DEPLOYABLE GETAWAY FOR THE INTERNATIONAL SPACE STATION

Imhof, Barbara*, Hoheneder, Waltraut**, Vogel, Kaspar***
LIQUIFER Systems Group, 1020 Vienna, Austria

Top performance is the key issue for astronauts and cosmonauts onboard the International Space station (ISS).

With the bigger crew of 6 since March 2009, group dynamics changed and people might seek a place to escape to either stay on their own for a while or to get away from the predominant laboratory environment. Additionally, the ISS serves as a test-bed for future long duration stays in space and transfers to other planetary bodies such as Mars.

This paper describes the current status of an on-going research activity named "Deployable Getaway for the International Space Station" initiated by LIQUIFER and funded by the Austrian Aerospace and Space Agency.

The main objectives are to improve habitability with the help of adaptive equipment during crew overlap periods like crew exchange periods and short-duration missions or to provide a flexible set-up for more privacy during long-duration missions.

The term "Deployable Getaway (DeGe)" refers to the design of deployable crew quarters which allows space-efficient storage and at the same times more flexibility to create private spaces for recreational periods either for individual leisure time and breaks or for sleep phases on ISS.

I. Introduction

In 2008, LIQUIFER Systems Group won a contract in the frame of the national space research program of the Austrian Aerospace and Space Agency to develop the project "Deployable Getaway for the International Space Station". The team comprised two architects and designers, one physician with an expertise in occupational health, one expert for systems engineering, one expert for human factors engineering and two people as design support.

During the project the situation on ISS changed drastically. The crew had been increased from three to six people and NASA delivered four new crew quarters (CQs) until April 2010. Due to this development the authors decided to concentrate on their flexible design concepts and discontinue the refinement of their stationary, in-built design concepts. There were mainly two reasons: firstly, alternative designs will still be needed for future developments and fit into the scope of ISS being a test-bed for future missions to Mars, and, secondly the lack of additional crew quarters for crew overlap periods which will represent a challenge especially after the Shuttle Retirement.

The results presented in this paper will focus on two flexible equipment units which can be positioned at any suitable location on ISS: the Comfort Case which can be unfolded into a crew cabin using a "folding box principle". Two of them can be stored in one International Standard Payload Rack (ISPR).

Complementary to the crew cabin, an enhanced sleeping bag, the Visitor Kit, was developed which can be used inside a crew-cabin or independently as temporary, light weight equipment for visiting crews as it comprises individually applicable features such as private storage facilities and facilitates either a "sleeping mode" or a "working mode" for the user.

All designs were built as 1:1 functional mock-ups and were tested in a simulation environment, using harnesses for the test subject. Further development and project enhancement are planned.

* Dr. techn. MSc. Arch. Barbara Imhof, LIQUIFER Systems Group, Obere Donaustraße 97/1/62, 1020 Vienna, Austria, T: +43 1 21885-05, F: +43 1 21885-056, bimhof@liquifer.com
** Mag. Ach. Mag.rer.soc.oec. Waltraut Hoheneder, LIQUIFER Systems Group, Obere Donaustraße 97/1/62, 1020 Vienna, Austria, T: +43 1 21885-05, F: +43 1 21885-056, whoheneder@liquifer.at
*** Dr. Kaspar Vogel, LIQUIFER Systems Group, Obere Donaustraße 97/1/62, 1020 Vienna, Austria, T: +43 1 21885-05, F: +43 1 21885-056, kaspar.vogel@liquifer.com

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Figure 1: Comfort Case (deployable crew cabin) and Visitor Kit in "Sleeping Mode" (enhanced sleeping bag), photo © Bruno Stubenrauch, reworked LSG/Hoheneder

The consecutive steps in developing the designs were the following:

- Background research about ISS and crew quarters
- Analysis of the research data
- Specify requirements and design drivers
- Create different concept options
- Evaluate concept options using trade-offs, comparative analysis and occupational health evaluation
- Select baseline design
- Develop detail design
- Build functional mock-ups
- Test mock-ups

II. ISS Analysis of Crew Quarter Design Concepts

The ISS will reach its final layout and size this year (2010). However, specific experiments and changing payloads will be transported to the ISS with the Automated Transfer Vehicle (ATV), the Russian Progress Capsules launched on Soyuz, as well as with the Japanese HTV, and the COTS vehicles Cygnus and Dragon after the Shuttle termination. Thus the interior environment of the ISS is subject to continuous change. Since the American habitation module has been cancelled the habitation functions will be distributed amongst the other lab modules.

Habitation consists of the basic functions such as work, eat, drink, sleep and hygiene but also of living and recreation. Therefore, getaway spaces with a range of options for functions will be needed, now and in the future, especially when taking the ISS as a testbed for training for long duration missions to Mars.

For most long-duration astronauts the ISS becomes a kind of home, as Susan Helms, a crewmember of the ISS Expedition-2, described. "Before I went up on the ISS for five and a half months, I moved out of my place, put all my possessions in storage, and moved into the astronauts' crew quarter earlier than most people do. I didn't want telephone or credit-card bills, or anything except a bank account where my paycheck could go. I figured if I didn't have a home back here to worry about, the ISS could become my home."[1]

Since space is a very scarce commodity on ISS, there are obvious programmatic arguments in favor of a flexible, deployable type of private space designed for temporary use. This was confirmed by Constance Adams, architect at NASA's Johnson Space Center: "We do know from lessons learned in Phase 1 that having a portable sleep station and the ability for each crewmember to be in a separate module, even if it is not a module otherwise equipped with much crew station hardware, seems to be preferable to most crewmembers than being co-located in one module. So, a design for a portable sleep restraint system with some stowage containers for crew personal items, kind of like the old-fashioned steamer trunk that opened up to become a portable armoire (but not so big!), could be an excellent solution concept …" [Adams, C.; via personal email, 1.8.2007]

"Design and development efforts of long-term crewmember accommodations began with the US Skylab crew quarters. Skylab featured visual private space for each crewmember but lacked acoustic and light isolation and had very limited ventilation control. The Skylab crew indicated these deficiencies and a lack of headroom for taller crewmembers reduced the effectiveness of the private volumes."[2]

In the following the most recent and important concepts of individual crew spaces on ISS are presented and analyzed (an overview is shown in Table 1 on page 6).

A. Russian ISS Crew Quarters

The Russian crew quarter or Kayuta, Fig. 2, (remodeled after the MIR space station layout) contains a laptop computer, audio devices and personal stowage capacities, as well as one big additional asset that other crew quarters lack: a window (which, under certain circumstances, might also imply higher exposure to radiation). The Kayuta is outfitted with stowage nets for personal belongings and a work "desk" which can be folded away. On one side of the cabin a sleeping bag is mounted. Ventilation and individual lighting is provided in addition to private communication means. The color code is mostly beige with a soft texture and opposite the sleeping bag there is a mirror to visually enlarge the space.

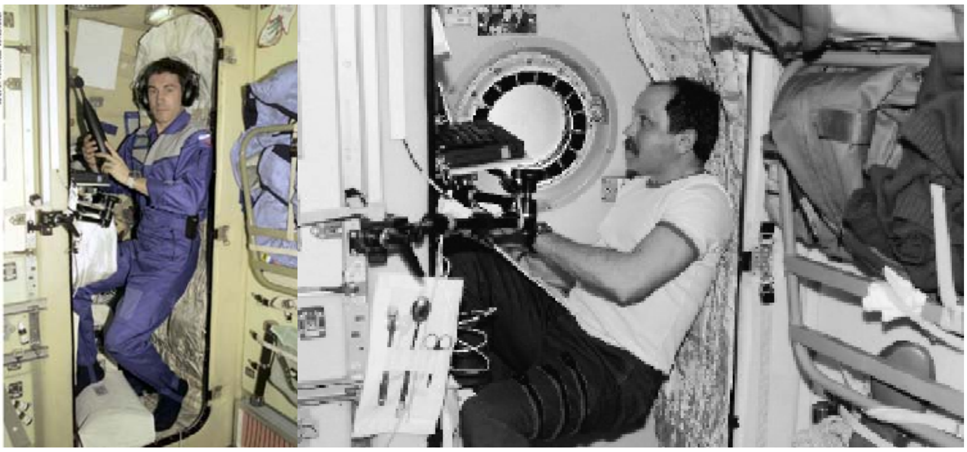


Figure 2: Russian Kayuta, Courtesy of NASA

"The Russian crew quarters, or Kayutas, were introduced with Salyut 6 and the basic configuration was used in Mir's base block and the ISS Service Module. 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. Valuable lessons were learned from participating in the Russian Mir program and were incorporated into ISS CQ."[2]

B. Temporary Sleep Station

"The Temporary Sleep Station (TeSS) (Fig. 3) provides crewmembers with a private and personal space to accommodate sleeping, donning and doffing of clothing, personal communication and performance of recreational activities. The need for privacy to accommodate these activities requires adequate ventilation inside the TeSS."[3]

"TeSS has acoustic blankets to muffle outside noise, a caution and warning system to head off malfunctions, and an air ventilation system. Astronauts using TeSS can take advantage of lights, work surfaces, handholds, sleep and foot restraints, and personal storage areas.” [Make room for one more astronaut, Express Lessons and Online Resources, NASA explores TESS, http://www.nasaexplores.com/show2_912a.php?id=01-086&gl=912, 2001]

Figure 3: TeSS onboard ISS, Courtesy of NASA

“TeSS provided limited functionality within a private volume consisting of a rack volume and a 31-cm bump-out into the aisle way,… 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 pair of LAB ventilation ducts into and out of the rack. The ventilation flow rate and directional was limited and some crewmembers have reported the inability to direct air as a source of discomfort. The TeSS structure was launched folded flat on a Resupply Stowage Platform (RSP) to minimize launch loads and had to be assembled on orbit.”[3]

The astronauts’ feedback concluded that it was too noisy inside. This also resulted from the fact that TeSS was installed in Destiny, the US laboratory which is the noisiest module. The new CQs were installed in the quieter Node 2 and acoustics were improved.

C. ISS Node 2 Crew Quarters

The following information about the Node 2 CQs is quoted from “International Space Station USOS Crew Quarters Development” (Broyan et al. 2008).

“The new CQs (USOS) 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 obtaining crewmember rest and comfort to enable long term crewmember performance.”[3]

An overview is given in Figure 4.

Figure 4: The Crew Quarters Installed in Node 2. Courtesy of NASA

D. Evaluation of the CQ Designs

A short summary of the different existing ISS crew cabin concepts and their strengths and weaknesses are presented in Table 1:

Analyses of ISS crew quarter concepts	
Strengths	**Weaknesses**
Russian Kayuta • Long time proven concept – already established on Salyut • Soft surface inside • Window implies an own view towards Earth	***Russian Kayuta*** • Sometimes too hot • Window also implies less radiation protection • Flexibility
TeSS • Folding geometry • Soft surface inside • Flexibility	***TeSS*** • Noise isolation not very good • Ventilation system not optimal • Color coding is not optimal
New CQ on ISS • Through the bump out spaces quite large • Very quiet in comparison to the other built private cabins • Good ventilation and good temperature regulation	***New CQ on ISS*** • All in one node, although astronauts prefer not be collocated

Table 1: Strength and Weaknesses of ISS CQ designs

E. Implications for the ”Deployable Getaway”

None of the crew quarters up to now were deployable including reversibility. TeSS was deployed (built together) in orbit for continuous use and a specific location was determined. The authors looked at the features and infrastructure carefully and found functional and programmatic issues to integrate into the design such as light, ventilation, private workplace, stowage bags for private items and the use of preferred light colors. Radiation issues were not considered in detail for this development stage since the location should be variable and the crew cabin to be (partially) protected from the surrounding racks and material.

III. Design Drivers and Requirements

The team’s consultant Berengere Houdou, ESA-ESTEC Human Factors, gave primary Human Factors specificities for a Getaway, which comprised the following aspects: safety (to stay alert for survival purposes in case of problems), multi-functionality (allow working, sleeping, relaxing, communicating) and usability (orientation cues, fixation in weightlessness environment).

The requirements from Kaspar Vogel, occupational health expert, are divided in two categories. The requirements in the first category relevant for the Baseline design include:

- Structural robustness (when outside crewmembers pass by they cannot change the form)
- Flexible and short-term usability
- Structure ensuring visual privacy
- Haptics (haptic properties reducing the need for physical control in a zero gravity environment)
- Control of environment (e.g. the crewmember using the deployable getaway can see approaching fellow crew members)
- Internal and external noise reduction
- Good ventilation

The second category of requirements is relevant in the detail development:

- Adjustable environmental conditions (lighting and color can be controlled)
- Optional communication facilities (video calls, audio, visualizations, supporting relaxation techniques such as bio-feedback)
- Structure possibly enlargeable (for two occupants)

The following citations add to the Human Factor requirements:

- “Stimulate creativity - Ryumin: I need a flight of sufficient duration so that in addition to the basic program I could accomplish experiments that I sense needed to be done but which had not been stipulated officially. In short flights, the entire program was time dependent. There was positively no time for creativity. Barely had time to turn around and it was time to descend." (Ref. 4, p. 309)
- “A distinguishable environment for crew members - as space stations have progressed the working and living conditions for the crews have been improved. It has been possible to counteract hypodynamia (insufficient motor activity, leading to decreased work capacity and reliability of work) by enlarging the work and living quarters.”[4] (Ref. 4, p. 60)
- “Minimize noise level – in rest areas 40 dB should not be exceeded” (Ref. 4, p. 170)
- “Mitigate negative psychological effects (for example, claustrophobia)” (Ref. 4, p. 60)
- A distinct ‘Gestalt’. By ‘Gestalt’, the authors mean “a configuration having specific properties that cannot be derived from the summation of its component parts; a unified whole.” And “overall aesthetic expression of an object (building, machine, etc.) based on form, material, surface and structure.” (Ref. 4, p. 60)
- “In rest and recreation areas warm, relaxing colors with a color contrasting trim” (Ref. 4, p. 136)
- “For sleeping quarters *muted*, cool color tones. (This will create a feeling of coziness and the impression of increased space.)” (Ref. 4, p. 136)

With regard to the inputs stated above as well as the analysis of the existing crew quarters the general requirements for the “Deployable Getaway” were defined as follows, depending on the configuration of the Deployable Getaway (Table 2):

Stored configuration
Usability: the getaway shall be functional by guaranteeing access to personal belongings at any time
Integration capacity: the getaway shall be easy to integrate in given work place or ISS layout
Space efficiency: the getaway should fold into a minimal volume
Process of deployment
Usability: the getaway shall be deployed easily and quickly, the deployment of the getaway shall be self-explanatory
Flexibility: The emplacement of the getaway shall be as universal as possible
Deployed Configuration
Usability: the getaway shall be functional and safe concerning access and egress, orientation, handling of equipment, control of environment and allow for sufficient circulation space around it
Robustness: the getaway shall be robust in its construction and fixing
Health Factors: the design of the getaway shall support the physical health of the user concerning ergonomic design of the equipment, adequate ventilation, noise reduction, radiation shielding, anti-microbial materials or coatings, thus promoting healthy and sufficient recreation and sleep phases
Comfort: the getaway shall provide comfort to the user by the possibilities of individualization with the help of adjustable furnishing (size, light, sound, communication infrastructure)
Privacy: the getaway shall allow privacy by visual shielding
Multi-functionality: The getaway shall be suitable for a range of recreational possibilities
Identification: the getaway shall provide the possibility of identification

Table 2: Requirements

IV. Concept Design

The authors established a design procedure combining the main relevant fields of architecture, design and engineering with occupational health. After collecting and analyzing the research data about ISS concerning the existing crew quarters and defining the requirements, the next step was to identify possible locations for deployable getaways on ISS.

A. Locations for a "Deployable Getaway" on ISS

The selected locations put a special focus on the possibilities for stationary, in-built deployable crew quarters, which were finally not developed further after NASA delivered four stationary crew quarters until April 2010 to be installed in Node 2. But the results of this early concept design phase are presented nonetheless in order to show an overview over the envisioned design concepts.

The drawing in Fig. 5 shows suitable places for installment. Appropriate are areas where there are windows, e.g. in the Destiny module, in Node 3 (Cupola) or in the Kibo module; or where there are "dead-ends", so no "through spaces" such as the rear end of the Columbus module and the Kibo module or in Node 2 and 3. All the mentioned modules present a similar standard; their interior layout is based on the ISPR. When looking for suitable spots this was a criteria to select-in, whereas the Russian modules have a different standard and thus a different interior habitable (free) volume; it is smaller. Therefore, these modules were selected out.

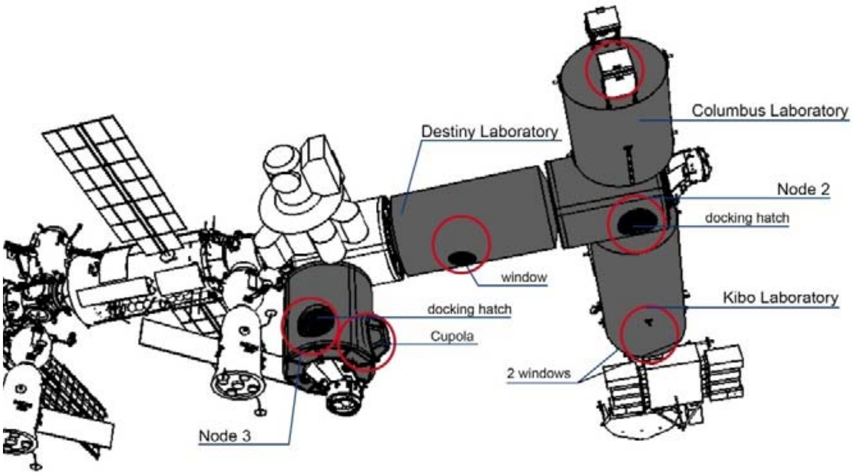


Figure 5: Identified Positions within the Selected Modules, © LSG/rendering: Waclavicek based on public data from NASA

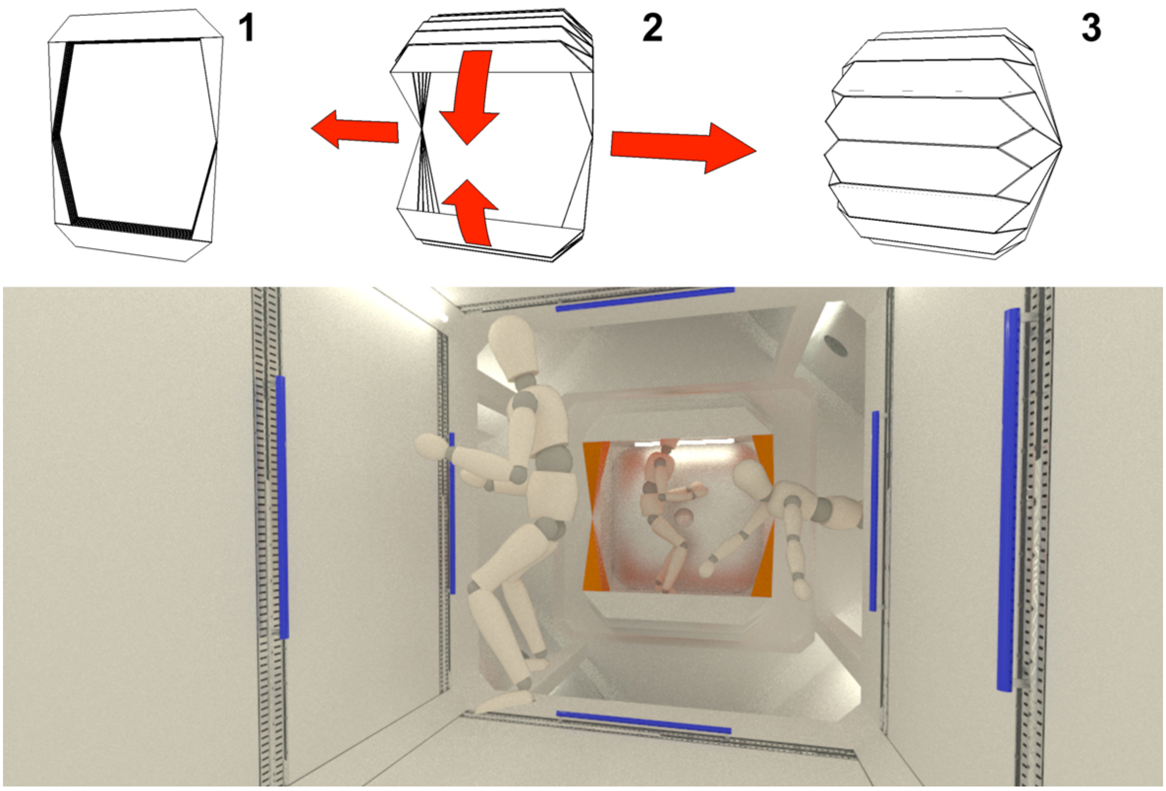
B. Design Concepts' Creation and Evaluation

The design concepts were:

1. Ladybird DeGe
2. Visor DeGe,
3. Comfort Case,
4. Telescope Home,
5. Visitor Kit

Figures 6a-6d identify the strengths and weaknesses of the developed concepts.

1. Ladybird DeGe



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Strengths:

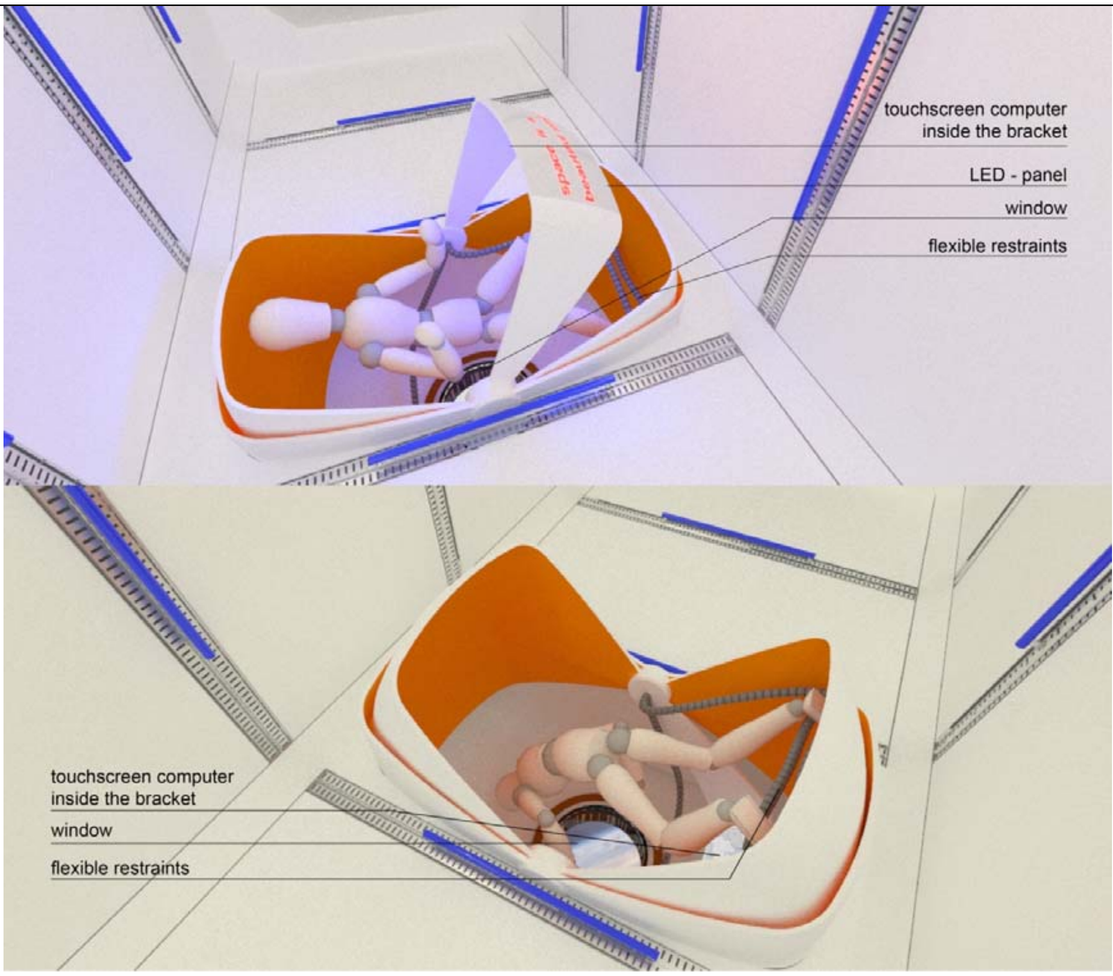
- Crew cabin is deployable
- Introduces new texture and form into an environment which is modular and rectangular without differences in shape, texture or light
- Valuable from a psychological environment point of view
- Playful infrastructure brings a new level of perception and connectedness to the astronauts
- Introduces leisure activity in a scientific lab module
- **Very large personal cabin, can also be used for two people**
- **Does not consume extra storage space in folded configuration**
- Can be adapted and used as a tourist getaway for space hotels such as the one planned by BIGELOW

Weaknesses:

- Mechanism is not easy to install into ISS environment
- Introduces leisure activity in a scientific lab module
- It needs to be deployed – even if it is quick it consumes some time
- Leisure has little priority on ISS
- **Ladybird DeGe cannot be positioned within a rack's size volume but only at the end of a module**

Figure 6a: Ladybird DeGe Assessment of the Concept

2. Visor DeGe



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Strengths:

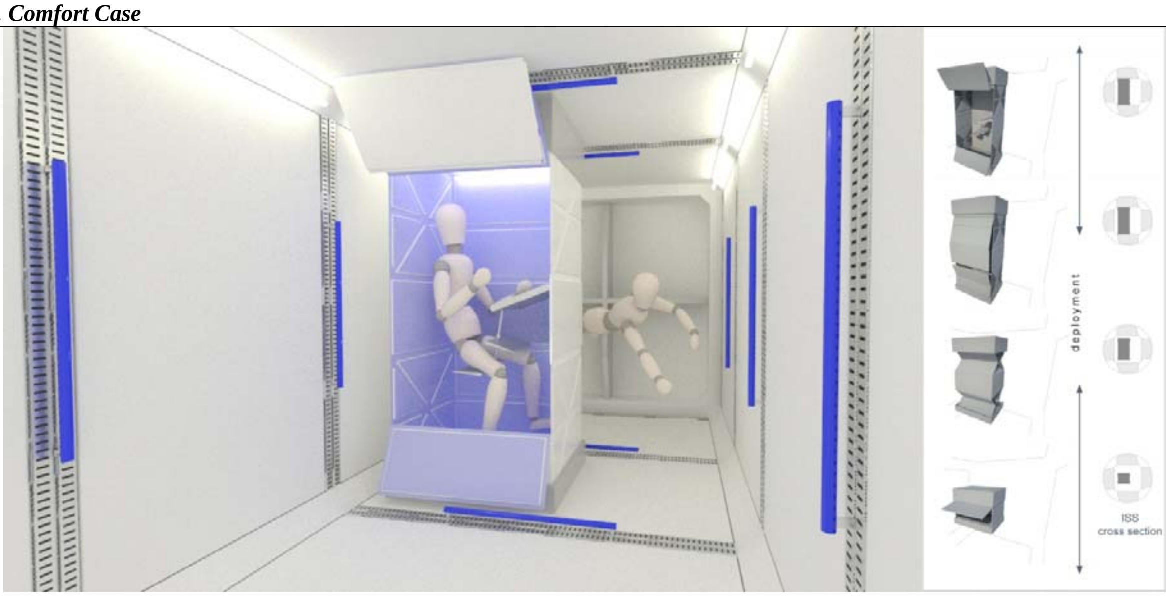
- Crew cabin is deployable
- Introduces new texture and form into an environment which is modular and rectangular without differences in shape, texture or light
- Valuable from a psychological environment point
- **Combines astronaut's leisure activity of watching Earth with new leisure activities**
- **Does not consume extra storage space in folded configuration**
- Playful infrastructure brings a new level of perception and connectedness to the astronauts
- Easy to install
- Easy to deploy
- Very large personal cabin, can also be used for two people
- Can be positioned within a rack's size
- Can be adapted and used as a tourist getaway for space hotels such as the one planned by BIGELOW if a rack-based system is used

Weaknesses:

- Introduces leisure activity in a scientific lab module
- It needs to be deployed – even if it is quick it consumes some time
- Leisure has little priority on ISS
- **Not flexible in it's position**

Figure 6b: Visor DeGe Assessment of the Concept

3. Comfort Case



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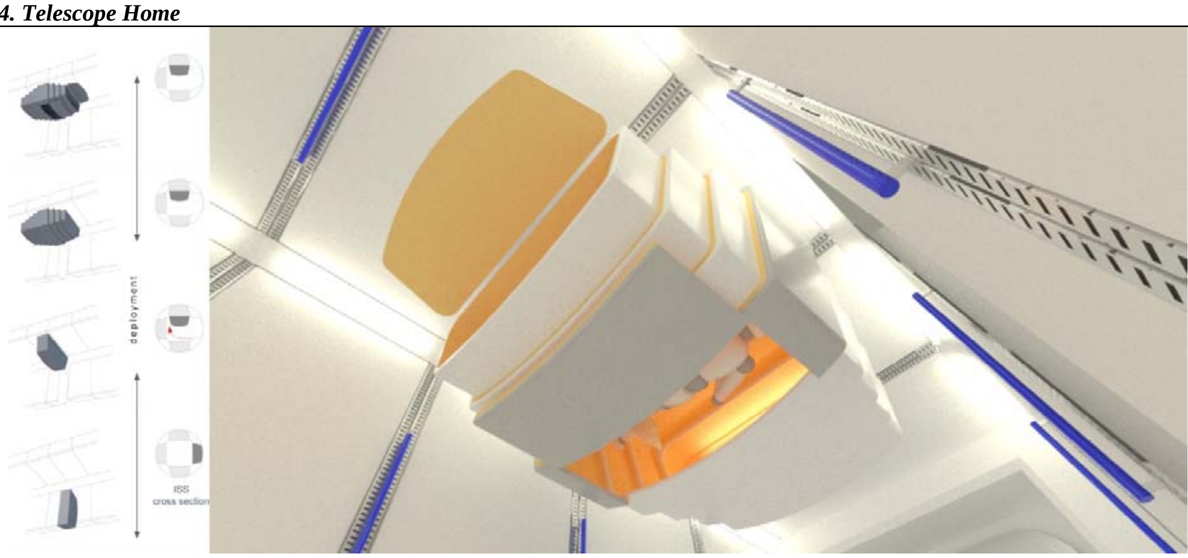
Strengths:

- Crew cabin is deployable
- Cabin can be easily stored and deployed if necessary
- **Only needs half a rack of stowage when not deployed**
- **Can be fixed anywhere on ISS where space is available and where the astronaut/cosmonaut prefers**
- Can be adapted and used as a tourist getaway for space hotels such as the one planned by BIGELOW

Weaknesses:

- Not being fixed in one place can also be a disadvantage – depends on the individual perception of a crewmember
- It needs to be deployed – even if it is quick it consumes some time

4. Telescope Home



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Strengths:

- Crew cabin is deployable
- **Only needs half a rack of stowage when not deployed**
- **Two entrances/exits**
- **Very large personal cabin, can be used for two people**

Weaknesses:

- **Space consuming**
- It needs to be deployed – even if it is quick it consumes some time

Figure 6c: Comfort Case and Telescope Home Assessment of the Concepts

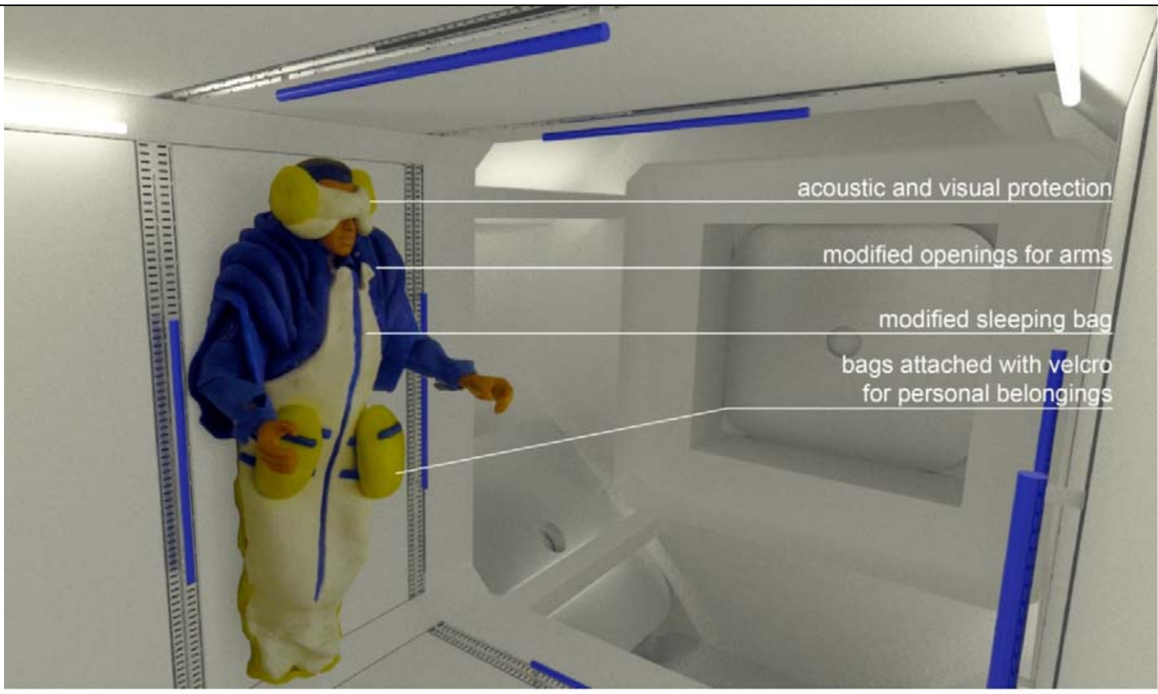
5. Visitor Kit	
 *© LSG/rendering Waclavicek*	
Strengths: • Improved sleeping bag • **This is a good enhancement (through acoustic, eye protection and personal pockets) for ISS visitors or crew exchanging** • **It needs very little storage space** • Easy to install • Flexible	***Weaknesses:*** • **It is not a crew cabin** • No visual protection from outside

Figure 6d: Visitor Kit Assessment of the Concepts

The two flexible concepts were chosen to be developed further: Visitor Kit and Comfort Case.

V. Selected Designs

The analysis showed that the **Comfort Case** got very good results regarding the following issues and shows advantages compared to other design options such as Telescope Home, Visor and Ladybird DeGe:

Advantages over the other crew cabin concepts:

- Can be fixed anywhere on ISS where space is available and where the astronaut/cosmonaut prefers
- Can be adapted and used as a tourist getaway for space hotels such as the one planned by BIGELOW
- Mechanical and folding mechanisms including ergonomics and Human Factors can be tested in a parabolic flight
- Two Comfort Cases fit into one ISPR
- Can be easily stored in a rack and deployed if necessary

The authors were interested in simulating how the design could be accommodated in the real environment ISS (see Fig.7). The following collage shows how the Comfort Case could be integrated on ISS. Due to it's flexibility it has the capacity to be integrated in more crowded modules as it can also be positioned parallel to the circulation space (not shown in Fig. 7).

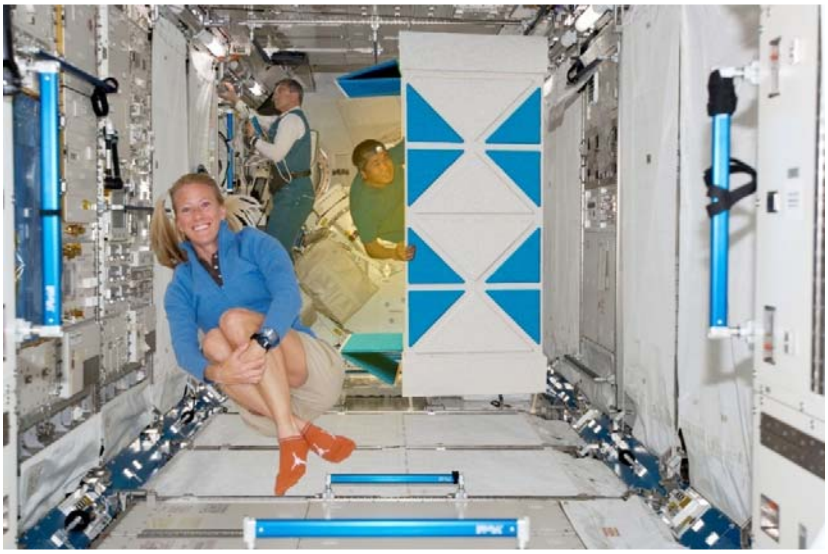


Figure 7: Comfort Case within ISS, Collage © LSG/rendering Stürzenbecher, ISS image courtesy of NASA

The other concept chosen for further development is the **Visitor Kit**:

Advantages over the other (not selected) crew cabin concepts:

- Can be fixed anywhere on ISS where space is available and where the astronaut/cosmonaut prefers
- This is a good enhancement (through earmuffs, sleep mask and personal pockets) for ISS visitors or crew exchanging
- It needs very little storage space
- Flexible (e.g. complementary to the Comfort Case)
- Can be used with or without a crew cabin

In order to illustrate the enhancement of the Visitor Kit in comparison to a sleeping bag such as the Russian sleeping bag currently used by all crewmembers on space station the next table shows the differences, additional options and enhancements. (Table 3)

	Visitor Kit 	**Russian sleeping bag** 
Size	Adjustable through special shoulder straps	Not adjustable
Ventilation	Front: two L-shaped openings approx. 30x6cm und 6x7cm and two square-shaped approx. 20x5cm all filled with mesh fabric and two zips one on each side with a length of 40cm	In the front six square shaped ventilation openings approx. 6x6cm each made of mesh fabric
Opening to enter	Two middle zips which create bigger opening and ensures easier accessibility	One middle zip
Pockets for personal belongings	One integrated flat pocket in the cotton liner and two personal bags attached with a size of 20x28x15 cm (w/h/d) each with 2 or 3 compartments for storing different goods	One integrated flat pocket in the cotton liner and one flat pocket in the upper material with a size of approx. 15x20cm (w/h)
"Cushion"/ hood	Attachable "collar pillow" and individually attachable "cheek cushion"	Liner "cushion" hood
Liner	Velcro attached cotton liner with integrated pocket	Velcro attached cotton liner with integrated pocket
Sleep mask	Provision of sleep mask – creates complete darkness in front of the eyes and the fabric can be worn slightly detached from the eyes through additional soft patch creating a distance between the eyelid and the mask sitting on the outer rim of the eye socket	None
Acoustic protection	Earmuffs with attachable "cheek pillow"	None
Additional features	Table for attaching books and laptops with two different positions : landscape or portrait format	None
Color	White (front side), blue (back side), black zips and strips with patches of red, grey	White
Appearance	More fashionable and cozy appearance	Technical reminds of a laboratory set-up – astronaut becoming a lab-subject

Table 3: Comparative Table Visitor Kit and Russian Sleeping Bag

A. Occupational Health and Ergonomics Aspects

From the perspective of occupational health, by facing space flights in common, working and living in space stations, furthermore planning of future touristy programs, numerous aspects have to be taken into account.

Criteria require the opportunity to work and live healthy with respect to working conditions, working environment, tasks and individual condition. Consequently, a well-balanced relation between work and regeneration should be reached by taking care of individual physiological and psychosocial factors. Sufficient sleep, the efficiency of breaks and regenerative behavior help to gain best working results and promote sustainable health. In highly motivated crews, and when planning working schedules for these, an information and training policy is needed to make the positive aspects of time-outs understandable in order to prevent psychic or physical exhaustion. Short term flights might be less demanding, mid-term or long-term flights should even more concentrate on regeneration, privacy, sufficient sleep and individual rhythm patterns.

Comfort Case and the Visitor Kit were developed under these considerations. The criteria listed and described below in Table 4 focus on ergonomic characteristics, gear integration and usability.

	Comfort Case	**Visitor Kit**
Usability	Availability: allows fast access to stored configuration in International Standard Payload Rack (ISPR) and time saving deployment Easy handling: assembling is self explanatory and offers visible hints for mechanism and fixation points Accessibility: flexible door size in comfort case allows easy access depending on different body dimensions	Easy handling: simple fixing inside crew cabin or module Accessibility: can be dressed easily
Integration Capacity	Designed for ISPR integration in stored configuration Dimension of comfort case in stored configuration leaves space inside for personal belongings and sleeping bag In stored configuration an additional box for personal belongings can be accessed at any time	Can be stowed inside comfort case or at any other suitable place Small package size Optional side-bags for individual belongings are easy accessible in stored configuration
Flexibility	Can easily be transferred to other modules of space station in case of emergency, evacuation or different logistic demands	Can easily be transferred to other modules of space station in case of emergency, evacuation or different logistic demands
Robustness	Stable construction	
Health Factors	Cleaning (disinfection, washing): surface and material are resistant to disinfection or cleaning measures, which could be necessary in case of disease management, smell reduction, sweat etc., alternatively anti-microbial materials or coatings are desirable Materials chosen comply with outgassing standards of the ISS Climate (air condition, ventilation), breathable material: system supports integration of air condition, active ventilation, door size can be enlarged individually, materials used are breathable Noise reduction: noise reduction by material, control of external stimulus (also visual and olfactory)	Cleaning (disinfection): material supports cleaning procedures, alternatively anti-microbial materials or coatings are desirable Materials chosen comply with outgassing standards of the ISS Temperature regulation, breathable material: supports preservation of thermal balance, evaporation of moisture, allows additional individual temperature regulation by zipper Noise reduction, protection against light: headset (earmuffs and sleep mask) supports control of external stimulus (visual, auditive), allows universal use inside space stations

	Reduction of electrostatic charge: material prevents electrostatic charge Fire resistant material Radiation shielding: material should reduce radiation	Reduction of electrostatic charge: material prevents electrostatic charge Fire resistant material except for the liner
Comfort	Dimension of Comfort Case fits to different personal behavior and space demands Haptics: convenient surface Color: visual support of relaxation, taking psychological impact of color into account	Adjustability: supports adaptation to different body sizes and sleeping habits Optional side-bags offer storage capacity for individual belongings Optional neck and cheek cushions
Privacy	Customize configuration in opened or closed position and fixtures allow adaptations to personal demands (privacy, memorabilia)	
Multi-functionality	Extensibility: integration of further development of mechanisms to support regeneration e.g. audiovisual systems which could be used to reinforce habitual biorhythms, entertainment, working sphere	Extensibility: optional fixation of mobile devices (laptop, table) to act in comfortable controllable position Optional function as emergency bag
Identification	Identification, attraction: closed coverage type supports identification due to privacy experience	

Table 4: Comparative Table Occupational Health Aspects Comfort Case and Visitor Kit

B. Detailed Solutions

Preliminary investigations for the manufacturing of a Comfort Case prototype have been done.

1. Comfort Case

Figure 8 shows an individual panel. A noise isolation panel is coated with Nomex and the individual panels are connected together. It shows how different panels are set together ensuring the consideration of the different folds and single panels are stitched together considering the geometry - valley and mountain folds. (Fig. 9)

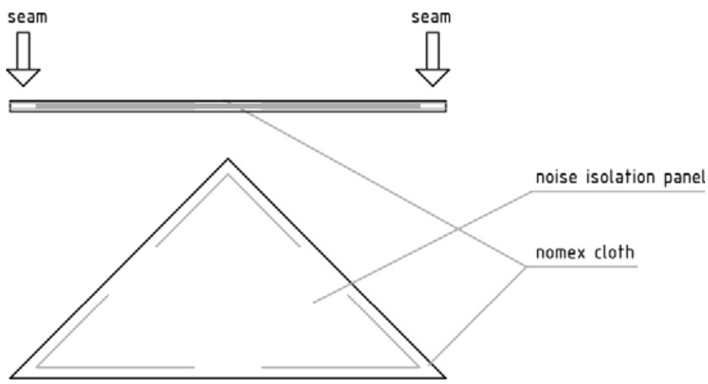


Figure 8: Two Panels Folded and Stitched Together, drawing © LSG/Imhof

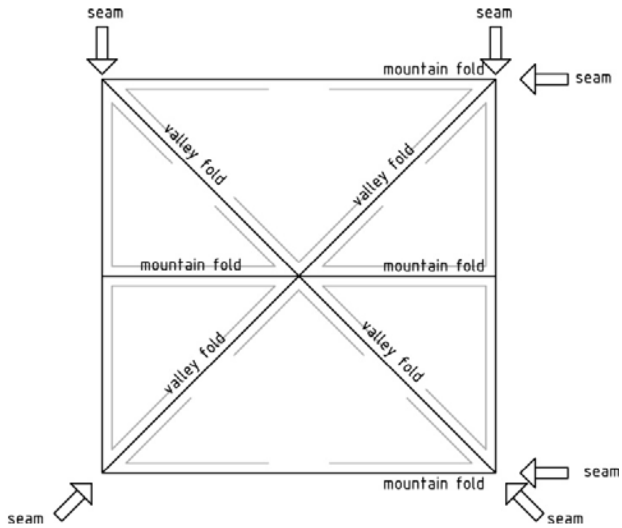


Figure 9: Six Parts – one Square of the Side Elevation of the Comfort Case, © LSG/Imhof

In Figure 10 the folding mechanism is depicted. Because of the zero-g environment there is no support structure needed. The panels are self-supporting and the fold is induced by the way the single parts are connected together.

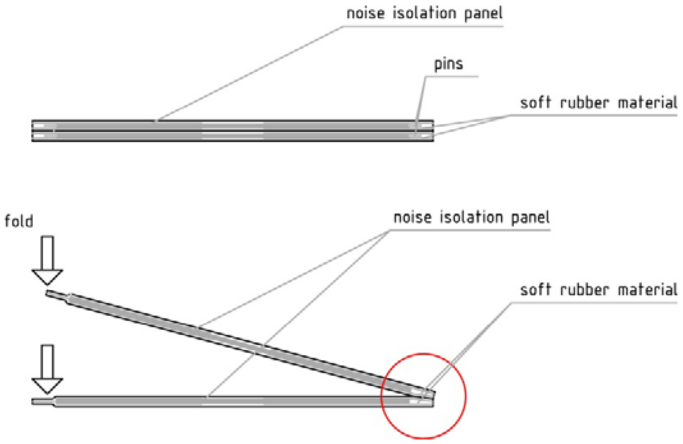


Figure 10: Two Parts Fold Together, drawing © LSG/Imhof

Figure 11 shows the logic of the folding geometry. There are mountain and valley folds and the specific arrangement including the geometry of triangles and rectangles lead to the folding box principle. The openings have to follow the same logic. The only non-folding parts are the two boxes on each side of the body which contain the technical equipment for light and ventilation (see Fig. 16).

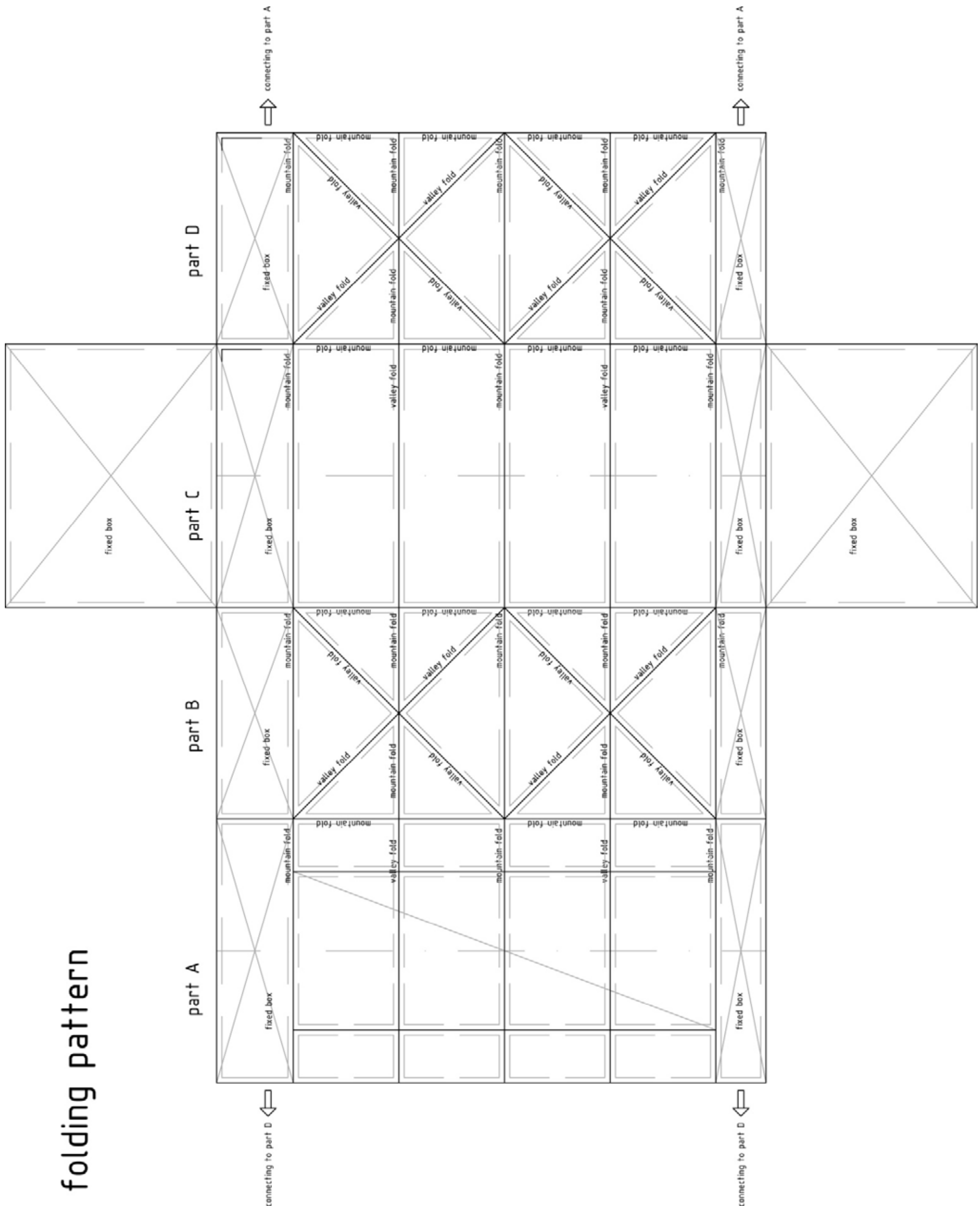


Figure 11: Folding Pattern, drawing © LSG/Imhof

Figures 12 and 13 describe one possible sequence of the folding process of the Comfort Case and shows that two elements can be stored in one ISPR.

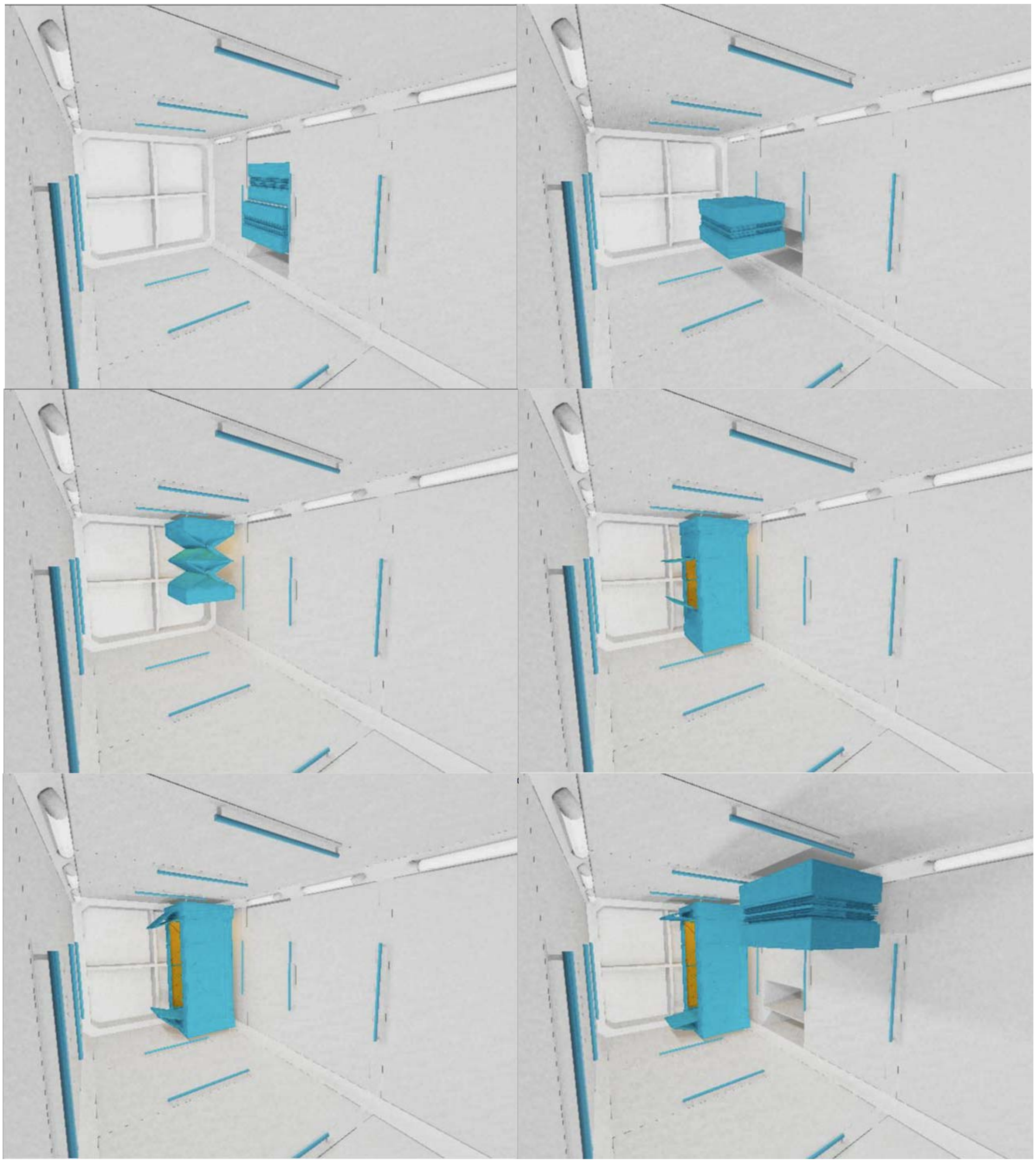


Figure 12: Screenshots from the Deployment Animation of the Comfort Case (part 1), © LSG/animation Stürzenbecher

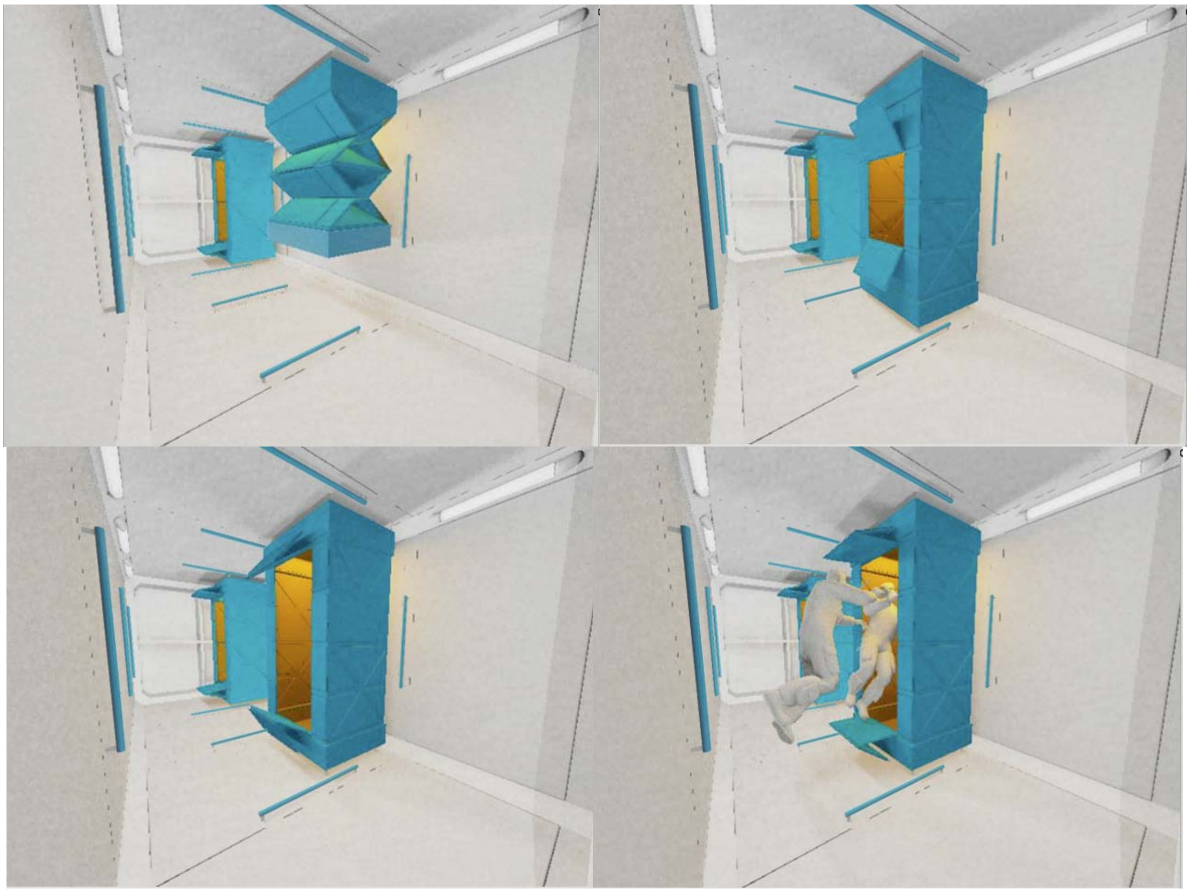


Figure 13: Screenshots from the Deployment Animation of the Comfort Case (part 2), © LSG/animation Stürzenbecher

To support the re-deployment process after the Comfort Case has been unfolded, nylon strings are threaded through the whole structure according to the plan in Fig. 14. This supports the astro/cosmonaut when handling the getaway and they provide straps to fixate “stuff and things” in the cabin space.

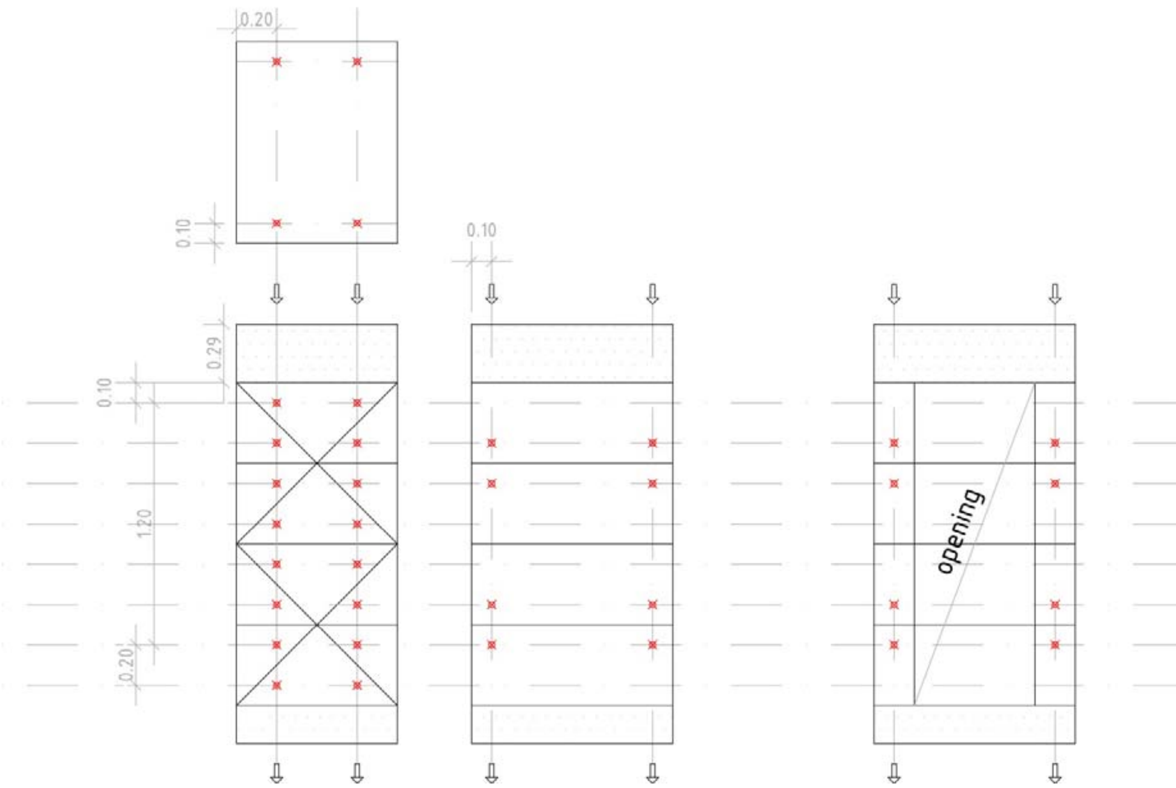


Figure 14: Strings Re-deploying the Comfort Case, drawing © LSG/Imhof

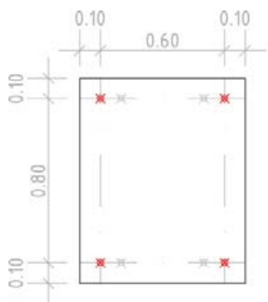


Figure 15: Suspension Points Comfort Case, drawing © LSG/Imhof

In Figure 15 the suspension points (to be applied top and bottom) are depicted (red). Hooks with elastic thin ropes are fixed which connect to the various points within the rack structure onboard ISS.

In Figure 16 one can see the **ventilation mechanism** and the foreseen installment places in the Comfort Case including the **lighting provisions.** Both systems rely on batteries that can be charged when stored in the rack.

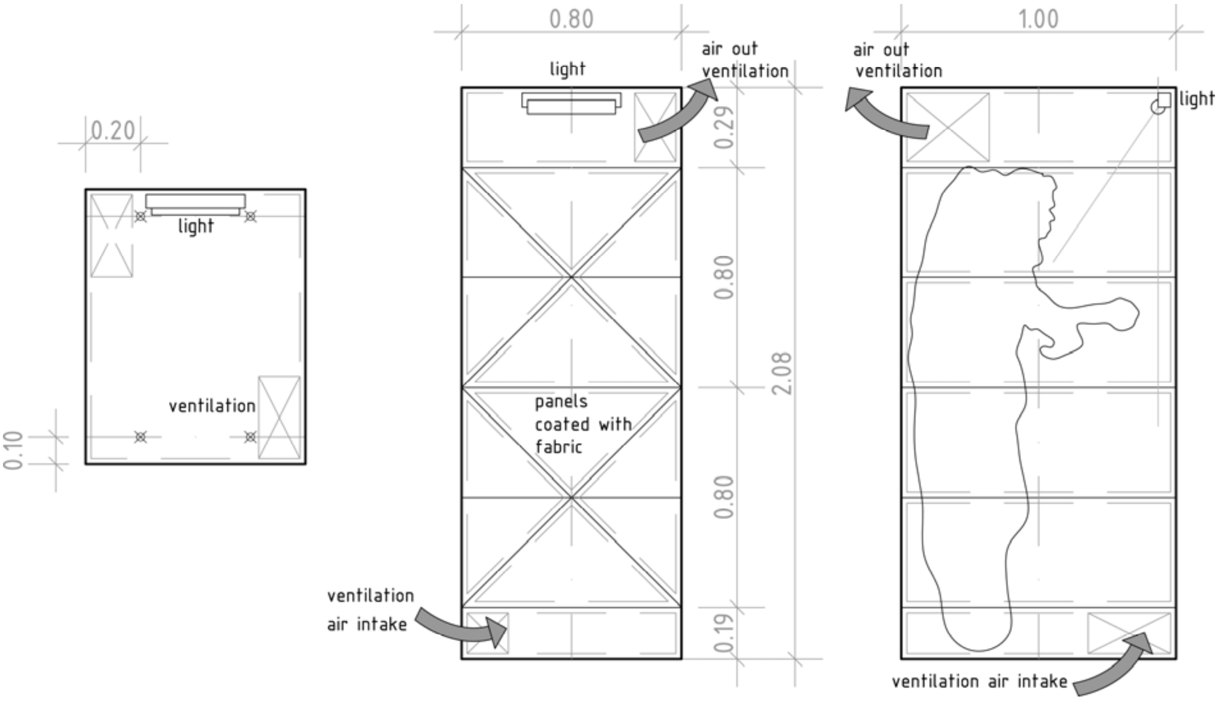


Figure 16: Light and Ventilation, drawing © LSG/Imhof

The colors chosen for the Comfort Case resemble the color palette of ISS to a particular extend: the fabric color of the interior is mainly white (stretch fabric) or off-white and has a check-stitched pattern apart from the few parts of ribbed pattern. All in all it appears very light and emits a comforting atmosphere. Through an individual small lamp the overall interior atmosphere appears even more comfortable because the whole space is submerged into a yellow light.

The exterior has a pattern which is formed through different mostly triangular panels necessary for the folding box principle. The triangles appear in dark gray or blue (see also Fig. 7) alternating with the white smooth Skai material. The pattern stresses the borders of the cabin so the overall outline of the volume becomes easily visible on the space station, which is considered important for easy recognition and orientation. The materials described in the color palette were only used for the functional mock-up (see Fig. 17). A real prototype will have to comply with the standards on ISS.

Figure 17: Color Palette Comfort Case, © LSG

Current investigations with NASA and JAXA specifically on the issues of materials suited for a 'Deployable Getaway' were done. After investigating all types of standard documents e.g. the "Space Station Requirements for Materials and Processes - SSP 30233 Revision E"[5], NASA and the "Safety and Material Requirements for ISS Experiment Flight Equipment (Pressurized Elements) Project Specific Annex" - GPQ-010-PSA-111 Issue 1[6], the summary including personal email exchange is as follows:

Standard materials for ISS include [Via email from Constance Adams, NASA JSC, architect, 28.1.2009]:

- Nomex
- Aluminum
- Velcro (in limited quantities)
- Combi-Therm
- Kapton tape

The materials used e.g. for TeSS are the following [Via email from Broyan, James L. ,JSC-EC3, 3.2.2009]:
"Combination of several materials with quilt stitching: Nomex next to CQ composite walls and Goretex next to crew member on all blankets. Inside of blankets it varies: the interior of the blanket is either Thinsulate or the exterior blanket interior is Bisco and Durrette felt for sound absorption and reflection."

"Basically any materials can be used for hardware in ISS as far as they satisfy the requirements specified in the specification. That is any soft material such as textile, forms ... However for such non-metallic materials, flammability, toxicity, and fungus requirements are applied for from the safety standpoint. Therefore it is necessary to demonstrate that the material in question satisfies the requirement by testing in accordance with the standard test procedure, in case of JAXA it is NASA -STD-6001, or by analysis.NASA has the electronic material database called "MAPTIS"(Materials and Processes Technical Information System) and a lot of material test data are stored in it." [Via email from Dasgupta, Rajib, JSC-ES4, 8.2.2009]

"But even if the material does not satisfy the requirement, it can be used. In this case, one shall submit the application form, generally called "MUA"(Material Usage Agreement) that describes the rationale for usage of the material with some theoretical evidence. For example, paper is flammable and does not satisfy the requirement on flammability but it is controlled not to ignite in ISS. With this procedure paper can be used. (For) most textiles (it) is the same except for some special non flammable ones." [Via email from Yasufumi Matsuo, Japan Manned Space Systems Corp. that is a support contractor for JAXA in the ISS program, 1.2.2009]

The main materials used for the Comfort Case will be Nomex, Velcro and Aluminum or Carbon Fibre insulated with Bisco and Durette as the main structure.

2. Visitor Kit

The details result from sewing and are standard sewing solutions. The material will be Nomex combined with cotton as currently used on ISS. As the configuration is flexible a Velcro tape was used to allow personal adjustments. The US and Russian sleeping bags are made of Nomex fabric material. They also use a removable cotton insert that is easy to clean and replace. But since the cotton is flammable, it is always stowed in metal lockers or racks in ISS except when the crew member is using it during sleep periods.

Nomex is available in various colors e.g. in white, blue, red, grey and mustard so that implies that the color palette the authors chose represents the guideline for the prototype. The main colors of the Visitor Kit are grey, off-white and white Skai (table - same material as the interior of the Comfort Case), blue, red and black (only used with zippers, Velcro or little patches); see Fig. 18.

The Visitor Kit also has a liner which can be exchanged and is used by only one person at a time. Velcro connects it to the outer layers. The head cushion is covered by an additional layer of fabric which can be detached. The colors are off white for the inner liner and dark grey for the cushion. Both shall be made of breathable and light material which wears comfortably on the skin. On ISS cotton is used and stored away daily for fire protection.

Figure 18: Color Palette Visitor Kit, © LSG

Figure 19 shows the overall appearance of the Visitor Kit without the sleeping mask and the acoustic protection.

Figure 19: Visitor Kit 1:1 Functional Prototype, photo © Bruno Stubenrauch

VI. Testing of Functional Mock-ups

The testing of the two mock-ups took place in an approx. 25m^2 room with a height of 3.10 meters. The ceiling was equipped with 4 hooks for the Comfort Case and 4 hooks for suspending the test subject. The test subject wore standard climbing adjustments and an astronaut’s jumper suit. The crew consisted of four and most times five people: one test subject, one photographer, one person for counterbalancing the weight of the suspended person, one person supporting the test subject with zero-g positions and poses, and one person for documentation.

The 1:1 functional mock-ups accelerated the development of the project and the testing in simulation produced knowledge about the issues that need to be enhanced or corrected. Ultimately, the functional mock-up testing assured the team that the design concepts are feasible and worth pursuing. The testing showed that the size, the proportions and the layout work well. However, the handling and aspects of ergonomics as far as this is possible need to be tested in zero-g. The Figures 20-23 show the different positions and handling options during the testing.

The proportions of the interior space in the Comfort Case and the handling were adequate. The width of 100 cm could be reduced to 90 cm which would be beneficial for easing the storing into the rack and the perception of the spaciousness would not suffer. The height of the Comfort Case was perceived comfortable since there is sufficient height above one's head. The ventilation box (not shown in the image) will only need one part of the volume above the astronaut's head. Light was adequate and the yellow shine created a cozy atmosphere.

Restraints/fixation inside and on the outside of the Comfort Case need to be integrated in a next step as well as the slight enhancement of the folding mechanism. How to deploy and re-deploy the Comfort Case could be simulated to a certain extent. How to handle the Comfort Case box in its stored configuration could not be tested. The comfort of the Visitor Kit could only be tested to a certain extent.

For the last issues a zero-g test would be needed. The knowledge of the handling and comfort of the cushions and bedcovers of the Visitor Kit could be improved through such a test.

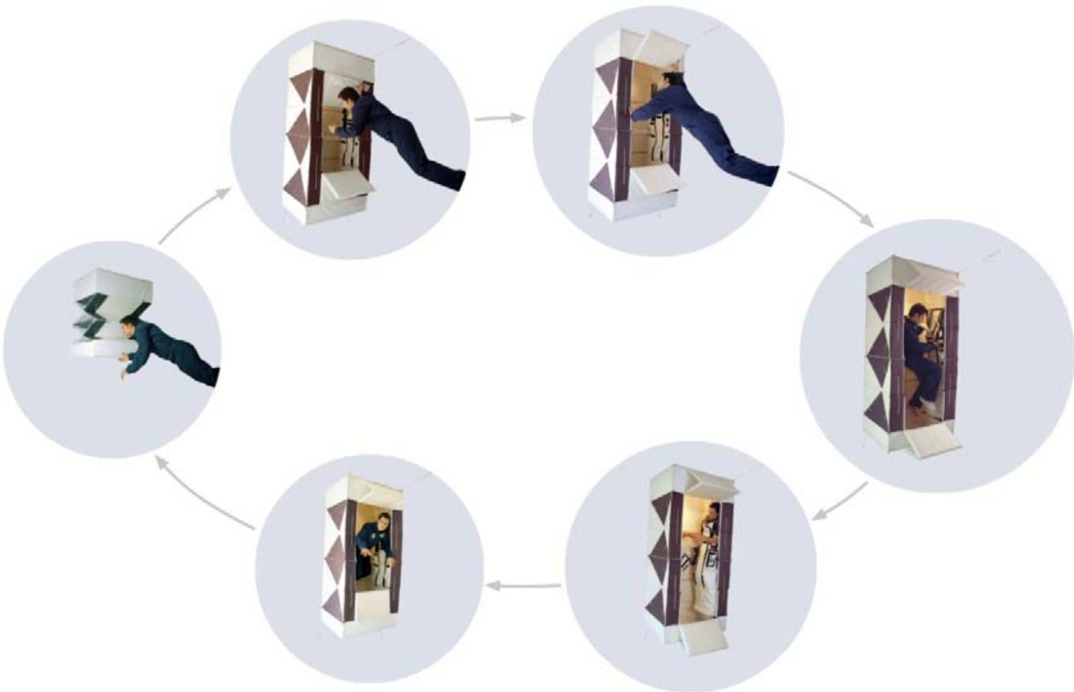


Figure 20: Comfort Case Deployment and Use, photos © Bruno Stubenrauch

Figure 21: Inside the Comfort Case – Left: Astronaut Sleeping in Visitor Kit using Acoustic Protection and "Cheek Cushion", Right: Astronaut Sleeping in Visitor Kit using Acoustic Protection, "Cheek Cushion" and Sleep mMask, photo © Bruno Stubenrauch, reworked: LSG/Hoheneder

Figure 22: Left: Inside the Comfort Case – Astronaut Sleeping in Visitor Kit, Right: Inside the Comfort Case – Astronaut Working in Visitor Kit using the "Table" in "Portrait Format", photo © Bruno Stubenrauch, reworked: LSG/Hoheneder

Figure 23: Inside the Comfort Case – Astronaut Working on a Laptop in Visitor Kit using the "Table" in "Landscape Format", photo © Bruno Stubenrauch, reworked: LSG/Hoheneder

Application of the Visitor Kit and the Comfort Case

The application potentials of the Comfort Case are summarized below:

1. **ISS application**: Visiting crews could use the Comfort Case during their short-term stay on ISS.
2. **Space tourism application:** for a space hotel this could be a deployable tourist-quarter. As a space hotel will not get into operation in the near future, companies could use the Comfort Case as a promotional tool. (See EADS mock-up of a human rated ATV at the aerospace-fair Le Bourget 2009).
3. **Earth application:** the Comfort Case can serve as a demonstrating object in connection with a comparable Earth getaway (with a different design) which the authors develop at the moment for extreme working conditions in busy open-plan offices to promote Space Earth synergies in a tangible way and inspire the public.

The Visitor Kit application can mainly be found in the space sector as described below:

1. **ISS application**: Visiting crews could use the Visitor Kit (also independently) during their travel to ISS and then on the station. It provides them with sufficient private stowage bags.
2. **Space tourism application:** for the first space hotels one can imagine that tourists use this kind of Visitor Kit if it is for a short duration stay. The Visitor Kit can be enhanced for that kind of application adding a large hood around the head for more privacy.
3. **Earth application**: this is very unlikely as there is already a wide range of sleeping bags developed with hi-tech materials for every kind of Earth's extreme environments. However, even if there are a great variety of sleeping bags already, it could serve for specific industry as promotional kit in the realm of design and fashion, e.g. under the slogan "already used in space".

VII. Synergies

B. Houdou describes the two environments of work situation on Earth and in space in a comparative diagram. (Fig. 24) The main issues or stakes seen from her perspective are listed. She says, "The stakes of a getaway in microgravity are multiple and encompass those of a getaway on Earth."

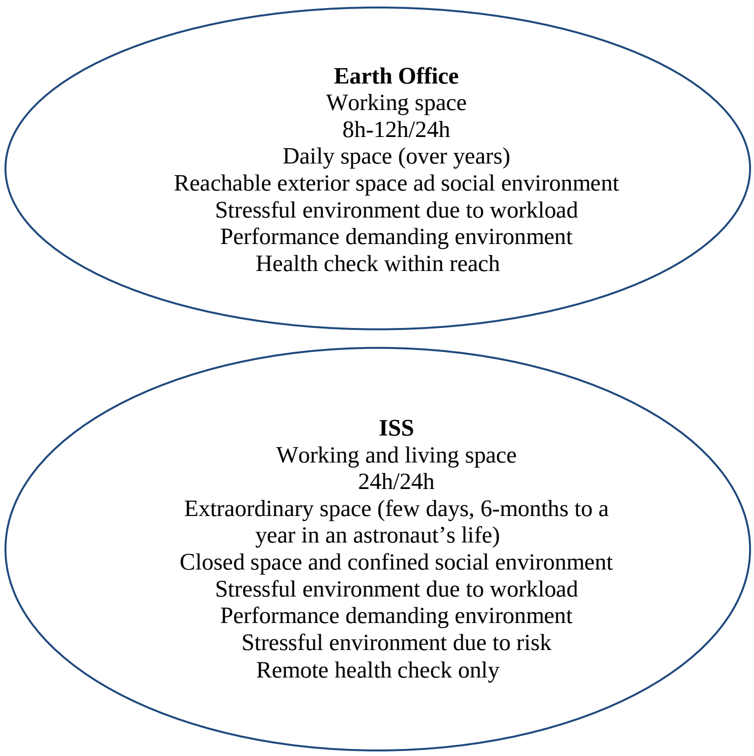


Figure 24:
Comparative Table Earth and Space Environment by Berengere Houdou

There are several aspects allowing for synergy effects: human proportions (e.g. minimum size, sleeping bag, bed, desk height, chair), general behavioral aspects (e.g. negative stress due to excessive workload) and technological aspects such as materials (e.g. composite materials for vehicles in space and on Earth) as well as life-support systems and ecological building technologies or the "technical services" on a space ship and in an office building equipped with modern technology. In these fields, technologies developed for a specific environment and its conditions can be transferred into another environment. The key advantage of synergy effects lies in their implied sustainability. Currently there is renewed and high interest in this aspect – the economical use of resources – just as in environmental protection.

The principal aim when starting this project was to consistently keep in mind both environments, space and Earth, and to find out whether this approach might even inevitably produce synergies.

VIII. Conclusion

So far the project with its two designs has come to a development phase equivalent to TRL 3 or 4. The aim of a follow-up study is to present a refined design according to the feed-back from various experts of the respective fields such as the ESA-EAC Astronaut Office, the Medical Operations division at ESA-EAC, the ESA-ESTEC Research Operations Department, and astronauts to define the strategy for testing and evaluating a refined design in zero-gravity and finally on ISS. In a next step all the necessary operational procedures will be investigated so that a refined design will fit into the ISS specifications as well as into different ISS scenarios.

The possibilities of testing and evaluating a "Deployable Getaway"-design on ISS appear most promising for an enhanced version of the Visitor Kit. The whole package could be fitted into the standard size of an ISS soft stowage package (400 x 400 x 400 mm) and will weigh below 10 kg. With these basic specifications it can be stowed nearly anywhere in a launch vehicle and eases the procedures and operations.

The ultimate goal is to develop a design which is tailored to the needs of astronauts and which allows sufficient possibilities for individual configuration to accommodate the different personal and cultural preferences of human beings.

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