AIAA 2010-6021

My Home is my Spaceship

An Investigation of Extra-Terrestrial Architecture from a Human Perspective

Sandra Häuplik-Meusburger [1]
TU Vienna, HB2, Austria

Today we look back at a series of realized space habitats – as well as the presently orbiting International Space Station. These highly technological habitats have been providing living and working space in a hostile and socially isolated environment for various users over long periods of time and are especially subject to careful planning, building and design. In this context Habitability becomes an important design issue.

This paper presents the results of a recently completed study on the interface between people, space and objects in an extra-terrestrial environment.

Selected case studies were: the Apollo Spacecraft and Lunar Module, the Space Shuttle Orbiter, and the Space Stations; Salyut, Skylab, Mir, as well as the International Space Station. These case studies were evaluated and summarized according to the activities: Sleep, Hygiene, Food and Work in relation to the characteristics of the built environment. Information was gathered from technical reports, published books, reviews, and lessons learned, as well as from personal interviews with astronauts.

The paper (1) introduces the selection criteria and an alternative framework for a design-in-use study, differing from usual analysis in that human activity is assigned a more significant role. The results of the study are further formulated as design directions for each category of human activity. (2) Referring to the statement of an interviewed astronaut: 'Your Home is your Spaceship', this paper showcases the findings, with examples of design directions that deal with the issue of private versus group space.

I. Introduction

Non-appropriate or even faulty design presents a threat to the crew's health and the overall mission. In his book 'Off the Planet' Jerry Linenger records an interesting strategy for overcoming faulty design. In 1997, a fire broke out on the space station Mir, when a backup solid-fuelled oxygen canister was being activated. The fire was finally extinguished. Hardware was damaged, but the crew was not injured. Linenger reports that later they were told the canisters were 'now' safe to use. *"They were deemed safe not because the cause of fire had been determined, but rather because mission control in Moscow now introduced the requirement that whenever we activated one of the canisters, we stand by with a fire extinguisher."* (Linenger, 2000 p. 116)

Times have changed and a lot of research and effort has gone into providing better habitability and safety for the crew. However, rather recently in 2004, a flexible air hose caused a leak at the International Space Station. (Banks, 2004) The hose was located in the Destiny science module, close to an optical window used for Earth-observation. Due to a lack of appropriate handholds, the astronauts repeatedly held onto the air hose to stabilize themselves when looking out of the window. This finally resulted in a leaky hose, through which internal air left the station. It has now been widely acknowledged that 'window gazing' is among the top leisure activities for astronauts and cosmonauts (Connors, et al., 1999), and that they have been spending a lot of time in front of windows looking at the Earth. In the author's opinion, if designed from a more human-oriented perspective rather than a solely engineering one, the window would have been provided with appropriate means to hold on.

[1] Univ.Ass., Hochbau 2, TU Vienna, Haeuplik@hb2.tuwien.ac.at, Senior Member

Although the consideration of habitability and human factors has been integrated in the design process of manned spacecrafts, there is still a requirement to improve habitability. This is also valid for the design of commercial spacecraft.

II. Research Opportunity and Objectives

Extra-terrestrial habitats have been more or less inhabited over the last 30 years of space exploration and offer an interesting field to investigate the relationship between the built environment and its users. Living and working in such habitats means being subjected to very harsh environmental, social, and psychological, conditions. Obviously this results in a very demanding "partnership" between the habitat and the inhabitant. Habitability becomes an important design issue.

Data that is considered to have particular relevance for the design of extra-terrestrial habitats is available from so called Earth analogues, such as experiences of underwater habitats (cf. NASA [Neemo], 2007), habitats in polar areas (cf. Stuster, 1996) (Harrison, 1991), space simulator missions (cf. SSC RF) and other extreme terrestrial environments. This literature primarily provides important information on behavioural, psychological and sociological factors based on experiences in an extreme Earth based environment.

Additionally there is a lot of available data on extra-terrestrial habitats. Online information is available on the NASA technical report server and from other space agencies. Books and reports about lessons learned from past space stations and presently the International space station have been published. This kind of literature primarily provides important information on very specific technical and mission-related issues.
Further information on living and working in an extra-terrestrial environment is available from the personal experiences and anecdotes of astronauts in the form of books or interviews. These kinds of resources provide information from an individual's point of view that is more qualitative than systematic.

The publication of some data has been prevented by national space agencies for security reasons. However, a lot of specific data is available, but is 'spread out'. If for example someone is looking for information related to the design of specific equipment, one has to gather information from many different sources. For this research a lot of time is needed and already some knowledge of where to find what. Furthermore, basic knowledge is required to read the available plans and images in order to recognize shortcomings and potentials. In addition information from different sources may not be comparable.

This paper introduces a research project, wherein the attempt is made to select, summarize and identify architectural issues that have direct implications upon the relationship between the user and the built environment. In order to accomplish this task a new framework for a design-in-use-study has been developed, which will be introduced in this paper.

III. Selection of Case Studies

The case studies were selected according to the following criteria:

(1) Selected buildings had to be extra-terrestrial, implicating that it is the most hostile environment in terms of physical, social and psychological means.
(2) Selected buildings had to be realized, in order to allow post-evaluation with personal feed-back from the users – the astronauts.
Further habitats were selected that hosted a (3) minimum crew of two with (4) mission lengths exceeding 30 days, to provide minimal interaction between crewmembers over a certain time within the built environment.

Selected case studies were: the Apollo Spacecraft and Lunar Module, the Space Shuttle Orbiter, and the Space Stations; Salyut, Skylab, Mir, as well as the International Space Station. The Apollo Spacecraft & Lunar Module did not fulfil the selection criteria (12 days), but were chosen, because of their importance for current lunar mission architecture studies and because they were the only realized manned mission series to the lunar surface. The Space Shuttle Orbiter (7-16 days) did not fulfil the selection criteria but was chosen, because it is still in use.

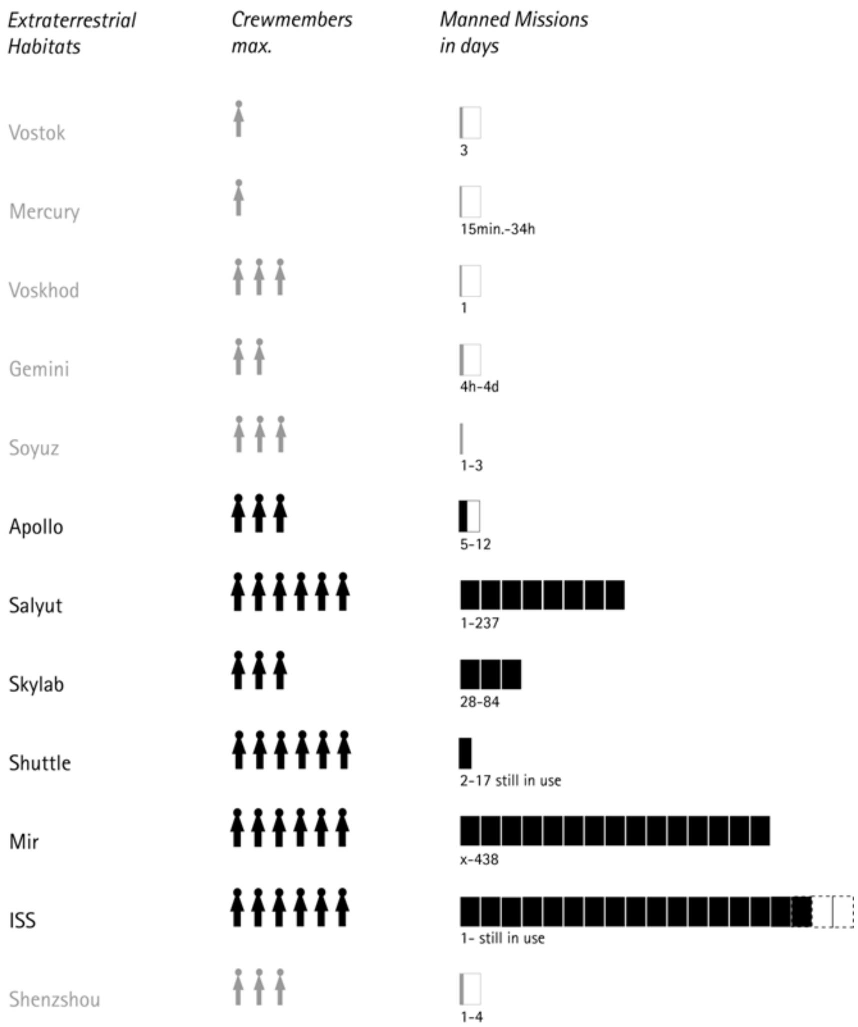

Figure 1. Selected Case studies. *The Apollo Spacecraft and Lunar Module, Salyut Space Station, Skylab Space Station, Space Shuttle Orbiter, Mir Space Station, and the International Space Station*

IV. Methodology of Research

The principal function of a habitat is to provide an optimum living and working environment for humans. Basic human requirements don't change in different environments. A human must sleep, go to the toilet, eat and be active in some way. (cf. Maslow's hierarchy of needs). Therefore a comparative analysis focusing on human activities within a built environment was chosen as the method for this research. Fig. 2 shows the diagram of the workflow. The research and compilation of data according to human activities represents a new approach.

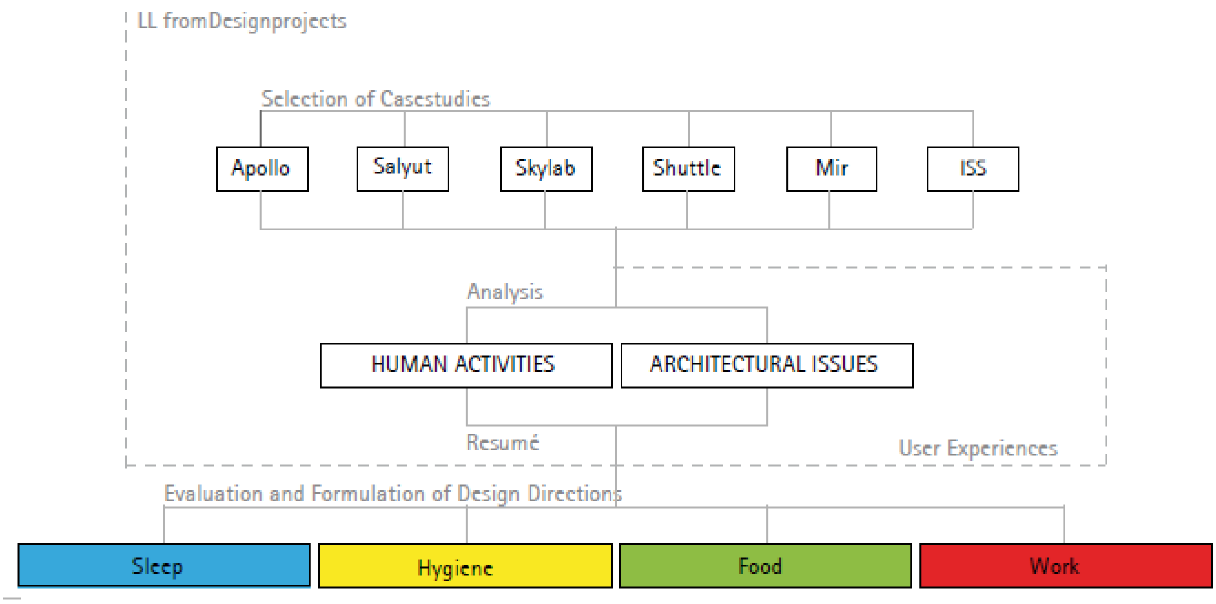

Figure 2. Workflow Diagram. *The framework was especially developed for this study and applied to the selected case studies.*

The diverse human activities were grouped with the main human activities: SLEEP, HYGIENE, FOOD and WORK. Sub-categories have been added where needed and could further be expanded when new facts or research directions emerge. To facilitate orientation and to ease comparison with architectural drawings and diagrams each category was assigned a specific colour.

The human activity category 'SLEEP' (blue) includes the sub-activities rest; relaxation and sleep; as well as associated translation and stowage.

The category 'HYGIENE' (yellow) was further divided into the sub-categories '*Personal Hygiene*', '*Shower*', '*Toilet*' *and* '*Housekeeping*'.
The sub-category '*Personal Hygiene*' includes the sub-activities: full and part body cleansing, clean and change clothes. The sub-category '*Shower*' was a special activity on Salyut, Mir and Skylab. The sub-category 'Toilet' includes the sub-activities: collect, store and process waste; as well as associated translation and stowage.

The category 'FOOD' (green) includes the sub-activities: to prepare, grow and consume food and drinks; to collect, store and process waste; as well as associated translation and stowage.

The category WORK (red) relates to the English meaning of "being active". It was divided into the sub-categories 'Operation' and 'Work'.

The sub-category ‘*Operation*’ includes the sub-activities: work tasks; conducting experiments and communication; education & training; as well as associated translation and stowage. The sub-category ‘*Leisure & Exercise*’ includes the sub-activities: leisure, exercise, intimate behaviour; as well as associated translation and stowage. For future research more sub-categories could be added to allow more in-depth research into specific issues.

The framework developed here for a design-in-use study differs from usual analysis in architecture in that human activities are assigned a more significant role. The human is in the foreground, because first, it is extremely complex and expensive to take a human being off the planet, and second, being there they have to use the short time optimally in order to fulfil the assigned tasks 100%. Therefore this ‘up-valuation’ is not a question of comfort, but rather one of high mission priority.

V. Part 1 – General Characteristics of Selected Habitats

For each case study (Apollo, Salyut, Skylab, Mir, Shuttle and ISS) information on: mission-related objectives, the general configuration and layout of the extra-terrestrial habitat, as well as the time and spatial allocation of human activities, was collected. Information was gathered from technical reports released from space agencies, published books, reviews and lessons learned as well as from personal interviews with astronauts.

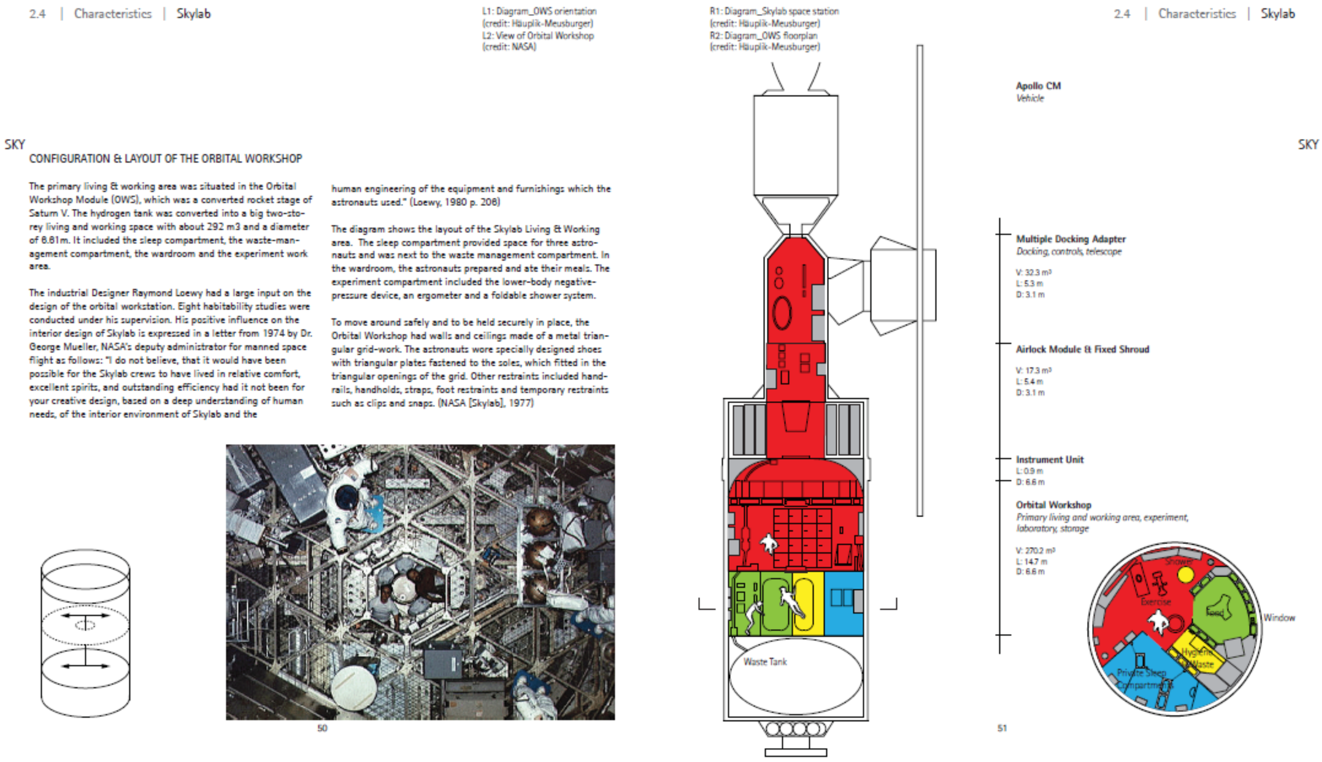

Figure 3. Habitat Characteristics. *Example, how the main topics related to the configuration and interior layout of the OWS in Skylab were summarized.*

In order to make information from different sources comparable, data collected from Russian and American extra-terrestrial habitats was compared using drawings and diagrams. Fig. 3 shows an example layout (Skylab) used for concentrating the basic data.

Comparisons of all selected case-studies were made according to the following parameters: architectural configuration, spacecraft and crew autonomy, life-cycle and maintenance, habitable volume, mission lengths, crew size, spatial orientation and allocation of human activities.

Fig. 4 shows an example of such a comparison: The summary and comparison of human activity areas and their internal and external relations for the Apollo and Skylab mission. The Skylab diagram shows for example, that the human activity areas *Work*, *Food* and *Sleep* in the OWS of the Skylab station were spatially separated, that the activity *Shower* temporarily overlaps with the activity *Work*, that the activity areas *Food* and *Work* are spatially separated, but visually connected and that the activity area Food is visually connected to the outside. In the Apollo Command Module and Lunar Lander all functions were in the same module.

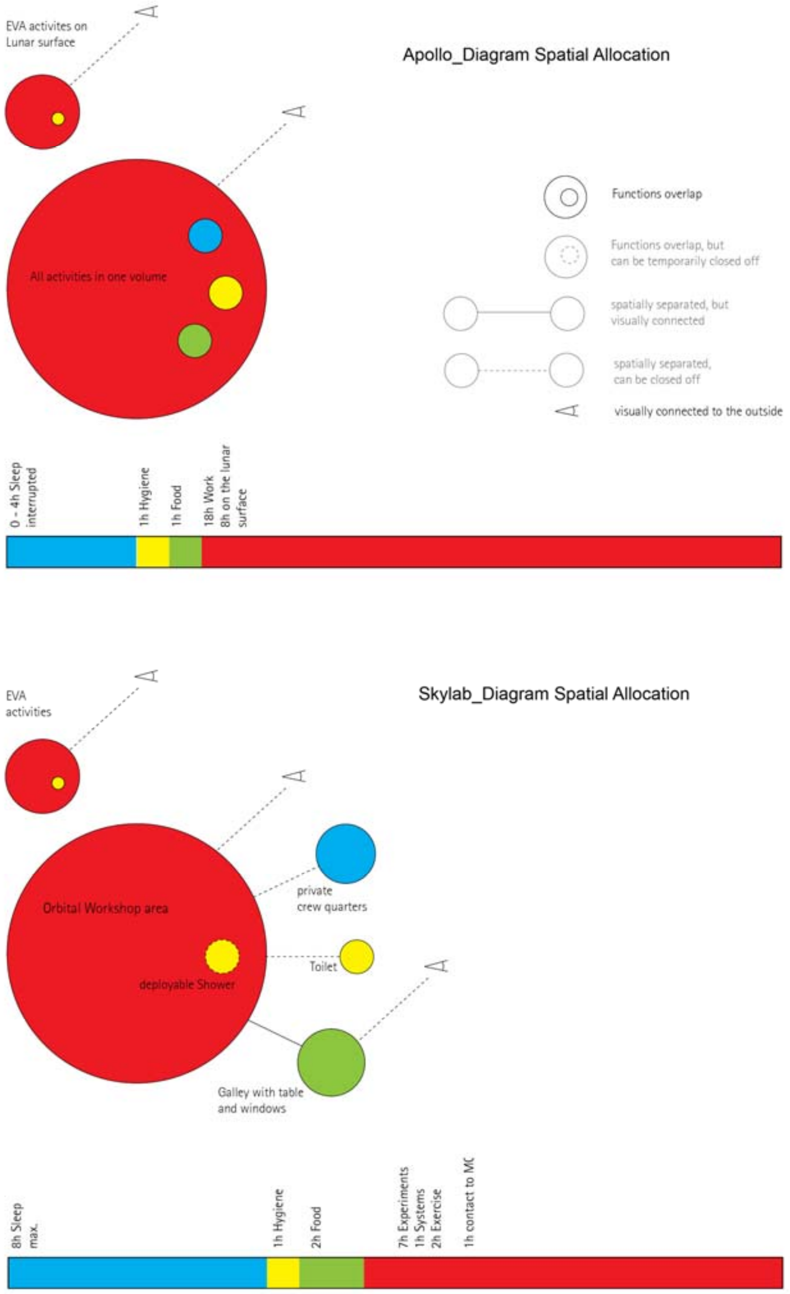

Figure 4. Comparison: Allocation of Human Activities: Apollo and Skylab

VI. Part 2 – Design-in-use Study according to Human Activities

Following the introduction of the selected case-studies, the work has been structured according to the main human activities: *Sleep*, *Hygiene*, *Food* and *Work*. Within each category, related information from each case study was compiled. In addition to the data available from technical reports, books and research documents, personal interviews with the real users were included in the study. Structured interviews with astronauts were conducted with a special focus on human activity, from which new facts emerged. The findings from relevant literature and analysis based on drawings and images were compared with the personal experiences of users.

Fig. 5 shows an example layout of the compilation *Sleep* for the Space Shuttle. The main facts are shortly summarized and enriched by statements from astronauts that provide a different point of view on the topic. Concise diagrams and images illustrate the content.

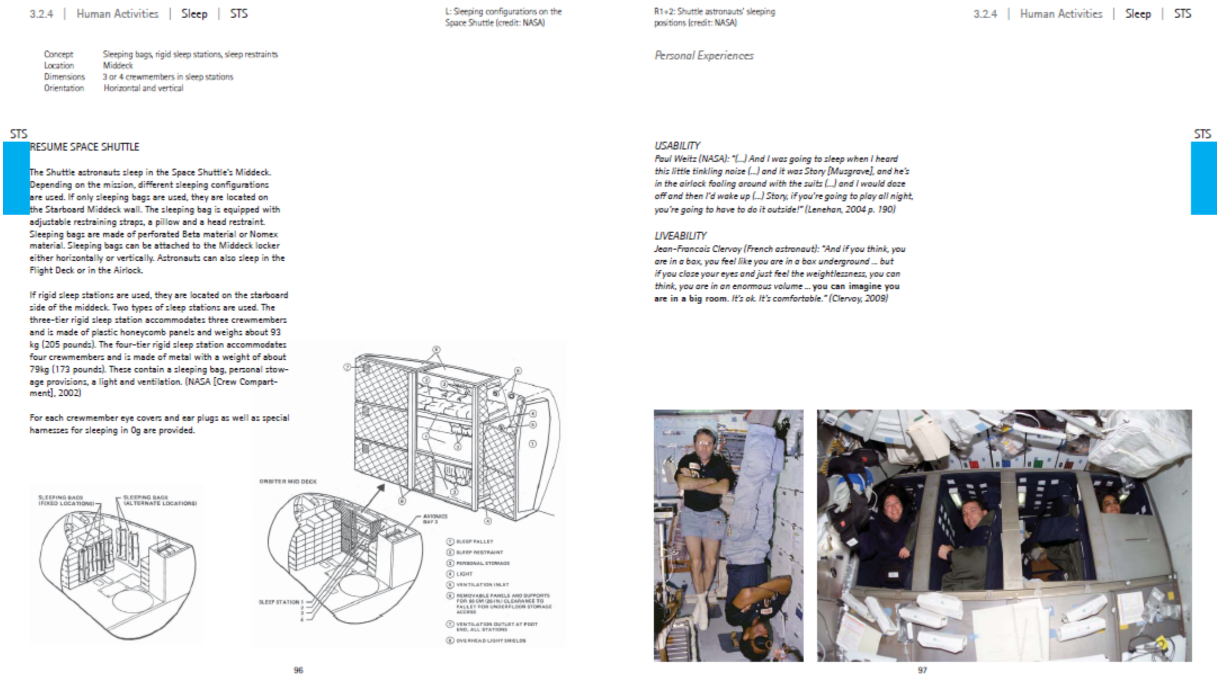

Figure 5. Human Activities: Sleep in the Space Shuttle. *A resumé of data and personal experiences from astronauts for each human activity and case study was conducted.*

Sleep concepts applied within the selected habitats range from sleeping bags, to hammocks and boxes to private crew quarters. Fig 6 shows an example for the summary of the activity category *Sleep*. Such a comparison, in the form of text and diagrams was made for each human activity category.

SLEEP	***Apollo***	***Salyut***	***Skylab***	***STS***	***MIR***	***ISS***
Concept	Sleeping bag Hammocks	Sleeping bags, Sleeping bags attached to the wall	Permanent private crew quarters with sleeping bags in vertical position, private storage and communication	Sleeping bags, private sleeping boxes	Permanent private crew quarter (kajutes) with sleeping bag, desk, intercom and a porthole	Two permanent private crew quarters with sleeping bags; four soft flexible temporary crew quarters
Review	"What a waste of time" (Cernan, Apollo 17)	Blinds to close off areas were installed, but total separation of crewmembers was rejected due to the possibility of emergencies	Crew quarters were basically satisfactory; Astronauts requested flexibility on the restraint system and in blanket arrangements	Different sleeping configurations are used, depending on the mission schedule (boxes, sleeping bags)	Some cosmonauts preferred to sleep in the attached modules, such as Kristall in order to have more privacy and better radiation protection	Some astronauts chose an individual location, such as the Node to place their sleeping bag and private storage
Potentials	Hammocks may be an option for additional sleeping possibilities in off-nominal situations or for short term missions (eg. Rover missions).	Cosmonauts wanted to be close on short missions. Could also be a topic during future exploration missions	Individual thermal control and flexibility in blanket arrangement will be integrated	Adaptability in sleep configuration depending upon 'scenarios' seems useful	Windows are important, but not necessarily in the crew quarters. A dedicated private space is mandatory for long term mission.	Sleeping provisions could be flexible in location; virtual windows can replace real windows in certain cases.

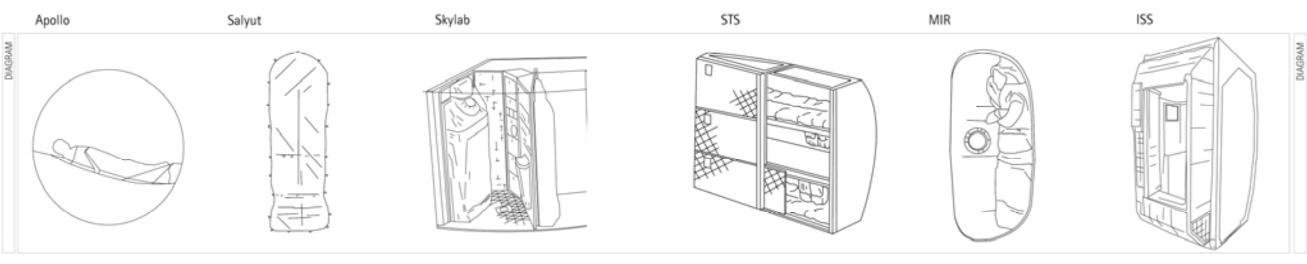

Figure 6. Summary Sleep. *Different concepts from the selected case studies.*

In order to make a comparison the same themes for every human activity were applied. The selection has been derived from relevant evaluation themes on architecture (cf. Van der Voordt, et al., 2002) and themes raised by astronauts. Technical and mission-related aspects were only taken into account as far as they have directly influenced the relationship between the user and the built environment. The following themes were used for the comparison and evaluation.

Selected architectural themes:	
Usability Aspects	- Availability & Equipment (used potential of the social and physical environment) - Spatial arrangement (spatial orientation, relations between rooms & zoning) - Object management (storage concept and management) - Ergonomic safety
Liveability Aspects	- Territoriality (individual versus social areas) - Sensory perception (light, sound, temperature, humidity) - External relations (Windows and relations to the outside) - Internal relations (spatial relations to other activities)
Flexibility Aspects	- Spatial flexibility (variations in size and locations) - Object flexibility (variations in usage) - Individual flexibility (ergonomic and user orientated variations)

As an example Fig. 7 illustrates the comparison of selected Usability aspects. In this work, the term usability covers the topics that are connected to the availability of space and associated equipment, their spatial arrangement, and object management in order to assure a user-friendly and trouble-free use over longer periods.

SLEEP Usability	*Apollo*	*Salyut*	*Skylab*	*STS*	*MIR*	*ISS*
Availability & Equipment	Command Module: sleeping bags and couches for three crewmembers Lunar Module: hammocks with blankets for two crewmembers; slept in space suit on first missions	Sleeping bags for all cosmonauts; on Salyut 3 one standing and one foldaway bunk; Sleeping bags with air vents and napped fasters	Private crew quarters for each astronaut; included sleep restraints, private storage lockers, privacy curtains and communication system	Different configurations depending on the mission: three-tier or four-tier rigid sleep stations or just sleeping bags Additional Equipment: eye covers, ear plugs, 0g-harness, etc.	Two private crew quarters for two crewmembers, sleeping bags for the others; Cabins were equipped with a port hole, sleeping bag, desk and mirror	Two permanent sleeping compartments and four temporary crew quarters for permanent crew; visiting crews use sleeping bags
Spatial Arrangement	Command Module: crewmembers slept next to each other Lunar Module: hammocks across the module	In the large-diameter Work Compartment on the ceiling; next to the food supplies, some slept in the Orbital	Private sleep compartment in the Orbital Workshop	Astronauts sleep in the Middeck. sleeping bags are on the starboard wall; Rigid sleep stations are on	Located in the large-diameter Compartment in the Mir Base Block; some slept in Kristall and Kvant 2	Two sleep compartments in the Zvezda module, one sleep compartment in the U.S.Lab, two in the

		module		the starboard side		Harmony Node, one in JEM; sleep restraints
Object Management	No personal stowage	No personal stowage	Personal stowage in crew compartment; triangular grid for fasten equipment	Personal storage lockers, personal storage in sleep stations	Dedicated place for personal stowage in crew cabin (only for two)	Personal stowage in sleep compartment
Ergonomic Safety	Individual fit of astronaut couches sleeping bag = sleeping restraint	Special netting around sleeping area; to avoid breathing in small parts straps to restrain bed to the alotted sleeping area	Materials used were non-flammable and especially developed for Skylab, grid system for moving around; individual and modular sleep restraints	Durable, non-flammable and non-offgassing materials, no sharp corners, ventilation system in sleep stations, restraints; a variety of sleeping restraints	Less radiation protection in crew quarters (window)	Durable, non-flammable and non-offgassing materials, additional radiation protection and warning systems in the new crew quarters, a variety of sleeping restraints

Figure 7. Human Activity – Sleep – Comparison: Usability. *A resumé of data and personal experiences from astronauts for each human activity and case study was compiled.*

I. Part 3 – Formulation of Design Guidelines

Finally, the attempt was made to briefly summarize the most important findings. Architectural issues that were found to have direct implications for the relationship between the user and the built environment were identified and formulated as design directions. The directions are expressed generally by numbered headlines to summarize the main points in a short sentence. In total 31 design directions have been formulated.

The following guidelines were derived from the study:

SLEEP 1. Design for undisturbed, safe & quiet sleep 2. Sleep areas to provide privacy 3. Integrate private storage 4. Sleep areas to be used during the day 5. Integrate external & internal relations 6.Take advantage of specific environmental conditions 7.Allow flexibility to changing mission & crew objectives 8. Allow adjustment to individual preferences 9. Consider intimate behaviour	FOOD 16. Design for varied tasty and nutritional food 17. Foresee a dedicated area for food preparation 18. Encourage “cooking” activities 19. Design for social activities 20. Use the Greenhouse to increase Habitability 21. Consider plants as green friends
HYGIENE 10. Design for user-friendly & comfortable use 11. Design for maximum level of privacy 12. Take varying user standards into account 13. Allow individuality in clothing & items 14. Design for easy housekeeping 15. Use resources efficiently	WORK 22. Design for efficient work 23. Design for easily manageable storage 24. Integrate standardized interfaces 25. Take advantage of specific environmental conditions 26. Integrate autonomy of the users 27. Integrate on-going training 28. Allow flexibility of the work area 29. Integrate playful leisure activities as counterpart to work activities 30. Allow unique and experimental activities 31. Integrate windows

In the following example design directions will be explained. The title of this paper refers to the following statement of an astronaut: “Your home is your spaceship”. (Astronaut, 2009) His answer to the question: *What is it that you can say – This is my home?* was: *This is MY bed, this is MY KITCHEN, this is MY cupboard, with MY stuff in it. Don’t mess with it. (Astronaut, 2009)*

A short summary of the empirical background for example design directions, that deal with the issues of private versus group space, from each of the four main human activities are presented.

A. Example Guidelines SLEEP

Design Direction # 2. Consider sleep areas to provide privacy

Most of the literature and experience from the interviews indicates that astronaut's requirements of privacy level up with mission lengths. Likewise research from analogue environments show that under prolonged isolation and confinement the need for private space increases. (Stuster, 1996) (Kanas N., 2003) (Connors, et al., 1999)
During the Apollo missions astronauts slept next to each other in one volume and had no privacy, but since "most pilots are not used to privacy (...) it was not a problem." (Astronaut, 2009) The use of 'hammocks' or temporary sleeping provisions within a module are not sufficient for long-term missions, but may still be an option for short term missions or when additional sleeping provisions are temporarily needed.

The Salyut cosmonauts slept on the "ceiling" of the large-diameter work compartment. Although the Salyut cosmonaut Lebedev was against the provision of separate cabins for astronauts in 1982 for safety reasons (Lebedev, 1990), the installation of private crew quarters has been favoured since. The requirement of separating sleep and work or at least having the possibility of separating them from the group domain using moveable divisions was integrated early on. Skylab was the first space station that provided private crew quarters. On Mir, individual cabins were provided for two cosmonauts, but they were located in the core module which was very loud. Today private crew quarters are provided for the permanent crew of six at the ISS.

Most of the interviewed astronauts reported that they had little requirement for privacy during their short-term missions: "You don't need a bedroom. I don't need a bedroom" (Astronaut, 2009). But there are many anecdotal references, especially from long-term astronauts, that privacy - as well as social life - is important to crewmembers.
According to Connors, "Visual access and visual exposure are the two key aspects of privacy regulation." (Connors, et al., 1999) A space that on the one hand accommodates all crew members and on the other hand offers disclosure to provide individual private areas is important for the functioning of a group. "To have your place for personal activities, thinking, concentration (…)" (Astronaut, 2009) is something that needs to be integrated into the design.

The provision of a space where astronauts can retreat from the others is of importance for long-term missions. Due to spatial restraints, large dedicated areas for privacy will probably not be feasible in the future. The installation of personal crew quarters offers an easy possibility for providing astronauts with a private and individual place, although an astronaut reported that a crew quarter provides the absolute minimum of privacy, "more would be better" (Astronaut, 2009). For long-term missions more complex spatial solutions will have to be developed and the potentially arising wish to be closer on more hazardous missions (cf. Lebedev) may be solved with technology.

Design Direction #3. Integrate Private Storage

Another requirement leading to the provision of private crew quarters was the provision of storage for personal items and clothes, already requested by the Apollo astronauts and repeatedly an issue on the Salyut and Mir space stations. Anecdotal references show that astronauts put their private belongings next to the places where they slept (Astronaut, 2009). A dedicated private area seemed not to have had priority for some astronauts; more important was to have a place where they could put their camera or paperwork. The need for an area to place and secure hardware and items where "nobody disturbs anything" (Astronaut, 2009) seems to be one of the reasons why astronauts stored personal items next to their sleeping areas.

The integration of a possibility for storing clothes, laptops and other private items in an exclusively private area therefore seems very relevant. In addition to an exclusive private space, mobile facilities for each crewmember may allow easy handling and transfer from one place to another.

Design Direction # 7. Allow Flexibility to changing Mission & Crew Objectives

The Space Shuttle is the only spacecraft where sleeping provisions can be configured on Earth depending on its mission. When the crew has to work shifts, three- or four-tier sleeping boxes are provided; otherwise the astronauts use sleeping bags.

Once a space habitat is in orbit, it is difficult to make major reconfigurations. But considering future long-term missions, an option for reconfiguring the habitat should be implemented. An interviewed Astronaut pondered about future spacecraft design "ok, today I will completely change the layout of my bedroom, because I am fed up with seeing that the bed is always there... if sometimes you decide, ok, my sleeping station for the next month will be there. Would be nice. Yes that is nice." (Astronaut, 2009)

Flexible sleeping stations could be used to personalize the mission crews "home" and thus reflect the community's identity and preferences. Flexible partitions can further enhance usability, to for example, temporarily close off work and sleep areas.

Design Direction # 8. Allow Flexibility to Individual Preferences

It is noteworthy that throughout the history of spaceflight, astronauts have chosen their individual sleeping position in the habitat, some developing their "own style" of sleeping positions. Skylab was the first space station that provided individual private crew quarters, which were generally appreciated by the astronauts, but obviously not by all. In an interview, Skylab astronaut Paul Weitz, mentioned that he had difficulties sleeping "hanging from the wall". Thus, every night he would unbuckle his sleeping restraint from the metal frame and take it up to the big open area in the Orbital Workshop stretched it across the modules and slept horizontally. (Weitz, 2000)

The space station Mir provided private crew quarters for two cosmonauts, having the third one sleep somewhere else in the space station. American Mir astronaut Jerry Linenger slept upside down on the wall in the module Spektr, to be next to an installed fan on the opposite floor. To avoid free floating, he was using a bungee cord or a piece of Velcro. (Linenger, 2000 pp. 90, 182)

On Mir, some astronauts slept in the module Priroda because it had "one of the nicest windows", some slept in the module Kristall, because it was one of the more radiation protected modules and some astronauts had their sleeping bag loosely fixed to ropes running through the station, which were used as movement aid. (Astronaut, 2009)

Sleeping areas have always been personalized by astronauts. The new crew quarters on the ISS have integrated interfaces for that. Already on the Salyut stations, cosmonauts put up pictures and personal items around the area where they slept (Bluth, et al., 1987 p. I_77). In addition individually adjustable airflow controls as well as individual lighting add to habitability. (Portree, 1995 p. 319)

Different users have different preferences. "Sleeping is individual, just like here on Earth", said one astronaut about sleeping, "and you would almost have to talk to everybody to get the full spectrum." (Astronaut, 2009)

B. Example Guideline HYGIENE

Design Direction #11. Design for Maximum Level of Privacy

Early astronaut's suggestions were that toilets and hygiene facilities be divided from other functional spaces, such as the sleep compartments "to minimize noise disturbance to sleeping crewmembers." (NASA [Skylab LL], 1974 p. SLL2_6) On Skylab missions the power module of the faecal and urine collector disturbed sleeping crewmembers, thus astronauts suggested to locate it as far away from the sleeping area as possible. (NASA [TM], 1974 p. 117)

According to Linenger's experiences with the toilet on the Space Shuttle, "noise that one might generate" while on the toilet could be heard outside and thus be embarrassing for the one inside. (Linenger, 2000 p. 59)

Thus the best solution would be to locate the waste management area far away from the place where astronauts sleep or work. However in a very small volume, this might not be possible. In this case, in addition to functional placement, the waste management compartment needs a special sound-proof enclosure.

In addition to noise, smell is an issue to be dealt with. “We care about smell, but we care in advance, so we don’t have strong smells in space” (Astronaut, 2009). Good smells to be remembered include the soft smells from personal hygiene products.

Limitations on hygiene facilities and waste management problems have been high on the list of discomforts reported by individuals in confinement experiments. Already the Apollo astronauts requested individual hygiene kits, instead of having only one. (NASA [Debriefing A11], 1969 p.149)

The transparent shower in the OWS of Skylab used by the only-man-crew was considered a pleasant experience, but the activity was too long and too time-consuming (NASA [TM], 1974 p.430).

Presently no shower is in use on the ISS. A full body cleansing facility that works and is pleasant has still not been developed. The attempt to transport the shower concept from Earth to space has failed.

According to Connors, problems associated with hygiene and waste management are well known and will receive continued attention. (Connors, et al., 1999)
The presently used concept of “sponge-baths” seems to be adequate, but the integration of private full-body cleansing, needs to be considered regarding future space exploration missions. Cosmonaut Lebedev wrote about Savitskaya in his diary: “Sveta spent a long time making herself beautiful in the transport vehicle.” (Lebedev, 1990 p. 194)

C. Example Guidelines FOOD

Design Direction # 19. Design for Social Activities

People carry their habits and customs with them. Designs of extra-terrestrial habitats are often derived from habitual social rules. One example is having dinner together. Astronauts generally dislike talking to an adjacent colleague who is upside-down while having dinner together. On Skylab missions, crews refused to ‘float’ over the table, as it was seen as inappropriate behaviour. Social roles are taken to space, at least for now.

Having dinner together is a social activity shared by many cultures. On Skylab, astronauts had, for the first time, a large dedicated area for food preparation and dining. They were eating together on a specially designed table, eating with knives forks and spoons. From then on, a table for having meals together has been considered of importance by the crew and became a requirement.

Still, having dinner together is an important social activity in space. “At dinner at night, we have a time, even if you are busy; you set this time to make jokes and to have fun (...) (Astronaut, 2009)

Design Direction # 18. Encourage “Cooking Activities”

According to Shayler, Salyut cosmonauts were “cooking” on-board, leading to a “renewed pleasure” (Shayler, et al., 2005 p. 309). Today a variety of food is available for astronauts, but still available food can get boring if you are on a long-term mission. To increase the variety of tastes astronauts are inventive in creating new meals by mixing food ingredients – they are doing space “cooking.” Sandra Magnus, astronaut on Expedition 18 has two logs in her online-journal about cooking in space. (Magnus, 2009) Her favourite food item is the tortilla, because it allows a lot of variation.

“So it is possible to cook in space with a few hours, lots of dry and wet wipes and the basic tools of duct tape, plastic bags, foil pouches, and a small knife. It is fun and certainly an adventure!” (Magnus, 2009)

In the future especially designed facilities may improve the astronaut’s habitability by supporting them in food experimentation.

D. Example Guidelines WORK

Design Direction # 26. Integrate Autonomy of the Users

Apollo astronauts and Salyut and Mir cosmonauts had to follow a strict schedule. Life on-board was constantly monitored by mission control. However, anecdotal evidence shows that throughout human space exploration history, crewmembers have pushed for more autonomy.

Compared to today, early astronauts and cosmonauts are often reported to have had a military like behaviour, thus following strictly the schedule depicted. But there are some anecdotal references that relate to the fact that these humans did not always follow the “line”.

Lebedev wrote in his diary about an incident where he asked FCC to postpone their exercises for ten (!) minutes in order to finish a geological air survey. They had arguments and although he finally got the permission to continue the experiment, he felt very upset long after. “All in all today I felt rather sad, because so many things had built up inside me, and I remembered so many things”, he wrote in his diary. (Lebedev, 1990 p. 166)

According to Jones, the third crew of Skylab astronauts turned off the radio, as a protest to heavy workload. They refused to talk with Houston Mission Control and declared that day for an unscheduled day off. (Jones, et al., 2002 p. 238) However Skylab astronaut Gerald Carr tells the story differently. He said that on their day off they forgot to configure the radio in the correct way, and mission control couldn’t get through to them. (Carr, 2000)

Also the Salyut cosmonauts had their way to fight against the authority from the ground. They did not tell ground control everything (cf. Linenger, 2000), which is also illustrated in Valentin Lebedev’s diary. The Salyut cosmonauts had to do plant experiments with the Oazis Greenhouse. One day they were sent some onion bulbs for a biological experiment. Instead of planting them, they ate the onions with some bread “right away”. “They were delicious”, Lebedev wrote in his diary, telling ground control that they were growing well. The story blew when Lebedev exaggerated telling the biologists that the onions even had shoots. Onions had never bloomed before in space, so they finally had to tell the excited biologist the truth. (Lebedev, 1990 p. 133)

One reason for the cosmonaut’s autonomy despite the scheduled work might be that Salyut and Mir cosmonauts had no constant communication with ground control at the time. They could only communicate via line-of-sight circuits from Earth to Soviet mission control. E.g. during the fire on Mir in 1997, the crew was out of communication range with mission control in Moscow for about half an hour. Only the ham radio would have worked, but that meant “broadcasting to the blind” (Portree, 1995 p. 106). The cosmonauts had to decide themselves how to deal with the situation. They decided not to leave the station as it may have been foreseen in the proceedings and fought the fire successfully.

Today at the ISS, astronauts have the freedom to call any telephone on Earth at any time. But a constant communication line also means constant supervision from ground control, “the speed of the ventilators tells mission control if somebody is in a module or not.” (Astronaut, 2009) This is because sensor and monitoring data from the ISS and the astronauts is sent to ground station via telemetry.

Experiments are scheduled to be technologically and scientifically supported by ground personnel. Astronauts have to exercise 2h per day. As there is only limited exercise equipment on-board, these times are also scheduled.

“Well we have a scheduling program on board that has in it all of the details that we need to know in order to do the day’s work. It tells us when we should go to sleep, when we should get up, when we should exercise, when to eat our meals, when and what information we need to do our tasks.” (Magnus, 2009)

The integration of some autonomy in decision-making and of having some ‘blanks’ in the work schedules will play an even more important role when heading towards exploration.

“The missions were planned, but there was a lot of open time. We were doing a lot of different things that were not planned for (...) Because, we didn’t know what to plan for. We had a lot of time for spontaneous observations and discovery. That’s what exploration is all about. You have to be careful not to program too much.” (Astronaut, 2009)

Design Direction # 28. Allow Flexibility of the Work Area

"We had decorated the station with balloons and hung up Lenin's portrait. [On the 65th anniversary of the October revolution]" (Lebedev, 1990 p. 259)

Cosmonauts and astronauts have always adopted their environment, just like they do at home, but with a minimum of available possibilities. Astronauts and cosmonauts still use private images and gifts to "decorate" their (temporary) home – the International Space Station. It also shows the changes over the years depending on the crew on-duty. Adaptations may also be required due to stowage operations: "In reality, storage [requirements] change over time (...) and that is a critical issue." (Astronaut, 2009)

In addition to marking the crew's territory, larger adjustments might have to be made in future missions. The number of people to accommodate may change, or new and more advanced equipment may have to be replaced, etc.

Already the Salyut cosmonauts made experiences with the adjustment of their working environment, but had a rather brute approach. "When a crew arrives, the cosmonauts may rearrange things to make themselves feel at home. This kind of work usually requires moving a lot of material and equipment. Sometimes this requires sawing of metal, which not only litters the station but also takes lots of time and effort." (Lebedev, 1990 p. 137)

Also today at the ISS, flexibility of work areas is required. The long-term use of a station as well as the changing users may benefit from a design that allows adjustment to not yet known objectives.

II. Conclusion

The presented work is based on an investigation of extra-terrestrial architecture that was inhabited by more than two people over more than one month from the perspective of various human activities.

In order to accomplish this task, a new framework for a design-in-use study was developed, which differs from usual analysis in architecture in that human activity is assigned a more significant role. The human is in the foreground, because first, it is extremely complex and expensive to take a human being off the planed, and second, being there they have to use the short time optimally in order to fulfil the assigned tasks 100%. Therefore this 'up-valuation' is not a question of comfort, but rather one of high mission priority.

All major realized Russian and American space habitats have been evaluated from the point of view of human activity (sleep, hygiene, food, work), and a user's perspective. In addition to the available data, astronaut's personal experiences have been integrated into the evaluation. Relevant issues have been summarized within each category of human activity. Comparable drawings and diagrams have been prepared in order to facilitate comparison. Furthermore the attempt has been made to summarize the most important findings in the form of design directions.

To try and integrate the very personal experiences of the users with the various technical requirements seems to be a promising approach. A lot more information would have to be evaluated, but this work is a first step towards a more human-oriented design approach for space exploration. In addition the present framework could be adjusted according to specific research tasks.

Acknowledgments

I would especially like to thank the following astronauts for sharing their personal experiences in an extra-terrestrial environment with me (in the order of the interviews): Jean-Francois Clervoy, Jean-Pierre Haigniere, Reinhold Ewald, Michel-Ange Charles Tognini, Franz Viehböck, Hans Wilhelm Schlegel and Harrison Schmitt.

I would also like to express my gratitude to my doctoral thesis supervisor Prof. Richard Horden (TUM). His supervision provided valuable discussions and a high degree of motivation in concentrating my work. I thank Maria Perino and Alessandro Bergamascamo from Alcatel Alenia Spazio in Turin, Italy for the possibility to work with them on habitability issues within the 'Pressurized Lunar Rover Study'.

References

Astronaut, 2009. unpublished. [interv.] Sandra Häuplik-Meusburger.
Interviews with Jean-Francois Clervoy, Jean-Pierre Haigniere, Reinhold Ewald, Michel-Ange, Charles Tognini, Franz Viehböck, Hans Wilhelm Schlegel and Harrison Schmitt

Banks, Jim. 2004. Space.com. [Online] 23.01.2004 [Cited: 10 07 2006.] http://www.space.com/missionlaunches/exp8_update_040123.html.

Bluth B.J., Helppie M. 1987. Soviet Space Stations as Analogues. NASA Headquarters Washington : NASA Grant, 1987. NAGW-659.

Carr, Gerald P. 2000. Oral History Transcript - Gerald P. Carr. [interv.] Kevin M. Rusnak. Huntsville, Arkansas, 25 October 2000.

Connors, Mary M., Harrison, Albert A. and Akins, Faren R. 1999. Living Aloft, Human Requirements for Extended Spaceflight. Washington, D.C.: NASA, Ames Research Center, 1999. SP-483 / ISBN: 1-4102-1983-6.

Harrison, Albert A. 2001. Spacefaring - The Human Dimension. Berkeley / Los Angeles / London : University of California Press, 2001. 0-520-22451-1.

Jones, Tom. 2006. Skywalking, an Astronaut's memoir. U.S.A. : HarperCollins Publisher, 2006. ISBN 0-06-088436-3.

Kanas N., Manzey D. 2003. Space Psychology and Psychiatry. Pg.l. : Springer, 2003.

Lebedev, Valentin. 1990. Diary of a Cosmonaut - 211 Days in Space. United States and Canada : Bantam Air & Space Series, 1990. Vol. Vol.4. ISBN: 0-553-28778-8.

Linenger, Jerry M. 2000. Off The Planet - Surviving five perilous months aboard the Space Station MIR. U.S.A. : McGraw-Hill, 2000. ISBN 0-07-136112-X.

Magnus, Sandra. 2009. Sandra Magnus' Journal. [Online] NASA, 6 January 2009. [Cited: 10 February 2010.] http://www.nasa.gov/mission_pages/station/expeditions/expedition18/journal_sandra_magnus_6.html.

NASA [Debriefing A11]. 1969. Apollo 11 - Technical Crew Debriefing. Houston, Texas : NASA, Manned Spacecraft Center, 1969.

NASA [Neemo]. 2007. NEEMO NASA Extreme Environment Mission Operations. [Online] NASA, 5 September 2007. [Cited: 12 December 2008.] http://www.nasa.gov/mission_pages/NEEMO/.

NASA [Skylab]. 1974. MSFC Skylab Orbital Workshop Vol. III. Alabama : Skylab Program Office, George C. Marshall Space Flight Center, 1974. Technical Memorandum. NASA TM X-64813.

NASA [Skylab LL]. 1974. Lessons Learned on the Skylab Program. Houston, Texas : NASA, Lyndon B. Johnson Space Center, 1974. JSC-09096.

NASA [TM]. 1974. MSFC Skylab Crew Systems Mission Evaluation - Technical Memorandum. Alabama : George C. Marshall Space Flight Center, 1974. Technical Memorandum. NASA TM X-64825.

Portree, David S.F. 1995. MIR Hardware Heritage. Houston, Texas : NASA, Lyndon B. Johnson Space Center, Information Services Division, 1995. NASA RP 1357. Princeton University, Farlex Inc. 2003

SSC RF. MARS-500. [Online] SSC RF - Institute of biomedical problems of RAS, Moscow, Russia. [Cited: 5 July 2009.] http://www.imbp.ru/Mars500/Mars500-e.html.

Stuster, Jack. 1996. Bold Endeavours: Lessons from Polar and Space Exploration. Pg.l. : US Naval Institute Press, 1996. ISBN-10: 155750749X.

Van der Voordt, Theo and Van Wegen, Herman. 2002. Ex Post Evaluation of Buildings. [book auth.] T.M. De Jong and D.J.M Van der Voordt. Ways to Study and Research Urban - Architectural and Technical Design. Delft, NL : DUP Science, Delft University Press, 2002, pp. 151-158.

Weitz, Paul J. 2000. Oral History Transcript - Interview with Paul J. Weitz. [interv.] Rebecca Wright. 26 March 2000.