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DEPLOYABLE AND PORTABLE EMERGENCY SHELTER FOR MARS

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The Mars surface infrastructure as anticipated for future human missions will probably include habitation, rover and other support facilities. With regards to potential EVA / science activities to be performed on Mars and related safety issues, we propose an additional crew support element: A portable and deployable shelter which can be employed in the event of an emergency requiring immediate action and where return to the base / rover is not possible without undue risk.
Following the study of possible emergency scenarios and the definition of design criteria, a series of preliminary designs for an emergency shelter have been developed within an academic design studio. A 1:1 prototype was built and tested during the Morocco Mars Analog Field Simulation in February 2013 as part of an operational evaluation of this deployable and portable multipurpose shelter.
On-Site, in Morocco the operability (deployment and retraction), the durability (multiple deployments), functionality (human-equipment-shelter) and adaptability (functional usability) were tested by analogue astronauts. Additional issues that were explored and evaluated included spatial usability, ergonomic suitability to actions and individual perception of comfort in relation to the required activities.
This paper introduces potential emergency scenarios and the design criteria for an emergency shelter.
Furthermore, selected design concepts will be introduced and the current prototype will be presented, concluding with lessons learned and updated design requirements.

1. INTRODUCTION

Space craft design teams all over the world are working to minimize the hazards of the harsh Martian environment on astronauts. Extravehicular activity (EVA) in unknown terrain and in a hostile environment will be a key component of a crewed mission to Mars. This will increase the risk of injuries. Exposure of an unprotected human body to the Martian atmosphere, caused for example by malfunction of the space suits' life support system, can result in serious medical conditions or even death. Several such emergency scenarios have been simulated under Mars analogue conditions (e.g. Groemer et al. 2003, Mauschitz et al. 2007, Zea et al. 2010, Diaz et al. 2013). The increased workload and physical exhaustion lead to an increase of the risk of traumatic injuries (Groemer et al., 2010). An injured astronaut will require biomedical monitoring and support, while waiting for help (Ferrario et al. 2011).

Therefore it is important to provide the astronauts with an additional crew support element that could be used in case of an emergency. For this purpose, a team at the Vienna University of Technology developed a deployable emergency shelter design.

2. EMERGENCY SCENARIOS

Potential emergency scenarios were discussed and developed. As a preliminary result the following critical situations were considered highly relevant to extravehicular activity on the Martian surface:

- One astronaut loses consciousness but is still breathing.
- One astronaut suffers from dizziness and has to rest for a while.
- Astronauts get exhausted and have to rest for a while.
- One astronaut has an unforeseen reason for needing to remove the helmet.
- One astronaut falls down and suffers from a traumatic injury.
- The space suit of an astronaut is malfunctioning and there is no option to get back to the base / rover in time.
- The rover or the quad has a malfunction and the astronauts cannot return to the base.
- A solar particle event occurs whilst away from a pressurized shelter.

Three emergency scenarios were evaluated to be the most important / most likely to happen and therefore chosen for further inquiry:

A. One astronaut loses consciousness but is still breathing.
B. Astronauts get exhausted and have to rest for a while.
C. One astronaut falls down and suffers from a traumatic injury and/or space suit malfunction.

These scenarios were further analyzed regarding functional and spatial requirements for the rescue activities. One of the goals was to define the minimal space envelope necessary for the emergency shelter. This is strongly related to other design criteria like the maximum size and weight possible to be carried by one astronaut.

3. PRELIMINARY DESIGN CRITERIA

Based on the analysis of the emergency scenarios, the shelter has to be designed to accommodate two astronauts for up to 48hours until rescue arrives or the immediate emergency ceases (successful first aid, change of conditions).

Design criteria for the shelter are strongly related to the EVA suit design. Depending upon the selected suit, design parameters will change, such as the ergonomic shape and size. For example shelter design solutions appropriate for the current NASA Z-1 spacesuit (NASA 2013) or the Russian Orlan types of suit with rear entry would differ significantly from that required for a two piece type suit. The current design of the shelter was developed to be used in conjunction with the OEWF spacesuits simulators in order to test the preliminary concept.

The design principles for the shelter concept were formulated as follows:

1. The shelter shall be compactly packed into an emergency package
2. The package shall contain the emergency shelter (MASH), an additional oxygen supply for the astronauts, an emergency power supply for the space suit, an emergency food supply, and an emergency toolkit.
3. Altogether it should not weight more than 20 kg (6.6kg on Mars).
4. The EP (Emergency Package) shall be transported by a rover and carried by one astronaut when leaving the rover
5. The shelter shall be easy to deploy by one astronaut

6. It shall accommodate up to two astronauts wearing space suits, e.g. one injured astronaut and one assisting rescuer.
7. The shelter shall temporarily provide a breathable atmosphere (to take the helmet and/or gloves off) with the same atmospheric pressure as the space-suit.
8. An outer layer should isolate the interior of the shelter from the ground and provide topographic adjustability to accomodate different ground conditions (rocks, uneven or sloped terrain, etc.)
9. In order to maintain minimal volume, the structure should be adaptable to the functional requirements of the astronauts (different body positions)

Based on these design criteria, students in the Master of Architecture programme at the Vienna University of Technology developed a series of emergency shelter design concepts during the 2012 winter term. A few of them are introduced below.

4. CONCEPT DEVELOPMENT

At the beginning of the design studio the students were asked to conduct research in three main topics related to the preliminary design criteria.

4.1. Research on Activity-based Spatial Analysis

The students carried out an Activity-based spatial analysis (cf. Häuplik-Meusburger 2012) to define the relationship between the required human activities during emergency situation and potential architectural solutions. 2D and 3D diagrams, and analogue simulations performed by the students were analyzed during this research (Fig.1). The evaluation then served as a basis for roughly determining the shelter size.

Fig. 1: Suit tester assessing mobility (Foto: TU Wien, HB2)

4.2. Research on structure typologies

A second group of students were concentrated on potential structure typologies for the shelter and related materials. The students analyzed different deployable systems like pneumatic systems, deployable bar and surface structures, hanging films and bells (cf. Aguzzi et al. 2007, Petrova, 2008; Häuplik-Meusburger et al. 2012). Basic kinematic concepts were worked out (Fig. 2), and specific case studies were simulated. All systems were evaluated with regards to design criteria like weight, stability, handling and reusability.

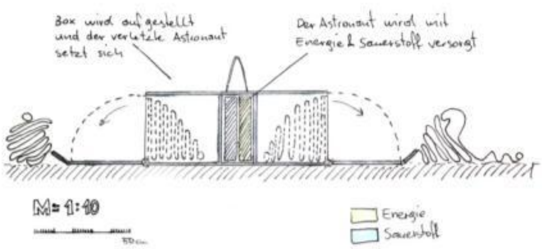

Fig. 2: Potential folding concept (Drawing: TU Wien, HB2)

4.3. Research on specific features

One group investigated interesting ideas and partial solutions for potential challenges of the specific environment such as functional and topographical adaptability of the shelter. Different mechanical devices to control the shape of the structure consisting of rigid foldable frame elements, pneumatic muscles or cables, were explored with a focus on usability, robustness and simplicity (Fig. 3).

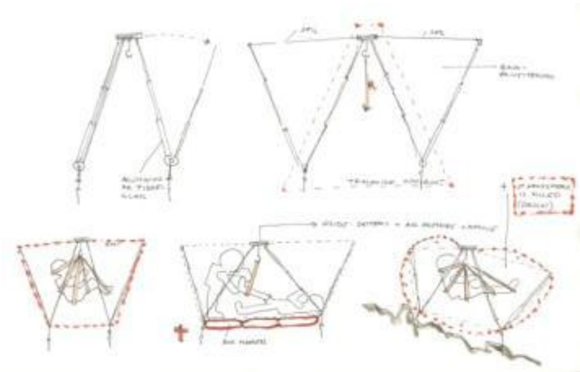

Fig. 3: Possibility to adapt to the ground with telescopic struts (Drawing: TU Wien, HB2)

Based on these research issues the students developed a variety of conceptual designs for the shelter. The concepts ranged from supporting pneumatic tube structures, inflatable envelopes, to foldable architecture made by hinged rigid plates and self-deployed structures.

Concept: Flexible spiral system (Fig. 4)

The shelter's deployability, collapsibility and flexibility are based on simple screwing and stretching of a pneumatic spiral, which serves as the main structural element. Depending on the air pressure inside this tube, the shelter can be adjusted to different configurations.

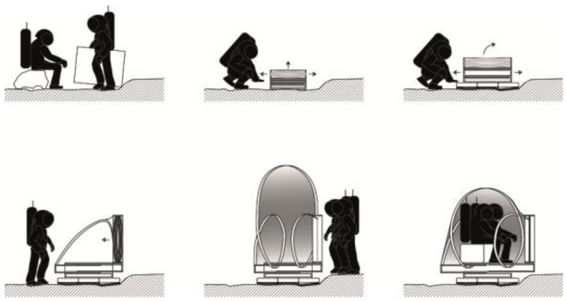

Fig. 4: Deployment Sequence for the spiral system (Drawing: TU Wien, HB2, Kerekrétyova, Mathe, Mitrovits)

Concept: Deployable shelter (Fig. 5)

This structural concept is based on an interaction on different folding techniques. The support bar structure is arranged radially and forms rhomboids with different angles braced by cables. The rim of the structure consists of four arcs composed of scissor-like elements. The whole shelter is deployed automatically by the internal pressure while inflating the shell of the structure.

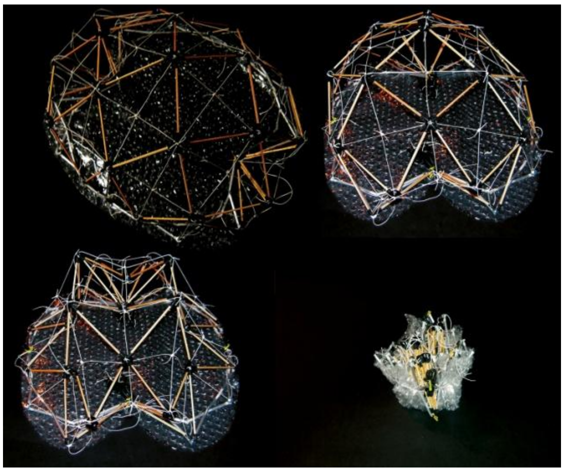

Fig. 5: Model 1:20 scale to test deployment of the structure (Foto: TU Wien, HB2, Stefan)

Concept: Pneu

This design concept refers to the fact that the parts of the emergency shelters in direct contact with the Mars surface must have different properties than the rest of the habitat. A foam rubber mat was chosen for the floor of the shelter as it provides sufficient insulation.

It can be rolled into a compact bundle. The membrane of the shell and all other auxiliary parts of the structure are rolled inside the rubber mat. Its shell is a pneumatic structure which is inflated automatically after the floor mat unrolls. Fig. 6 shows the deployment sequence.

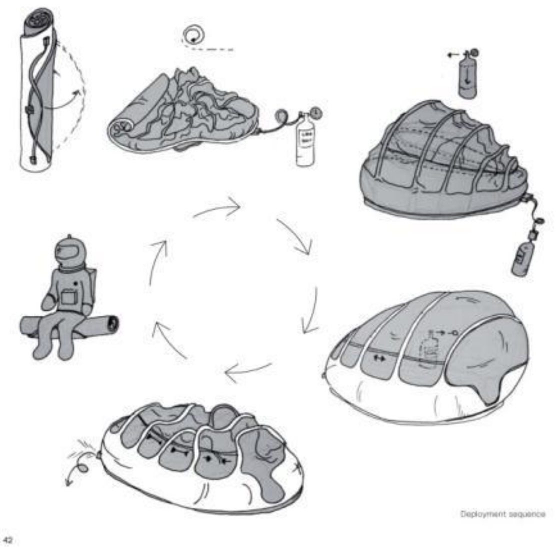

Fig. 6: Deployment sequence for the Pneu project (Drawing: TU Wien, HB2, Aigner, Nanu, Zodl)

<u>Concept: HTV-Shelter</u>

The design concept is a Human Transport Vehicle which can be used by the astronauts during EVA. In addition a deployable shelter is integrated in the vehicle and can be used in case of emergency or exhaustion (Fig. 7).

The wheels of the vehicle are tubeless and are stabilized by curved ribs which can absorb shock caused by the uneven topography. The folded shelter and the life support system are integrated in a box in the lower part of the vehicle. The shelter is a pneumatic construction stabilized by L-shaped (about 45 ° inclined) inflatable seats and supporting pneumatic tubes.

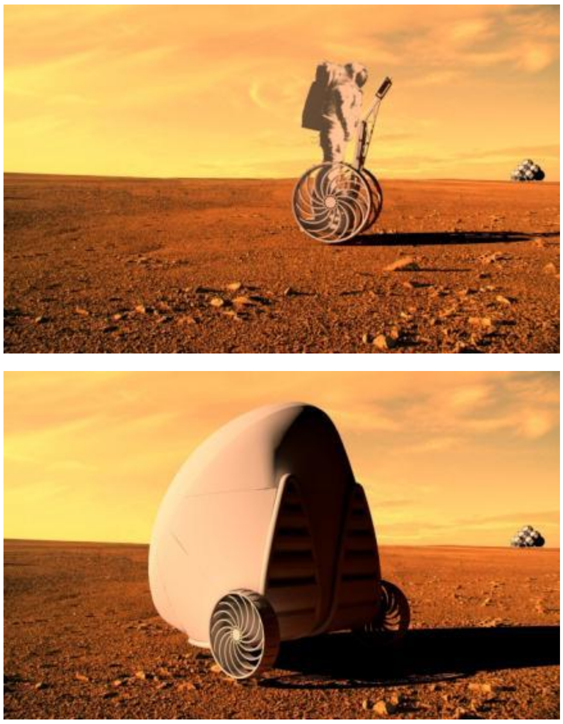

Image 7: Transportation concept for HTV shelter (Rendering: TU Wien, HB2, Benesch, Galonja, Milchram)

Following extensive reviews by the project team and external experts the most promising concepts were selected for further development and resulted in the following choice of design.

<u>Project: res[C]ue me</u>

The shelter consists of two identical, connected areas, along whose seam a flexible rod is mounted, which holds the entire structure in tension. Using a special folding technique, it is possible to fold the emergency shelter [150 cm diameter] into a disc [80 cm diameter and 15 cm in thickness]. Thus the whole structure is convincing on the one hand by its compactness for transportation, and on the other hand the „res[C]ue me“ can be set up and used without auxiliary materials [pump, air compressor, air tanks] within a few seconds. Image 8 shows an emergency procedure using small-scale models.

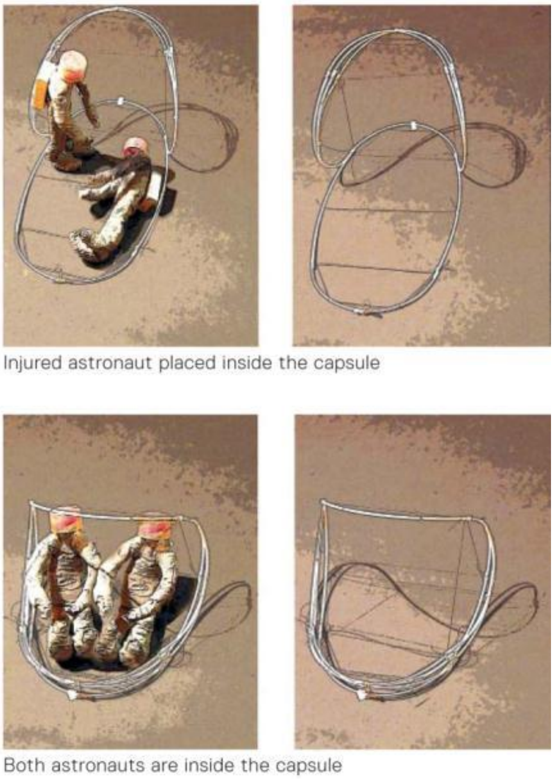

Image 8: Usability study for emergency scenarios (Small-scale Model: TU Wien, HB2)

Based on the res[C]ue concept a full scale prototype was developed and built.

5. PROTOTYPE DEVELOPMENT

The shelter prototype has a ball-like shape and consists of two identical curved surfaces similar to a tennis ball (Fig. 9). Highly elastic glass reinforced plastic rods (GRP) support the outer shell and holds the construction in tension. In the compact state (disc of 80 cm diameter and about 1
5 cm thickness), the structure is under tension, which leads to an immediate unfolding when unpacked.

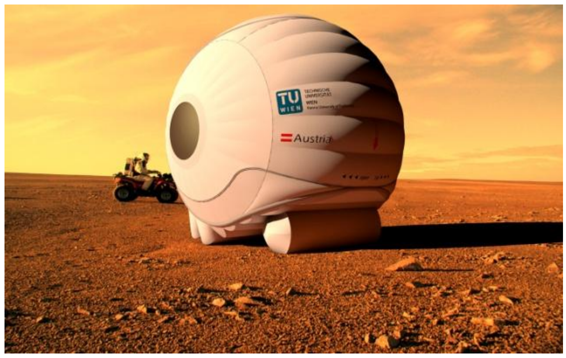
Image 9: Prototype design (Rendering: TU Wien, HB2)

The entrance of the shelter is along the seam. Opening the structure with a zip fastener forces the upper part of the structure to roll back. The bottom surface remains in place. It is now possible to move the injured astronaut on to the base of the shelter. The rescuer enters the shelter. To separate the interior from the Martian surface the bottom part of the structure is designed as a pneumatic system which inflates automatically. A specific amount of air pressure in the pneumatic cushions changes the curvature of the floor mattress, causing the upper part of the shelter to tilt over the heads of the astronauts and thus automatically close (Fig. 10). The shelter is then locked (zipped) by one of the astronauts using supporting ribbons.


Image 10: Closing the deployable shelter (Foto: OEWF, Zanella-Kux)

The prototype was designed to provide functional adaptability which allows the sitting and lying positions to be adopted to enable the necessary procedures for emergency scenarios to be undertaken. The change between the two positions is achieved through air shifting between two supporting pneumatic cushions, one in front and one in the back of the shelter. The same mechanism allows adjustment to different terrain conditions and slopes.

In total three prototypes were developed and tested. The second prototype was tested with the suit tester during a Dress Rehearsal Meeting in Innsbruck. The third mock-up was then tested during a field simulation in the Sahara.

Image 11: Field Simulation (Foto: OEWF, Zanella-Kux)

6. FIELD SIMULATION

Between 1. and 28. February 2013, the Austrian Space Forum (OEWF) conducted an integrated Mars analogue field simulation in the northern Sahara near Erfoud, Morocco in the framework of the PolAres programme (Groemer 2013). The emergency deployable shelter was among the experiments preparing for future human Mars missions, conducted by a small field crew.

The emergency scenarios were tested by the student team and the OEWF analogue astronauts during the analogue simulation mission (Fig.11). The restrictions to be expected from a Mars spacesuit were provided by the Aouda.X spacesuit simulator (Groemer 2012). This 45-kg simulator reproduces all the major limitations to be expected from a pressurized suit during an EVA, such as limited vision, realistic weight, atmospheric counterpressure, high cognitive workload) and allows for continuous biomedical monitoring including video and voice feed to the base station, such as ECG, temperature, respiratory gas composition (CO_2 and O_2) and respiratory rate.

In addition to the 45kg Aouda.X prototype, a simplified version of the suit simulator, Aouda.S was also used. This version weighs only 25 kg and has a simplified biomedical monitoring system.

At all times, the test subjects were monitored by the medial team at the base station in Morocco as well as the Mission Support Center in Innsbruck/Austria. Both analogue astronauts were also supported by dedicated safety personnel at all times during the tests.

Functional usability of the prototype

The prototype was made to fit a number of human activities based on the most likely emergency scenarios during an EVA on Mars. The selected emergency scenarios (scenarios A, B and C) were tested during the simulation:

Ergonomic usability and its adaptability

All scenarios were tested and evaluated according to the following criteria:

- Interaction between the proposed structure and its users (handling and activities in the shelter)
- Off-nominal situations to test the flexibility of the prototype
- Ergonomic and spatial suitability to actions and
- Individual perception of comfort in relation to these activities

Deployment procedure

On-site, the University of Technology student team and the OEWF analogue astronauts tested the following deployment procedures:

- Handling and transportation of the mock-up in packed state and transportation
- Deployment of the structure, including opening the package and inflating the floor membrane
- Deployment of the structure under different topological conditions
- Retraction of the Shelter and

- Function of the pneumatic system

7. RESULTS

The evaluation indicated good functionality of the mock-up. The results were as follows:

Handling and transportation of the mock-up in packed state and Transportation

Although the handling of the packed shelter was not a design criterion at this stage this activity was tested by the analogue astronauts over a distance of ca. 200 m. Rolling of the ‘suitcase’ was possible, although it was recognized that a better means of transportation would be required.

Deployment of the structure

The deployment (pop up) worked as expected and took less than 1 minute. Opening (unzipping) the shelter was tested a number of times. Some difficulties were detected due to the small size of the zip pull tabs. Additional ribbons were then connected to the pull tabs allowing easier use with the space suit gloves. The floor surface (pneumatic cushions) cannot be automatically inflated in the current mock up thus the deployment procedure of the pneumatic floor cushions was not tested due to time constraints. In all of the tests carried out by the analogue astronauts the pneumatic mattress was inflated before they entered the shelter. The deployment on a slope and rocky surface worked well.

Entering the shelter

A stick was used to hold the shelter up in order not to interfere with the EVA suit antenna. The procedure of entering the shelter worked well.

Closing the shelter from inside

The mechanism for closing the zip with the integrated ribbon worked well. The stick used as an aid to enter the shelter was sometimes a barrier in closing the shelter. In addition all parts have to be constructed with high precision in order to work well.

Different Body positions

The prototype was designed to allow functional adaptability including the adoption of the sitting and lying positions for the astronauts. The change between the two positions is achieved through air shifting between two supporting pneumatic cushions, one in front and one in the back of the shelter. The change between the two positions was tested with two astronauts inside the shelter. The mechanism worked well and efficiently. The analogue astronauts reported that sitting in the shelter was very comfortable and allowed them to fully relax. The measurements of the astronauts CO_2 levels (carried out by the ÖWF) support this finding. The sitting height was sufficient. The position of the arm-supports could be increased by 5-10 cm. The ergonomic usability in the lying position, however, was not sufficient. The problem was that the life support system on the back and the antenna did not allow the analogue astronauts to lean back, leading to discomfortable.

Size of the Shelter

It was possible for the non-injured test person to take off the helmet of the injured one. More free space to move and for facilities to allow the helmets to be stored could be implemented in the next prototype. In an unsuited scenario analogue astronauts tested the application of a splint to a suspected tibia fracture, applying a triangular bandage to a broken arm/wrist and the use of a cervical collar after a neck injury. The space was large enough to accommodate these operations.

Leaving the shelter

While getting out of the shelter the astronauts sometimes had to kneel. In the spacesuit simulator Aouda.S it was significantly easier to leave the shelter than when wearing the Aouda.X. . When doing the test after a long EVA (when the suit tester was already a little exhausted), it was more difficult. In that case, Aouda.S had to get out first and then assist his/her colleague getting up.

Retraction of the Shelter

Although retraction of the shelter was not the main design focus, it was tested by the analogue astronauts. The folding procedure was not possible for just one astronaut. For two astronauts it was possible but took too long.

Pneumatic system

The shelter's pneumatic system which enabled the sitting position to be adopted and which inflated the shelter floor to separate the interior of the shelter from the Martian surface worked well. For further development some adjustments will have to be made.

For maximizing user comfort and to prevent undesirable weight redistribution destabilizing the shelter, a more differentiated chamber configuration is needed (additionally, the inner pressure can be increased).

External parts like the control panel and the inflation system have to be integrated in the shelter structure to avoid the need for post-deployment operations from the exterior.

Finally, manually operated actions should be minimized or avoided. If possible all system-related procedures should be automated and controlled using an interface.

8. MEDICAL EVALUATION and UPDATED DESIGN REQUIREMENTS

In the event of an emergency during an EVA it is imperative that astronauts receive immediate assessment and support to help stabilize their health. The MASH design could provide a safe environment to offer this support to an astronaut who has become acutely unwell. Having reviewed the emergency scenarios, fifteen medical issues and human factors that are important in providing a safe environment for astronauts in these scenarios were identified. Four medical issues with the highest level of risk have been examined in detail. Specific recommendations were made for the modification of the shelter's design to address these issues. Recommendations were also made to improve the overall efficiency of the shelter based on the remaining issues.

Several recommendations were formulated by the design and medical review team. The most important issues that can be used as a guide for a future design of the MASH are listed:

1. The shelter is designed to be lightweight and should be deployed in close proximity to a rover.
2. The shelter should be easy to use in a spacesuit, ideally it would be self-deploying.
3. The shelter should at least have enough space for 2 astronauts to lie down.
4. Radiation protection should be considered.
5. Provision of a basic medical kit, airway adjuncts, wide bore cannulas, blood glucose monitor and AED
6. Provision of high flow oxygen at 15L/Min through, and a bag valve mask
7. Inclusion of a compact monitoring system that can monitor an astronaut's heart rate, respiratory rate, core temperature and blood oxygen saturation.
8. Heat could be conserved by using a delivery system that provides heated oxygen. Heat loss should be minimised with equipment like Mylar blankets.
9. Provision of small food bars containing glucose and a water supply for 48 hours.
10. Energy efficient electrical or chemical lighting should offer a good level of visibility inside.
11. Humidified air should be provided by the oxygen delivery system. Suitable materials should be used for maintaining a pressurized enclosure.
12. Materials, such as a garment to absorb urine and faeces for 48 hours could be integrated.
13. The shelter should contain a distress beacon and its position should be easily spotted on the Martian surface.
14. A pressure indicator should be integrated which shows when the shelter is fully

inflated and allows the internal pressure to be monitored

In the dark small lamps and/or phosphorescent elements on zipper sliders and ropes, support stick, and maybe the contour of the shelter, should be included in the design.

15. Provide a pressure seal indicator by e.g. including an electronic indicator to activate a LED light when the zippers from left and right are touching

9. IMPLICATIONS FOR FUTURE RESEARCH

NASA and the European Space Agency (ESA) are working together to design and build the Orion spacecraft and service module. This craft is being designed for deep space exploration missions. Mars is a potential target for this exploration and under the current timeline such a mission would not commence before 2030. Such a timeline allows the MASH team room for modifying the design of the shelter for eventual use on Mars.

As a next step, future designs should be tested in more extreme environments such as sandstorms in the Saharan desert and the low temperatures of the Arctic or a combination of low temperatures, extreme winds and low barometric pressure such as that found on Mount Everest, as a means to simulate conditions on Mars.

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