Postprint of: Kozicki J., Kozicka J., Human friendly architectural design for a small Martian base, Advances in Space Research, Vol. 48, Iss. 12 (2011), pp. 1997-2004, DOI: 10.1016/j.asr.2011.08.032

Human Friendly Architectural Design for a small Martian Base

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Abstract

The manned mission to Mars is expected to last almost three years. A human factor must be taken seriously into account in such a long-term mission. A big comfortable habitat can help to overcome sociopsychological problems, that occur in ICEs (Isolated and Confined Environments). Authors have come forward to this issue and have developed a Martian base design as a human friendly habitat. The project is based on researches of extreme conditions on Mars, architecture in ICEs and contemporary building technologies. The base consists of five modules: a Central Module (CM), an Agriculture Module (AD), a Residential Module (RD), a Laboratory Module (LD) and a Garage (G). Each element has its own functional purpose. The CM is a metal capsule similar to the Reference Mission module (RM, NASA, 1997). Domes are inflatable multilayer structures, which interiors are "open planned". Interiors can be arranged and divided into rooms by using modular partition walls designed by authors.

Key words:
Extraterrestrial architecture, Martian base, Habitat design, Inflatable architecture

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26 August 2011

1 Introduction

Sociopsychologists analyzed people behaviour in Isolated Confined Environments (ICEs) like space, polar and submarine stations (Dudley-Rowley, 2001). Different physiological, sociological and psychological problems have been spotted. The most common ones are: headaches, insomnia, homesick, problems with concentration. Rare but more troublesome ones are: hallucinations, depression, psychological breakdown, aggression (Kass, 1995; Brunelli & Guena, 1996; Allen et al., 2003). Those problems arise because of restricted living conditions, e.g. confined living space, artificial surroundings, lack of basic comforts: sunlight, landscape view and privacy. In harsh environments the key issue is to keep people alive. The space or submarine stations are basically the shelter only. A human factor in their architectural design has a very low priority. It is acceptable for short duration missions. Sauer et al. (1997) convince that: *Humans are able to tolerate even very unfavourable conditions* but only *for a limited period of time*. However, the mission to Mars is expected to last almost three years. It is a dangerous and stressful journey: crewmembers will be alone, far away from Earth, with many difficult tasks to carry on, relying only one on another. In this case the human factor must be taken into account seriously. It is proved that the more human friendly living space, the better well-being of the inhabitants (Evans et al., 1988). In comfortable conditions "marsonauts" would be able to work more efficiently. Thus a chance of mission failure is decreased. Various solutions for space habitats (e.g. Benaroya, 2010; Dubbink, 2001; Sadeh & Criswell, 1996; Zubrin & Wagner, 1996) and the human friendly architecture (e.g. Evans et al., 1988; Grandjean, 1973; Wise & Wise, 1988) have been recognized by authors in the scientific literature. Some of those solutions have been successfully introduced in habitats in extreme conditions. Based on this information and restrictions related to the mission to Mars, authors have developed the Martian base design as a human friendly habitat in extreme conditions. The project is presented in this article.

2 Design Goals and Assumptions

The Martian habitat, that has been presented in Reference Mission (RM, 1997) is a small metal cylinder – 8m in diameter and 8m in height (shown in Fig.1). It is expected that eight people would live and work there during the whole three-years long mission. In authors' opinion, considering the human factor in the long duration Mars mission, it is important to improve the habitat design. Authors have decided to develop an architectural Martian base concept, based on several main design goals, that follow:

- larger flexible living space;

Fig. 1. The Martian station proposed in Reference Mission (RM, 1997), NASA

- private personalize-able space for each crewmember;
- contact with sunlight, landscape view and nature;
- separate different areas: work and leisure, noise and quiet spaces etc.;
- ability to move partition walls for the interior rearrangements;
- ability to expand the base by attaching additional modules;
- adhere to COSPAR Policy on Planetary Protection guidelines to avoid harmful contamination and a quarantine capability (COSPAR, 2011).

A bigger habitat can be a bigger problem. Thus the authors have outlined several design assumptions that should minimize troubles related to construction on the surface:

- perform transportation in the same mission module as in NASA Reference Mission (8x8 meters cylinder),
- easy delivery and easy deployment,
- automatic deployment process (it can be only finalized by people),
- exclude leveling the terrain before deployment and provide a flat floor.

3 Structure choices

Authors assume that providing a bigger space in the Martian habitat is a key issue. However building a big base can be very expensive. Based on scientific literature (e.g. Benaroya, 2010; Dubbink, 2001; Kozicka, 2008a; Zubrin & Wagner, 1996), authors have recognized two ways to lower this cost. The first one is using ISRU (In Situ Resources Utilization) technologies on Mars in the construction (Noever et al., 1998; Gertsch & Gertsch, 1995). The second one is sending an expandable structure from Earth (Cadogan et al., 1999; Freeland et al., 1998). The first solution is assumed by authors as less adhering to COSPAR (2011) guidelines. Properly sealed, sterile structure made and tested on Earth would function as a bioshield for the Martian base to provide minimum biocontamination hazard. ISRU methods are more invasive to the natural environment and hermetic sealing of the *in situ* made structure would be more difficult to achieve. Based on sizes of the RM module, the authors

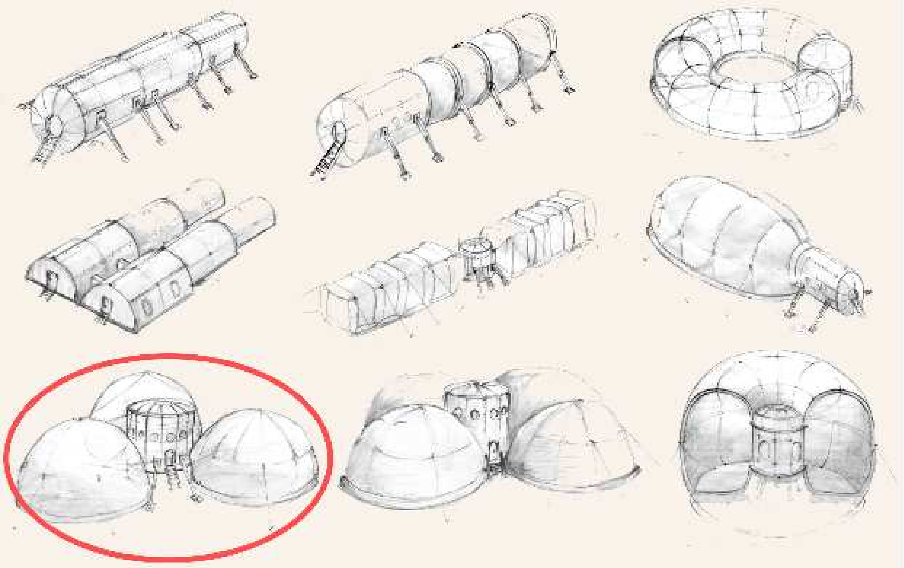


Fig. 2. The authors' concepts for the Martian base

have developed various solutions for the expandable structure. Examples are shown in Fig.2. The concept of three inflatable domes around the central module has been chosen as the best solution of all. The central module is a metal cylinder with sizes exactly the same like of the module in RM. The rest of the habitat is packed inside the module during the flight to Mars, so there is no need for more volume in the rocket. The weight is not much bigger either, because the packed structures are made of light elastic materials. The deployment of domes is very easy – they just have to be inflated with the artificial atmosphere, that is necessary anyway (stages of the deployment are presented in details by Kozicki (2004)). A lot of free space is obtained by inflatables - 1000m^2. Between domes there is enough space for ergonomic communication routes. Dividing the habitable area into several separate parts allows functional zoning (greenhouse, home and work). The buildings are connected with short communication routes – it results in quick escape and better usage of the additional space in the habitat.

4 Design

4.1 Plan design

The plan of the authors' conceptual Martian base is shown in Fig.3. The settlement consists of five elements:

- Central Module (**CM**), d=8m, A=150m^2,
- Agriculture Dome (**AD**), d=24m, A=450m^2,

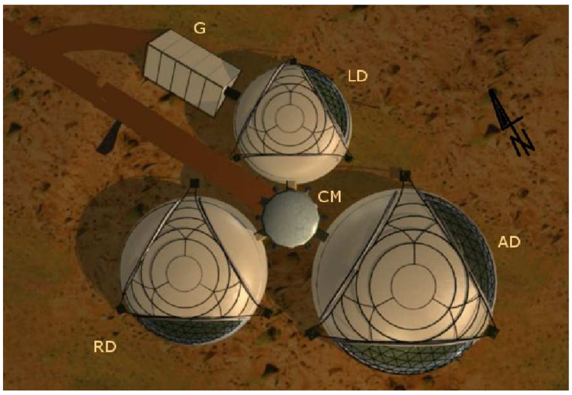


Fig. 3. The plan of the authors' conceptual Martian base

- Residential Dome (**RD**), d= 20m, A=315m^2,
- Laboratory Dome (**LD**), d=16m, A=200m^2,
- MPV Garage (**G**), 8x12m, A=96m^2.

The base presented here has a central plan. In the middle there is the metal Central Module. It has two entrances to the habitat: one for "marsonauts" on foot and one for Mars Pressurized Vehicle MPV Team MSP (2002) docking. Elastic sleeves are attached to the CM. They give pass to three inflatable domes: Agriculture Dome, Residential Dome and Laboratory Dome. As the names indicate, each module contains functionally different area: greenhouse, home and work. They are separated to provide a comforting feeling of going to work and coming back home (Dubbink, 2001). The biggest dome is AD. It is pointed to the south to collect as much sunlight as it is possible (assuming the habitat is localized on the northern hemisphere). Through two big windows sunlight can penetrate intensively the whole interior (so the artificial lighting for plants is less energy consuming). Two other domes have only one window. They are less sunlit, but better insulated against radiation. The Garage is a long tent, where the MPV can be kept and protected from dust. It is connected to the LD, so it would be easy to bring samples to examine from the vehicle to a laboratory. Also a workshop is localized in the LD near the passage to the G (look Fig.5). The MPV has easy access to the G and to the CM – the routs are shown in Fig.3. Every dome has three points where a door can be installed. This solution enables to expand the base in future.

4.2 Architectural design

The visualization of the base is presented in Fig.4, the ground plan design, with a proposed internal walls arrangement, is shown in Fig.5 and Sections – in Fig.6.

The CM is a metal cylinder with three decks. On the first floor there is the

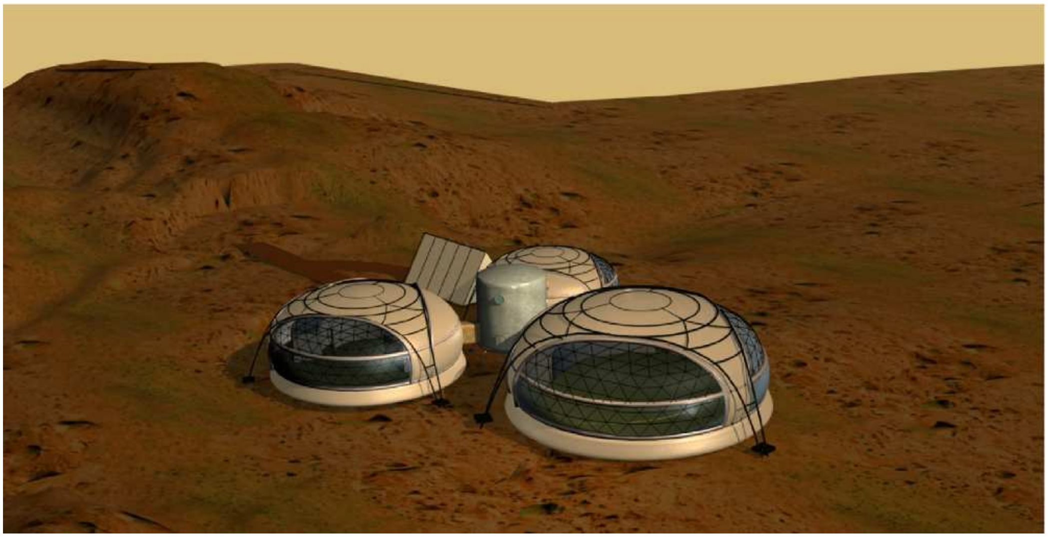


Fig. 4. The concept of the Martian base - visualization

main corridor, airlocks, a first aid point and a toilet. During the transportation to Red Planet domes are packed in the corridors. On the second floor there is a shelter, where "marsonauts" can hide during solar events. It is surrounded by 2m thick water storage tank. On the third floor there are technical rooms, ALSS (Advanced Life Support System) (Henninger et al., 1996) equipment and a nuclear reactor providing electricity to the base (more by Kozicki (2004)).

The AD is the biggest module of the base. It contains a Biological Life Support System. Plants harvested inside produce food. Bumblebees pollinate flowers and provide honey. The behaviour of those insects have been already tested in lower gravity (Yamashita et al., 2010). Algae collect carbon dioxide and produce oxygen for people to breathe. They are very efficient oxygen providers as it was proved in BIOS-3 programm (Salisbury, 1997). Pure evaporated water is collected in a tank to supply drinking water. A robot can autonomously take care of crops while crewmembers are busy with mission tasks. Nearby there is a small recreational area in green surroundings – as the contact with nature is very comforting for people. Many storerooms can be used for food and seeds storage.

The RD is designed with an "open plan". It means that the space is flexible and configuration of internal walls can be rearranged. The partition walls are inflatable modular elements. They can be easily moved, so the functional layout can be organized in different combinations. The possibility of changing interior design gives people comfort - they have an opportunity to personalize their private or social area and it helps fighting the boredom (Evans et al. (1988), Suedfeld (1998)). In the suggested rooms configuration (shown in Fig.5) there are eight similar private cabins, kitchen with storage rooms, a gym and a large recreational public area. Researches conducted in Mars Analogue Research Station program indicate that people prefer smaller private room in

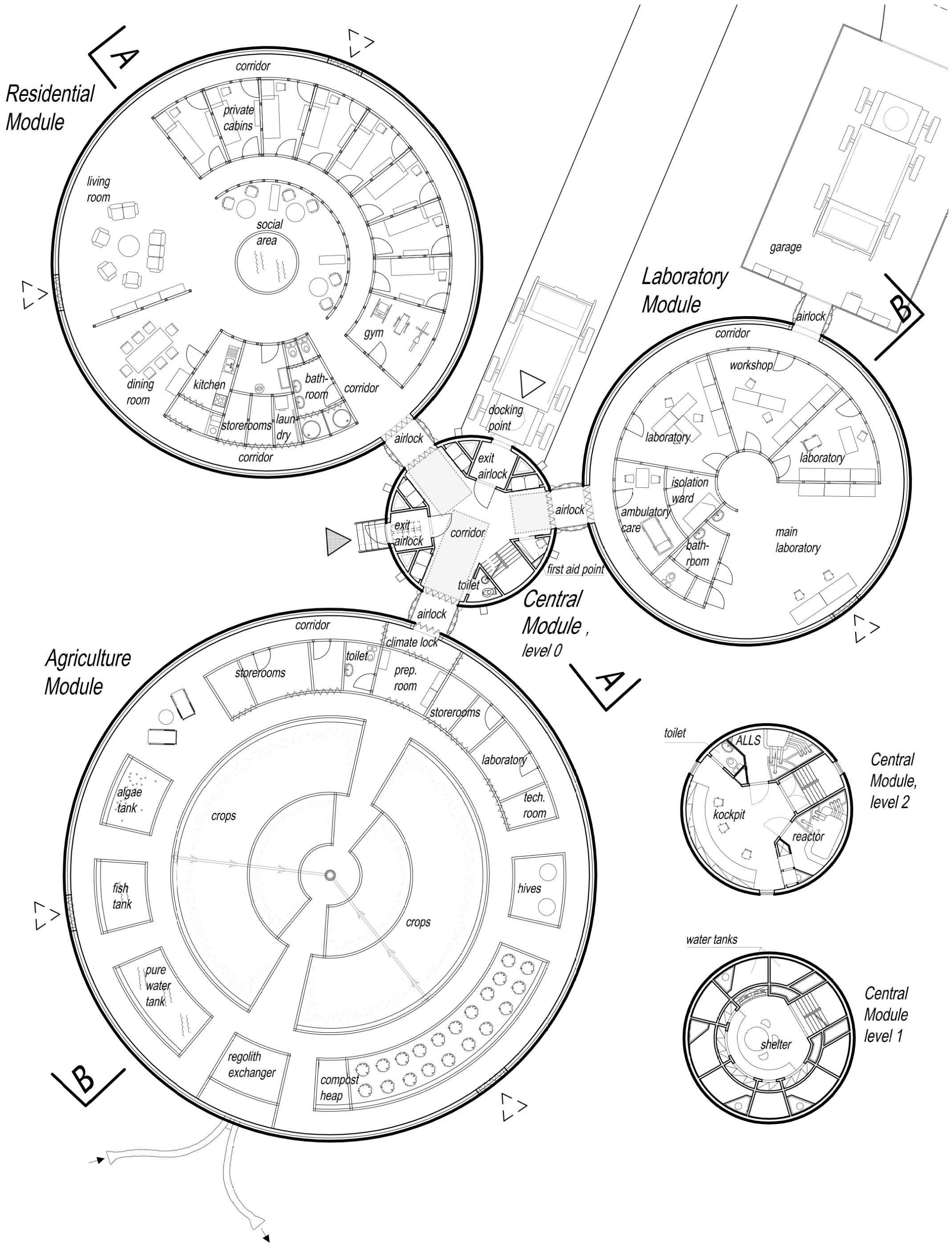


Fig. 5. The ground plan with suggested internal walls arrangement

favour to larger public area (Clancey, 2001). It is proved to be very comforting when each person has his/her own room to rest, to be alone, to keep private things (Dudley-Rowley, 2001). In each cabin there is a bed, a desk with a chair and a wardrobe. People can come to their rooms from the recreational area or from the more private external corridor. The common area is well sunlit as it is placed near the big window. Looking through windows is very relaxing,

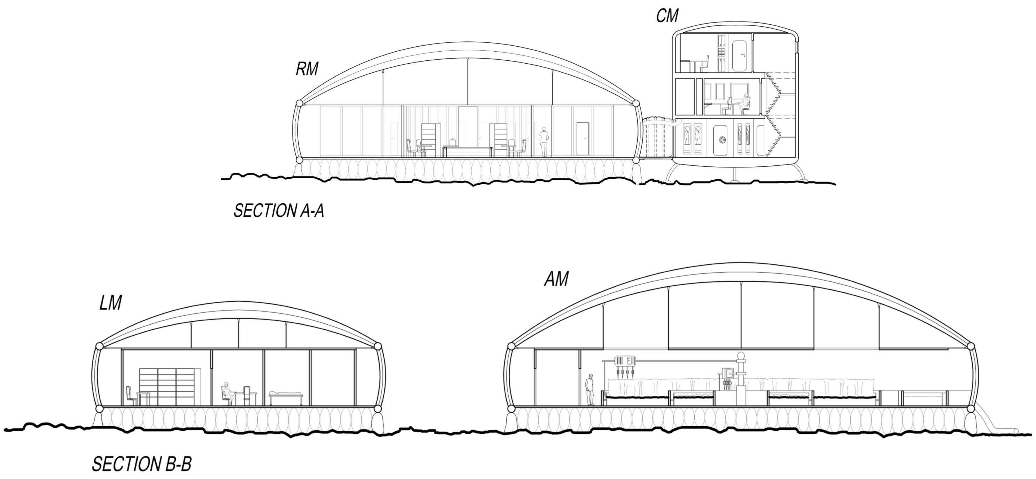


Fig. 6. The concept of the Martian base - section A-A and B-B

as many participants of space missions have claimed (Kanas, 1998) and the contact with a landscape view is provided. There are different rest areas, so people can choose a way of spending their leisure time.

The LD has also the "open plan". In the LD (with suggested partition walls assembly) there is one open laboratory area and two separate laboratories. A workshop is near the entrance to the garage so the vehicle parts and the laboratory equipment can be fixed in one place with proper tools. An ambulatory is near the entrance to the rest of the habitat, so the injured person can be brought the shortest way.

4.3 Structure design

The base assembly consists of two kinds of structures: metal and pneumatic. The metal structure is the CM. It is similar to the RM module and other space habitats designed for space missions so far. Thus it is assumed by authors as a reliable structure, proved in extreme extraterrestrial conditions. The rest of the habitat modules presented in this paper, have multilayer pneumatic structures. This kind of structures have been already investigated for space appliances (Cadogan et al., 1999; Covault, 2004; Hublitz et al., 2004; Sadeh & Criswell, 1996)). They are designed from different flexible materials that provide: mechanical resistance, thermal insulation, radiation protection and hermetic sealing. The protection against micrometeorites is unnecessary in the Martian habitat structure design. The Martian atmosphere is thick enough to burn micrometeorites before they can reach the surface.

Mechanical resistance: The atmospheric pressure on Mars is very low (about 7 hPa). Inside the habitat a pressure of the artificial atmosphere must be much higher, so people can breathe easily and feel well. Even if the internal pressure is 340 hPa (like it was on space station Skylab), there is still a big pressure difference between the inside and the outside. It results in high tensions in the habitat external walls. Two layers with atmospheric air gaps of intermediate pressures are designed by the authors to lower those tensions. A Kevlar (DuPont, 2011) fabric sheet is chosen for an external layer of the dome cover. This material has a very high tensile strength. It is also very difficult to damage, because of its excellent mechanical characteristic. It was used in other space habitats designs (Cadogan et al., 1999).

Radiation protection: The thin Martian atmosphere (without magnetosphere as strong as on Earth) provides only partial radiation protection for human bodies and electric equipment. As it is explained in Safe on Mars (2002), there are two main sources of hazardous radiation on Mars: GCR – Galactic Cosmic Radiation and SPEs – Solar Particle Events. GCR particles deliver lower dose of radiation. However they reach surface of Mars constantly. During solar events large proton flares deliver a very high dose radiation. Those events usually last only about a few hours. As Simonsen (1997) suggests, the amount of shielding required to protect the "marsonauts" would depend on the duration of the mission. In her opinion, the Martian atmosphere does provide a significant amount of protection against GCR. However for the long duration missions, the GCR dose could become career limiting. To lower cosmic rays radiation inside the habitat, the layer of Demron (Radiation Shield Technologies, 2011) is introduced into the dome cover structure. Although Demron is light and flexible, it provides a very good radiation protection. This material was also chosen for a prototype Mars suit design (Marcy et al., 2004). Solar events are more dangerous for people than cosmic rays, because of high dosages of radiation. However, solar events can be predicted soon enough (even a week ahead) to conduct a crew evacuation to the shelter in time. In the CM in the middle deck there is the shelter room for "marsonauts". It is surrounded by a thick layer of water. Material made of light elements – like water of hydrogen and oxygen – provides the best radiation protection during solar events (Borggräfe et al., 2009).

Thermal insulation: Spaceloft (Aspen Aerogels, 2011) is chosen for the thermal insulation in the habitat structure. It is a flexible aerogel – the best thermal insulator. It has low thickness combined with a very low thermal conductivity.

Hermetic sealing: There are different polymer films with low permeability of gases and moisture, that could be used as a sealing layer in the Martian habitat cover. The authors concentrated on transparent materials, which can be used both in the main cover of the dome and in windows as well. As transparent structures in the habitat will be deprived of the layer of strong Kevlar fabric sheets, only the most mechanically resistant films were investigated.

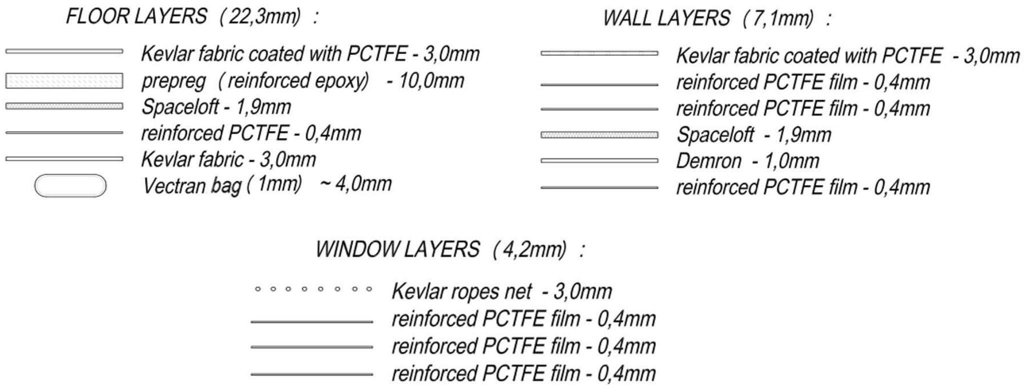
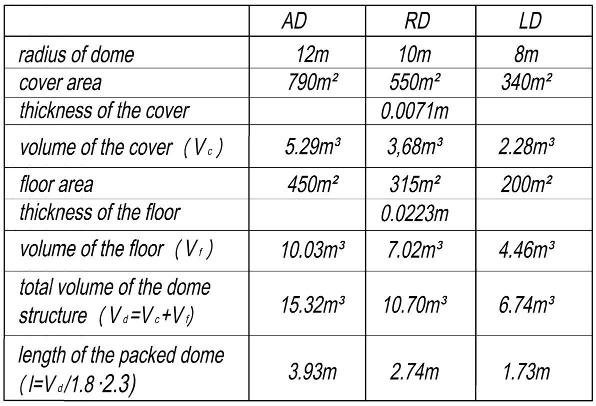


Fig. 7. A proposed layers configuration for domes' elements: floor, wall and window

Also Spaceloft is not transparent, so it won't be used in window structure. Thus only materials resistant to very low temperatures can be taken into consideration (at least for an external layer of the window); more by Kozicka (2008b). Based on those constraints authors decided to choose a PCTFE (Polychlorotrifluoroethylene) film for a hermetic sealing layer. This material can be used even in -240°C. It has a very low permeability of gases such as: CO_2, O_2 and N_2; it is unabsorbable and nonflammable. It is antistatic and nonadhesive (Saechtling, 1995; Massey, 2002; Boedeker, 2011), so the Martian dust will not stick to its surface. To increase tensile strength of PCTFE, fibers (e.g. of Kevlar, glass, carbon) can be introduced into the film. Also a Kevlar webbing tightens each window (see Fig.4).

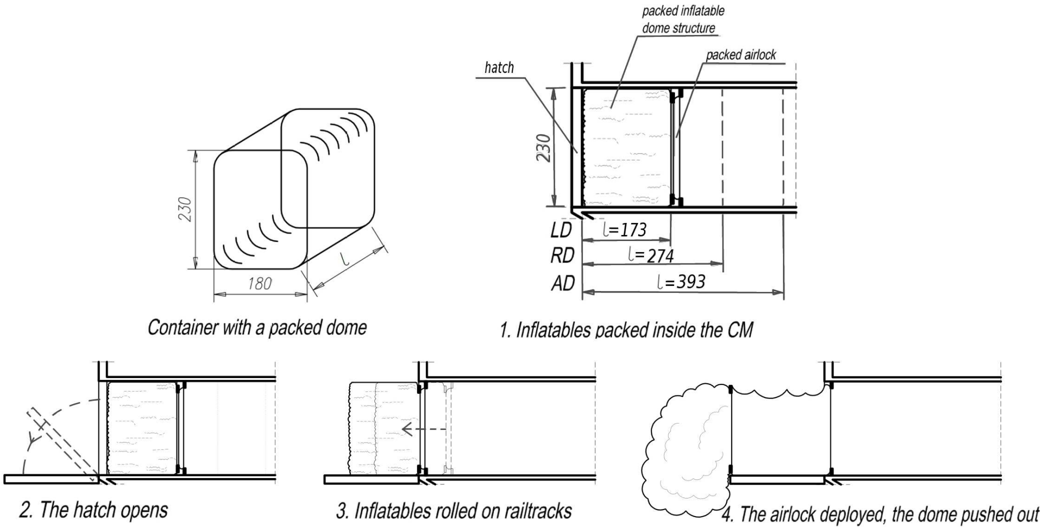
It is unnecessary to level the robust terrain before domes are unfolded. The CM has 6 legs to stabilize its position on the ground, and domes have a special floor structure (designed by authors). Numerous Vectran bags are assembled to the bottom of the floor. They are inflated the way to adhere to the rough terrain and provide a flat floor. The process is controlled by sensors and a computer. After the floor bottom is leveled properly, a special rigidizable flooring structure is hardened to achieve a flat surface. This structure is made of a fibers-filled composite material with a long-life matrix – prepreg (Kondyurin, 2006). The layer of inflated Vectran bags and Spaceloft blanket should provide enough thermal insulation from the cold Martian ground. Because of strong winds that occur on Mars, each dome is anchored to the ground. A net of Kevlar ropes tightens and compresses the inflatable structure. Ropes are attached to the anchorages inserted into the ground in three points around the dome. Details of anchorages are presented by Gyula (1997).

Each dome structure consists of three types of elements: floor, wall and window. A proposed layers arrangement are listed in Fig.7. Approximate material thicknesses were assumed based on available product data provided by manufacturers. Rough calculations have been made to specify volume of packed domes. Results are presented in Fig.8. During the flight to Mars each dome



	AD	RD	LD
radius of dome	12m	10m	8m
cover area	$790m^2$	$550m^2$	$340m^2$
thickness of the cover		0.0071m	
volume of the cover (V_c)	$5.29m^3$	$3,68m^3$	$2.28m^3$
floor area	$450m^2$	$315m^2$	$200m^2$
thickness of the floor		0.0223m	
volume of the floor (V_f)	$10.03m^3$	$7.02m^3$	$4.46m^3$
total volume of the dome structure ($V_d = V_c + V_f$)	$15.32m^3$	$10.70m^3$	$6.74m^3$
length of the packed dome ($l = V_d/1.8 \cdot 2.3$)	3.93m	2.74m	1.73m

Fig. 8. Calculations of the packed domes' sizes



Container with a packed dome

1. Inflatables packed inside the CM

2. The hatch opens

3. Inflatables rolled on railtracks

4. The airlock deployed, the dome pushed out

Fig. 9. Stages of a packed dome deployment

is packed in a bag behind a hatch. Three hatches are located symmetrically in the CM, on level 0. After the landing hatches would open and packages would be rolled out on railing tracks (as it is shown in Fig.9). The bag with the packed dome must get through the hatch opening (measuring about $3.9m^2$ area). Thus the length of package is different for each dome (l value). The area necessary for each package accommodation inside the CM module is signed in Fig.5 by a dotted line.

4.4 Interior design

Inside each dome there is a large space to accommodate. Partition walls are needed to divide this space into ergonomic and functional rooms. To provide easy assembly of internal walls and lower the weight of the habitat equipment, the authors designed pneumatic modular partition walls and the system of

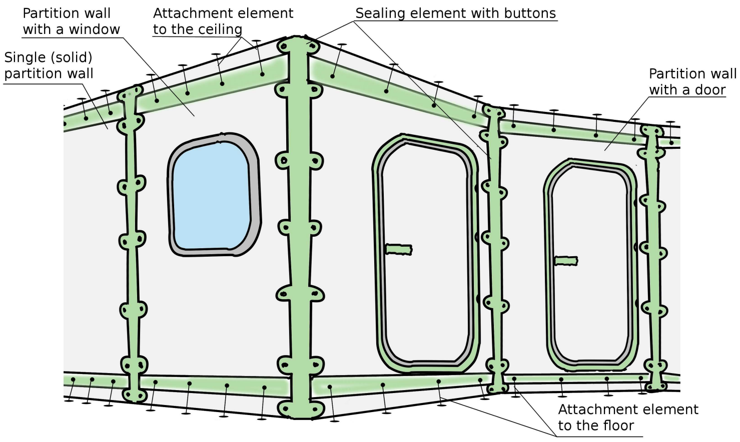


Fig. 10. Partition walls – the assembly

their attachments (look Fig.10). Each partition wall is an inflatable rectangle that can be attached one to another by sealing elements with buttons. In the floor and in the suspended ceiling there are hidden small attachment points in modular arrangement. By using several attachment elements one wall can be anchored to the ceiling and to the floor to stabilize it vertically, so it would not collapse. There are three kinds of walls: solid, with a window and with a door. Windows and doors are also inflatable elements. They have frames with magnets, so they can be shut by touching the metal opening-frame. The acoustic insulation inside rooms can be provided by mats made of Spaceloft.

5 Conclusions

The human factor in the Mars long-duration mission design is very important. Well-being of the crew would result in efficient tasks management and the success of the whole mission. In spite of many requirements resulted of extreme conditions on Mars and restrictions in cost and weight, the comfort and human friendly atmosphere in the Martian base can be introduced with a proper architectural design. Authors, based on scientific researches, created the example of such a habitat. All solutions introduced in the design are related to the contemporary achievements in technology and architecture. However, the details must be brought to perfection by engineers, and an analog of the structure should be tested.

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