# PAPER 705

# ESA HABITAT DESIGN WORKSHOP – LESSONS LEARNED

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## ABSTRACT

The consideration of habitability is one of the most relevant issues in designing habitable pressurized spaces for long-duration space missions. It is widely accepted, that habitability issues, such as group composition and interaction, communication, work, leisure and other human activities have direct implications on the success of a mission.

In 2005 the authors were organising managers of the ESA Habitat Design Workshop at ESTEC, NL. It was the first workshop that employed a multidisciplinary mix of participants in an interdisciplinary process for both the organisation team of the workshop and the thirty postgraduate students selected for the workshop. The participants were drawn from disciplines such as engineering, medicine, physics, architecture and industrial design with the task of developing and designing human habitation concepts for the Moon, Mars and Phobos based around specific mission scenarios.

For successful and sustainable human spaceflight, the engineering disciplines must be strongly supported by other disciplines which have knowledge and skills related to human requirements and enhancement of the working environment.  Experts from disciplines such as architecture, industrial design and medicine, social psychology etc. should be included alongside the traditional engineering focused design approach at appropriate stages in the planning and design process. In parallel, strategies for maximising the effectivness of such an interdisciplinary design process should be investigated.

As a first step of this investigation, the ESA Habitat Design Workshop 2005 is presented as a case study to evaluate the effort of multidisciplinary teams in the development and output of innovative habitat solutions for Moon, Mars and Phobos.

For Europe to go beyond Earth orbit and enable human exploration of the Moon, Mars and beyond, the space community must embrace the complexities of human space systems. This means we must explore and understand the complex interactions between humans and their environment, human-human interactions as well as the technological and logistic complexities involved in space missions.

Those who will face the challenge of stepping away from Earth to explore the solar system are currently studying at schools and universities, or are just beginning their careers. Thus, the challenge over the coming decades is to create and execute a sustainable program of exploration, utilization and settlement of the solar system. This challenge is inherently interdisciplinary, meaning that science and technology developments go hand in hand with economics, industry, politics and society.

## WORKSHOP ORGANISATION

Supported by ESA's Aurora Exploration Program, the 1st Habitat Design Workshop was a week-long event, hosting thirty post-graduate students and young professionals from a broad range of backgrounds and nationalities in ESTEC's Erasmus Centre during the first week of April, 2005.

The Habitat Design Workshop Team comprised of 10 post-graduate students, doctoral researchers and young professionals from many countries, with diverse backgrounds but united by their shared passion for space[1]. Together they endeavour to further the efforts of returning to the Moon and the first manned missions to Mars by actively preparing via stimulating research into various aspects of human exploration of the solar system via design workshops, symposia and seminars and their personal works.

## DESIGN PROCESSES CONSIDERATIONS

This section briefly describes the main approaches, that were included in the development and final implementation of the workshop.

<u>Engineering approach to habitat design</u>

The very phrasing of the engineering approach to habitat design undercuts its position with respect to other approaches to habitat design. A very important distinction to be made here is that 'engineering', is a way of approaching a problem and not a discipline in of itself. To be sure there exists separate disciplines such as aeronautical engineering, civil engineering, maritime engineering etc., but their key feature is what they share: a way of thinking towards a (design) solution.

The current dominating approach to space mission design is historically linked to a process of design from the aviation industry. The approach, known as systems engineering attempts at bringing all constituent elements of a space mission together into a holistic design.

Within this approach the mission goals, i.e. the design drivers, are translated into system and sub-system requirements which serve to constrain the design. Priority to different requirements is determined by a trade-off process, throughout the design process, implementation and impact of which diminishes with progression through said process.

In past human space flight missions, the characteristics of the inhabited environment were strongly constrained by traditional requirements including launch bay volume, mass restrictions (due to launcher and cost of mass per orbit), power, insertion into orbit, mission lifetime, drag (in LEO missions), etc.

Efforts of engineers are perennially focussed on making all parts, of a system or project, work together in the most efficient and economical way. However, traditionally, requirements of the most important 'part' of human inhabited space systems, the human, were missing, leading to problems later on when the system, i.e. an orbital station, was used.

Satisfaction of requirements, such as safety and reliability, does not assure an adequate habitat; both form and function need to be considered, especially when considering the extension of the space mission duration.

Thus, the critique of the traditional systems engineering approach is twofold. Its focus on constraints and requirements at the outset of the

[1] refer to CONTACT DETAILS at the end of this paper

design process has been too narrow, excluding those that focus on human factors. One can almost state this approach has become standardized to the extent of being formulaic (see Space Mission Analysis and Design, 3rd edition, Wertz and Larson) omitting other design criteria which may be important for the execution of long-term human spaceflight such as that needed for Moon and Mars missions. Conventionally, technical and technical operations requirements are included whereas human based operational requirements and human needs, which contribute to the efficiency and well being of the crew have been backgrounded.
Furthermore, this means a lot of possible out-of-the-box options are not included in the first design phase, since the same constraints/requirements approach to defining a space mission does not change (it has become standard) excluding some of the out-of-the-box possibilities. One could argue that this is mirrored in human spacecraft and habitats that have been launched to date (tin-can modules

These possible limitations stimulated the organization team to explore the possibilities of extending the systems engineering approach to include other criteria which traditionally have been explored by other disciplines such as medicine, architecture, industrial engineering etc.

These have been explored to some extent in long-term space flight programmes such a Salyut, MIR and in isolation studies such as SFINCSS-99.

Moreover, from Salyut to the ISS we have seen an increasing number of non-military users (inhabitants) of orbital stations and increasingly from many different fields of scientific research. Many of these experts receive only a short period of training in how to deal with, and work in, an extreme environment. For effective use of such space stations, habitability is becoming more relevant. However it is evident that all efforts spent on improving habitability aspects of the ISS where focused after the main configuration definition.

Thus, intuition tells us that involving multi-disciplines for systems design of a space habitat ensuring that engineering thinking encompasses not just 'engineering' criteria but also those related to habitability and functionality of habitats such as determined by industrial engineering and architecture, along with medical disciplines in addition to natural science disciplines (for reasons of research in space exploration) could make improved habitat concepts.

Before exploring some of the other approaches and criteria we decided to include in the systems engineering of a habitat design, we will discuss in brief the concurrent engineering design approach to mission design. Concurrent engineering provides a basis in which many different design approaches, disciplines and evaluation criteria can be included in a design exercise and was the fundamental approach taken within the Habitat Design Workshop 2005.

## Concurrent Engineering (CE)

Concurrent design originated in the field of product creation processes in order to create the best products by reducing costs and time-to-market by speeding up the process of design, thus beating competition. This system has been adopted to manage the innovation of complex products, avoiding the cost due to the sequential process of design, in case of failures or change in the predefined requirements.

Still today, in order to manage innovation in the process of design it is important that all disciplines are involved in the process from the very first step. This can be considered as a valid approach of design not only for economical or marketing reasons but also for the following reasons:

- The use of a concurrent approach can avoid large setbacks in case of failure or can avoid continuing to the next phases of the project with sub-optimal solutions. In the specific case of the habitat, the experts cannot be involved later, when the main architecture has been defined, but they can concur from the earlier phases in the habitat definition. This assumption is strengthened by the fact that with the increase of the mission duration the human factors cannot be ignored.

- Adopting a concurrent design approach, distributed among different disciplines, allows not only for a better data transmission, but also a greater circulation of experience and knowledge among different disciplines at a crucial stage in the development of a human space mission. Data and knowledge communication is necessary to increase the interdisciplinary view of the problem and this can stimulate the creative solutions to the complex problem of designing for human inhabited systems.

- The human being is a complex system and to address this complexity requires experts from many different fields. Having expertise in life support systems alone is not enough to support all the human needs during a mission. Moreover, this complexity needs to be addressed at the earliest possible stage of the design process in order to avoid limiting human related aspects of the design, in essence a sub-optimal design and thus a sub-optimal space mission.

CE is "a systematic approach to integrated, concurrent design of products and their related processes, including manufacturing and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life-cycle from conception through disposal, including quality, cost, schedule, and user requirements" (Larson, W.J. and Pranke L.K., (1999). Human Spaceflight, Mission Analysis and Design, McGraw-Hill, ISBN 0-07- 236811-X )

In addition, concurrent engineering is part of the Aurora programmes approach to mission design and thus is interesting to explore further development of the approach for use within the Aurora programme.

In the following subsections, we will explore some of the insights gained from other design disciplines (Product design and architectural design) along with other aspects to be included in the concurrent engineering approach to Habitat design.

<u>The Product design approach</u>

The basic design cycles of product design, have been deeply studied by many authors. Roozenburg & Eekels describe the basic design cycles such as "trial-and-error process that consist of a sequence of empirical cycles, in which the knowledge of the problem as well as the solution increases spirally". This cycles is similar to the problem-solving model of the System Engineer (Hall). Both cycles can be considered as an implementation of the Empirical Scientific Cycles (Groot) which derive from the most generic empiric cycles.

Market maturity, improvement of connectivity and globalisation are just few examples of drivers that have caused an adjustment in the working procedures of industrial designers.

The today increased complexity of most of the products has affected the working approach of industrial designers, generally pushing toward a multidisciplinary methodology. Preliminary brainstorming among experts from different disciplines, visualization of the process, virtual prototyping and mock-up building are basic steps in this framework.

A design of space habitat can benefit from a product design approach also because a habitat can be conceived like a product. Like a product, a habitat module for space has a certain weight, predefined life cycle, must consider its relation with the external context and user-operations should be evaluated thoroughly. The attention on human factors in a user centred design approach is another important aspect of the design that can give a relevant contribution in habitat design of space.

Beyond this, insights from interior design could be considered as a significant contribution towards habitability and for volume optimisation.

<u>The Architect design approach</u>

As comprehensive the topics of architecture are, the multifaceted and complex are the role of an architect.

One task and ability of an architect is to preview humans within a built environment. Architects not only think of HOW a building could work, but also WHY it works in a certain way. This is very important as both humans and the environment are in a reciprocal relation to each other.

Usual fields of work include but are not limited to designing and planning for building construction, construction management, cost control and facility management. As - depending upon the size of the building project - the collaboration with various specialists e.g. structural engineer and experts in transport planning, urban designer is required, the architect needs high ability in communication- and coordination strategies.

The architect combines mechanical and structural engineering with Know-How and Experience from other fields, like sociology and psychology and applies it to the construction of human inhabited spaces.
Communication and Interaction with experts from various disciplines is not only promoted while being educated, but a must in contemporary working processes.

To date, the architects' role is becoming more and more important in space mission design. Based on the experience made and relating to future plans of the human space program, Human Factors and Habitability have become major design drivers for space missions.
In the early days of the Space Shuttle and Space Station, David Nixon and Marc Cohen, were one of a handful architects, who were involved in the US space programme.
In the second half of the 90s, Constance Adams and Kris Kennedy where involved in incorporating architect design approaches to the development of Transhab.

The LIQUIFER Systems Group (LSG), Vienna [2] was established in 2004 with the objective of creating a multidisciplinary task force that could take on space systems design and engineering projects for the European Space Agency (ESA) and the European Industry, at all levels of complexity.

The LSG uses the Systems Design Engineering (SDE) methodology for problem articulation and problem solving. Unlike methodologies employed by traditional engineering disciplines that use a specific domain of expertise, SDE is characterized by its philosophy and approach to solving problems that are intrinsically multi-disciplinary.
The SDE methodology broadly encompasses:

(1) Definition, analysis and modelling of complex interactions among various components comprising a natural (e.g. eco-system) or artificial system (e.g. spacecraft), (2) Design and implementation of the system with creative and efficient use of resources.

The LSG comprises of a core group of experts based in Austria complemented by an external group of consultants based in Europe/ESA. [3]

This recent experience in involving architects from an early stage on into the design process, leads to an improvement of space habitat design.

Space Architecture - as Architecture – provides a multidisciplinary perspective, implicating the collaboration with experts from various fields, such as Structural Engineering, Science, Design, Physiology and Psychology.

<u>Science, Technology and medical criteria for the concurrent engineering project.</u>

Previous human space missions to other celestial bodies have been initiated and maintained by political drivers (Cold War). Currently, arguments for an orbital space presence have been articulated as science, technical or economic based.
For the first steps in a sustainable exploration and settlement of the Moon, Mars and beyond, there is little argument that 'political will' will drive the programme. However, unlike the first missions to the Moon where a footprint was the key goal of the mission, science and technology research will now have to serve as the main constituents of a human space flight programme if the political will is to be sustainable.

For the Habitat workshop designs, this means that the inclusion of scientific and technical objectives (as well as political) would be advantageous. A good example of this would be the inclusion of medical aspects into the design criteria (how to maintain a healthy astronaut for the duration of the space mission) as well as making them part of the scientific goals (understanding the role of various physical and socio-psychological forces on human behaviour, metabolism and physiology).

Now we have run through some of the design approaches and criteria we wish to explore, the

[2] Projects include: Human Mission to Mars (HMM): (Interior) Configuration Options, Habitability and Architectural Aspects of the Transfer Habitat Module (THM) and the Surface Habitat on Mars (SHM) (ESA/ESTEC CDF-TN-030). Paris, France: European Space Agency.

[3] A full list of members can be found via www.liquifer.at

following section outlines the workshop concept and aims.

## INTERDISCIPLINARY WORKSHOP CONCEPT

Traditionally, the design process has employed a linear 'over the fence' mentality, whereby the engineers would create a design capable of fulfilling the primary objective after which architects and industrial designers would attempt to modify this design to accommodate their needs as well as scientists trying to fit in their needs within that existing framework. This approach to design can lead to counterproductive results.

The human being is a complex system and to manage this complexity requires many experts focused on different fields.

The First Habitat Design Workshop was organized in an effort to demonstrate, learn about and foster a new interdisciplinary design process in a hands-on way by bringing together young people just starting their careers from disciplines such as: engineering, natural sciences, biomedicine, architecture, industrial design, psychology, physiology etc.

This interdisciplinary approach offers the following advantages:

- It provides a greater circulation of experience and knowledge among different disciplines at a crucial stage in the development of a human space mission.

- It can avoid large setbacks due to insufficient consideration of mission related aspects

- By having all these disciplines present from the very beginning, a human space mission focused concurrent design process could be developed ultimately leading to strong, novel and feasible habitat design concepts.

- As a consequence the participants as well as the management of the workshop would benefit greatly as they would exchange skills and ways of thinking, different ways of approaching problems and return to their respective fields and industries armed with a new and more effective approach to design.

This paper seeks to review the design projects by evaluating each design from the various disciplinary perspectives but also the workshop organization, management and implementation.

## WORKSHOP OVERVIEW

1. The Selection:

30 applicant were selected according to provide a balance in disciplines, nationality and gender.

2. Selection of Mission-Scenario

The Workshop Management prepared five scenarios, two for the Moon, and two for Mars and one for Phobos. The Participants applied for a specific scenario.

3. Preparation of Students for the Workshop

After the Selection, each Team started to work via Internet .Providing pre-workshop reading material proved very important to assure a minimum homogeneous level of knowledge of the participants with different backgrounds.

4. Expert lectures and interaction

A number of experts had been invited to give talks on topics relevant to the workshop. The presence of these experts was to ensure a running start for the participants, familiarizing them with concepts from different disciplines and to provide feedback during the design process.

5. Team Working at the Workshop

Refining the scenarios was a challenging phase. Providing a brief description of scenarios was helpful as a start, and allowed the members work together from the beginning in refining the scenario and allowed the teams to break the initial communication barriers, improving the results of the design phase

6. Definition of Mission Objectives

Each group defined the objectives of the mission and the characteristics of the major subsystems (power, life support system, radiation protection, dust removal, telecommunication…) needed to achieve the mission. Concurrently the main objectives of the mission also lead to characterization of the functional distribution of the inner volume .

6. Schedule daily comparison session

A daily session of group reviews was scheduled which allowed for a step-by-step look at the development of the design projects.

7. <u>Early Prototyping</u>
Keeping in mind the concurrent design abilities of the different professions, the organisation team encouraged “early prototyping” in the form of small models, drawings and even 1:1 experiments from the beginning.

8. <u>Final Presentation</u>
At the end of the week, students presented their results to a jury composed of ESA staff, industry representatives and external experts and Habitat Design Workshop organizers[4].

**REVIEW OF DESIGN PROJECTS**

This section provides short summaries of the proposed mission scenarios, main aspects of the designs and a review, in terms of the main approaches involved, as well as with respect to the collaboration within the teams, i.e. the interdisciplinary features of the design process.

**Project Moon 1 – Fram**

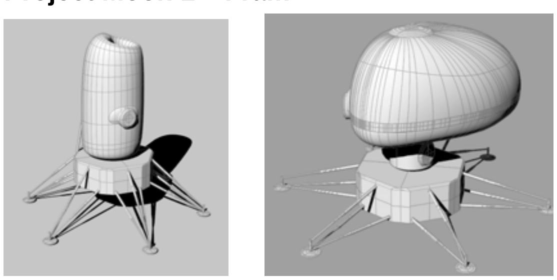


*Fig. 1Deployable Habitat using Inflatable Technologies*

<u>MISSION SCENARIO</u>
The first of a series of missions to place a permanent base for humans on the Moon within 10 years. Minimal mission duration of 3 months. The double goal of the mission is to carry out scientific activity and to dedicate part of the crew time to Public Relation and filming, as important source of funding.

<u>MAIN DESIGN ASPECTS</u>
Focus on social and cultural aspects in the habitat design is translated into a two-floor design that is partially open without separation in order to give the crew the most spacious living conditions possible.

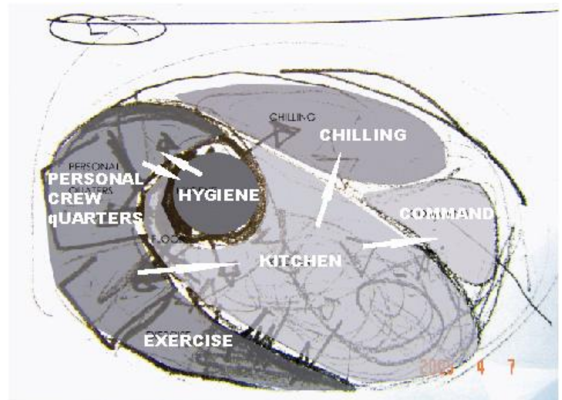



*Fig. 2 Relation of the different Functions to each other*

The habitat design is also planned to be flexible not only as a single unit, but for future expansion when additional modules are added to a web like “Moon town” where different modules can be specialized into certain functions like a module allocated solely for living or science

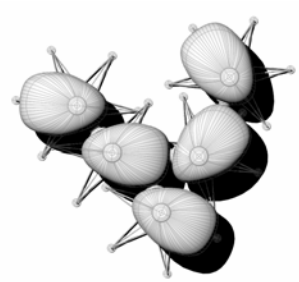


*Fig. 3 Expansion Strategy*

The project refers to technologies with a high TRL: Melissa derived system for Life Support, Inflatable material and radial deployment system (Transhab derived), Aluminium for core material (like ISS), and Nuclear power production (already flown in Russian satellites).

<u>REVIEW AND LESSONS LEARNED</u>

<u>Architecture and Design</u>: Moon1 team provided a clear presentation of their concept with references to social design components, bridging the gap between the technical feasibility and human factors.

[4] Refer to CONTACT DETAILS at the end of this paper

One focus was laid on translating the social and cultural aspects into the habitat layout. The proposed layout offers a lot of freedom for reconfiguration using inflatable technology

The proposed structural system featuring inflatable modules seems appropriate in terms of meeting the requirements and habitability. However this innovative technology could have been exploited further to improve the spatial configuration of the habitat. Shielding the light habitat structure seems to be one of the technical challenges.

Proposing an expansion plan in the design concept is a positive effort, yet in a next phase it would need to be better integrated to the structural and spatial concept.

<u>Engineering and CE aspects</u>

The team succeeded in implementing a concurrent design approach beyond the traditional engineering by including psychological and social aspects. They included present day technologies as part of the design, which, although not all of them are space tested, reasonable for a 1st generation lunar base.

Power, life support, structure, mass and volume considerations also feature prominently in this design.

The strategy for expansion is interesting and the use of inflatables is also attractive in the design,

Design concept is a little bit like the Apollo lander with added inflatable for increased habitable volume.

In a next phase the group would need to provide reasons for expansion, as this was hardly argued. Another Critique and action point was the little use of resources near to the landing site of the base.

<u>Science, technology and medical aspects</u>

According the mission scenario science and PR were to be the main goals, however the habitat design seems mostly focused on the human factors. Science and technical aspects to the mission remained on the back burner, due to the focus on social and cultural aspects. This is understandable, but the total avoidance of a scientific programme even though it was stated in the mission scenario as a driver is disappointing.

The heavy emphasis on socio-cultural as a driver for the habitat complex makes it a little unfeasible for a 1st stage lunar base, and is not sufficient reasoning for expansion of the base. More argumentation for the socio-cultural focus is in order, or further development of a basic science package and reason why the base should be expanded. In summary, more attention could have been paid to investigate what kind of scientific activity should/could and how this impacts the design.

**Project Moon 2 - Kubrick**

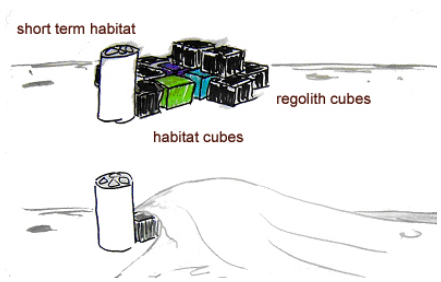



*Fig. 4 Expansion strategy*

<u>MISSION SCENARIO</u>

The design scenario is based on the establishment of a permanent human presence on the moon. The module should enable a crew of 6 to 8 to live and work on the moon, in the South Pole region.

<u>MAIN DESIGN ASPECTS</u>

A number of design objectives were created in order to steer the design towards certain goals:

To develop a novel construction system and radiation shield using modular elements and in-situ resources

To implement a settlement system, which allows for modular, flexible, and expandable in-situ resources based enclosures

Two different habitats are proposed:

A short term habitat with a standard “tin can” approach which provides ~40m3/person;

A long-term habitat that provide a volume of ~90m3/person.

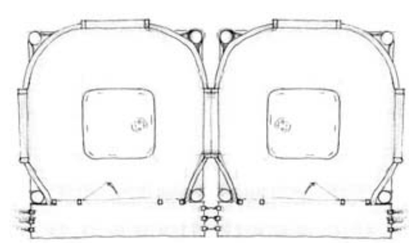


*Fig. 5 Joined Habitat Modules*

A simple expandable cube is devised that could serve as the support structure for such an inflatable. The concept derives from a crushed box that can be expanded by twisting the entire assembly.

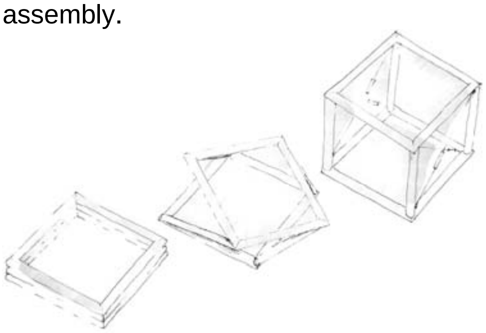


*Fig. 6 Kubrick's unfolding concept*

REVIEW AND LESSONS LEARNED

Architecture and Design:
The work of Moon 2 concentrates on developing a structural system with its basic unit rather than proposing a habitat design.
The idea of using a foldable basic structural element in connection with local materials that can function as a construction material and habitable spaces is promising. However this innovative structural system needs to be adequately detailed and integrated into a well defined design concept, in order to demonstrate its advantages in transportation, shielding, habitability, spatial versatility etc.
The use of prototypes was particularly impressive in this team, from small table-top models, to larger basic constructions where they could climb in.

Engineering and CE aspects
The development of a two-stage strategy was a definite plus. The use of in-situ resources in the form of a sandbag approach allows for establishing a lunar presence with proven, off-the-shelf technology and demonstration of an innovative structural system with many applications. The concurrent design approach worked well which was visible in the step-by-step approach.
Although the structural system is conceptually very strong, an investigation into the immediate use of it beyond a radiation shield would be promising for the next phase . As a radiation shield the technology seems very promising although interfacing the blocks with the primary habitat as well as any sub-system (such as electrical, life support) did not receive any attention.

In addition, the focus on the basic building block disregarded many of the aspects within the mission scenario including the reasoning why they targeted the South Pole.

Science, technology and medical aspects

The main focus of this team was on developing the structural system and determining its applications, which was valid given that the mission scenario only called for establishing a lunar presence. As such the habitat, in its current form, would serve best as a demonstration of the concept.[5] The science part was left out of the design entirely. (e.g. Lack of use of other in-situ resources (other than the regolith)

**Project Mars 1 - Elysium Base**

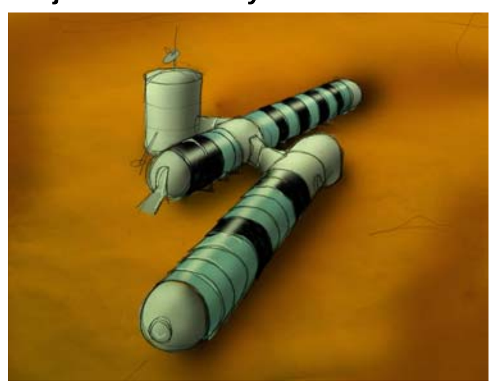


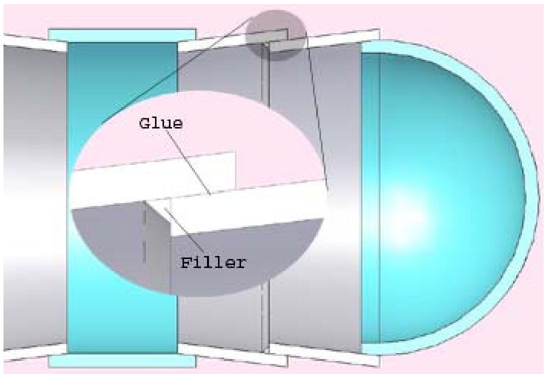
*Fig. 7 Habitat external view*

MISSION SCENARIO
Mars 1 presents a novel concept to provide the astronauts with a large, comfortable habitat on Mars, while launching a small, lightweight habitat from Earth. The small habitat will be extended on Mars by the astronauts using In-Situ Resource Utilization (ISRU).
Mars 1 proposes an ISRU plant must be landed before the human mission to collect the required soil and treat it if clear glass is desired.

MAIN DESIGN ASPECTS
The proposed habitat will have a cylindrical shape and will consist of three parts: semi-spherical aluminium end caps, an aluminium cylindrical middle part and a cylindrical part made from locally produced glass. The semi-

[5] Such a demonstration could perfectly well be carried out on Earth.

spherical end caps and the aluminium middle part will be launched from Earth and contain all equipment, interfaces and docking ports. The cylindrical glass part will consist of a number of cylindrical segments that are made from the regolith.




The cylindrical parts will be combined and placed in between the two semi-spherical end cabs. In this way a spacious habitat of more than 200 $m^2$ can be constructed with only a single shape of locally produced constructive elements.

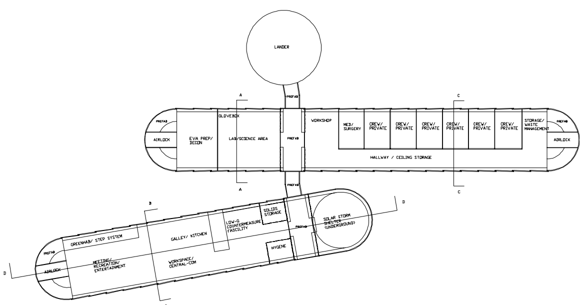



*Fig. 8 Plan view*

## REVIEW AND LESSONS LEARNED

Architecture and Design: Mars 1 focused on the proposed technology to produce the glass structural components and presenting a basic structural layout for a habitat. A detailed study provided with the concept presents the technical feasibility of this uniform design, based on cylindrical glass modules, while leaving the broad range of structural alternatives, thus, rich spatial configurations aside. The idea of creating a sturdy and transparent outer shell with local material around the inner layout is fascinating and fundamentally a good solution in such an extreme environment. Taken as a demonstration of an innovative structural technology, the work of Mars 1 can lead the way to further structural concepts utilizing the in-situ resources.

Engineering and CE aspects:
One criticism on the process, rather than final design, would be the almost immediate polarization on one design, proposed by one group member  Broader exploration of options would have been preferred with a trade-off phase. Other than this early polarization, the team performed well, exploring some of the interior designs leading to a strong, well-balanced design, the main concept which allowed for a more in-depth investigation of to be used future technologies, internal/external layouts and habitat sub-systems. Although the key technology, that of ISRU glass moulding, would be a tough sell as a first Martian presence technology, human factors did receive a great deal of attention because of it.

Science, technology and medical aspects :
Other than the ISRU fabrication technology, which is quite an endeavour in itself, the science aspect did not receive a lot of attention. Again the main reason seems to be that the team focused on establishing a first presence that could be expanded upon, with all other possible mission drivers were left on the back burner or ignored totally
In their final report it was stated "*Science would be catered for by a comprehensive array of tools including capacity for deep drilling*". Further elaboration in the design and possible scientific objectives are needed if an appropriate design of the base is to be developed. For example, if the scientific objective is to look for signs of life, or to explore the geology of Mars, then one would assume a sample-loading bay, separate compartments to avoid cross contamination etc. would influence the design.

**Project Mars 2 -**

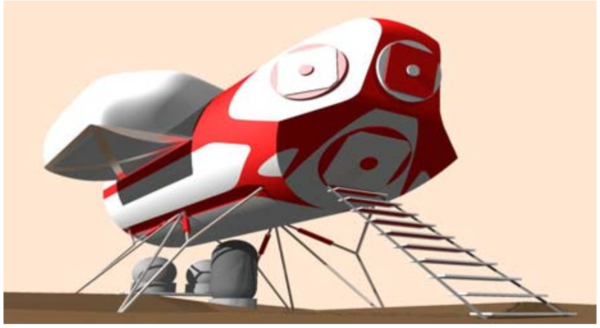


*Fig. 9 Rendering of Habitat*

MISSION SCENARIO

For the first manned mission to Mars, Mars 2 proposes the establishment of an expandable core unit for the exploration of Mars at an equatorial landing site. Effectively this will be the 'seed' mission for the development of a constantly manned and maintained settlement. The core unit is designed to allow for easy expansion in a variety of ways. The duration of the first crew rotation will be one synodic year, and their outpost will be a stationary base.

MAIN DESIGN ASPECTS

The design went through a series of phases; Inflatables were utilized in the final design. Windows were considered vital in the design of the habitat.

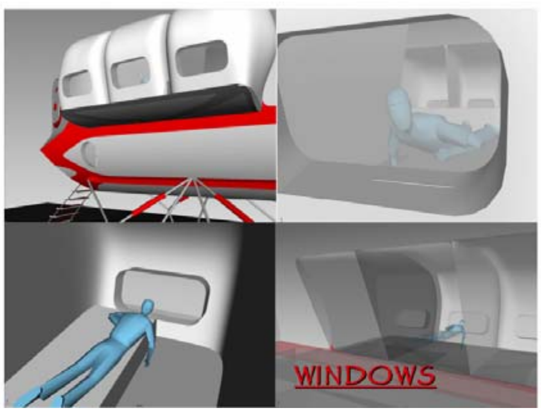



*Fig. 10 Illustration of Windows in the Crew quarters*

During the entire development of the habitat design, safety was considered to be of prime importance. Both the internal design of the habitat and the honeycomb-like nature of the base after expansion allow for the sealing off of any area hazardous area in the event of an emergency, leaving all remaining areas accessible.

The concept allows expansion of the habitat based on the core unit.

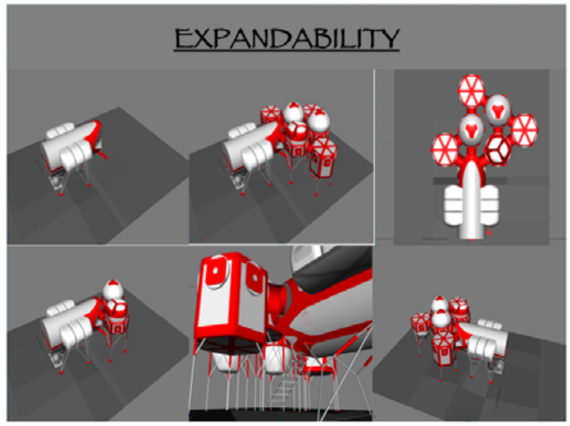



*Fig. 11 Expansion Concept*

REVIEW AND LESSONS LEARNED

Architecture and Design: Based on conventional prefabricated modules, enriched with inflatable extensions, Mars 2 Team proposes a refined concept using current technology with a reliable expansion system. Though the structural approach is not the most innovative one, the smart internal layout, use of inflated extensions for spatial flexibility and the well-defined expansion concept shapes this good functioning Mars habitat.

The phases, the habitat will go through are basically defined and the changing spatial layout in connection with the expansion concept is demonstrated. The shielding of the light structure is as usual a technical challenge to be solved. The clear objectives and a decisive approach led Mars 2 team to present a detailed design concept professionally. Various layouts considering the flexibility in function of the station can be studied on as further work.

Engineering and CE aspects:

A great design. The team gelled very quickly and implemented architecture, engineering, science and medical aspects early on. Schematics and function plans were worked out first and then many concepts for achieving these functions were developed together. A lot of time was spent on conceptualising the internal and external design and although the team converged perhaps too quickly to a baseline design, mainly due to graphic modelling efforts

of some team members which meant a large investment into a single design rather than playing with a number of concepts.
The final design included expansion (as the mission scenario outlined) Safety issues were placed high on the list of functions, and various egress points and ways of isolating parts of the habitat complex were integrated well.
The team carried out a well argued step-by-step approach where engineering and human factors requirements were met equally. Imagined as a seed mission, the habitat design not only reflects the unsurprising first presence goal, but also the team members' willingness to allow for interdisciplinarity to take place. In that light the design is perhaps a bit bland, betraying no specific purpose other than being a shining example of concurrent engineering.

Science, technology and medical aspects:
The science aspects where incorporated early in the list of functions of the design team, although the main goal of the mission was Mars exploration. One can see the result in the elevation of the habitat on legs to minimize the possibility of cross contamination, which may pollute the environment and thus improves the search for (signs of) life in the surface of Mars. A little more investigation into the types of exploration and mechanisms of doing so would have improved the design, adding more functionality.

**Project Phobos**

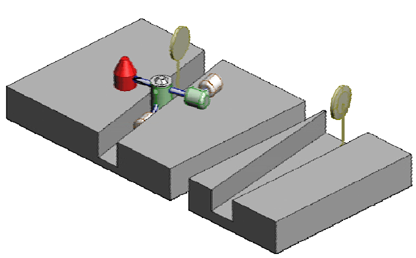


*Fig. 12 Final configuration of the Phobos Habitat*

MISSION SCENARIO
The scenario for this project is a scientific base on Phobos. Due to the hostile Phobos environment, the habitation module is assembled and in operation before the crew arrives.

MAIN DESIGN ASPECTS

The final set up of the base includes multiple prefabricated cylindrical modules set up in a groove on Phobos.

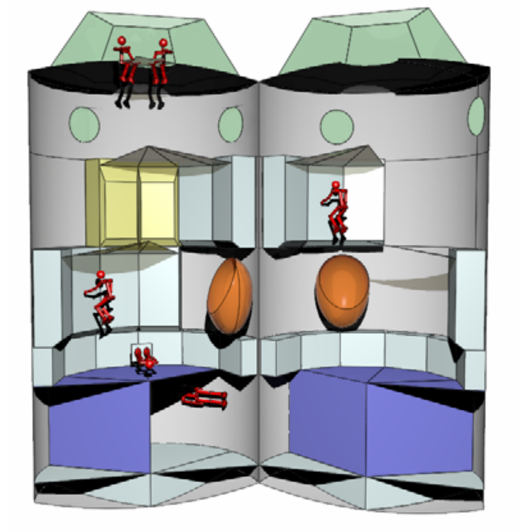


*Fig. 13 Internal configuration of the Habitat*

Additional inflatable structures can be added to docking ports. The habitat is made up of several layers. Spider web configuration provides flexible space. Large numbers of combinations with the use of multilayer foldable screens are possible.

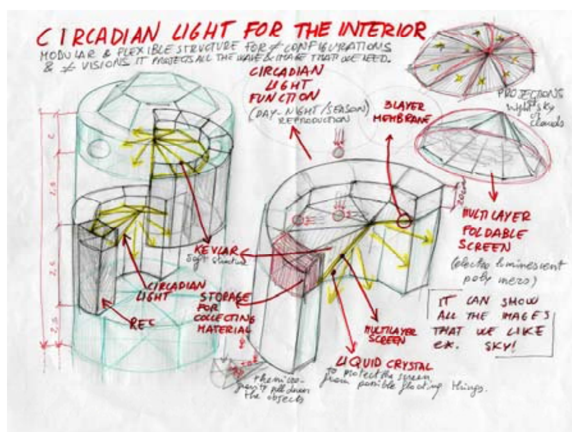



*Fig. 14 Circadian Light for the Interior*

REVIEW AND LESSONS LEARNED

Architecture and Design: The design concept of the Phobos team is constructed on the off-the-shelf technologies, thus presenting a technically reliable but less innovative solution to the habitat design problematic.

The team presented innovative ideas for the interior enclosed in a conventional structural system, demonstrating an impressive effort in a formally limited scope.
The team worked on human motion in microgravity to construct a spatial concept for the habitat interior, which is a defining factor in this environment. Expansion concepts within the possible growth models in the exploited topography of Phobos can be a further focus point for the future work on this concept.

Engineering and CE aspects:
Unlike the other teams, the Phobos team faced the challenges of the microgravity environment and developed the design concept on conventional prefabricated modules, placed in grooves on the surface of Phobos thus minimizing the exposure to the radiation generated by the nuclear power plant.
The team had many problems in progressing with a concurrent approach to design. The engineers dominated and this polarized the design approach after 2 days of no progress due to frictions between disciplines. Moreover, due to the specific constraints of the Phobos environment, engineering requirements were considered more stringent than others. This hampered the concurrent design effort.
The team overcame the disciplinary boundaries but still the engineers dominated and one can see this reflected in mission and exterior designs.
Nevertheless, the team did manage to find a compromise along the way, but mainly in terms of interior habitat design. Novel features such as foldable screens for visual display and a short-arm centrifuge for combating micro-gravity effects, were the result.
Integration of the base into a larger programme for exploration of Mars was attractive in addition to their plans for expansion.

Science, technology and medical aspects:
The science aspects where embedded quite early on in the design process. Exploration of Phobos and long distance reconnaissance of Mars was a key aspect. Further development of life support systems and microgravity effects on human physiological systems was also integrated, and a major driver of the whole concept.
Using the base as an astronomical platform was also discussed, although exploration of the effect of the Martian atmosphere on such an observatory was not explored.

## CONSIDERATION ABOUT INTERACTION

However, during the workshop a number of observations have been made with respect to interdisciplinary interaction.
- Where engineers tend to follow a rather linear step-by step approach, architects and designers, like to ‘skip ahead’ in the design process and peak at what the design could be like in its final incarnation. Theirs is a more visual, conceptualising design process that can stimulate new and unorthodox ideas.
- It has been argued strongly that inclusion of other human factors related disciplines in the design process, from the very start is pivotal for a well balanced design that caters to all needs
- New working approaches and strategies should be tested and explored to find the optimal cooperation between the disciplines. Interdisciplinarity is the key in the overall design process, but due to specific profession might not be required at all stages.

## CONCLUSION

The added value of this Habitat Design Workshop is the combination of analysis and design of habitat concepts from combined perspective from systems engineering, natural sciences, architecture, design and human factors perspective.
Reflecting the multi-disciplinarity needed for the development of extraterrestrial human habitats, the participants comprised of students from disciplines such as engineering, medicine, physics, architecture and industrial design.
The Habitat Design Working Group believe that overcoming the challenges of a sustainable program of exploration, utilization and settlement of the solar system, an interdisciplinary approach to extraterrestrial habits is promising for success but successful integration of the multiple disciplines into a design needs to be explored further, and the interdisciplinary design method shows promise over the linear (over the fence) method of integrating multiple disciplines.

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The participants of the 1st Habitat Design Workshop are listed below.

Moon 1: Arno Wielders (Physicist, Engineer, NL), Jesper Jorgensen (Psychologist, DK), Julia Tizard (Physicist, UK), Anja Fischer (Architect, DE), Stefano Zanini (Designer, Ergonomist, IT), Hanna Västinsalo (Biologist, FR)

Moon 2: Nils Pokrupa (Space Engineer, CA), Rachel Beth Tullet (Medical Doctor, UK), Emanuele Tracino (Physicist, I), Serena Olivia (Industrial Designer, IT), Mehmet Cevdet Erek (Architect, TR), Horst Philip (Artist, AT)

Mars 1: Bas Lansdorp (Mechanical Engineer, NL), Eirik Sonneland (Bioninformatics, NO), Maria Gurtner (Physicist, G), Guy Michael Murphy (Architect, AU), Kristian von Bengtson (Architect, DK), Olathe Jean Clark (Biologist, CA)

Mars 2 : Gabriele Messina (Aerospace Engineer, IT), Nathalie Pattyn (Medical Doctor, Psychologist, BE) , Emily Mac Donald (Astrophysicist, UK), Nina Mair (Architect, AT), Nils-Peter Fischer (Architect, DE), Julien-Alexandre Lamamy (Space Systems Engineer, FR)

Phobos : Lars Jonas Jonsson (Space Engineer, SE), Laura Parker (Space Engineer, UK), Gaelle van de Steen (Physicist, BE), Rene Waclavicek (Architect, AT), Irene Schlacht (Industrial Designer, IT), Mark Sliphorst (Aerospace Engineer, NL)

## REFERENCES

The Pre-Pack for the Students included an extensive List of References and Projects. Listed below is only a Selection.


- Adams, Constance, 1999-01-23137 Habitability as a Tier One Criterion in Advanced Space Vehicle
- Connors, Mary M.; Harrison, Albert A.; Akins, Faren R,Living Aloft: Human Requirements for Extended Spaceflight (1985), http://www.hq.nasa.gov/office/pao/History/SP-483/cover.htm
- Eckhart, Peter, The Lunar Base Handbook, An Introduction to Lunar Base Design, Development and Operations, 2000, Primis
- Wiley Larson, Pranke, Linda K. , Human Spaceflight: Mission Analysis and Design; (1999 October). New York, New York, USA: McGraw-Hill.
- Man-System Integration Standard, Vol. 1, NASA STD 3000, Rev.B (1995), NASA-Johnson Space Center, Houston, TX
- Wendell Mendell, (Editor), Lunar Bases and Space Activities for the 21st Century , Lunar and Planetary Institute Conference Proceedings, Houston
- ESA/HUMEX: Study on the Survivability and Adaptation of Human to Long-Duration Exploratory Mission; SP-1264; November 2003; ISBN 92-9092-976-6
- Final ESA/MMW Report.


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## THE HABITAT TEAM

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Invited external experts were: Bernard Foing, Enrico Gaia, Barbara Imhof, Christophe Lasseur, Susmita Mohanty, Petteri Nieminen, Guerric Pont, Stephen Ransom, Andreas Vogler