IAC-25,A5,IP,6,x94586

Transformation and adaptation of a habitat for parastronauts : a parastronaut feasibility study on an existing space analogue habitat and its implications for Mars habitats

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Abstract

With an average of 225 million of kilometers separating Earth from Mars, future manned space missions will require increased autonomy from the crew with Earth, as well as proper habitats and settlements to provide shields and better living conditions to carter for the long mission durations. The increased autonomy will be reflected in communication type, - with the time-delay between Earth and Mars varying between 4 and 20 minutes (one way), which in turn will be reflected in the emergency protocols as well as general procedures in spacecrafts, habitats and all science and logistics. A typical planification that will require modification, is the existing protocols and spacecraft logistics currently applied to astronauts: with newly selected parastronauts, as well as the increased probability of accidents on Mars and lack of quick-access hospitals, small and large injuries can become disabilities rapidly. The large range of potential disabilities requires thorough investigation, testing and planification to provide the correct habitat structure, communication types and protocols to reduce the danger that a disability might cause to an astronaut or parastronaut. This can be done using analogue space missions, simulations of space missions on Earth. In this study, the analogue space mission facility Habitat Marte, in Natal, Brazil, is being adapted to host parastronauts as well as a full parastronaut crew mission, and the resulting mission evaluated. To this effect, the characteristics of the habitat are being investigated, then modified (including sleeping quarters, laboratory, hygiene station). A flight plan is being developed using the feedback of each parastronaut regarding the extra time different tasks might require due to their disability, to adapt and provide a realistic timeline for the realization of the experiment load. The crew is planned to be composed of 4 parastronauts with 3 different disabilities, including a sensory disability. Existing protocols are being modified to carter to the limitations imposed by the disabilities of the crew as to maximize crew efficiency, comfort and mission success. To this end, protocols are also being assessed by the crew. The list of physical as well as written modifications will serve as a significant example for the adaptation of other habitats and for knowledge transfer to future Moon and Mars missions. Parameters such as costs, complexity for the modifications as well as crew and mission lead satisfaction will also be parameters, with questionnaires being sent to all crew members to provide overall results

Keywords: Martian Habitat, Parastronauts, Architecture

Acronyms/Abbreviations
HM: Habitat Marte
ISS: International space station
OP: Operating Procedure

1. Introduction

Inclusion of parastronauts in analogue and extraterrestrial missions requires a systematic approach that goes beyond compensatory adaptations for individual impairments. It needs holistic embedding accessibility principles into the habitat's design, daily operations, and emergency procedures. Studies on accessibility in space architecture have shown that such improvements not only enable the participation of astronauts with disabilities but also increase resilience and redundancy for all crew members.

1.1 Accessibility challenges in existing habitats as considerations for accessible mission design

For efficiency purposes we are going to analyse 2 habitats through the prism of 5 main categories of disability and then select a few to focus on.

Firstly, mobility, with a focus on wheelchair users as they face the most constraints in these environments. Secondly and thirdly, disabling hearing and vision impairment as they are some of the most common disabilities , respectively 1 in 25 people globally [1] and 4.2% globally [2].

Lastly, dexterity and then cognitive as they both cover a large number of sub-categories and are also both commonly caused by the high stress nature of the extra-terrestrial environment. [3]

An analysis of the first habitat, Habitat Marte (HM) reveals several structural and ergonomic barriers, analogue habitats often generally face at the start of the process making it accessible. This assessment was conducted using videos and photos provided by the Habitat Marte director. Access to the main entrance shouldn't be hindered by a step, the airlock door width of only 50 cm prevents wheelchair passage, and the lock to certain modules mustn't be positioned out of reach for seated users. Furthermore, the airlock itself is often narrow, while adaptations within the sanitary and hygiene modules have to be undertaken with special care and planning, to meet special needs of different abilities of analogue parastronauts.

Next the system currently doesn't mention visual, auditory and/or vibratory alarms in case of emergency or simply to call in potential crew members with a sensory disability. On the same topic including braille indications and other sensorial ways to orientate would allow diverse crew members to evolve more easily in the premises. Regarding the greenhouse, while most of previous remarks apply, the paving and delimitation of walkable way are already a reasonable start allowing for some specially-abled crew members to evolve in this part of the habitat without too much trouble.

Such considerations illustrate the persistence of terrestrial architectural standards that overlook the diversity of crew abilities. These issues are not unique to HM; they reflect a broader pattern in space architecture, which historically has been designed for a narrow anthropometric standard.

Further investigations of the existing protocols and integration of the first mission's feedback in the creation of new protocols will ensue. However the priority was given to the point aforementioned and the lessons learned from lunar missions.

1.2 Lessons from LunAres Research Station

In contrast, the **LunAres Research Station** in Piła, Poland, has implemented several measures that can serve as models for accessible design in analogue and future planetary habitats. Following feedback from missions conducted between 2017 and 2019, LunAres introduced a dedicated sanitary module that incorporates accessibility features, including widened circulation areas and adapted bathroom facilities. This was directly linked to the ICARES-1 mission, in which an accident scenario simulated a vision-impaired, disabled crew member, underscoring the need for ergonomic and functional adaptation.

Similarly, LunAres has emphasized modularity and adaptability in its infrastructure. The use of container-based modules allows for flexible reconfiguration, levelling of floor surfaces to eliminate steps, and potential expansion of habitable areas. This modular approach aligns with recommendations from accessibility studies that call for multimodal and modular systems, enabling different modes of interaction (manual, voice, tactile, visual) depending on the user's abilities.

Finally, LunAres has explicitly incorporated psychological and procedural preparedness into its mission design. Its campaigns include scenarios in which crew members operate with simulated impairments, training all participants in the use of adapted equipment and in alternative operational procedures. This approach reflects broader findings that astronauts must be prepared for temporary impairments resulting from accidents or health conditions, not only pre-existing disabilities.

2. **Generalized requirements for parastronauts feasibility**

Synthesizing the limitations observed at HM and the advances at LunAres, as well as insights from the ESA parastronaut feasibility framework, the following categories of requirements emerge:

1. **Barrier-free access and circulation**
   - Step-free transitions between modules;
   - Minimum doorway widths of 60, ideally 90 cm;
   - Airlocks and hatches with sufficient manoeuvring space and no vertical thresholds.

2. **Ergonomic reachability of controls and equipment**
   - Positioning of critical switches, locks, and interfaces within the ergonomic reach zone (80–120 cm);
   - Multimodal operation (voice, tactile, visual, haptic feedback) to accommodate sensory and motor impairments.

3. **Accessible sanitary and hygiene modules**
   - Bathrooms and showers with transfer space, support rails, and adapted fixtures;
   - Redundancy in hygiene systems to ensure usability across different levels of mobility.

4. **Modular and reconfigurable interiors**
   - Furniture and workstations adjustable in height and layout;
   - Modular components allowing adaptation to changing crew needs, including impairment scenarios.

5. **Psychological and operational preparedness**
    - Inclusive crew training in accessible systems;
    - Simulation of accident scenarios to prepare astronauts for impaired conditions;
    - Integration of accessibility into emergency evacuation procedures.

The measures assist in making astronauts as autonomous as possible and their work as easy as for their fellow astronauts. These modifications will also be of importance in the event of temporary impairment of normally able-bodied astronauts.

3. Implementations and implications for Martian habitat design

While HM highlights the challenges that persist in accessible analogue station design yet, LunAres already demonstrates that accessibility can be integrated into habitat design without compromising operational objectives. For future Mars habitats, these requirements must be understood not as optional modifications but as core design criteria. Accessible designs benefit all astronauts by increasing redundancy, safety margins, and operational flexibility. Moreover, given the extended mission durations envisioned for Mars, the probability of temporary impairment due to injury or illness is high, making accessibility a mission-critical concern rather than a secondary consideration.

As a proposed way ahead and for further improvement of habitat we created a checklist based on the 5 main disability categories we mentioned earlier, as displayed in Tables 1 to 5. The checklist allows a rapid assessment of whether a habitat is accessible or not for these 5 general categories. Due to variety in disabilities and severity of impairments, this checklist only provides a rapid assessment to define if a habitat is currently broadly accessible, rather than fully ready without any modification. The authors expect that for every parastronaut, a tiny adjustment in either protocol, training program, or even tool might be necessary for the mission, without yet disqualifying the habitat from being suitable for a parastronaut mission.

The following checklist also refers to navigability, accessibility in broad teams. These should be fine tuned to individuals.

Table 1. Mobility impairments

Area	Key Accessibility Factors
Terrain	Is the terrain navigable by the user wheelchair, crutches, or prosthetic users? (limited gravel, sand, stairs, or steep slopes may be a barrier)
Doorways & corridors	Are entryways ≥80 cm wide? Can doors be operated by someone using different limbs? Are some doors automated?
Bathrooms & hygiene access	Is there space and support for transfers to a toilet from a wheelchair? Are sinks, showers heights adjustable?
Bunk/bed access	Are sleeping arrangements accessible from a sitting position, without climbing ladders or narrow steps?
Donning/doffing suits	Is there assistive equipment or enough space for independent or assisted donning?
Emergency evacuation	Are exits accessible in an emergency? Can a wheelchair or unconscious person be extracted in an emergency?
Seating/workspace access	Are control stations, lab benches, and kitchens heights adjustable?
Transportation	Can users board/unboard rovers or vehicles without climbing?
Charging/mobility storage	Space and power for wheelchairs, powered prosthetics, or walking aids?
Task design	Are EVAs, maintenance, or lab tasks adaptable to reduce standing/bending strain?

Table 2. Hearing Impairments

Area	Key Accessibility Factors
Visual alarms	Are all critical alerts (fire, pressure drop, EVA comms) available visually?
Vibratory or light-based alerts	Can haptic buzzers or flashing lights back up audible signals?
Clear sightlines	Can lip-reading users see their teammates easily in common spaces? (evaluation of the lighting conditions)
Captioned comms	Are briefings and training sessions accessible via captions or transcripts?

Radios/intercoms	Can radios support text transmission or auto-captioning software?
EVA comms	Does the suit support visual or tactile feedback for critical info?
One-on-one communication	Is there an agreed alternative way of communication? sign language, typing, or gestures?
Ambient noise	Is the station compatible with the hearing aid used by the crew members?
Emergency protocols	Can deaf users independently detect and respond to emergencies?

Table 3. Vision Impairments

Area	Key Accessibility Factors
Tactile markings	Are buttons, doors, or hazard zones marked with textures or Braille?
Audible aids	Are sound cues used to indicate equipment operation?
Screen readers	Are computers or data systems compatible with text-to-speech?
Contrast and lighting	Is ambient light sufficient and surfaces designed for high visual contrast?
Clear signage	Are labels large, high-contrast, and non-glare?
Orientation	Are the different rooms, walls and systems identifiable by touch or sound to blind users? Are there measures in place? (modification of the wall texture)
Tools & controls	Are tools and controls labelled or shaped for tactile recognition?
Digital accessibility	Are procedures and schedules available in screen-reader friendly formats?
Workspace organization	Are shared spaces organized to reduce navigation effort? (Steps, turns, low doors…)
Emergency markers	Are exits and emergency gear easily findable by touch or sound?
HUD/feedbac k in suits	Can information be conveyed audibly or haptically for low-vision users?

Table 4. Dexterity or Fine Motor Impairments

Area	Key Accessibility Factors
Suit controls	Can life-support, comms, and tools be operated with one hand, no hand or reduced grip?
Interface design	Are buttons large, spaced, and responsive to low-force input?
Zippers/closures	Are suit and habitat closures usable without fine pinch grip or two hands?
Tool usability	Can mission-critical tools be used with limited finger control or prosthetic grip?
Redundant input methods	Can tasks be controlled via voice, foot switch, or single large switch?
Kitchen and lab tasks	Do containers, instruments, and devices full dexterity to open or operate?
Maintenance procedures	Are delicate or high-precision tasks adaptable (e.g. simplified connectors and latches)?
Workspace height and reach	Can key surfaces be accessed without overextending or twisting wrists?
Emergency devices	Are fire extinguishers, first aid, and egress tools operable with low dexterity?
EVA prep and recovery	Is assistance built-in for donning gloves or manipulating suit controls?

Table 5. Cognitive / Neurodivergence

Area	Key Accessibility Factors
Procedure clarity	Are all OPs simple, clear, and written in logical step-by-step format?
Redundant communication	Are key messages given via voice, text, and diagrams for clarity?
Visual schedules	Is the day's structure easy to track with visible cues/reminders?
Noise and distraction	Are there quiet zones to reduce sensory overload or improve focus?
Error tolerance	Are systems and workflows forgiving of mistakes (e.g., undo steps, alerts, watchdogs)?

Emotional regulation spaces	Is there a private space for decompression or regrouping?
Team briefings	Do leaders use inclusive language and confirm understanding?
Predictability	Is the daily routine consistent and predictable where possible?
Autonomy supports	Can tools like checklists or personal task trackers be used?
Training materials	Are videos/subtitles/slides available for different learning styles?

4. Results & Discussion

The mission of August 2025 at Habitat Marte revealed a lack of accessibility of the green house with a mobility scooter. Physical exercises for health maintenance during the mission were only partially adapted to the analogue astronaut presenting muscular dystrophy and a weakness in the hip. While the exercises were adapted in terms of range of movement and form, the suggested workload was not and could potentially lead to injuries and exhaustion. This enhances the need for a bigger preparation and tailoring of activities as per the needs of a parastronauts, with a baseline measurement conducted in the pre-flight phase.

While the mission at Habitat Marte of August 2025 showed limited adaptation to a wheelchair user, it has displayed the interest and pull in that topic. So far LunAres has brought the analogue missions the furthest, with already more than 5 disabilities represented and adapted for. Interestingly, in between missions, some of these modifications were removed as they did not necessarily suit another disability adaption. This showcases once more the need for individual assessments of requirements while being able to accommodate quickly and efficiently to carter to different abilities.

The authors believe that to tailor to specific abilities, the habitat layout, systems and accommodations should be clearly presented to all participants to clarify what can be adapted and cannot, as it directly impacts the activities that can be performed by the analogue astronauts during the mission. Videos, photos, discussion and exchange help in understanding the limitations, to a certain extent.

6. Conclusion & Way ahead

The authors were able to identify some of the biggest accessibility challenges that need to be prioritarily addressed to ensure an accessible mission. The biggest limitations to modifications to habitat seem to be in time and budget constraints, rather than lack of knowledge. In addition, the time resources that need to be allocated to the modification of habitats is also one to be considered. The authors recommend that participants with specific needs should receive a thorough briefing months before the mission to anticipate specific adaptations in protocol or layout of the habitat. In addition, in the pre-flight phase, the habitat should be visited or tested by the analogue astronaut, especially if the habitat did not yet receive an analogue astronaut with a similar disability. This would allow a few days to the adapt flight plan, protocols and remove participant frustration by providing a clear picture of what is accessible or not.

Due to the diversity of disabilities, the authors recommend the use of different navigability and accessibility apps, as reported in the article by Prandi et al. [4] , to assist in understanding navigability and accessibility limitations in public transportation in everyday life, and to apply these to habitats in addition to the check lists prepared.

Acknowledgements

The authors thank CHASM & PARACHASM, LunAres Research Station and Habitat Marte for the resources and development.

References

[1] L. M. Haile *et al.*, “Hearing loss prevalence and years lived with disability, 1990-2019: Findings from the Global Burden of Disease Study 2019,” *Lancet*, vol. 397, no. 10278, pp. 996–1009, 2021, doi: 10.1016/S0140-6736(21)00516-X.

[2] IAPB, “IAPB Vision Atlas - Global Eye Data.” Accessed: Sep. 01, 2025. [Online]. Available: https://visionatlas.iapb.org/

[3] NASA, “Human Health Countermeasure Spaceflight Risks.” Accessed: Sep. 01, 2025. [Online]. Available: https://www.nasa.gov/humans-in-space/hhc-spaceflight-risks/

[4] C. Prandi, B. R. Barricelli, S. Mirri, and D. Fogli, “Accessible wayfinding and navigation: a systematic mapping study,” *Univers. Access Inf. Soc.*, vol. 22, no. 1, pp. 185–212, 2023, doi: 10.1007/s10209-021-00843-x.