issues, problems, solutions, and trained crew and ground personnel, the ISS could at least be used as an analog for deep space missions, and ISS modules may provide the basis for a Deep Space Habitat design. This was the assumption of the ISS-derived Cis-lunar Deep Space Habitat study, conducted in 2012-2013.

The Cis-lunar Deep Space Habitat consisted of two elements – an ISS node that would be outfitted as a core extension module for the Orion Multi-Purpose Crew Vehicle (MPCV) on a 80-day mission to lunar orbit or Earth-moon L1 or L2, and a refitted ISS Multi-Purpose Logistics Module (MPLM) augmentation element to fill out habitation functions needed for a 160-day mission.

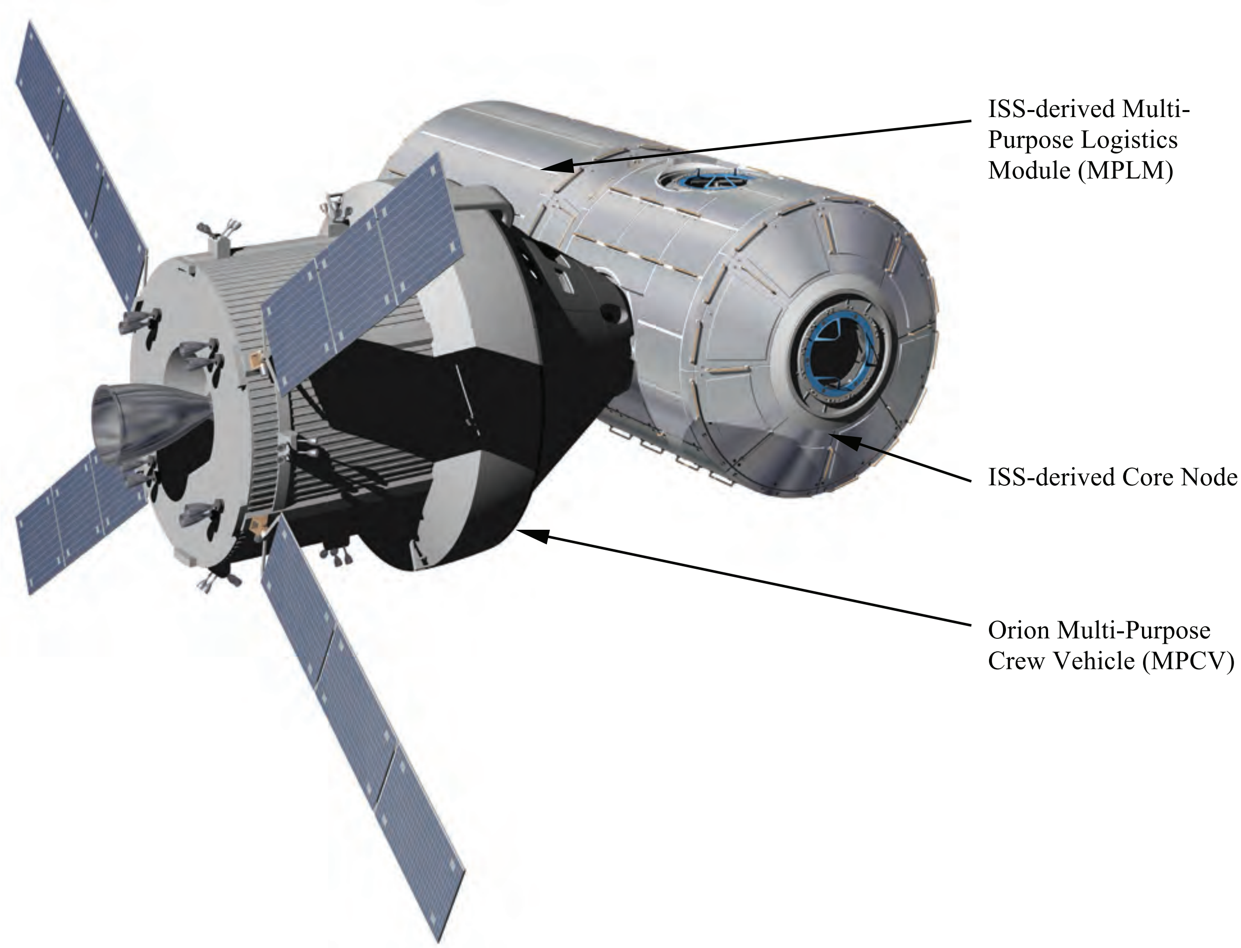

Figure 2: ISS-derived Cis-lunar Deep Space Habitat with some of the modules needed for a 160-day mission

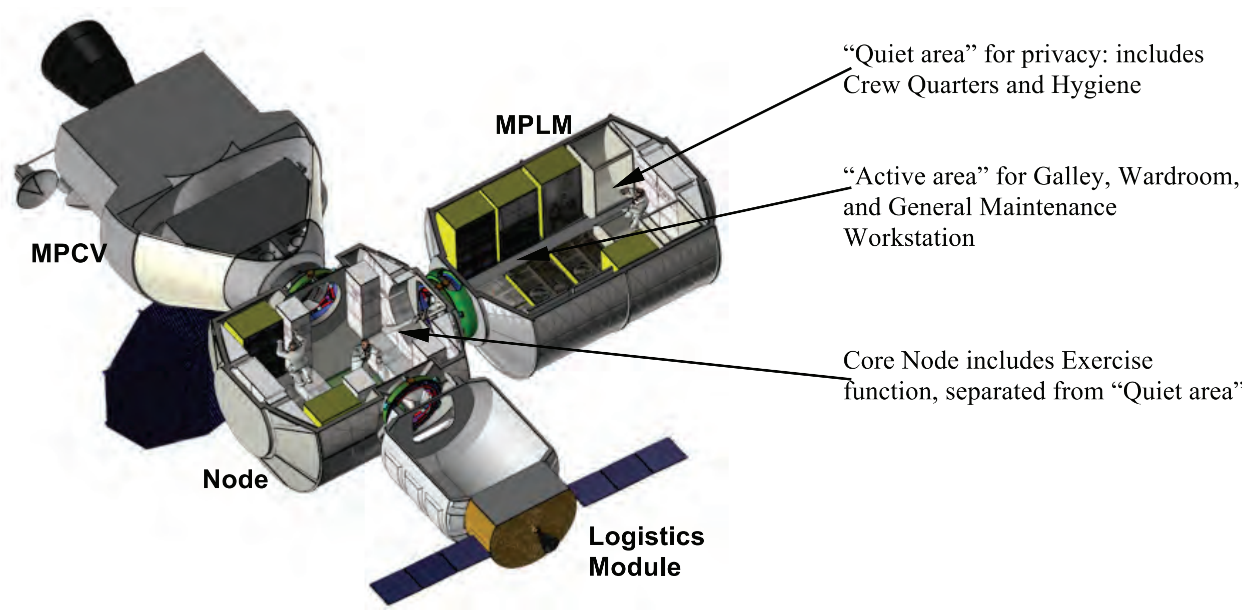

Figure 3: Cis-lunar Deep Space Habitat section (courtesy of NASA Marshall Spaceflight Center)

The 80-day mission stack configuration would include the MPCV, Core Node, Logistics Module (supplied by a commercial vendor), and upper propulsion stage, and could be fitted with a lunar lander for a sortie mission to the lunar surface. The 160-day mission configuration (Figure 2) maintained the 80-day configuration, which would dock with an MPLM augmentation module delivered later with its own upper propulsion stage. The combined configuration of MPCV, Core Node, MPLM, Logistics Module, and two propulsion stages were studied as a Deep Space Habitat that could be used for any Cis-lunar destination, and would become a functional analog for an eventual Mars transit vehicle and habitat.

IV. Workstations for Deep Space Missions

In the same way ISS modules were considered for transitional use from LEO to deep space habitation, current ISS internal outfitting was also studied as a baseline for crew workstations. Since the ISPR, EXPRESS, and ISIS standards have resulted in workable systems and available hardware, it was thought that it may be possible to design Deep Space Habitat crew workstations using available hardware or take advantage of established manufacturing facilities.

Habitation functions were divided among the two modules, as "quiet" or "active" as a way of establishing public space, private space, and adjacencies (Figure 3). Figure 4 shows a schematic of the Core Node and MPLM layouts in ISS rack diagram style. Rack bays oriented in an orthogonal cross-section of the modules were arbitrarily assigned a vertical orientation, with deck, overhead, port, and starboard for organizational purposes. Core functions, the "bare minimum" needed to extend the use of the MPCV were grouped into the Core Node (Figure 4, left), augmented with additional functions for longer missions in the MPLM (Figure 4, right).

A more thorough discussion of workstation layout has been reported previously (Griffin, Smitherman, Howe 2013). This study covers the design of Telerobotic Workstation (TRWS) in the Core Node, and General Maintenance Workstation (GMWS) and Galley / Wardroom in the MPLM.

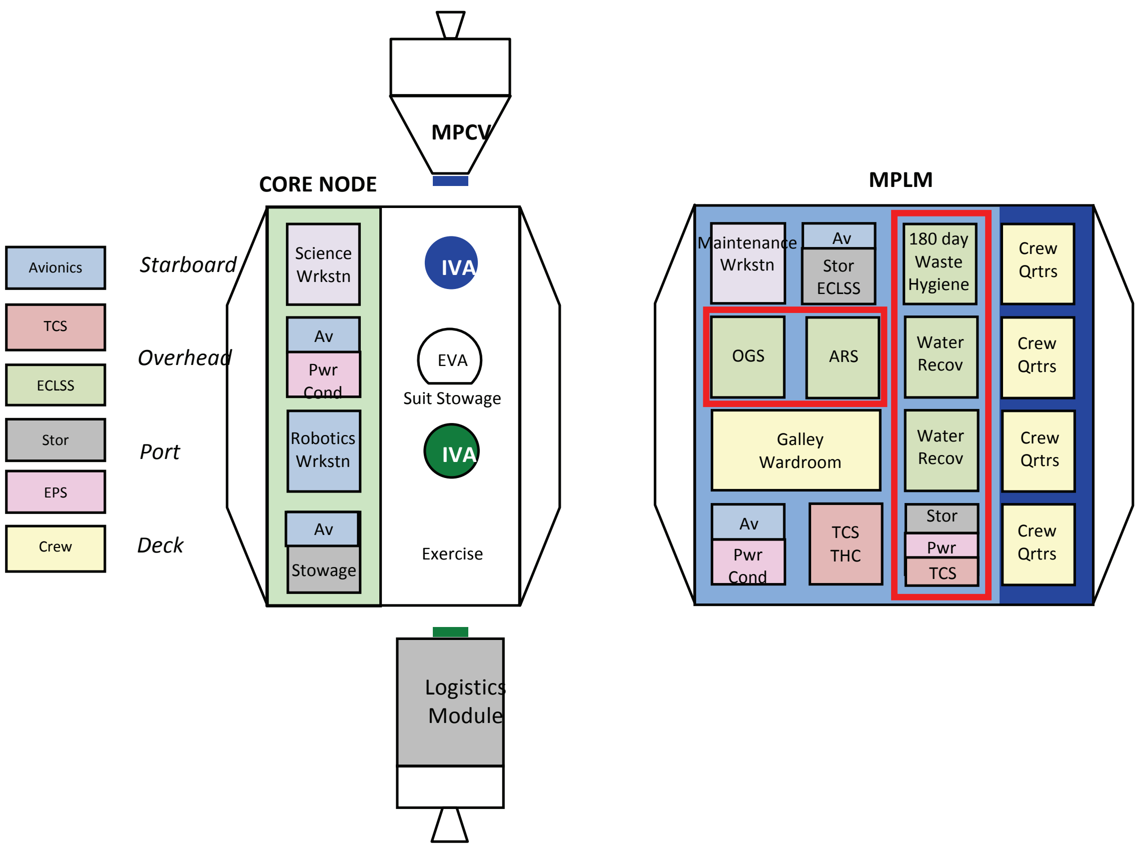

Figure 4: Cis-lunar Deep Space Habitat 180 day mission layout (courtesy of NASA Marshall Spaceflight Center) – this study covers Telerobotic Workstation in Core Node, and General Maintenance Workstation (GMWS) and Galley / Wardroom in MPLM.

A. Modular Deployable Work Surfaces

Deep Space Habitat team leader, astronaut Alvin Drew, often explained to the team that life in zero-g was only partially a three-dimensional experience, that may or may not be accentuated by larger or smaller volumes. More importantly, life in zero-g increased the number of surfaces that could be used – in other words where gravity environments punctuated the floor area as a useful metric, zero-g turned former walls and ceiling into usable floor area too. The clever use of all surfaces in a zero-g environment would be a defining feature of life and work in microgravity.

Part of the ISS-derived Cis-lunar Deep Space Habitat studies therefore included extensive exploration of modular, articulated, deployable work surfaces that could be put to use in a variety of orientations (Figure 5). It was assumed that some project, part, equipment, or incapacitated body could be positioned as desired for work, assembly, maintenance, or surgery, and restrained as needed (Figure 6).

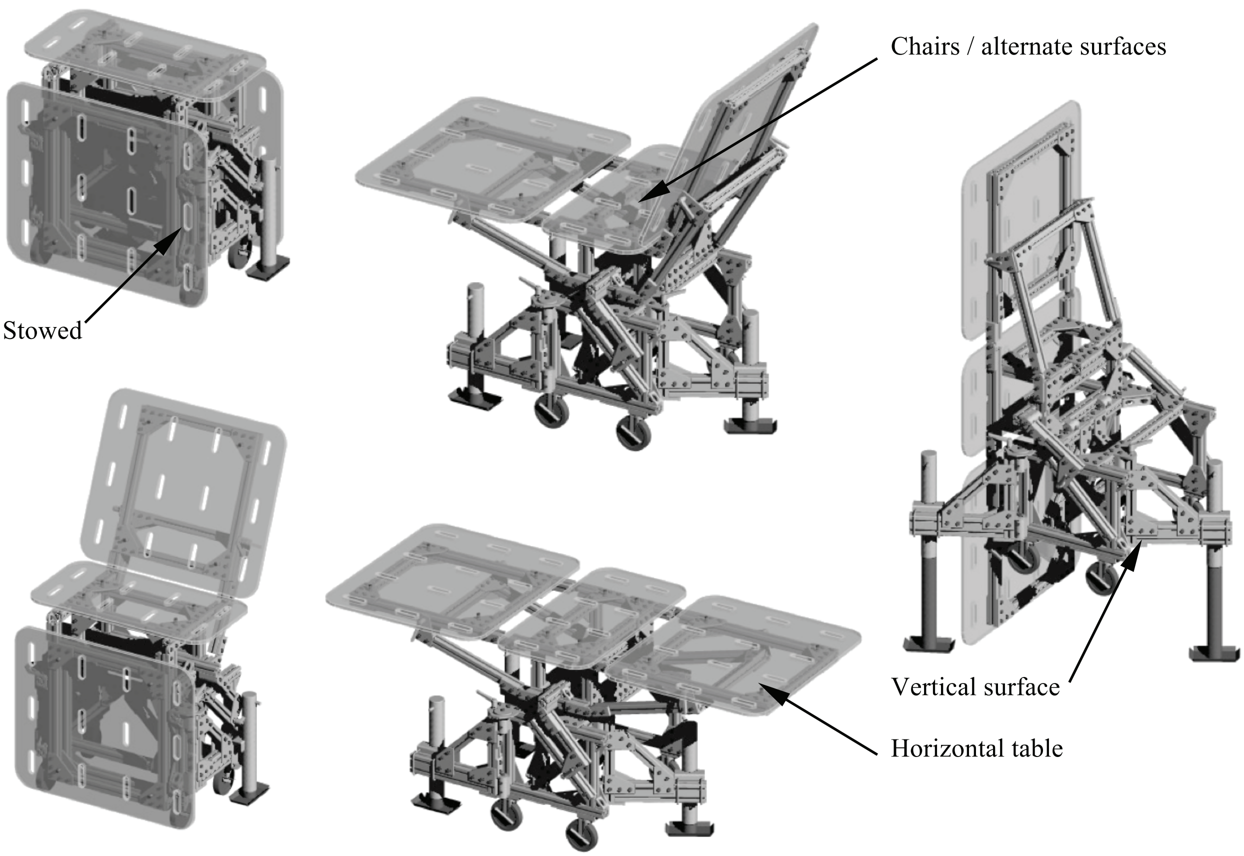

Figure 5: Modular deployable work surfaces study, exploring multi-fold, articulated, clamping surfaces for a variety of orientations

Initial studies for articulated work surfaces strove for an analog that could be constructed from simple kit-of-parts pieces, and rolled around the interior of a habitat prototype during mission operation tests to help determine which function needed what sorts of surfaces. Figure 5 is the final product of that study, as a wheeled table in a compact stowed block when not in use, and folded out to create chairs, tables, gurneys, and vertical surfaces on demand. Restraint of equipment could be accommodated through straps and clamps in slots and holes in the surfaces.

Target functions for articulated work surfaces included suit maintenance (Figure 6, left), telemedicine (Figure 6, right), general maintenance, manufacturing, reconfigurable enclosures or containment, and display boards.

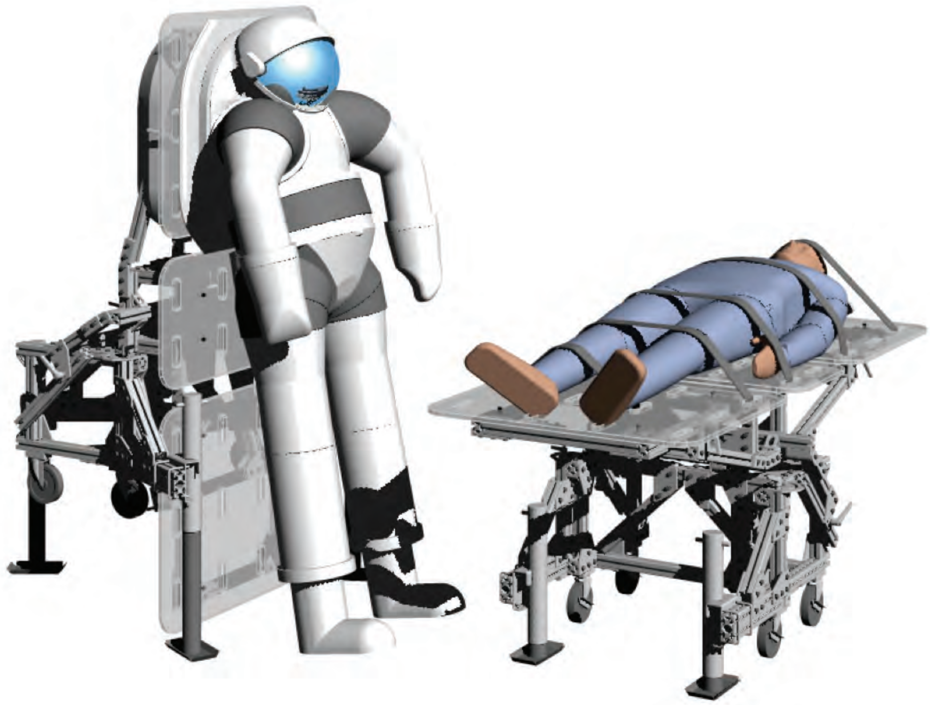

Figure 6: Alternative multi-orientation uses for re-deployable work surfaces in an earth-analog environment

B. General Maintenance Workstation (GMWS)

Workstation development built upon previous work and experience, including activities where crew feedback was obtained. Several generations of General Maintenance Workstation (GMWS) were explored during mission operations tests in NASA's Habitat Demonstration Unit (HDU) during NASA Desert Research and Technology Studies (D-RATS) 2010, D-RATS 2011, and NASA Mission Operations Tests (MOT) 2012 (Howe, Kennedy, Gill, et al 2013; Gill, et al, 2011; Kennedy, et al, 2011; Tri, et al, 2011). Lessons learned form these prototypes (Figure 7) were applied to an ISS-derived Cis-lunar Deep Space Habitat version of a GMWS.

Figure 7: Habitat Demonstration Unit (HDU) General Maintenance Workstation prototypes – Desert Research and Technology Studies (D-RATS) 2010 (left), D-RATS 2011 (middle), and Mission Operations Test (MOT) 2012 (right)

Table 1: General Maintenance Workstation (GMWS) functional requirements (provided by Robert Howard and Nathan Moore, Johnson Space Center)

Maintenance:
Soldering
Drilling
Metallurgical analysis
Bonding metal, composite, and other surfaces
Electronics analysis and repair
Computer inspection/testing and repair
Material handling
Precision Maintenance
Soft goods sewing, cutting, and patching
Suit Maintenance
Fabrication:
Metal cutting and bending
CAD Modeling
3D Printing
Dust/Particle/Fume Mitigation

It was assumed that 80-day or shorter missions would heavily rely on spares rather than have on-board maintenance functions. However, in missions greater than 80 days the availability of maintenenance functions would begin to reduce the mass required for spares, and reduce mission risk. Through HDU prototype experience, team members Robert Howard and Nathan Moore established a list of maintenance and simple fabrication functions that would be most useful on a 160-day mission (Table 1).

Features of the articulated work surface (Figure 5) studies were configured around the function list, assuming work envelopes for a variety of maintenance tasks. Figure 8 (left) shows the rack-based GMWS design in stowed configuration, which could be contained within the rack volume even if parts are being manufactured in the 3D additive printer unit. Figure 8 (left) shows one of the deployed configurations of the articulated work table.

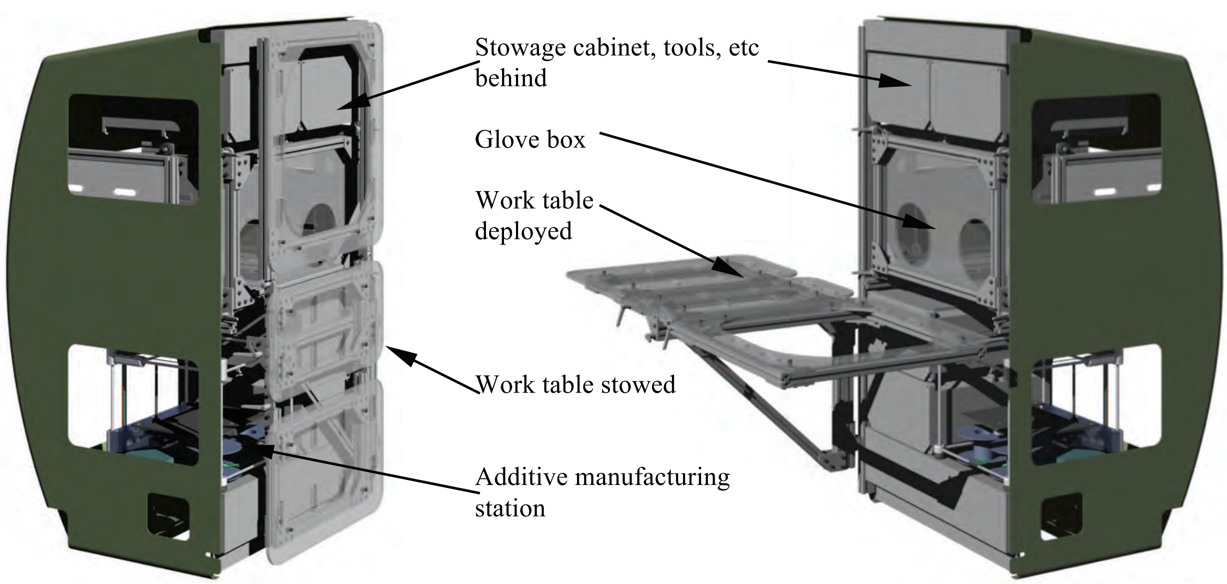

Figure 8: Rack-based General Maintenance Workstation (GMWS) design, stowed (left), and with horizontal work surface deployed (right)

The rack-based GMWS includes Shuttle Middeck Lockers (base on the ISIS standard) with full or half trays for stowage of tools, fasteners, glues, feedstock, and smaller raw material stocks. Larger sheet or linear stocks can be stowed at the sides of the glovebox, up to a certain size. Work surfaces can be constructed out of transparent materials for glovebox enclosure, or optionally can be constructed of opaque materials if there is not a need for see-through visualization. In this design, the filament feedstock 3D additive manufacturing station would be able to produce plastic parts with dimensions that do not exceed 250mm in each direction.

A glovebox can be slid out, lined with special disposable liners, and used for activies that generate particulates or overspray (Figure 9, left). The glovebox can be reconfigured into an additional work surface, opening up the glovebox volume for the placement of parts, assemblies, clamps, or tooling (Figure 9, right).

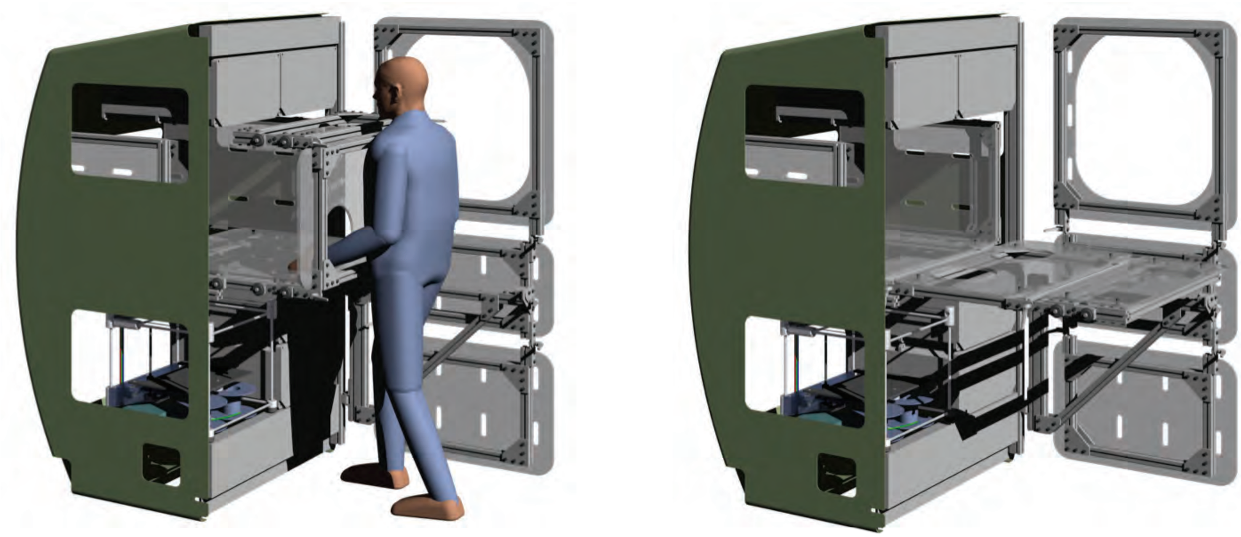

Figure 9: Rack-based GMWS with particulate containment glove box in use (left), and unfolded glovebox as additional work surfaces (right)

The GMWS can also be converted into a suit maintenance configuration, with EVA suits clamped onto the articulated table using identical marman clamp hardware that would be used in suitports (Figure 10, left). In cases where only the Personal Life Support System (PLSS) backpack needs to be worked on, a variety of orientatons can be accommodated using the articulated work table (Figure 10, right).

Figure 10: Rack-based GMWS in suit maintenance configuration (left), and Personal Life Support System (PLSS) adjustable maintenance configuration

C. Telerobotics Workstation (TRWS)

Similar to the GMWS, Telerobotics Workstation (TRWS) development built upon previous work and experience, including activities where crew feedback was obtained. Several generations of TRWS were explored during mission operations tests in NASA's Habitat Demonstration Unit (HDU) during NASA D-RATS 2010, D-RATS 2011, and NASA Mission Operations Tests (MOT) 2012 (only two years are shown in Figure 11). Lessons from these tests, and feedback from crewmembers resulted in a rack-based TRWS design.

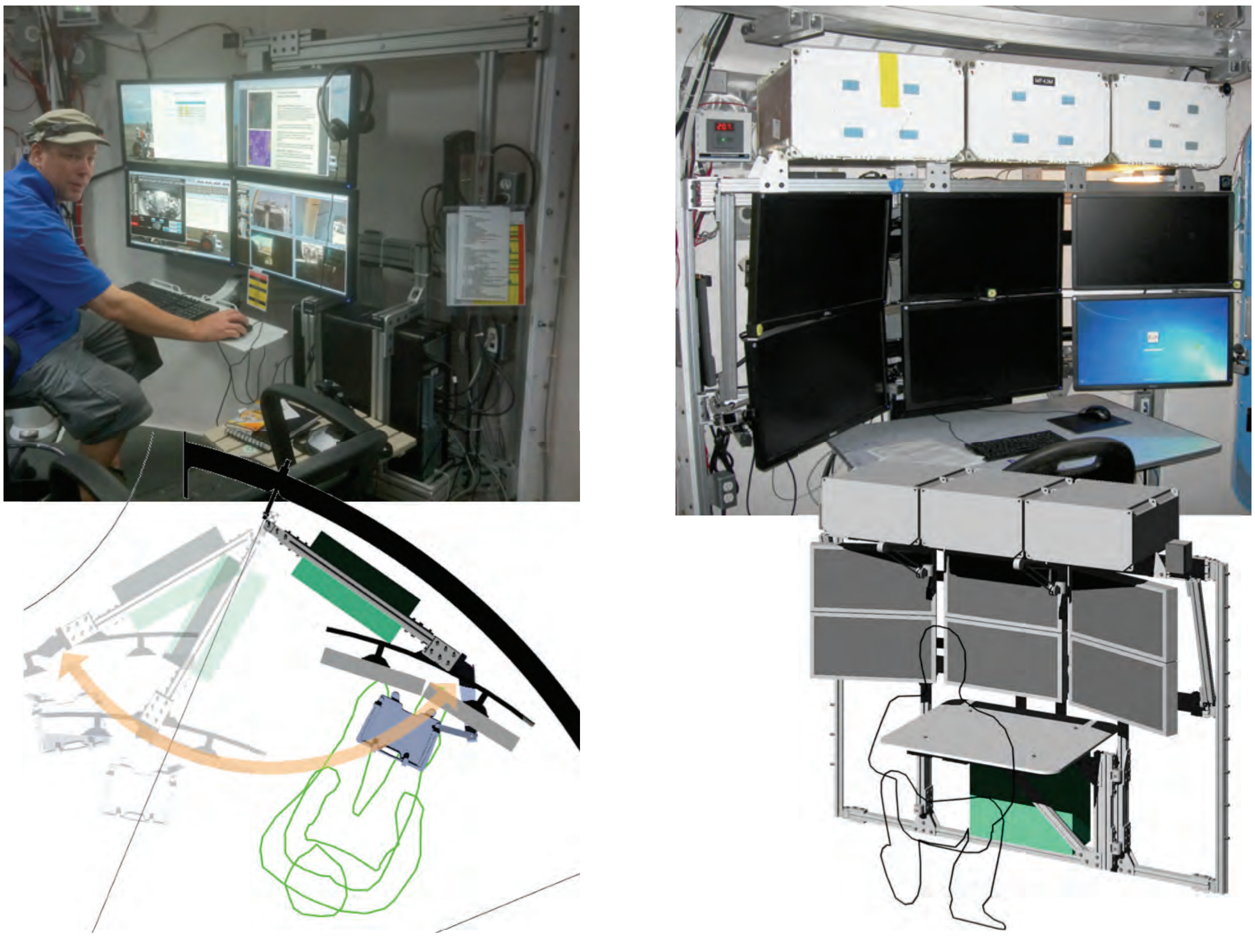

Figure 11: Habitat Demonstration Unit (HDU) Telerobotics & IVA Workstation prototypes – Desert Research and Technology Studies (D-RATS) 2010 swing-away design (left), and D-RATS 2011 deployable workstation version (right)

The TRWS is sometimes known as the Telerobotics-IVA Workstation due to the multitude of functions it accommodates. The telerobotics portion is used to remotely pilot robotic elements like Jet Propulsion Laboratory's All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE) robotic mobility system, Chariot mobility system, Robonaut, vehicles, rovers, probes, power infrastructure, landers, and other distant assets. The Intra-Vehicular Activity (IVA) portion is used for mission planning, mission communications, habitat systems monitoring, etc.

Figure 12 shows a longitudinal section of the Core Node, with TRWS deployed and in use. The TRWS consists of a CPU, multiple tiled displays, a work desk, stowage for accessories and manuals, and additional electronic components for telepresence and videoconferencing. The Core Node will have only one bay filled with racks in deck, overhead, port, and starboard slots, so the TRWS is designed to temporarily expand out into the exercise and work / translation volume in front of the EVA and IVA hatches, to allow for tiled video walls. The video wall (Figure 13) will consist of touch-screen thin-bezel displays slaved together when needed, or disassembled and used individually around the habitat like touch-screen pads (such as Apple's iPad, which were tested in D-RATS mission operations tests).

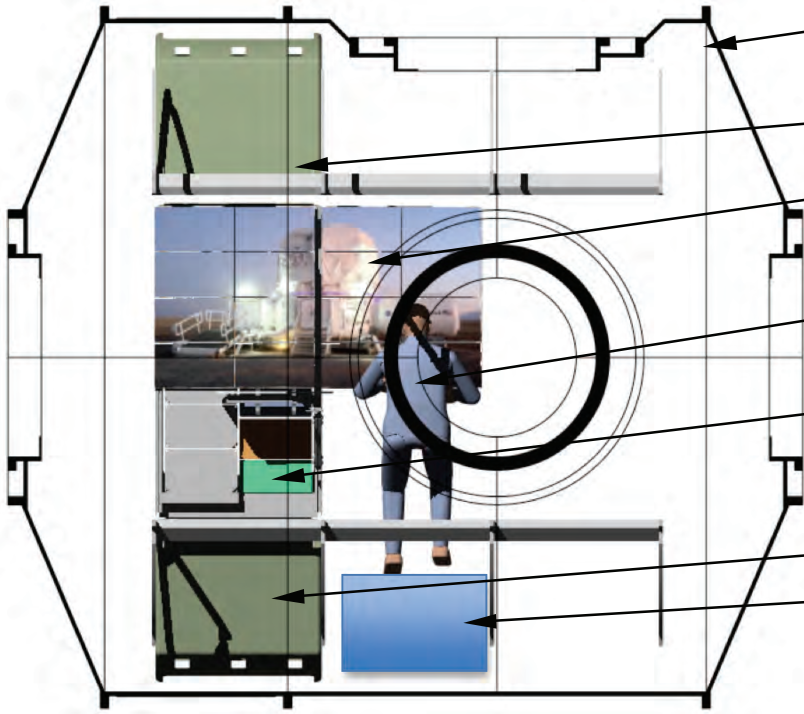

Figure 12: ISS-derived Cis-lunar Deep Space Habitat Telerobotics Workstation concept

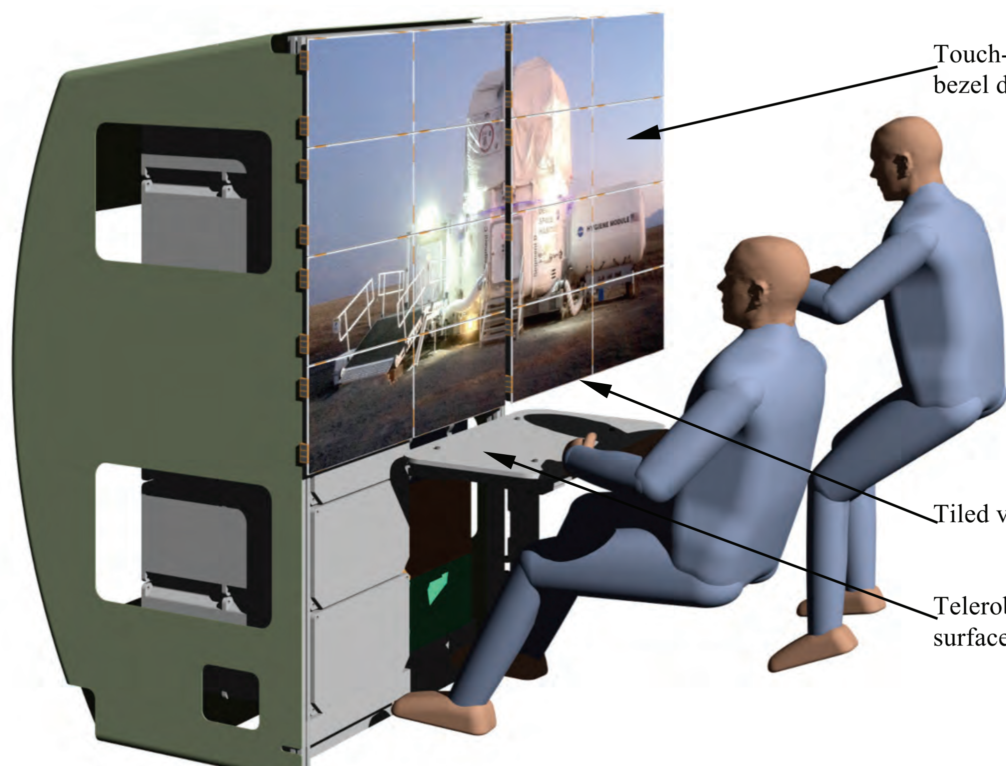

Figure 13: Rack-based Telerobotics Workstation concept with double-bank tiled video wall

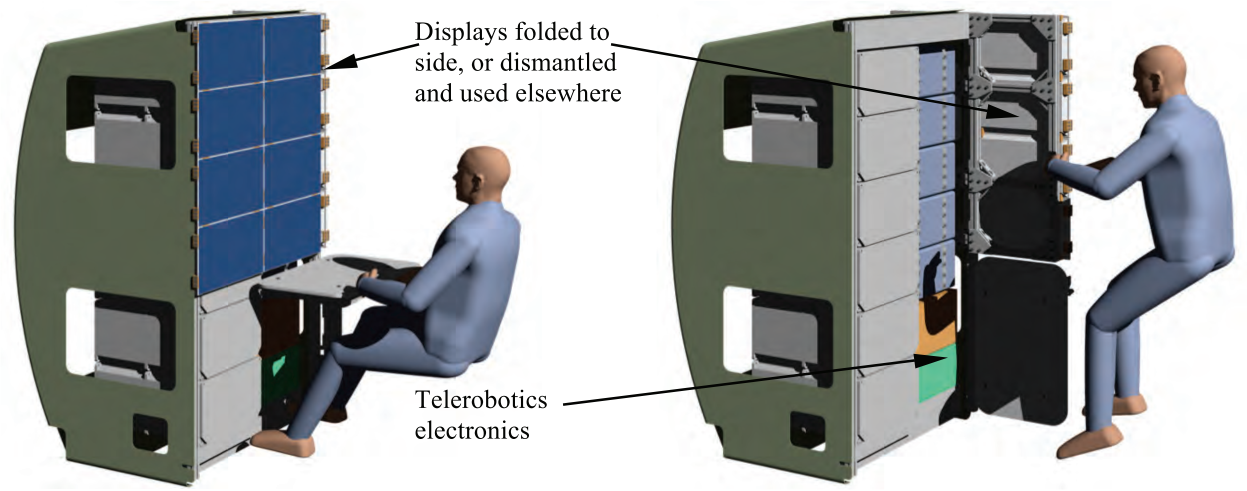

Figure 14: Rack-based Telerobotics Workstation, single-bank tiled video wall (left), and CTB stowage volume behind (right)

When tiled displays from the double bank (Figure 13) are folded away or dismantled for use elsewhere, a single bank of tiled displays remain (Figure 14, left) for permanent TRWS operations. The TRWS desk can be stowed away, and the display bank hinged to the side (Figure 14, right) to access CPU, electronics, and additional stowed Cargo Transfer Bags (CTBs).

D. Galley / Wardroom

The Galley / Wardroom function also went through several generations of D-RATS analog studies, including the somewhat haphazard, though functional arrangement shown in Figure 15. In the ISS-derived Cis-lunar Deep Space Habitat version of the Galley / Wardroom, actual racks were deleted from the slots and a modular wall with food warmers, refrigeration, water dispenser, folding tables, and articulated work surfaces were devised (Figure 16).

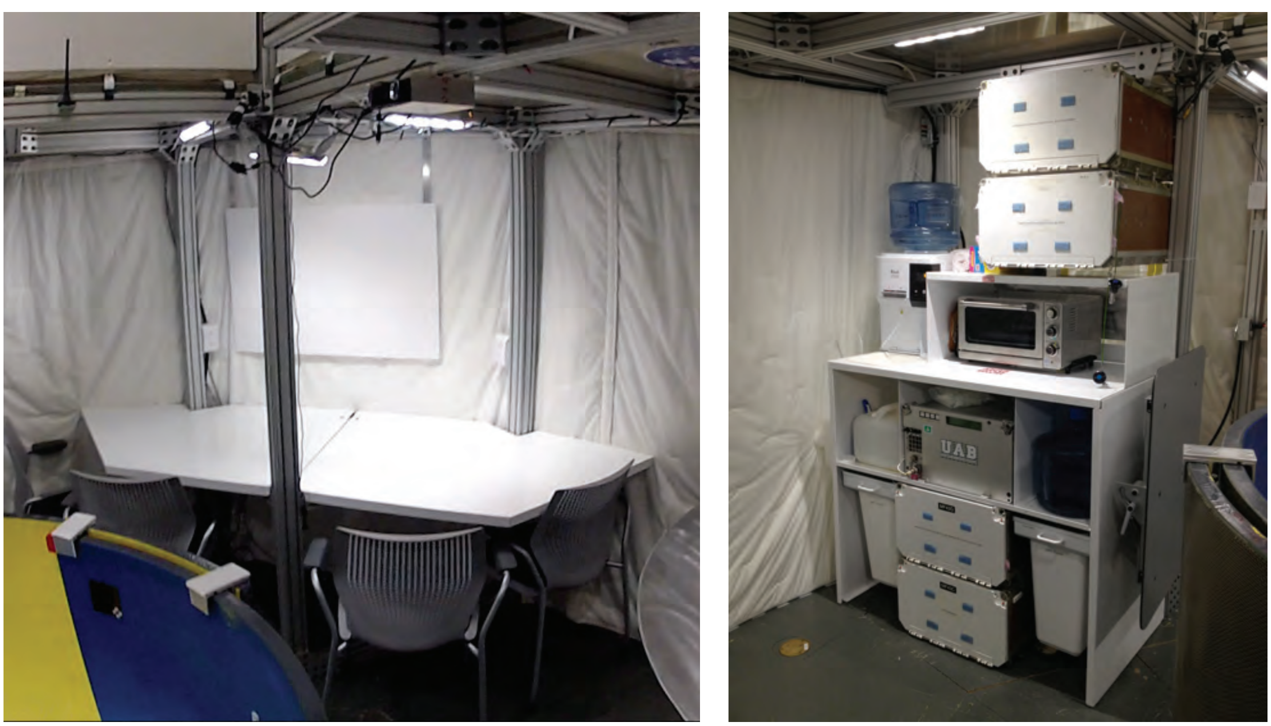

Figure 15: Habitat Demonstration Unit (HDU) Wardroom (left), and Galley (right) prototypes – Desert Research and Technology Studies (D-RATS) 2012

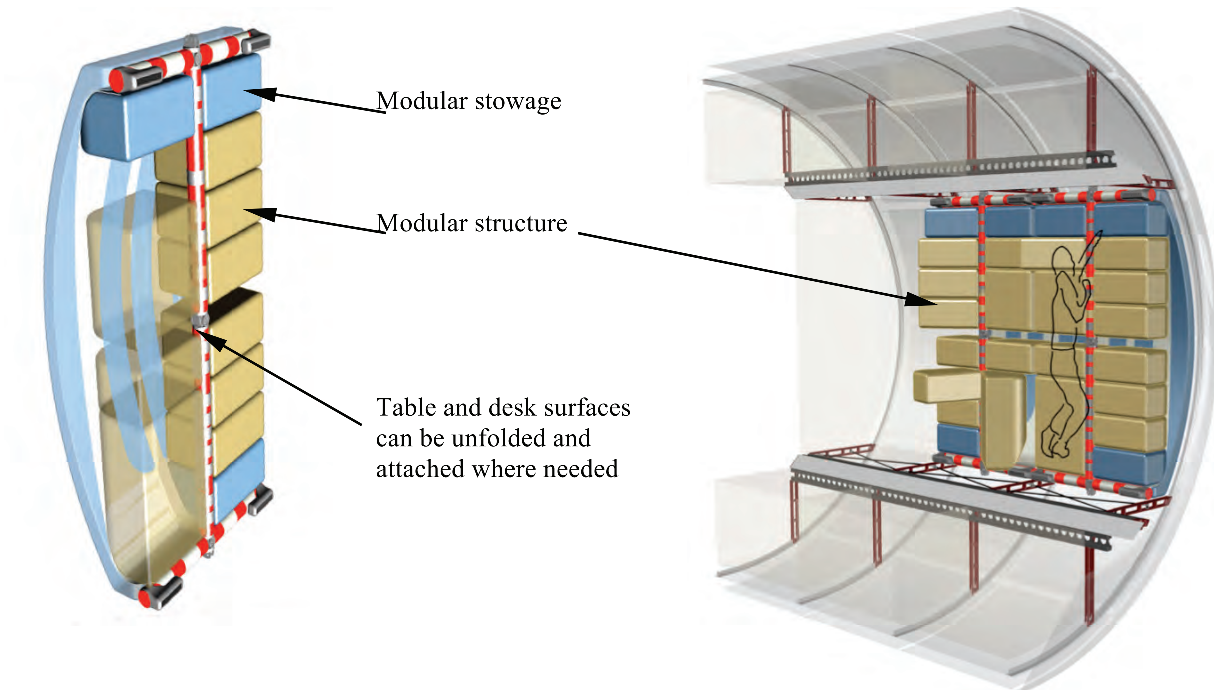

Figure 16: ISS-derived Cis-lunar Deep Space Habitat Galley / Wardroom concept by Raul Polit-Casillas, Caltech Jet Propulsion Laboratory

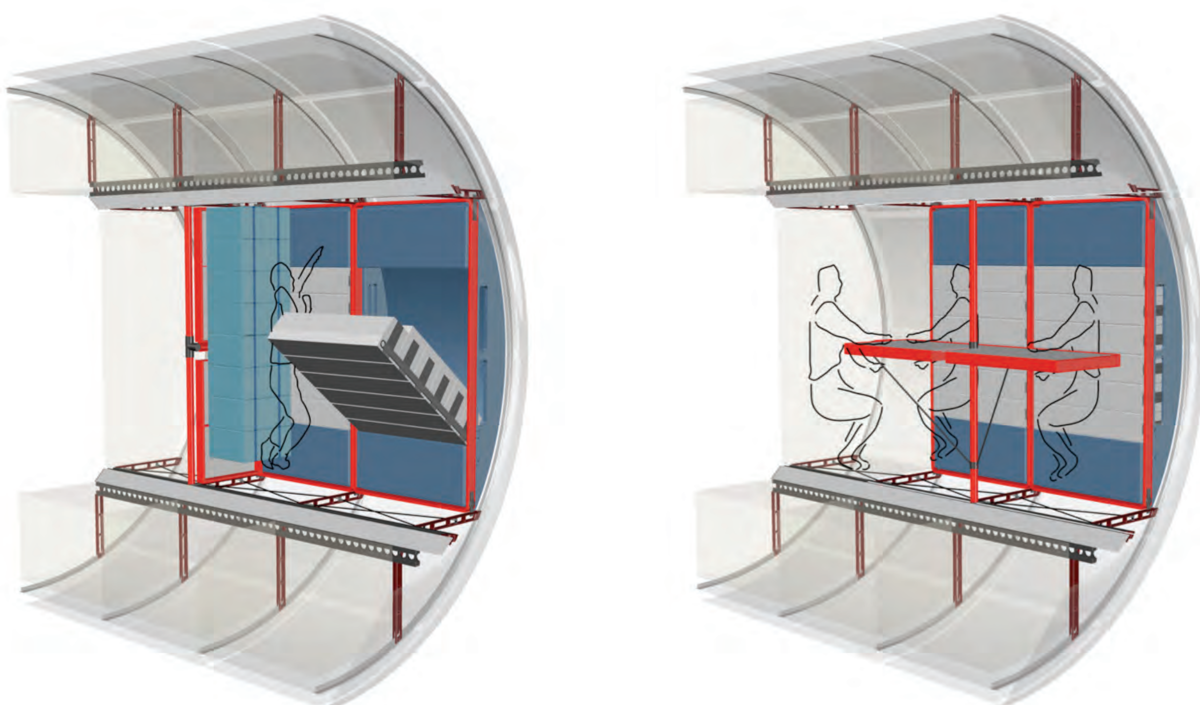

Figure 17: Galley / Wardroom stowage pallets (left), and deployable table (right) (courtesy Raul Polit-Casillas, Caltech Jet Propulsion Laboratory)

Folding tables (Figure 17, right) could be tucked out of the way to access flexible stowage pallets (Figure 17, left) containing utinsils and food for immediate needs. Figure 18 shows the articulated work surface design stowed (left) and deployed (right).

Figure 18: Wardroom folding table design stowed (left), and deployed (right) (courtesty Raul Polit-Casillas, Caltech Jet Propulsion Laboratory)

The various workstations were mocked up mostly as photo fronts (Figure 20, left) or simple prototypes (Figure 20, right) inside a shell mockup of the ISS-derived Cis-lunar Deep Space Habitat at NASA Marshall Spaceflight Center (Figure 19).

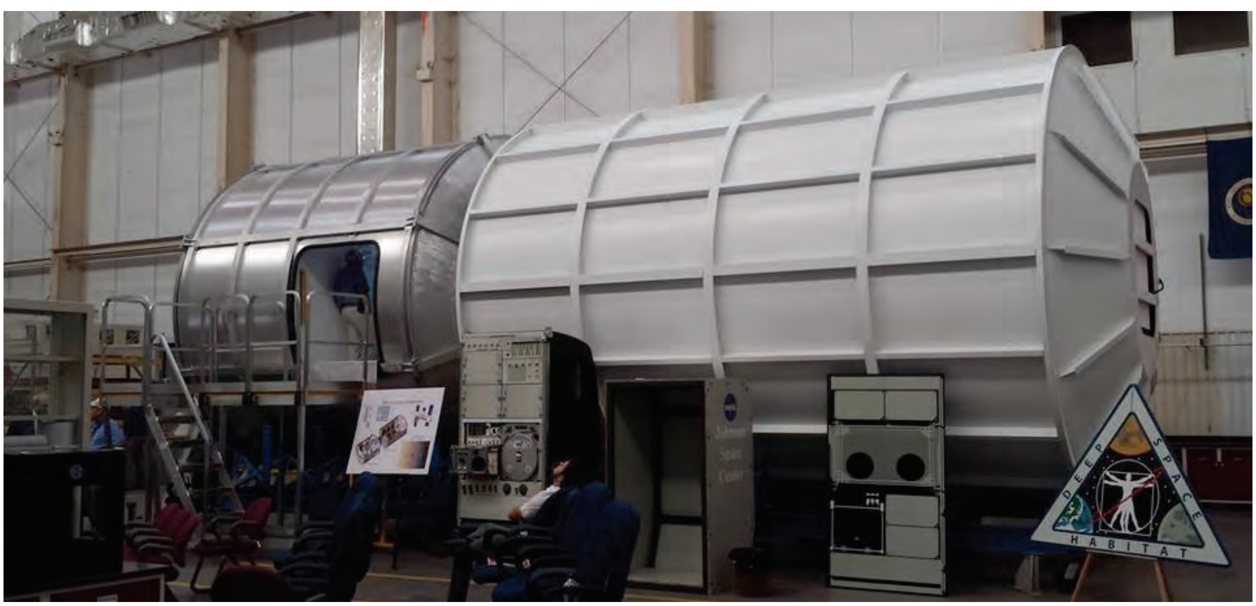

Figure 19: ISS-derived Cis-lunar Deep Space Habitat mockup at NASA Marshall Spaceflight Center

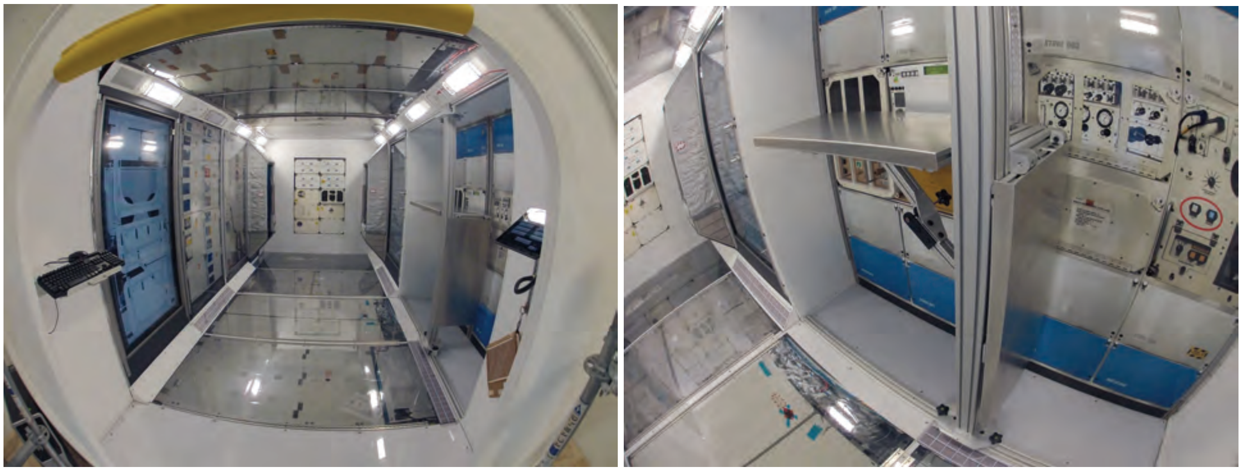

Figure 20: ISS-derived Cis-lunar Deep Space Habitat Multi-Purpose Logistics Module mockup interior, showing rack front likenesses (left), and Wardroom table mockup

V. Future Considerations

Though the design and layout of the ISS-derived Cis-lunar Deep Space Habitat 80-day or 160-day mission did not call for it, long-duration missions might need additional functionality such as telemedicine, expanded manufacturing capability, virtual window, plant growth systems, etc. Assuming the continued support of the ISPR system heritage, some brief explorations of telemedicine workstations were performed (Figure 21). Ideally, articulated work surfaces would be quickly deployable in an emergency, and should be able to extend out into the habitable volume in such a way as to allow complete access to a patient from all directions. The design in Figure 21 tries to approach this capability – deployable arm systems can bring the articulated gurney out away from the face of the rack, affording access in all directions. If the need arises and funding is available, the resolution of these configurations can be explored.

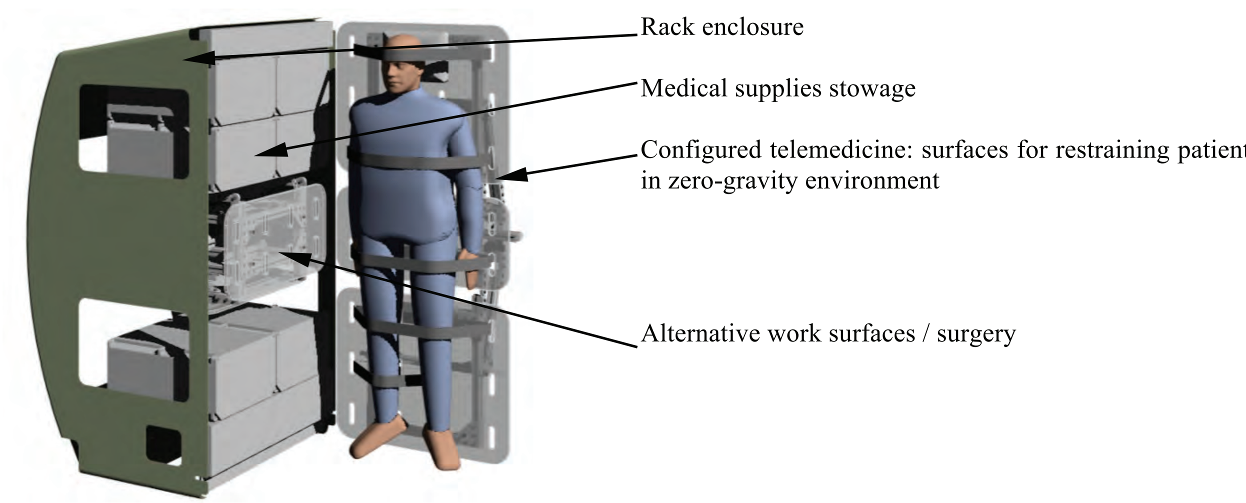

Figure 21: Using articulated folding work surfaces, a variety of functions can be accommodated, such as telemedicine workstation

As a baseline study, the ISPR system could be made to work, but may be a heavy solution for outfitting a Deep Space Habitat, and could have an avoidable mass penalty. In parallel research, we looked at systems that could be more optimized for deep space missions and proposed a light-weight Random Access Frame (RAF) systems (Figure 22) more appropriate for a next-generation Deep Space Habitat (Howe & Polit-Casillas 2014) as a replacement yet compatible layout system for the ISPR.

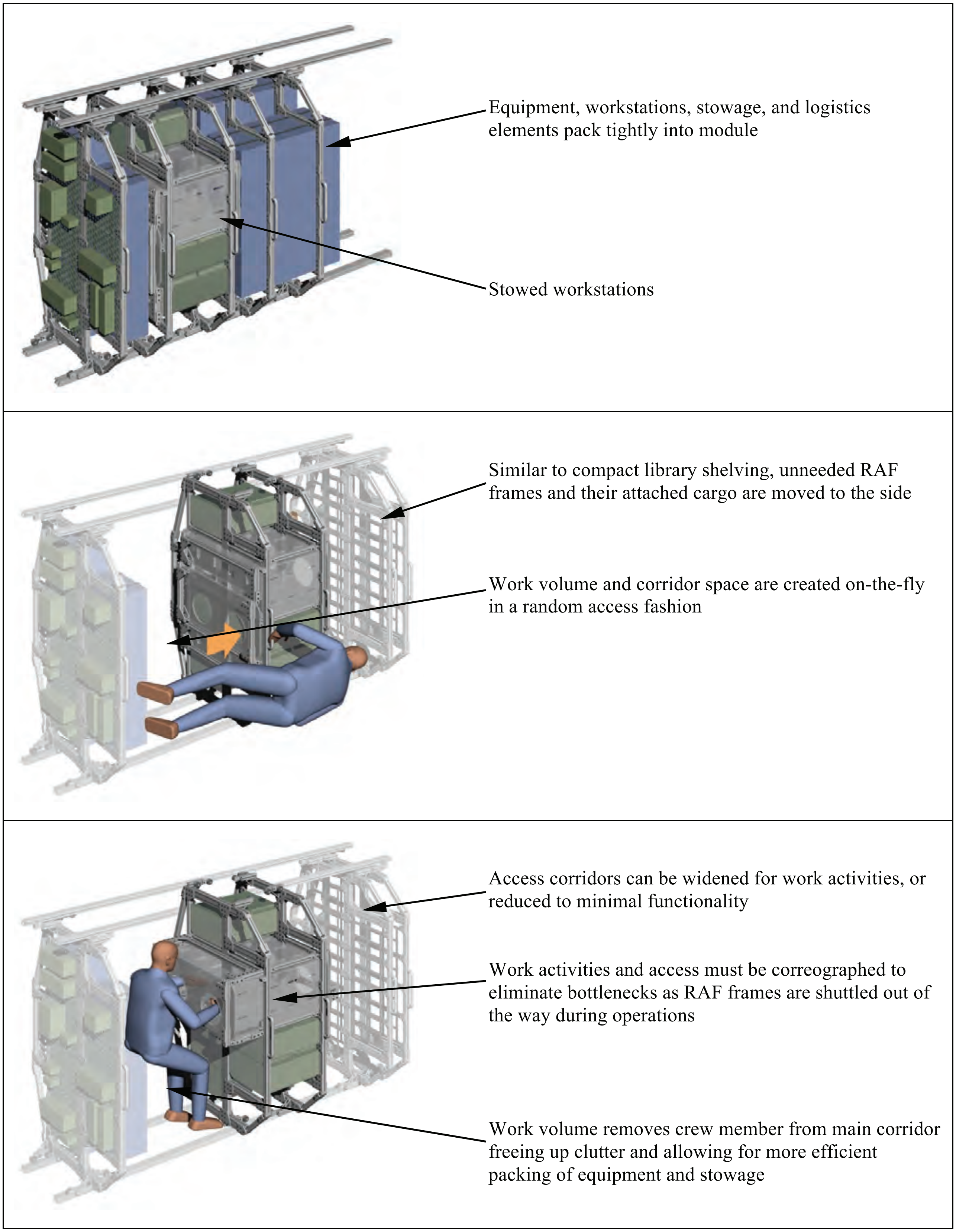

Figure 22: Random Access Frame (RAF) concept (Howe & Polit-Casillas 2014)

The RAF system uses the same International Subrack Interface Standard (ISIS) and EXPRESS system, but abandons the heavy rack encasements and complex interfaces.

In additional follow-on work, a non-ISPR In-Space Manufacturing Workstation test unit was designed and constructed using the help of California Polytechnic University of Pomona (Calpoly Pomona) architecture students Brice Colton, Brianna Wiley, Garrett Sanne, and Martin Saet (under professor Michael Fox in the department of architecture). The unit was constructed under NASA's eXploration Habitat (X-Hab) Academic Innovation Challenge managed by the National Space Grant Foundation (Howe 2012).

Table 2: Equipment list for In-Space Manufacturing Workstation created by Calpoly X-Hab students (based on requirements list by Robert Howard and Nathan Moore, Johnson Space Center)

TYPE	NAME	L (in)	W (in)	H (in)	WEIGHT (lb)	AIR (ft3/min)
3 in 1 sheet metal machine (finger brake, shear, roller)	Shop Fox 12in 3-in-1 Sheet Metal Machine	23	24	16	103	0
Desktop 3D Milling Machine (CNC)		23	21	25		0
Small corner sheet metal shear	Husky 1800 SPM 18-guage Air Shears	8	11	3	3	6
Air cutoff wheel	Northern Industrial Air Cutoff Tool -- 3in				3	3
Small bench belt/disk sander	Wel-Bilt Horizontal Air Sander - - 7in Dia	16			6	5.5
Small metal cutting band saw	Milwaukee Portable Band Saw	23	8	16	23	0
Pipe bender	Northern Industrial Space-saver Parts Bender				43	0
Hacksaw set	Grip-On Tools Professional Hacksaws -- 4pc Set	15			2	0
File set	Husky Flat/Curve Assortment File Set (10pc)	16	10	2	2	0
Angle grinder	EMAX Air Angle Grinder Industrial Duty	10	6	5	4	6
Air sander	Husky 6in High Speed Sander	6	2	7	2	4
Air nibbler	SPEEDWAY 16-guage Capacity Air Nibbler	10	3	7	5	6
Air hammer and rivet buck set	Ingersoll Rand Air Hammer with Quick Change and Chisel Set	10	9	3	6	4
Vacuum cleaner	Festool HEPA Certified Dust Extractor CT MINI	18	14	17	21	137
Dust cleaning brushes	Dustpan with brush	15	10	4		0
Small air compressor	NorthStar Belt Drive Single-stage Portable Air Compressor	43	22	30	207	5.5
Air blower kit						
Dust mitigation shroud						
Paint booth (aerosol application)						
Makerbot II		19	17	22		
High performance computer workstation SolidWorks ProEngineer						

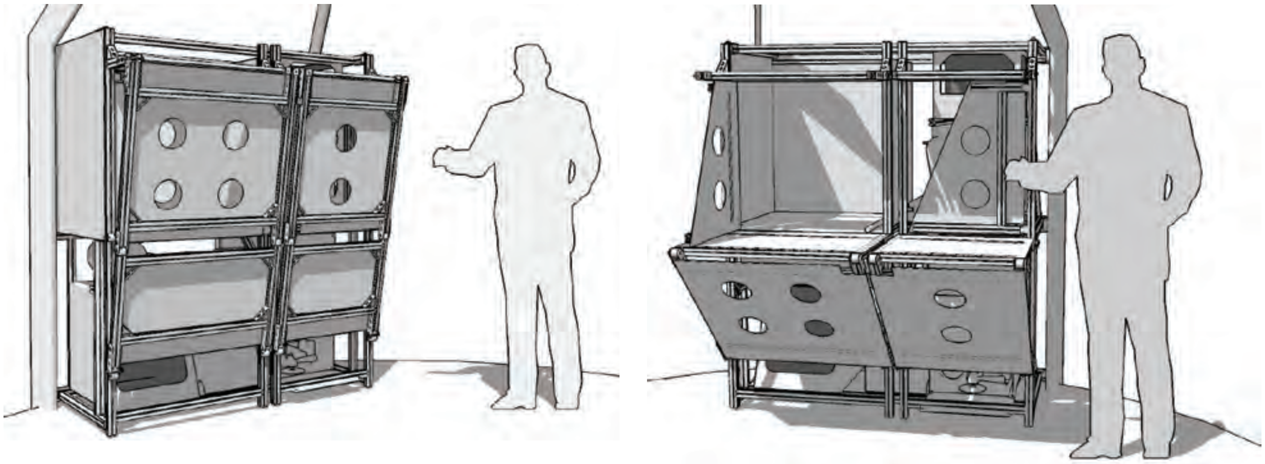

Figure 23: In-Space Manufacturing Workstation (ISMF) deployability / reconfigurability studies by California Polytechnic University Pomona X-Hab Students Brice Colton, Garrett Sanne, and Brianna Wiley

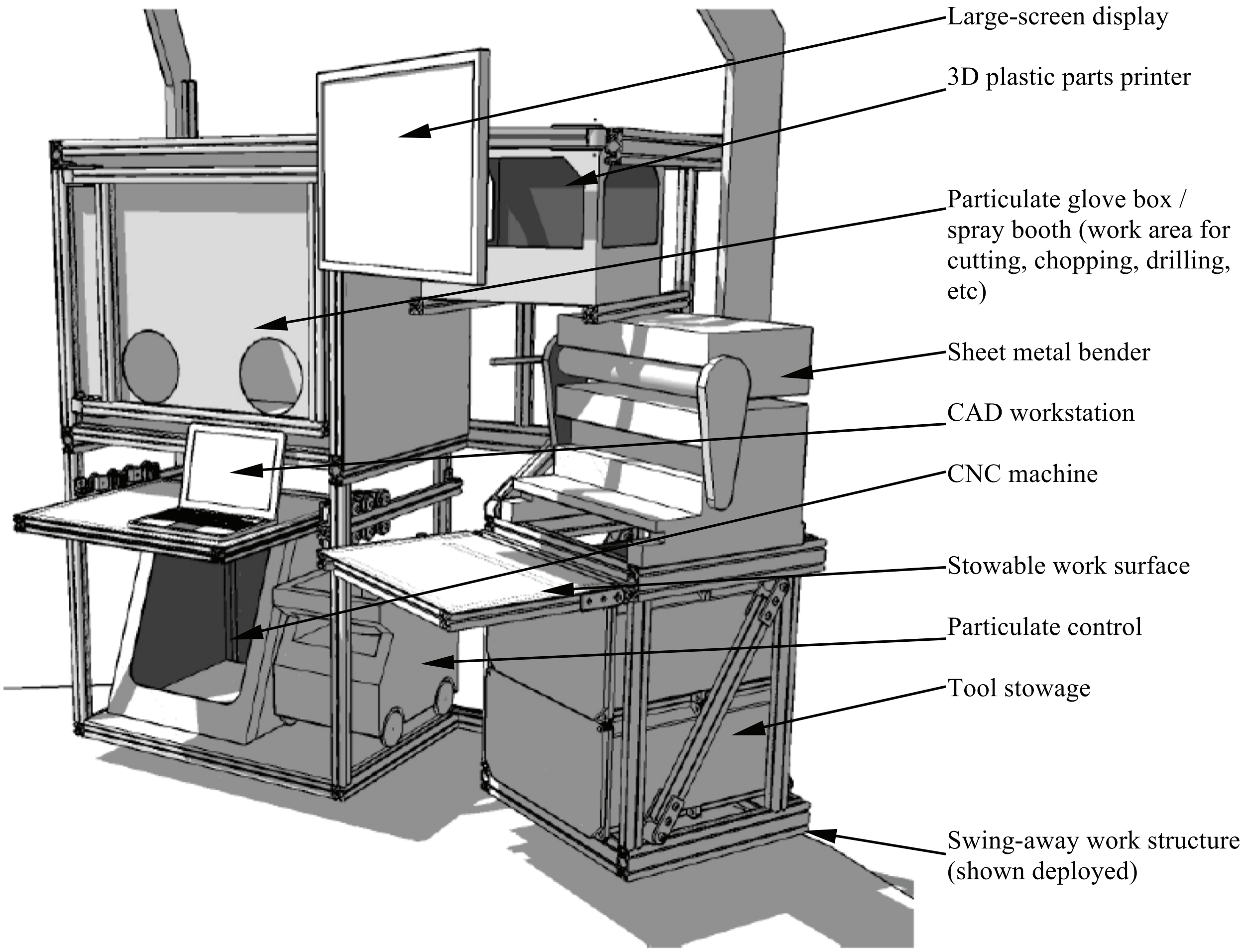

Figure 24: In-Space Manufacturing Workstation (ISMW) for NASA's Human Exploration Research Analog (HERA), designed by California Polytechnic University Pomona X-Hab Students Brice Colton, Garrett Sanne, and Brianna Wiley

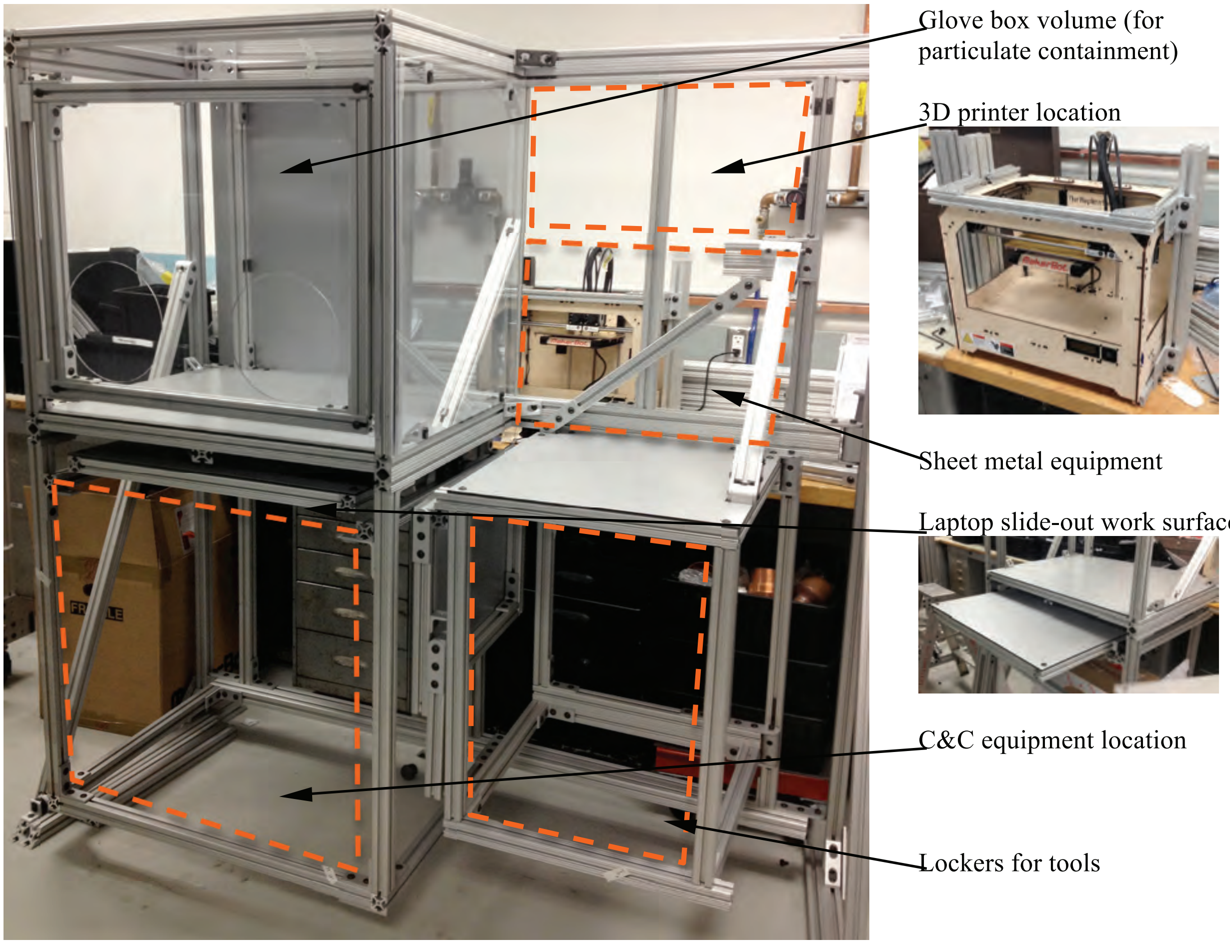

Figure 25: California Polytechnic University Pomona ISMW prototype work -- testing reconfigurability, deployable, and nesting structures (work in progress)

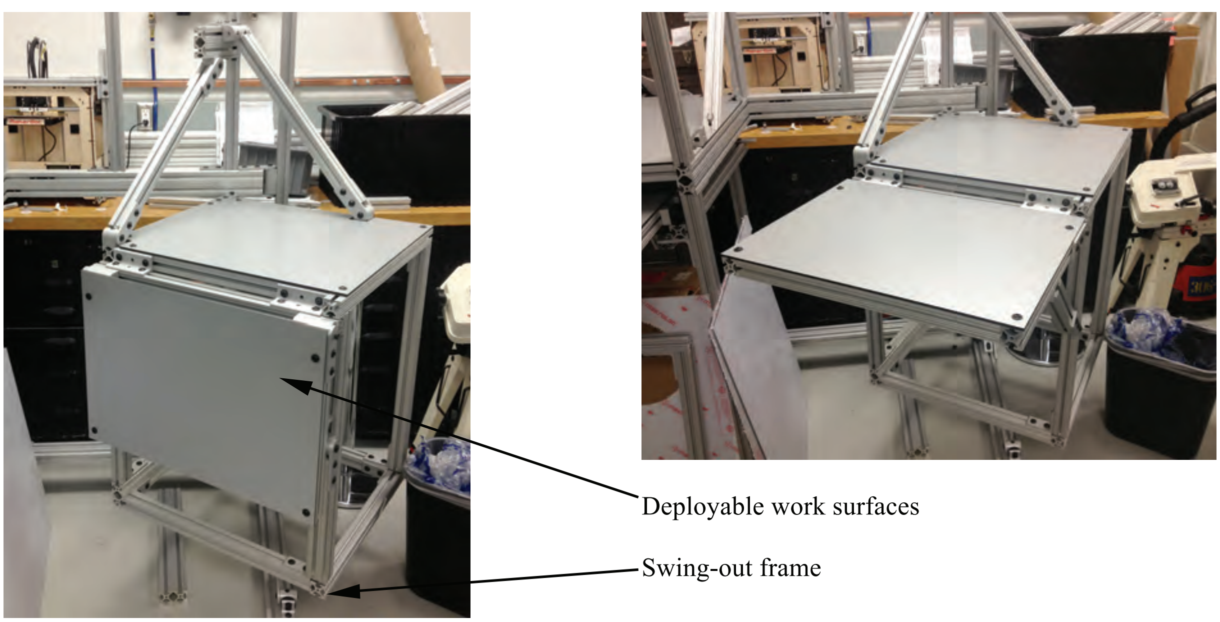

Figure 26: California Polytechnic University Pomona ISMW prototype work -- testing reconfigurability, deployable, and nesting structures (work in progress)

Based on requirements (Table 2) provided by Robert Howard and Nathan Moore at Johnson Space Center, the X-Hab team researched lightweight manufacturing tools, particulate control systems, masses, air handling, and deployable structures. The target workstation was intended for potential installation in the former Habitat Demonstration Unit (HDU), now repurposed as the Human Exploration Research Analog (HERA), which did not use the ISPR system for its layout but took advantage of the ISIS modularity. Initial X-Hab studies focused on workstation packagability, deployable articulated work surfaces, and stowage volumes (Figure 23). When combined with ergonomic requirements for tools, a more functional configuration emerged, with separate stowable shelves, swing-out frames, dedicated glovebox volume, and limited articulated work surfaces (Figure 24). 3D additive printer, CNC machine, and materials to construct the workstation were obtained, and the basic framework was assembled and tested (Figure 25, Figure 26). The workstation is currently a work in progress.

Lessons learned in the ISS-derived Cis-lunar Deep Space Habitat workstation layout and design will be applied to the NASA Advanced Exploration Systems (AES) Exploration Augmentation Module (EAM), which is a proposed flight habitatation element that will be used to develop deep space habitation technologies. These lessons will also be applied to Mars transit vehicle designs, and the NASA Evolvable Mars Campaign.

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