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CONCEPTS FOR 1ST GENERATION HYBRID AND INFLATABLE HABITATS WITH IN-SITU RESOURCE UTILISATION FOR THE MOON, MARS AND PHOBOS:
RESULTS OF THE HABITAT DESIGN WORKSHOP 2005

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ABSTRACT

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. The challenge over the coming decades is to create and execute a sustainable programme of exploration, utilisation 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.

The Habitat Design Working Group is a postgraduate led programme of interactive, international and transdisciplinary projects, which aims to get undergraduates and young professionals actively involved in MoonMars projects, workshops and other related events. This paper presents the results of the first of these activities: an 8-day long Habitat Design Workshop, held at ESTEC, the Netherlands. The workshop, bringing together 40 postgraduate students and young space researchers from across Europe, contained expert lectures covering subjects like the Moon/Mars environment, systems engineering, architectural design, human factors etc. and culminated in a design exercise which lead to the development of design concepts of Lunar, Martian and Phobos habitat.

This paper gives an explanation and discussion of developed habitats and scenarios that integrate new technologies, materials and strategies underlining the features of sustainable concepts through detailed discussion and illustrations.

The added value of this Habitat Design Workshop is the combination of analysis and design of habitat concepts from a systems engineering and natural sciences perspective with an architectural 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 programme of exploration, utilisation and settlement of the solar system, an interdisciplinary approach to extraterrestrial habits is essential for success.

INTRODUCTION

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.

Supported by ESA's Aurora Exploration Programme the 1st Habitat Design Workshop was a week-long event, hosting thirty post-graduate students and young professionals from a broad range of backgrounds in ESTEC's Erasmus Centre during the first week of April, 2005. The purpose of this workshop was to see if novel and innovative habitat designs could be found by bringing together people from various disciplines at the very beginning of the design process.

The Habitat Design Workshop organisation team comprises 10 post-graduate students, doctoral researchers and young professionals from many countries, with diverse backgrounds but united by their shared passion for space. Together they endeavour to further the efforts towards returning to the Moon and visiting Mars by actively preparing via stimulating research into various aspects of human exploration of the solar system via design workshops, symposia and seminars.

WORKSHOP CONCEPT:
Designing for human exploration

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 concurrent design approach (bringing various engineers together at the early stages see ESAs concurrent design facility) has demonstrated success in this approach, however for human space missions the design process needs more than engineering know how, but must include the complex interrelations between humans and their environment.

The First Habitat Design Workshop was organised in an effort to demonstrate, learn about and develop a new 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 etc. By having all these disciplines present from the very beginning, a human space mission focussed concurrent design process could be developed ultimately leading to novel and feasible habitat designs. As a consequence the participants themselves would also benefit greatly as they would exchage 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.

HABITAT DESIGN

The environment beyond the protection of Earth's atmosphere is hostile to humans. Orbital stations, interplanetary vehicles and planetary bases (in this paper we term all of these as "space habitats") must provide a shield to the harsh elements of the solar system as well as providing for the requirements for human existence.

Compounding this already challenging requirement of defence against the solar system environment and providing the physical requirements for human survival, the habitat designer must also consider a range of technological constraints such as the maximum volume and mass a launch vehicle is capable of accommodating, cost effectiveness, reliability, redundancy etc.

The evolution (and hurdles) of human inhabited space volumes

In past human space flight missions, the characteristics of the inhabited environment were strongly driven by engineering requirements. Although the efforts of engineers were focussed on making all parts, of a system or project, work together in the most efficient and economical way, many facets of human inhabited space systems were missing, leading to problems later on when the system, i.e. an orbital station, was used.
For example, living and working in the confined environments provided by the space stations MIR and Salyut were challenging problems for a human being's life in space. Moreover the

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.

In the past little attention was given to human factors due, on the one hand, to the available technologies that did not allow a more comfortable habitat, on the other hand to the mental attitude driving the design approach (space systems design originated from the military driven programmes following traditions of military design). In the earlier period, in fact, most of the astronauts were coming from the airforce, and were trained to bear extreme environments over short periods of time.

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.

The realised space habitat designs up to now feature the classic tin-can elements which are defined by the form and size of the payload bays of the launchers. This means that professionals such as architects, industrial designers and those involved with ergonomics start from the already defined architecture of the space module, with little chance to modify it.

Also, there are certain inputs which are not currently included in the design of habitats, such as biomedical specialists, social psychologist etc. They too have to work with an already defined module. This has consequences on the effectiveness of the space mission which is dependent on the efficiency of the crew, and if these human habitability issues are to be effectively overcome they must not be integrated into a design after the fact.

With current plans for future human exploration missions beyond Earth orbit and the subsequent increase of mission duration, habitability will become an even stronger aspect. Defining the habitat for a lunar or Martian base is a complex task, which involves numerous disciplines. As such, the concept of Habitability cannot be considered as project independent. It should be included at the start of the design process.

The human habitat

With the term *habitat* we commonly mean the set of physical and chemical factors that characterise the environment in which a species lives. But if we broaden the definition of habitat, we can indicate the environment congenial to human needs and incorporating the social as well as physcial space. This second definition is taken up in our design approach.

Habitats can be considered as the *result (or the best compromise)* of the relation between human beings and technologies, by technologies we mean the technologies related to each subsystem that achieves the mission, from launch to survival in extreme environment (to returning to Earth). Propulsion systems, landing systems, radiation shielding, thermal control, telecom systems, on board data handling system, life support systems etc. are all strongly linked to the technological part of the design and they are integrated into the requirements and constraints definitions of the habitat. At the same time these technologies and the correlated subsystems are influenced by the extreme environment conditions.

The human being is a complex system in itself. Providing life support and radiation protection is not sufficient to assure optimal habitability conditions for long duration missions. A human being has to live and work in, and often with, the habitat. This entails satisfying physiological and psychological needs (for example providing food, adequate solutions for sleep, privacy, intellectual and social stimuli, mechanisms of de-stressing).

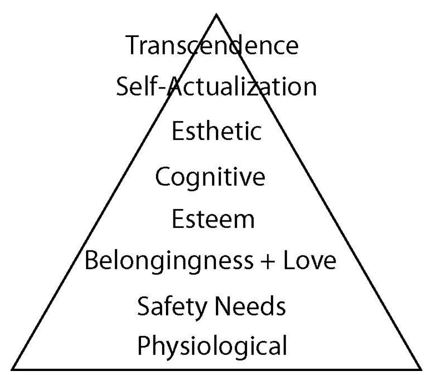


Fig.1: Needs Pyramid from Abraham Maslov

The architecture and design must assure the ability of carrying out the scientific experiments and the maintenance of the operational condition of the module. In reality, these two large groups of activities are not separated, but linked together in an environment with limited volume, and so these activities must be carried out in the same place or at the same time.

Designing a habitat for a space mission means to intertwine these two main groups of activities (living and working) with the rest of the environment: this leads to the human-machine interaction and human–human interaction.

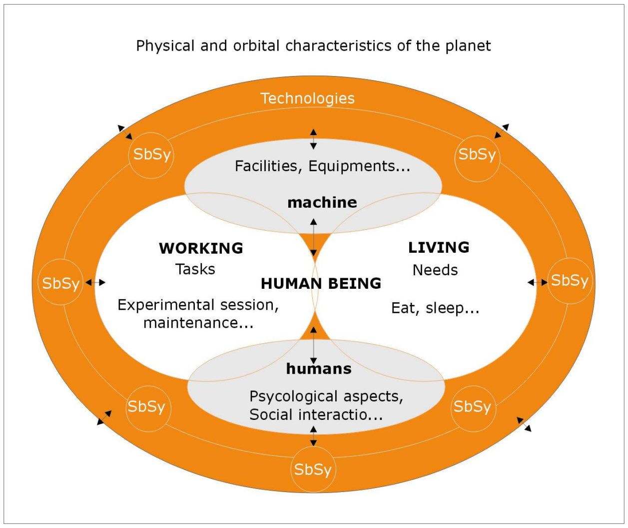


Figure.2 : Habitat Subsystems (SbSy)

If we consider a habitat not as a union of different engineering-driven subsystems but as the result of requirements coming from human needs and their interaction with the environment, we have to change the design approach and involve not only engineers but also space science, architecture, industrial design, ergonomics, biomedicine and psychology disciplines, to name but a few.

All these experts must consider human parameters during the whole mission definition. *"Too often, programmes consider the human element in a human-machine system after making other key decisions, only to raise mission or design problems they otherwise might have avoided"* [8]

For this reason during the definition of mission requirements and constraints the basic relations among physiological aspects and environmental parameters such as atmosphere, temperature, radiation exposure, acceleration, vibration, noise, and lighting have to be considered.
Metabolic parameters (since they interact with environment requirements), have to be considered: oxygen consumption and carbon dioxide generation, human heat production, caloric requirements and energy expenditure, water requirements and waste production.
From the physiological point of view a human being is also subjected to variation of gravity (0g during transfer mission, ~0g on Phobos, 1/6g on the Moon and 1/3 g on Mars). This can cause cardiovascular de-conditioning, muscle atrophy and bone degeneration at different levels of intensity.

So, considering all physiological aspects from the first phase of the mission with a multidisciplinary team, composed not only of engineers but also of physiologists, biologists, medics with a concurrent approach of design in which problems are distributed on each level, can mitigate problems derived from the interaction between human and environment.

However we have already assumed that the interaction between human and environment is a complex matter that involves not only the basic physiological needs, but it involves the human-human and human-machine interaction as well. Human Factors is a discipline that overlaps several other disciplines with the purpose of integrating the crew with their environment and equipment. During the definition of the mission objectives for example, human factors can help to define what can be expected by the crew in term of tasks in the environment described by scenario.

During requirement and constraint definition, the human needs for volume and surface per person (which derive also from the scientific objectives), the need for consumables (food and oxygen) and the need for tools and equipment can influence the habitat size, configuration, and hence the mass budget. [8] In the specific design of laboratories and crew quarters human factors have a relevant role. They depend on functions, activities and duration related to the mission as well as to the psychological and physiological characteristics of human being. All of these disciplines can have a significant role in all parts of the design process, from objective definition to design implementation.

When designing for a space mission which relies on humans working efficiently (i.e. a research mission), the design environment (location and the associated special conditions) have to be analysed and evaluated first. The implications of the environment (both internal and external to the habitat) on man and machine are equally important for such a complex system as a habitat to be effective, sustainable and of course realisable.

THE HABITAT DESIGN APPROACH

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.

<u>*A concurrent design approach*</u>

The concept of concurrent engineering was initially proposed as a means to optimise product development time. Since then, many interpretations of "Concurrent Engineering (CE)" have emerged in the literature.

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" [13]

The Computer–aided Acquisition and Logistic Support (CALS) office definition of CE [14] from military handbook-59 is "a systematic approach to creating a product design that considers all elements… CE is not the arbitrary elimination of the phase of the existing, sequential, feed-forward engineering process, but rather the co-design of all downstream process towards a more all-encompassing, cost effective optimum"

The concurrent design strategy presently used by ESA, has already demonstrated its validity in the sharing of data and knowledge during the design process with a relevant reduction of time and cost.

The definition of Concurrent Engineering that ESA has adopted for their Concurrent Design Facility is: *"Concurrent Engineering (CE) is a systematic approach to integrated product development that emphasises the response to customer expectations. It embodies team values of co-operation, trust and sharing in such a manner that decision-making is by consensus, involving all perspectives in parallel, from the beginning of the product life-cycle."*

The actual concurrent design approach of space products, however, had been developed and applied prevalently to connect different expertise from the same discipline, the engineering, including cost and technological implications.

If we consider the development of the design process for human space exploration, we have to consider the integration of human factors in this process. This workshop emphasises this issue.

Alternatively during design of human mission the human being can be considered as a payload that imposes requirements for volume, safety and other types of support. "*A different way to look at the crewmember is as a system, comparable to other (hardware) systems. The human has sensors (eyes, ears, touch), mechanical actuators (finger, arm, legs), self propulsion (walking) and an on board processor (brain). The human also has requirement for maintenance (sleep, hygiene), fuel or power (food and water) and a particular type of operating environment (oxygen, temperature)*". [15]

This way of considering the human being (and his relation with machines and other human beings in the environment) increases the complexity of the design process and again calls for broadening the design process to include non-traditional disciplines in the very early stages of human space mission design.

The workshop design approach

The design approach that was used in the Habitat Design Workshop 2005 was a concurrent approach shared by selected participants (with different disciplinary backgrounds and different nationalities (reflecting the member states of the European Space Agency) during all phases of the habitat definition.

The organisers of the Habitat Design Workshop decided on including a composition of disciplines in the teams: engineering, space science, architecture, industrial design, ergonomics, medicine and psychology. The design process in which the design teams were involved simultaneously was composed by different steps:

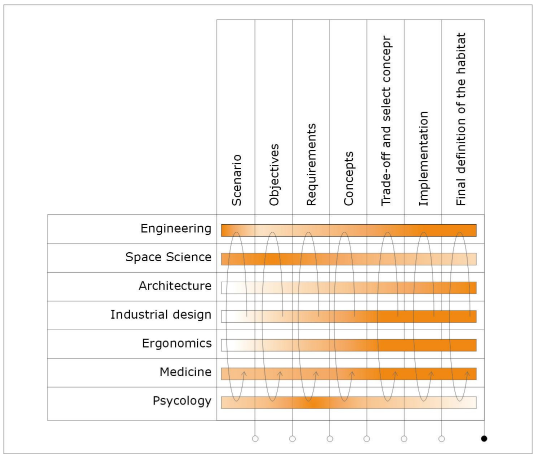


Figure.3 : The Interplay between the various disciplines

Providing pre-workshop reading material was necessary to assure a minimum (or starting) level of knowledge and to increase the communication level of the group (due to the short duration of the workshop, which was 6 days). Also the lectures provided by the experts during workshop time were useful for this purpose (see next section).

A large list of design drivers was discussed during the workshop and in the preparation material. Below is (not exhaustive) list of some of the design drivers that where part of this design workshop:

- Impact from micro & macro objects
- Radiation
- Temperature
- Pressure
- Exo Biology
- Dust
- Gravity
- The external/internal interface
- Deployment and packing configuration
- The minimum crew needed in terms of habitability
- Different possibility of In-Situ assembling
- Future extension of the base
- Mobility
- Habitat construction options
- Adaptability to changing mission requirements
- Rreaction to changing user-preferences
- Human/machine interface
- Safety
- Layout design ease of human motility.
- Thoughts about the social and organisational aspects of life in the base
- Social and psychological issues (effects of stress, recreation and exercise, interpersonal dynamics in space, personal space, privacy, crowding, territoriality

Although the organisation team suggested a few scenarios, a challenging phase was to define the scenarios. These first attempts at communication between different people, from different disciplines, with different social backgrounds, different cultures and different psychological characteristics was chellenging, and thus scenario definition was the first hurdle the group had to overcome together.

An daily session of group reviews was scheduled which allowed for a step by step look at the development of the design projects. This was helpful to motivate the design process and minimise delays by cross comparison and discussion (between the different design teams).

Each group defined the objectives of the mission and starting from this point defined 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 characterisation of the functional distribution of the inner volume as well as the interior configuration.

THE WORKSHOP CONCEPT IN ACTION

The intense schedule, the diversity of the events in the schedule and the group process called for a flexible organisational approach to the workshop. This meant the organisation team had to observe and manage the schedule, with some co-evolution of methodolgy with the progress of the particiapnts. This more reflexice approach to coordinating the design exercise resulted in a baseline schedule, that could be changed on the spot to ensure the maximum satisfaction and learning for the participants. As such, the workshop could co-evolve with the participants needs and their stage of design development.

During the design of the day-to-day schedule, great care was taken to find a balance between the teams' design time and the lectures they had to attend. The lectures helped the teams recognize vital aspects of habitation design and helped in making their design evolve both naturally and logically. Also, the participants could be in close contact with the lecturers. As the premise of the workshop was to use, learn about and ultimately refine the multidisciplinary design process, it was key that the lectures reflected that. The box below lists the experts who provided lectures during the workshop.

Douglas Robinson (organiser/project coordinator) about the programme and general habitat design approach in this workshop.

Bernard Foing (ESA) about the space environments.

Barabara Imhof (TU Wien) about space architecture.

Susmita Mohanty about space design and lessons learned from the Space Shuttle and Mir.

Dieter Isakeit (ESA) about existing technologies and crew conditions aboard ISS.

Stephen Ransom (Consultant) about space system engineering and designs of advanced human space missions.

Christophe Lasseur (ESA) about life support.

Enrico Gaia (Alenia Spazio) about inflatable structures.

Petteri Nieminen (ESA) about radiation and protection from it.

Guerric Pont (ESA) about lunar transfer.

Stephane Langlois (ESA) about inflatable structures and materials under investigation at ESA.

Sandra Hauplik (organiser) about future concepts of a mobile habitat.

Manuela Aguzzi (organiser) about SpaceLab and new concepts of habitability

Kursad Ozdemir (organiser) about novel concepts for extreme environment habitat

Andreas Vogler about physiological and psychological aspects of habitat design.

A good mix of lectures, which proved very conducive to the teams' design sessions both in terms of content and motivation. The experts also made themselves available for questions and many circulated among the teams during the design sessions to provide guidance and feedback. This was done after consulting with the organisers to ensure that the experts did not hamper the creative processes of the teams with too much influence.

With the aid of the lectures, the experts, flip charts, books, internet and modelling materials the design sessions were characterised by a great deal of constructive discussion, enthusiasm and creativity.

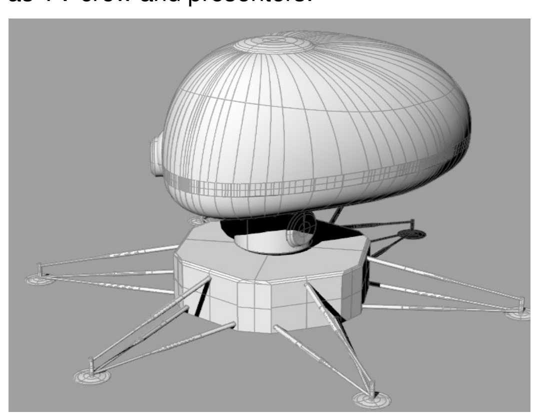
Indeed at the end of each working day most teams continued to work in their hotel to the early hours of the morning, and did so throughout the entire workshop.

During the design process, a very valuable tool was that of visualisation. The organisers believed they had adequately anticipated the need for this tool by providing flip charts. Much to their surprise almost every architect/designer of each team had brought along their own graphics software with which from the very first day onwards, exceptionally strong visualisations were made, advancing the design process much faster than hoped.

A very real concern for any effort comprising people from different backgrounds is whether these individuals will be able to overcome their professional differences and be able to function as a team. This workshop, especially given its premise, was no exception. The organisers could only address this by advocating discussion and patience. A group of people cannot be forced to work as a team. It was decided that the teams should be left alone as much as possible in this respect and let them form themselves. A variety of disciplines in a team is not the only possible cause for conflicts, different dominant personalities can and will clash. Although one team did experience some problems in this respect, continued communication and patience led to a truly excellent end result. Aside from this single event, different jargon and problem solving approaches were the main source of miscommunication.

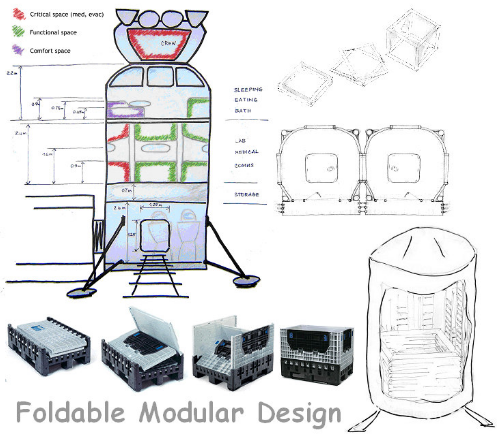
THE OUTCOME: DESCRIPTION OF THE 5 DESIGNS

Moon 1 – fRAM – A first stepping stone for a continuous human presence on the Moon.
The mission is to take place in 10 years, resulting in a permanent outpost in just 3 launches using the Energia launch system. The base would consist of the lunar lander modules with inflatable ovoid domes but future concepts would link up several ovoid structures together as the base expands. Both a scientific and a Public Relations package were entailed with the astronauts training as TV crew and presenters.



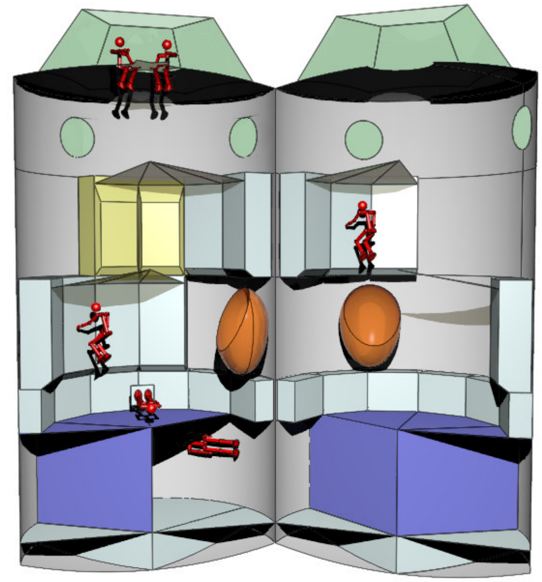
Moon 2 - Team Kubrick - To establish a permanent human presence on the Moon from a simple Lunar Base to a large Habitat using a novel construction system.

A novel concept using foldable three metre cubic structures combined with a highly adaptable use for the lunar regolith in building a structure, as well as its inherent radiation protection features. The permanent outpost on the Moon included a lunar observatory at the pole for infrared astronomy. Kubrick identified a future goal of testing this concept by building their cubes on a one to one scale, constructing a lunar analogue station on Earth to test practicality and human factors



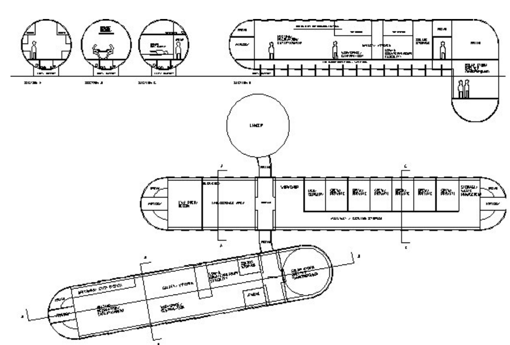
Phobos – R.I.P. Based on Fear - To establish a permanent base to research asteroids and install a Martian observatory.

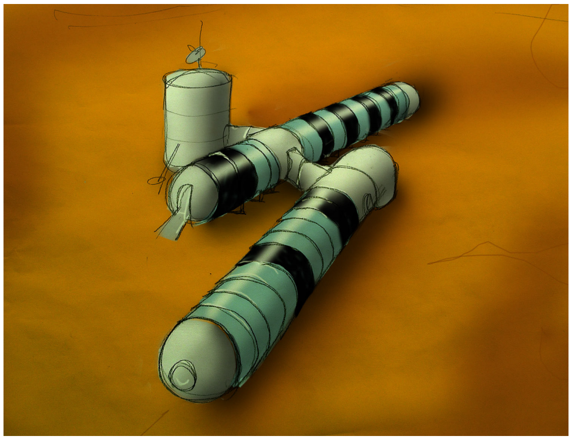
A permanent base utilising the ravines on Phobos to protect a habitat module. Powered by a nuclear reactor situated far away from the base beaming its energy in the form of a laser, the HALO module would offer respite from the essentially zero-g environment. The overall goal of the mission was to research Phobos as a stepping-stone to Mars. Future design would include a “rollercoaster-like” structure, which could be used to mine Phobos for minerals and fuel in addition to providing simulated gravity for the crew. The interior space was designed with comfort in mind and employed large plasma screens for displaying anything from Earth vistas to soothing nebulae to aid the crew psychologically. The Phobos team had also carried out a very comprehensive and in-depth study into life support.



Mars 1 – Elysium Base - To perform a 600-day science program on the surface of Mars and establish Elysium Base as the first permanent human outpost.

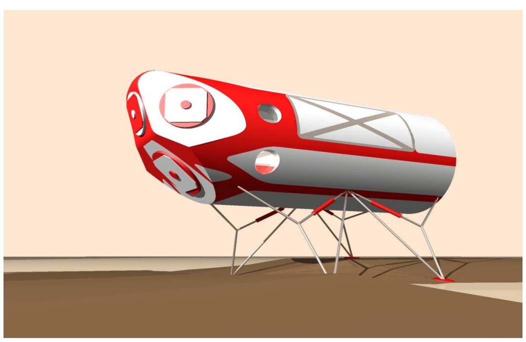
A Martian glass ISRU (In Situ Resource Utilisation) based design. The glass tubes were sealable segments toughened and thick enough to withstand almost all meteorites likely to make it to the Martian surface. The base of the tube structure would be semi buried in Martian regolith and the glass segments would alter from dark to clear glass offering greenhouse possibilities and solar heat absorption. The crew would rotate for 600-day missions to keep the outpost permanently manned and fulfil the scientific and explorative goals. Their location would allow them to explore the icepack sea of on Elysium Planitia prepared by precursor cargo missions. A radiation safe-haven for 6 astronauts would offer protection from extreme events. Science would be catered for by a comprehensive array of tools including capacity for deep drilling.

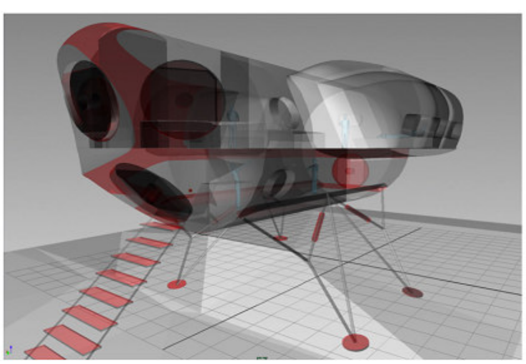




Mars 2 – name to be chosen by the future crew - To establish the core unit of an expandable outpost for the exploration of Mars.

The central module's performed a dual-role as a radiation shelter as seed for an expanding base, rather like a beehive of hexagonal stilted pods with inflatable domes. The initial crew of 6 on a 600-day mission would be there to do comprehensive science but the motivation would be exploration and adventure. The base was not linear so there would be plenty of escape routes should one path become blocked. A very in-depth study, which appeared to leave no stone unturned and yet keep the freshness and excitement of what is essentially a pioneering mission.





CONCLUSIONS AND REFLECTIONS

The Aurora Habitat Design Workshop 2005 was organised by a group of highly motivated PhD candidates, post-graduate students and young professionals in cooperation with the European Space Agency to achieve the following goals:

- Use, learn about, discover in practice the multidisciplinary design process
- Find novel and innovative habitat designs concepts
- Bring together space enthusiastic post-graduate students and young professionals on the verge of their careers to exchange knowledge, experiences and achieve a synergy thought and execution.

After spending an intensive week with thirty participants, ten organisers and various experts, working together to achieve the best results, some conclusions can be reached about this workshop, its underlying philosophy, its implementation, its success and on how to proceed.

Since the target was to develop a concept of an exploration habitat taking into account what was required from different disciplines, the methodological approach used was appropriate.

The first challenge to overcome was the collaboration of people from different countries and different disciplines given the relatively short time frame of the workshop, which was only one week.

Providing pre-workshop reading material proved very important to assure a minimum homogeneous level of knowledge of the participants with different backgrounds. Expert lectures during workshop itself reinforced the reading material along with the workshop ethos of providing as much opportunity for interaction with the experts as possible. Interaction between experts and participants was enabled by the flexible nature of the workshop design, and the use of enthusiastic as well as knowledgable experts. Thus exchange of knowledge was maximised.

Adopting a basic methodology for the design process to be shared by different disciplines was very important: define objectives and scenario, select the requirements, define the concept of habitat, implementation and conclusion. This methodological approach was useful because it bears strong similarity to basic scientific methodology. This is the most common approach used by all different disciplines, which come from our natural approach to problem solving.

While all different disciplines did adopt this basic methodology, its implementation did vary substantially. Engineering/science seemed to build its design or solution to a problem one step at a time arriving at a linearly arguable and justifiable result, whereas architecture and design approaches went to the end result and moved back and then forward in an iterative design approach which then came to equillibrium on the final design.

Some problems in the definition of requirements where however signalled, due to the complexity of the project. Complexity (in addition to the multidisciplinary aspect) is the second challenge that characterises this workshop.
The proposed design approach was concurrent in the sense that all disciplines involved were able to contribute to the design at the same time with the same weight in every step of the process. However some skills became spontaneously predominant in some specific phases of the process: For example, it was a general and recognised fact that the first decisions were mainly based on science and engineering, leaving the designers unsure of their role in the first 2 days. Once mass constraints and the purpose of the habitat were decided, however, the engineers satisfied themselves with merely constraining the design to fairing size and mass possibilities (although in some cases, the engineers where forced to put aside their standard linear approach based on fairing size). Psychological issues were strongly involved during requirement definition while design played the major role during the following phase where all requirements were synthesised in a visualized concept of the habitat. The speed and details of drawings and 3-D models that the architects and (industrial) designers were capable of amazed both other participants and organisers alike. Working together taught the participants a great deal of respect for the other disciplines that will be useful for the rest of their careers. The continuous presence of all disciplines during the whole process, however, yielded a development of the design from all perspectives.

Although a few scenarios had been suggested, a third challenge of the workshop was to define the scenarios. This was due to it being the very first step of the design process, hence the first attempt of communication between different people with different characteristics, different values, various approaches to problem solving and different cultures.

Scheduling daily sessions of public step- by step reviews of the designs was helpful in avoiding delays, verifying the design process and to allow mutual comparison between the groups.

The decision of the organisers to not interfere in the decision making process of the teams was positive in order to obtain fresh concepts.

All final results show that the multidisciplinary team was able to collaborate and define the concept keeping into account all the aspects and the related subsystem that play a role when defining a habitat for human exploration.

Each team defined the objectives of the mission and starting from this point each team defined the characteristics of the major subsystems (power, life support system, radiation protection, dust removal, telecommunication…) required to achieve the mission. At the same time the main objective of the mission also lead to characterisation of the functional distribution of the inner volume and the interior configuration.

Mars 1 differentiates itself by the concept of processing glass on the Martian surface. In this case to use ISRU is not simply a requirement of optimising the mission in terms of transferable cargo. By designing the habitat structure using glass also answers a human demand of having to see outside and could reduce the psychological effect due to the confined and dark environment of a typical habitat. It also allowed expansion using a reusable mould to extend the habitable volume of the base.

Mars 2 was characterised since the beginning by good communication between its members. They clearly defined the scenario, the requirements and the main subsystems. This team placed particular emphasis on the psychological requirements of the internal configuration of the space. The final habitat was well described by 3D modelling, which comprised a first study of the internal configuration. Their proposed way of expanding the main module is quite original.

Moon 1 was characterised by objectives strongly related to cultural exploration, educational and outreach. Their inflatable, asymmetrical shell design paid particular attention to habitability issues.

Moon 2 proposed a simple but smart concept. The cube solution (being similar to earth habitability system) offers a very different way to live in a moon base. The cubic concept has two main applications: one is that of habitat and one is as radiation protection bricks. Addressing these two issues with one solution is quite innovative.

Team Phobos experienced some difficulties with getting started as a few dominant personalities from very different disciplines and with very different languages clashed on matters related to the design process and to which issues priority should be given. Fortunately, the team members managed to overcome this problem and present a result that had a number of original features. Such as the use of very large plasma screens as virtual windows or open ceilings with the ability to display any vista or provide a user interface. A short arm centrifuge to combat the problems of gravity's absence was incorporated in the design as well. The entire habitat was to be powered by a nuclear reactor some distance transferring the power via laser transmission. The Phobos group impressed the organisation team near the end of their design process as compromises where made between the clashing personalities which showed the professionalism of the team members.

From the design point of view most of the designs venture deeply into the problems related to habitability and there is a good correspondence between the objectives and the final concept design. Most teams managed, even in the short time allotted, to define the internal layout.

This sentence in the Mars 2 scenario captures quite nicely the premise of this workshop:

"It is essential that a concurrent system design technique be implemented. A habitat is not a machine to live in, or a house to send to space, or a cage for lab rabbits; it is a functional integration of software, hardware, liveware and environment. Due to the complex requirements of the habitat, the functions it must perform and the needs it must meet, professionals from a range of backgrounds must be employed to cover all design aspects in a coordinated fashion."

This 'proof of approach' needs to be tested again and for longer time periods. Their collective results could then be compared on the basis of all habitat issues involved mentioned in this report. Conducting many workshops was not practical or feasible for the organisation team who created, designed and executed this project outside normal work hours (with considerable cost to their social lifes). However, we propose that this design approach is necessary (as we have argued in the first sections of this report) and that evidence points to the need of integrating these disciplines into the design phase. Moreover, bringing these disciplines together during the first concept development phase is advantageous since the design is still fluid and many constraints have not been imposed yet. Of course a concurrent approach throughout the design process would not be pertinent. However in concept development phase, over a short period of time, certain obstacles that would have arisen much later in the design process can be avoided or mitigated.

The 2005 Aurora Habitat Design Workshop was a great success, yielding original and fresh designs, exchanging knowledge and experience between people who would ordinarily never meet professionally and taking these new inputs back to their respective fields of expertise. The network of people established during this workshop can only grow with more such endeavours spreading this type of design methodology throughout the various industries, until the day these young professional are embedded in space related research and industry.

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Moon 1 Arno Wielders Netherlands, Physicist/ Engineer Jesper Jørgensen Denmark, Psychologist Julia Tizard United Kingdom, Physicist Ania Fischer Germany, Architect Stefano Zanini Italy, Designer / Ergonomist Hanna Västinsalo Finland, Biologist	**Moon 2** Nils Pokrupa Canada/Sweden, Space Engineer Rachel Beth Tullet United Kingdom, Medical Doctor Emanuele Tracino Italy, Physicist Serena Oliva Italy, Architect Mehmet Cevdet Erek Turkey, Architect / Artist Horst Philipp Austria, Ind. design / Artist
Mars 1 Bas Lansdorp Netherlands, Mechanical engineer Eirik Sønneland Norway, Bioinformatics Maria Gurtner Germany, Physicist Guy Michael Murphy Australia, Architect Kristian von Bengtson Denmark, Architect Olathe Jean Clark Canada, Biologist	**Mars 2** Gabriele Messina Italy, Aerospace engineer Nathalie Pattyn Belgium, Medical Doctor / Psychologist Emily MacDonald United Kingdom, Astrophysicist Nina Mair Austria, Architect Nils-Peter Fischer Germany / Sweden, Architect Julien-Alexandre Lamamy France, Space Systems engineer
Phobos Lars Jonas Jonsson Sweden, Space engineer Laura Parker UK, Space engineer Gaëlle Van de Steen Belgium, Physicist	René Waclavicek Austria, Architect Irene Slacht Italy, Industrial design Mark Sliphorst Netherlands, Aerospace engineer

REFERENCES

[1] Bridger R.S. (2003). Introduction to Ergonomics, Taylor & Francis, London

[2] Connors, Mary M., Living Aloft, Library of Congress, Cataloging in Publication Data, (NASA SP,483)

[3] Gifford, Robert, Environmental Psychology – Principles and Practice, 1987, Library of Congress Cataloging-in-Publication-Data, ISBN 0-205-10461-4

[4] Ferraris, S.D.. Working activity in space: preparation of the scientific experiments' performance; International Conference on Environmental Systems and European Symposium on Space Environmental Control Systems, 11-14 Luglio 2005, Roma

[5] Harrison, Albert A., Spacefaring, University of California Press (ISBN 0-520-22453-1)

[6] Häuplik S., Lorenz S., The Context of Space Architecture, Proc. ESLAB 36 Symposium, "Earth-Like Planets and Moons", ESTEC, Noordwijk (ESA SP-514, Oct. 2002)

[7] Häuplik S., Space and Society, IAC-04-IAA.3.8.1.04

[8] Larson W.J. and Pranke L.K., (1999) Human Spaceflight, Mission Analysis and Design, McGraw-Hill, ISBN 0-07- 236811-X

[9] Reynolds, David, Payload Developer: Lead Systems Engineer, NASA Flight Project Directorate Office, Marshall Space Flight Center, Huntsville, Ala. Web page http://www.spaceref.com/iss/payloads/pers.html

[10] Vogler, A., The Munich Model: Creating and environment for space architecture development, AIAA Space Architecture Symposium 10-11 October 2002, Houston, Texas. Paper number AIAA 2002-6122

[11] Robinson, D. K. R. The Space Station Design Workshop, (Participants notes), February 2002

[12] Robinson, D. K. R. Countermeasures for the negative effects of long term space exploration: Russian cosmonautics at the dawn of the 21st century. Final Project for the Masters of Space Studies, International Space University 2002, conducted at the institute of Biomedical Problems and Star City, Moscow Region, Russia..

[13] Larson, W.J. and Pranke L.K., (1999). Human Spaceflight, Mission Analysis and Design, McGraw-Hill, ISBN 0-07- 236811-X

[14] Winner, R.I.,J.P. Pennell, H.E. Bertrend, and M.M.G. Slusarczuk. 1988. The role of Concurrent Engineering in Weapons System Acquisition. IDA Report R-338. Alexandria, VA: Institute for Defence Analyses.

[15] CALS, Concurrent Engineering Task Group. 1991. "First Principals of Concurrent Engineering: A Competitive Strategy for electronic System development," Review draft, Washington D.C., CALS Industry Steering Group, Feb.1991