

International Space Station USOS Crew Quarters Development

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ABSTRACT

The International Space Station (ISS) United States Operational Segment (USOS) currently provides a Temporary Sleep Station (TeSS) as crew quarters for one crewmember in the Laboratory Module. The Russian Segment provides permanent crew quarters (Kayutas) for two crewmembers in the Service Module. The TeSS provides limited electrical, communication, and ventilation functionality.

A new permanent rack sized USOS ISS Crew Quarters (CQ) is being developed. Up to four CQs can be installed into the Node 2 element to increase the ISS crewmember size to six. The new CQs will provide private crewmember space with enhanced acoustic noise mitigation, integrated radiation reduction material, controllable airflow, communication equipment, redundant electrical systems, and redundant caution and warning systems. The rack sized CQ is a system with multiple crewmember restraints, adjustable lighting, controllable ventilation, and interfaces that allow each crewmember to personalize their CQ workspace.

Providing an acoustically quiet and visually isolated environment, while ensuring crewmember safety, is critical for crewmember rest and comfort to enable long term crewmember performance. The numerous human factor, engineering, and program considerations during the concept, design, and prototyping are outlined in the paper.

INTRODUCTION

As space flight has increased in duration from the several days of Gemini/Apollo, the few weeks of Skylab and Shuttle, to the extended months of Russian Mir and US ISS, the need for dedicated private crewmember volumes have become essential. These private volumes

are typically called crew quarters (CQ). The history of crew quarters has been documented previously, [1,2] but a few key milestones provide insight to the current development. Crew Quarters are to provide a relatively quiet retreat from cabin equipment noise, allow for private medical consultations, conversations with family, and restful sleep. The requirements for acoustic, visual, and light isolation introduce additional design, habitability, and safety challenges because a private volume introduces potential confined space hazards.

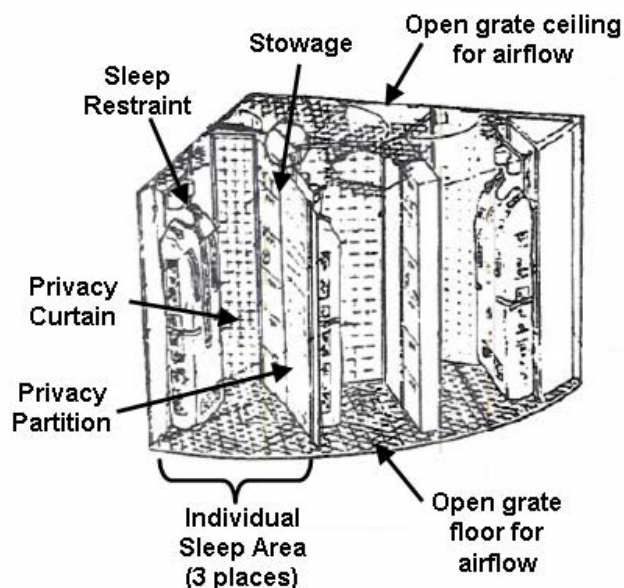


Figure 1. Three Skylab sleep quarters looking inward; general lighting was on the exterior wall and is not shown [edited from 2].

Design and development efforts of long-term crewmember accommodations began with the US Skylab crew quarters, see Figure 1. Skylab featured visual private space for each crewmember but lacked

acoustic and light isolation and had very limited ventilation control. The Skylab crewmembers indicated these deficiencies and a lack of headroom for taller crewmembers reduced the effectiveness of the private volumes [2]. The Russian crew quarters, or Kayutas, were introduced with Salyute 6 and the basic configuration was used in Mir's base block and the ISS Service Module, see Figure 2. The Kayutas provide an increased visually private volume with a 20-cm diameter window, but the window increases crewmember space radiation exposure. The Kayutas draw air from the cabin but are generally overly warm and do not provide sufficient acoustic attenuation of the cabin noise [2]. Valuable lessons were learned from participating in the Russian Mir program and were incorporated into ISS CQ.



Figure 2. Mir starboard Kayuta sleep station with sleeping restraint on right hand side [9].

Early Space Station Freedom (SSF) CQ volume was planned to be approximately one and a half equipment racks' (3.2 m^3). This provided increased storage, thermal control, and office space compared to the ISS CQ volume under development (2.1 m^3). Four SSF CQs were to be located in one end of the Habitation Module. The SSF CQs were not developed beyond the early conceptual design stage. However, the current ISS CQ requirements have maintained most of the functionality and basic anthropometric envelope but reduced the stowage, office utilities, and thermal adjustability of the SSF CQ concept.

In the late 1990s, concept development for what was termed Deployable Crew Quarters (DCQ) for ISS and the proposed TransHAB transit to Mars, [3] was initiated. In 2001, a reduced functionality derivative of the DCQ

called the Temporary Sleep Station (TeSS) protoflight unit was developed rapidly over a nine month development period. TeSS was launched on 7A.1 and located in the US Laboratory Module (LAB), *Destiny*, to increase the ISS crewmember size from two to three.

TeSS was designed as a short term solution with limited functionality until the full functional CQs in the Habitation Module were delivered. Given the short development time, many of the habitability and maintainability requirements were waived or reduced to goals [4]. The TeSS design is briefly described here to compare and contrast with the current ISS CQ design. TeSS provided limited functionality within a private volume consisting of a rack volume and a 31-cm bump-out into the aisle way, acoustic panels, and attachments for crewmember items. The TeSS had pass-through openings for electrical cables and to allow external alarms to be heard. These openings limited the effectiveness of acoustic and light isolation. The TeSS did not incorporate independent ventilation but completely redirected one LAB ventilation duct into the rack. The control of ventilation flow rate and direction was limited and some crewmembers have reported the inability to effectively control air as a source of discomfort. TeSS was a substantial improvement in crewmember on-orbit living, compared to Skylab sleep quarters and Russian Kayutas, and provided valuable lessons in acoustics, fabric liners, and crewmember preference over the last eight years.

The TeSS structure was launched folded flat on a Resupply Stowage Platform (RSP) to minimize launch loads and had to be assembled on orbit. Additionally, separate radiation blocks were launched and assembled inside the TeSS to reduce crewmember exposure to space radiation [5]. Both the initial installation and subsequent behind rack operations have resulted in substantial crewmember time to disassemble and reassemble TeSS. TeSS' operational life was extended beyond the originally intended two years after removal of the Habitation Module from the station configuration in 2002. Subsequently, the ISS Node 2 element was outfitted with provisions for accommodating four CQs.

The current ISS sleeping provisions for three crewmembers (two Kayutas and one TeSS) will be augmented with the ISS CQs under development. The ISS CQs, with additional regenerative life support racks, will increase the ISS crewmember complement from three to six crewmembers enabling the ISS to reach its full science research potential. This paper describes how human factors and conventional engineering are combined for successful USOS CQ design. The detail requirements of the CQ were defined by the ISS program Interface Control Document SSP (Space Station Program document) 50357 and Project Technical Requirements Specification SSP 50781 [7].

MPLM LAUNCH AND INTEGRATION TO NODE 2 ELEMENT

Initially, three CQs are scheduled for Space Shuttle launch in the Multi-Purpose Logistics Module (MPLM) on flight ULF2 in late 2008. Although a custom designed assembly, each CQ will occupy a standard US rack volume and use the standard structural attachment points. Once on orbit, each CQ will be removed from the MPLM and relocated to Node 2. Compared to TeSS, significantly less assembly work is required to obtain the final shape and outfitting with radiation reduction panels and electronics.

ISS Crew Quarters will be located in Node 2, *Harmony*, equipment bay 5 locations. Node 2 has the capability to accommodate four CQs and the individual CQ layout is based on the interaction of all four CQs. Node 2 connects the US LAB with the Japanese Experiment Module (JEM), *Kibo*, and European Laboratory Module, *Columbus*. The four CQs will be located in a 'ring' configuration, see Figure 3. Although the structural attachment points are identical, the four CQs are very similar but unique. To maintain a local vertical "heads up" orientation in port, starboard, deck and overhead locations, the CQs facing each other are partially mirrored in the bump-out and location of crew attachment surfaces.

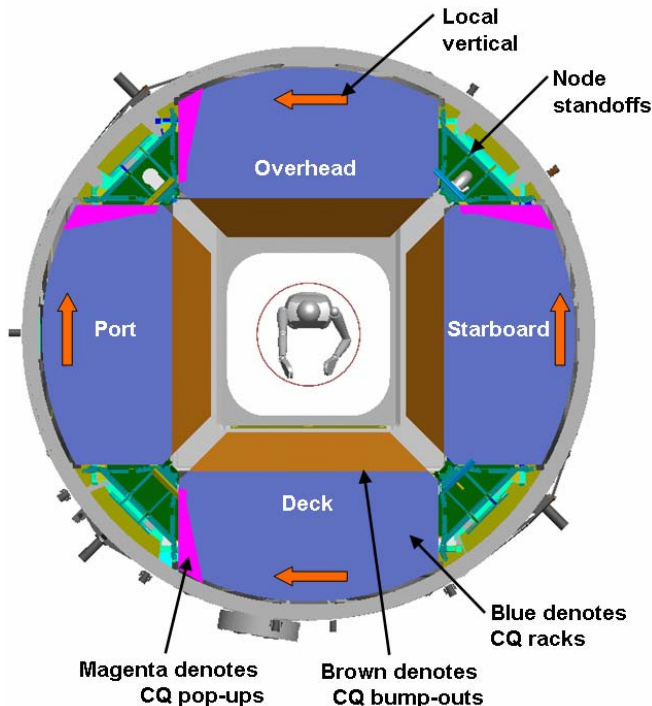


Figure 3. Crew Quarters location within Node 2 indicating the relative bump-out, pop-up and rack volumes.

The CQ envelope is restricted by the ISS vehicle configuration to a standard rack volume. The pop-up takes advantage of the 'free' space above the top attachment points. This pop-up volume in the Node 2 standoff is required to allow the back upper rack corner

to rotate through during installation but is 'empty' and available after installation is complete. The bump-out protrusion distance is limited by the ISS requirement to maintain a minimum clear aisle way of 152 cm, which allows for passage of rack-size hardware. The CQ doors must rotate inward to allow clear egress space for all four crewmembers during a Class I alarm situation.

Electrical utilities to the CQ racks are routed through the Node standoffs underneath the racks and enter through the floor panels, see Figures 3 and 4. Each rack has 6 cables providing power and data. The Node standoffs minimize the need for utility draglines.

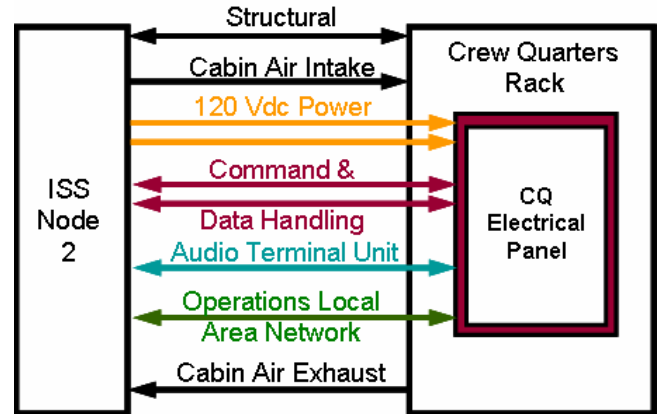


Figure 4. ISS CQ functional block diagram showing interfaces to Node 2.

CREW QUARTERS DESCRIPTION

The primary purpose of CQ is to give the crewmembers an area to retreat to from the noise and busy activity levels in the shared areas of space station. The CQ design is highly efficient in limiting acoustics to NC-40 levels, similar to levels experienced in a public library. Additionally, external light is shut out almost completely. The result is a private environment but also potential hazardous confined space conditions for the crewmember. Sufficient airflow must be maintained to prevent asphyxiation and to remove body heat. Lighting must be provided to allow crewmember activities.

Each CQ consists of an International Standard Program Rack (ISPR) sized envelope constructed of aluminum structure and composite panels. The majority of the back wall and ceiling area are constructed of approximately 6.5 cm of ultra high molecular weight polyethylene (UHMWPE) which provides shielding of the crewmember's head and blood forming organs from the ever-present cosmic radiation and occasional solar flares.

Crew Quarters has the same mounting interfaces as an ISPR. For launch, the bottom rear corners are pinned or bolted to the spacecraft, and z-shape kneebraces support the top front corners. On-orbit, the rack is attached by its four accessible front corners. Pivot pins at the lower attach points allow for the rack to be rotated

in and out of its bay. For launch the bump-out is reversed and the pop-up retracted.

The CQs provide a total interior volume of 2.1 m³. Inside CQ, one side wall is designated to be the sleeping wall, see Figure 5. The utility wall across from the sleep wall provides mounting for the electrical assemblies, computer workstation, lighting and other utilities. The back wall opposite the CQ doors is curved to follow the shape of the vehicle's pressure shell. This back wall provides stowage space with elastic bungees and hook-and-loop fasteners patches. The ventilation system is located in the bump-out, and is packaged efficiently around the interior of the CQ door.

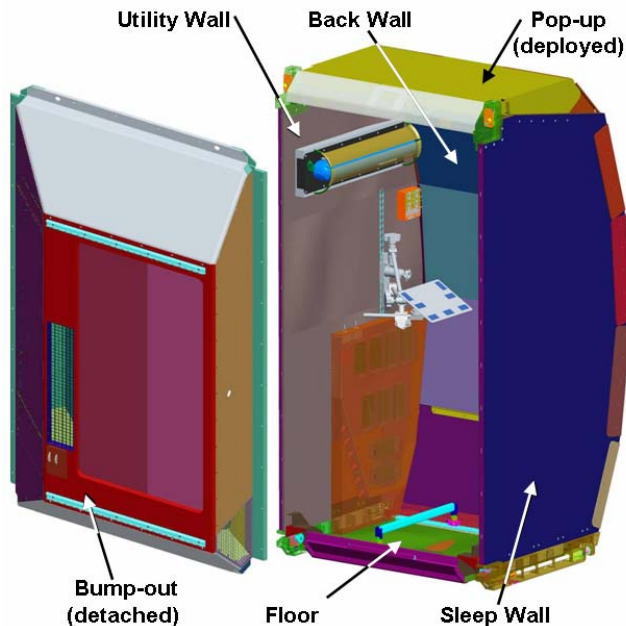


Figure 5. CQ major functional areas.

The CQ interior exchanges air with the conditioned Node 2 cabin air. There are two independent serial fans with a single speed control. Node 2 air is drawn into the CQ through a fan and acoustic “muffler” and enters the CQ interior through a large diffuser at the crewmember's head position. The airflow is drawn from the CQ interior by a separate fan near the crewmember's feet and returns the air to the Node 2 cabin. The returned air carries away heat and allows for smoke detection with the existing Node instrumentation. Three fan speeds provide adjustability for day and night operations and comfort. The fans' flow is adjustable but can not be shut off completely without removing power from the rack. The ventilation status is continually reported to space station. However, even if one fan should fail, sufficient airflow remains to prevent CO₂ buildup that might endanger the crew.

Illumination is provided by the standard ISS fluorescent light called the General Luminaire Assembly (GLA). It is installed at the top of the utility wall and has dimming and shading capabilities to provide customized lighting. At night, it can be turned off to achieve near total

darkness: Only two power LEDs on the electrical panel remain lit, and, in the case of an alarm, four LEDs will illuminate the door area.

The center of the utility wall has rails for mounting an adjustable shelf to support a laptop computer. Two 120V power outlets and an Ethernet port are provided on the electrical panel.

The back wall has two speaker boxes that generate Class I alarms from the station multiplexer-demultiplexers' (MDMs) commands. A third box located on the utility wall, provides audio and alarms from one of the Node 2 Audio Terminal Units (ATU).

CQ DEVELOPMENT CONSIDERATIONS

The CQ project followed the traditional systems engineering approach with distinct phases and control gates, namely system requirements, preliminary design, and critical design reviews (SRR, PDR and CDR). The SRR phase was thorough in ensuring early identification and incorporation of all stakeholder requirements, including an early volumetric mockup. During the following PDR and CDR phases, an integrated team approach was taken: working groups in the six functional areas (radiation, interior, structural-mechanical, avionics, thermal-ventilation, and operations) produced broad team discussion and consensus on all major design decisions. Design concepts were reviewed at integrated product team meetings, which included representatives of NASA Engineering, Crew Office, Mission Operations, Human Factors, Safety, and functional specialists as required.

LAUNCH/ON-ORBIT INSTALLATION

Several early CQ trade studies were performed to determine the basic CQ architecture. DCQ and TeSS were foldable structures and considered for the ISS CQ. Advantages are the folded structure requires simpler launch load consideration. TeSS was launched on a RSP along with several cargo bags for cabling, acoustic blankets, and radiation reduction bricks. However, the CQ goals for integrated electronics, ventilation, relatively thick radiation reduction panels, and stringent acoustic/light isolation make the foldable structure much less practical. TeSS could fold up flat because all these functions were brought in as draglines or launched separately. However this required significant crewmember assembly time for initial installation and subsequent rack rotation. Additionally, a TeSS-like ventilation system was not possible because Node 2 does not have sufficient cabin air diffusers and returns. Hence, CQ was required to develop acoustically isolated fan/duct systems.

The use of an ISPR was also considered for the basic CQ structure. The ISPR has multiple internal structural components that would require modification to accommodate the vertical stature of the ISS module. In particular, the lower utility interface panel, and upper

torque tubes would require extensive modifications. Additionally, almost all panel surfaces would require modification to accommodate radiation reduction materials, pop-up attachments, bump-out attachments, electrical assembly attachments, and provisions for acoustics. These significant modifications greatly reduced the benefit of starting with the ISPR.

The remaining option considered was a custom rack tailored to the functional requirements but using common rack attachment point mechanisms and overall rack envelope requirements. The custom rack allowed the greatest habitable volume, improved head space, integration of the radiation protection panels, integrated pop-up mechanism, efficient redistribution of the structural loads, and potential for the least amount of crewmember installation time. Additionally, mounting provisions for electrical components and crew items could be located based on anthropometrics rather than driven by where sufficient ISPR structure was located. The trade study indicated that the custom rack was the best rack approach to provide the required functionality and enable good structural integrity for launch loads and natural frequency.

Similarly, although the volume of the bump-out was defined, the bump-out functionality was traded to determine the best allocation of crew space and equipment space between the bump-out and rack volumes. The door, ventilation intake, and ventilation exhaust locations were previously set as requirements based on translation path and overall Node 2 ventilation patterns. After radiation reduction material, the ventilation system occupies the most volume due to the acoustic treatments necessary to meet interior noise levels. The ventilation ductwork was located entirely in the bump-out envelope to minimize the amount of on-orbit assembly and maximize the perceived head room by the crewmember in the occupied rack area. As will be described subsequently, the ventilation system required several electrical and safety monitoring circuits that require connection during installation.

The electrical connectors, duct work, and door structure are maintained within the bump-out envelope so the bump-out can be simply reversed for launch and mounted to the front of the rack structure. This enabled the standard rack envelope to be maintained for launch, and served as a structural stiffing plane during launch. This custom rack with standard attachments allows the use of standard racking handling, shipping, and ground support hardware to be utilized for launch preparation operations.

The ease of CQ installation to Node 2 was a high priority goal. The following overview briefly describes the major installation activities. The CQ rack is unbolted from the MPLM using the standard ISPR attachment mechanisms. Rack handling fixtures can be attached to translate to Node 2. The Node 2 bay 5 rack locations are prepared by removing the Zero-G Stowage Racks launched with Node 2, and detaching the data and

electrical cables stowed in the standoffs. The rack is docked on the standard Node rack rotation points. Shims and launch bolts are removed from the pop-up, door launch, and floor panels. The CQ is rotated into place and affixed using standard ISPR procedures. The launch bolts holding the bump-out to the rack are removed and stowed. The bump-out is removed from the CQ rack. The door launch bolts are removed and temporarily stowed to allow removal of the floor mounted launch bag containing the acoustic blankets, interior cables, speakers, and GLA. The CQ floor panel is removed and the Node 2 cables are routed through the floor. The bump-out is then reattached with the protrusion outward using quick turn fasteners. The CQ doors are then reinstalled, the pop-up is deployed, the acoustic blankets are unfolded and attached, and the electrical cabling and GLA are mounted. The CQ then requests for application of power via a station laptop. The CQ is then ready for outfitting with crew items (sleeping bag, laptop, and personal items). The CQ acoustic isolation, ventilation, and comfort of the crewmember will immediately be noticeable.

DOOR SYSTEM

Significant effort went into the design of the CQ doors, beginning with the term door itself. In the NASA system, some household words have connotations that automatically create a defined set of expectations. In the case of CQ doors, there is no need for latching; and they are different from standard hatches and area closures. Another design driver for the CQ doors is the need for a good light/air seal at all hinge points and seams to achieve the challenging noise reduction to NC-40 levels. Several hard construction and soft construction design solutions were developed, all of them driven by the one-handed operation needed in space.

The close proximity of adjacent Crew Quarters made soft fabric panels/flap solutions with zippers or hook-and-loop fasteners undesirable because of the sharp impulse noise created when opening and closing which could disturb neighboring crewmember's sleep. Operationally, when opening the doors, the attached acoustic blankets must fold up and stay completely out of the way. Given the topology of the CQ entrance, this resulted in two independent door halves, see Figure 6. One door rotates inward 90 degrees and the other door rotates inward 120 degrees. This provides an unobstructed door opening of 51 cm x 102 cm, which was based on favorable feedback on the TeSS door opening. A bi-fold door was not selected because it would require double-hinging to accommodate the bulk of the blankets when folded up.

The door halves are latched closed with a simple detent capture type latch at the top and bottom. The door halves are overlapped, so only one side needs to be secured. This type of latch provides enough resistance to prevent the door from accidentally being pushed open by a passer-by, and low resistance to allow easy egress by a 5th percentile female crewmember.