Comparison Between Industrial Design and Aerospace Approach in Interdisciplinary Projects for Human Exploration Mission

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Abstract

Because of the extension of mission duration time, the new targets of human exploration (Moon and Mars) require a deeper investigation of issues related to human being and habitability in space. This entails that engineering disciplines will be integrated in multidisciplinary teams. This raises the problem of the definition of an interdisciplinary process that can allow people from different disciplines to work together to achieve the same goal.

This paper presents a comparison between the aerospace engineering and the industrial design approaches in order to facilitate their integration into an interdisciplinary design process and to allow the designers to contribute to the development of future human missions.

The methodology used at present in the aerospace field for the design of satellites and habitat modules will be described and compared to the approach conventionally used by industrial designers for non-space applications that present high complexity and multidisciplinary.

Introduction

Nowadays, the aerospace field comprises many different sectors, ranging from communication satellites to robotics. The field of interest in this paper is Human Spaceflight.

After the second World War, Russia and America rushed to recruit the best engineers and scientists working in Germany under the regime of Hitler. In the late '50s they were all employed in the so-called "Race for the Moon". This period that comprises the Sputnik launch (1959), the Jury Gagarin launch (1961) and the "first step on the Moon" in 1969 can be considered the main phase of human spaceflight history.

The majority of the knowledge on human spaceflight can be credited to the development of orbital stations. Russia developed a series of Salyut Space Stations, and the MIR Orbital Base while the United States developed a Skylab Orbital Station and Europe developed the necessary know-how in the 1980s with the Spacelab programme.

Few but significant examples show how in the past the industrial designer contributed greatly to this field. Raymond Loewy is an emblematic example through his work at NASA on the definition of the crew quarters of the orbital base Skylab.[2]

We have to wait the end of the Cold War to see the first example of international collaboration materialized in the ISS International Space Station, the base orbiting around Earth with permanent human presence on board. [1]

While in the past space was a pioneering field for architects and industrial designers, in the last decade, they have been involved in projects related to habitability conditions of the ISS. For the ISS industrial designers developed operational scenarios and equipment (body restraints, equipment restraints, clothing…) to improve the working and living conditions, countering the problems due to the lack of gravity and isolation. [3][4]

While today the average stay of astronauts on the ISS is around three months, the future exploration of Moon and Mars will require an increase in the duration of the mission. For this reason the quality of the habitability condition becomes an essential issue for the success of human exploration missions.

Hence the involvement of architects and industrial designers from the early phases of mission development can be quite beneficial. They should be involved from the beginning, together with aerospace engineers, medical doctors, physiologists, psychologists, geologists, space scientists ad all the experts that can provide significant contributions in the definition of the design of human missions.

Aerospace methodology of mission development

In this paragraph "Life Cycle of Human Space Mission", "Space Mission Concept and Architecture", "Human Space Mission Design Process" and "Implications of Space Habitat Design" will be described.

Life cycle of human space mission

Design of a space mission is a complex and multidisciplinary task because on each level of the development several parties (Sponsors, Operators, Customers, Developers) and subsystems (power, thermal, data…) are involved. [5]
The development of Human Space Mission is a linear process. The "life cycle" used by NASA, ESA and DoD (Department of Defence) is shown in Fig.1

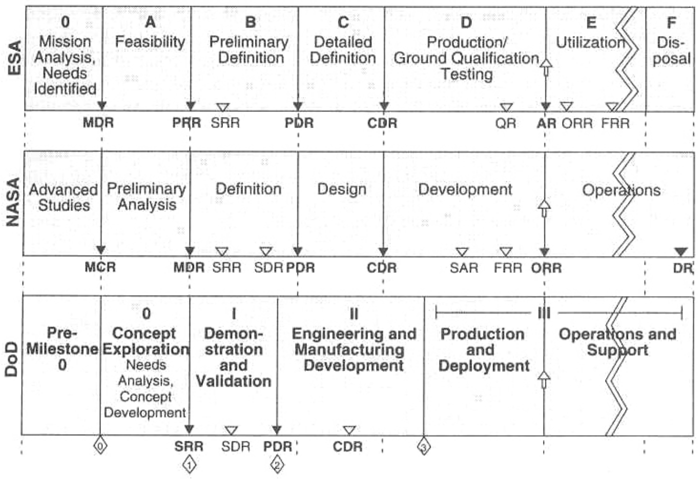

Fig.1 Programme development Phases for a crewed Space System. Diagram courtensy of Dr. Rehinold Bertrad, Space System Institure, University of Stuttgard. [5]

The main steps are now described using as a reference the NASA terms:
Advanced Study: This phase comprises advanced concepts investigation in new technologies, mission analysis, new propulsion system etc.
Preliminary Analysis: this is the initial study phase, which results in a broad definition of the space mission and its systems and approaches;
Definition: which results in a level of design necessary to support a Preliminary Design review;
Design: is the formal design phase, which result in a detailed definition of the system components and development of test hardware or software that can support a Critical Design review;
Development: is the construction of the ground and space based systems necessary for launch and operations;
Operations: is the day-to-day operation of the ground-and space-based systems, their maintenance, support, and logistical replenishment;
Disposal Phase: is the disposal of the physical and functional elements at the end of the mission life cycle. [5]

Space mission concept and architecture

What has been described above is the entire process of the mission development. Each space mission is composed of a series of elements that constitute the *Space mission architecture.* While the focus of the industrial designers and architects activities are *Crew* and *Surface Elements* in which human beings live, work and operate we have to consider the entire mission architecture.

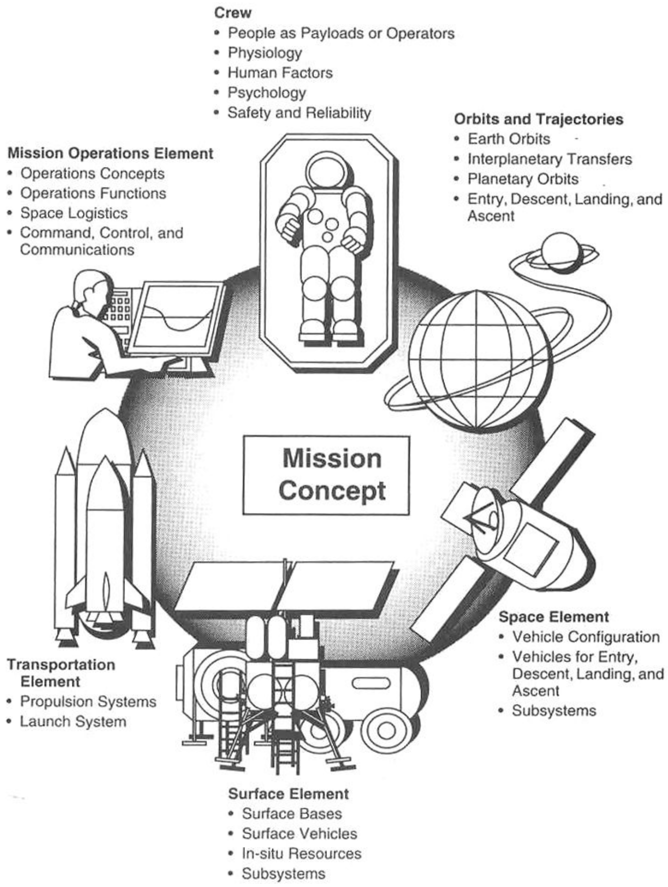

Fig.2 Architectural Elements of Crewed Space Missions [5]

The main elements presented in Fig 2 are now described:
Orbit and trajectory influence every element of the mission. They determine the mission duration, which is a crucial data for the design of a space habitat. Depending on the trajectory, the crew can be exposed to different types of radiation; this therefore influences the design of radiation protection of both the transportation vehicle and of the habitat vehicle on surface.
The space elements consist of orbiting space vehicle, transportation vehicles, and vehicles for entry, descent, landing and ascent. Characteristics of the space elements can influence mission duration and crew size.
The transportation elements include launch facilities, launch systems, and propulsion systems that place the elements in orbit or land and return it from the surface. This component puts constrains in term of mass, volume and costs on the overall mission.
Mission Operations includes the people involved on ground and space elements. The aim is command, control and communication from Earth of the activity in space.
People and surface elements are the real focus of industrial designers and will be deeply described in the following section. [5]

Space mission design

The first step of the mission life cycle is the *Preliminary Analysis* in which a broad definition of the space mission is given.
The first step is to define the *Space Mission Objectives*: this means to define "what we are trying to do". The second step is the definition of *Mission Requirements and Constraints*: this means to define "How well we must do it". In this phase Functional requirements, Operational requirements and Constraints must be defined. Mission have hundreds of requirements but an example of typical requirements concerns performance, duration, logistics, survivability and cost.
Then there is the development of *Alternative Mission Concepts and Architectures:* this means defining "How the mission will work" and "How systems and people perform to meet the mission

objectives". When different concepts have been developed a *trade-off* is performed considering mainly cost, performance and crew safety.
The output of this process is the *Definition of a Baseline Mission Concept and Architecture.*

Human habitat design

With the term *habitat* we commonly mean the set of physical and chemical factors that characterize the environment in which a species lives. But if we broaden the definition of habitat, we can indicate the environment congenial to human needs.
Habitats can be considered as the result of the interaction between environment, human beings and technologies (technologies related to each subsystem that achieves the mission). 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 are integrated into the requirements and constraints definitions of the habitat.
To illustrate this complexity and multidisciplinary the case of a Moon base will be used.

- Extreme environment characteristic
- Human beings characteristics
- Technology employed in the construction of the habitat

Characteristic of the Moon environment

Moon is the natural satellite of the Earth and is 3.84 10^6km from it. Due to the moon's orbital parameters at the Soul Pole there are a 2% area permanently illuminated. Here the installation of a base is suitable due to the constant presence of solar energy. The temperature on the surface granges from 114 C° to -180 C° depending on the solar illumination. Moon has a equatorial gravity of 1.62 m/s/s which has an evident impact on human movement and structure design. Moon has essentially no atmosphere and no magnetic field. Due to the lack of protection, the habitat must protect human being form Galactic Cosmic Radiation (GCR) and Solar Particle Events (SPE). Further habitat must protect human being from meteoroid (circa 1micron) that hit the surface with a velocity of 15 km/s and dust. [6]

Human Beings characteristic

From a physiological point of view human beings on moon require [5]:
Atmosphere: Since on Moon there is no atmosphere, habitat must provide 101.3 kPa total pressure with about 21% of O_2 and 78%-79% N_2. Further CO_2 levels must be kept to tolerable limits and humidity has to keep between 25 and 70% and a ventilation system must be provided;
Temperature: must be keep between 18.3 and 26.7 C°;
Radiation Protection: This can be assured by covering the habitat with advanced multilayer plastic materials, metal, water or regolite (lunar terrain).
Food and water: Caloric requirement depends mainly on age, gender, tasks and physical characteristic of the environment. Food and water are generally stowed by means of tanks and then processed by a physico-chemical life support system.
Waste management: liquid and solid human waste has to be disposed of in order to maintain an appropriate hygiene level in the environment.
Sleeping time: Sleep is a basic physiological need of human being and must be included in the time schedule of daily activities;
Hygiene care: includes personal body hygiene, which is fundamental to prevent fungal infections; habitat environment and clothing cleaning system must be considered.
On top of the above basic needs lighting, vibration, noise, odour are issues that need to be controlled.
A dedicated working area must be included also to carry out scientific experiments that the mission requires. Psychological needs must also be considered. This implies evaluation of workloads, relationship with the rest of the crew, the need for privacy and the interaction with tools, facilities and the related technology. Working and living in a confined environment with multiethnic,

multigender and multidisciplinary team leads to the definition of a common code of practice and private and communal areas in the habitat.

Technology level and human interaction

To design a human habitat means also to compare the design solution with the current and near-term technological levels:
Launchers: the technology available for launchers dictates the available volume in which to fit the habitat structure.
Power system: different power generation system can influence the design of the habitat: photovoltaic cell, fuel cell, nuclear reactors.
Thermal control system: passive or active thermal control for internal ad external environment (cold plates, radiators, pumps) [6]
Radiation protection: different material such as plastic, metal or regolite are under evaluation.
Life support system: the choice between closed or open loop; physico-chemical or bioregenerative system can influence the design of the habitat, as they require different volumes, mass and infrastructures.

Concurrent design process

The concept of concurrent engineering was initially proposed as a means to optimise product development time. Since then, many interpretations of “concurrent engineering” have emerged in literature.[7][8]
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."* [9]
Concurrent design has proven to reduce costs and time-to-market by speeding up the process of design. This system has been adopted to manage the innovation of complex products, avoiding the cost due to the sequential process of design, in the case of failures.

Industrial Design Discipline Approach

So far it has not been possible to define a single common methodology to all design disciplines because it has always dependent on the specific application.
However, today increased complexity of most of the projects has affected the working approach of all industrial designers, generally pushing toward a multidisciplinary methodology.
Market maturity, improvement of connectivity and globalization are just few examples of common drivers that have caused a change in the working procedures of industrial designers. Nowadays the designer is frequently working in a multidisciplinary and multiethnic teams were projects are influenced by many parties and components.
“The most advanced companies and groups in the design field do not guarantee individual creativity but they assure a consolidated and tested research and design approach, based on specialist and multidisciplinary expertise” [10]. This approach is currently adopted by IDEO, Doblin Group and Design Continuum.
IDEO [11] based innovation in a collaborative methodology that simultaneously examines user desirability, technical feasibility and business viability in a comparable process to that used for habitat design. IDEO innovation process employs a range of visualization techniques that evaluate and refine opportunities for design and development. The methodology comprises: Observation, Brainstorming, Prototype and Implementation.
Observation: User observations are the starting point for every design program. While Human Factors specialists lead the effort, all designers are observing people and how they interact with the environment.
Brainstorming: “The best way to get a good idea is to get a lot of ideas." -Linus Pauling

Brainstorming is partially an act of art, partially a scientific procedure. Brainstorming is not just a good idea but an inexhaustible source of inspiration and fresh thinking.
Prototyping: Ranging from simple proof-of-concept models to looks-like/works-like prototypes that are practically finished products, prototyping is the problem-solving part of the methodology.
Implementation: Implementation completes the cycle of ideation bringing the concept to its final form. All the possibilities have been evaluated, the prototypes validated and refined, and what is left is to do it. The project team performs detailed design and engineering, chooses manufacturing partners if necessary, and works with the client to perform a timely and successful launch.
Another example to test approach to complexity and multidisciplinary that also characterizes human mission development and habitat design projects is the study carried out by Carnegie Mellon University [15]. In this study a User-centred Interdisciplinary Concurrent System Design Methodology (UICSM) that takes a team of electrical engineers, mechanical engineers, computer scientists, industrial designers and human computer interaction students that work with an end-user to generate a complete prototype system has been developed. The design methodology proceeds through three phases: conceptual design, detailed design, and implementation.
The above examples show how designers are following the news codes of complexity.
"From a distinct process focused on the development of new products, services or systems, innovation becomes more linked to dynamic interactions between the basic research and development phases of the project, where knowledge is partially already known and partially built in real time". [10] Pizzoccaro S. suggests a double modality of the design activity: "Design as a organizing activity" (organizing design) and "Design as a production practice" (science of design).

Industrial Designer in Mission Development Process

The double modality of the design activity described by Pizzoccaro S. can be applied to Mission Design if we consider that the industrial designer can be involved in two phases of the mission development process:

In *Phase A of Feasibility study*, the designer is involved from the beginning in the scenario definition in order to assure the designation of a set of requirements that will permit the development of an adequate habitat in the next phases. In this context designers are working in a multidisciplinary team as described in the previous section (IDEO and Design Continuum). In this case industrial designers and architects can work on the habitat feasibility study.

In *Phase B or Definition* the designer and architect can move deeper in the definition of the habitat, facilities and equipment. At this level the designer should manage the relationship among human, technological and environmental requirements and the complex interaction among these factors with the aim of defining usability scenarios.

Examples of involvement on phase A

Supported by ESA's Aurora Exploration Programme the 1st Habitat Design Workshop [12] hosted thirty postgraduate students and young professionals from a broad range of backgrounds in ESTEC's Erasmus Centre. The purpose of this workshop was to see if novel and innovative habitat designs could be found by bringing together people from various disciplines right at the start of the design process. Traditionally the design process has employed a linear 'over the fence' mentality, whereby 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. This approach to design can lead to counterproductive results. The concurrent design approach has demonstrated remarkable success. However for human space missions the design process needs more than engineering know-how, and must include the complex interrelations between humans and their environment.
Fig. 3 shows the foldable modular design of Kubic Group. They proposed to use as a container a foldable cube made by tissue. It can also be used as a brick to protect the crew from radiation effects when is fill with lunar regolite. [12]
Fig. 4 show the habitat developed for Phobos, the natural satellite of Mars. Due to its steroidal characteristic Phobos has no gravity so the habitat has been conceived like an ISS module. [12]

Fig 5 is a habitat conceived for Mars. Some components are brought from Earth while some are made on the martian surface using In-Situ resources. [12]

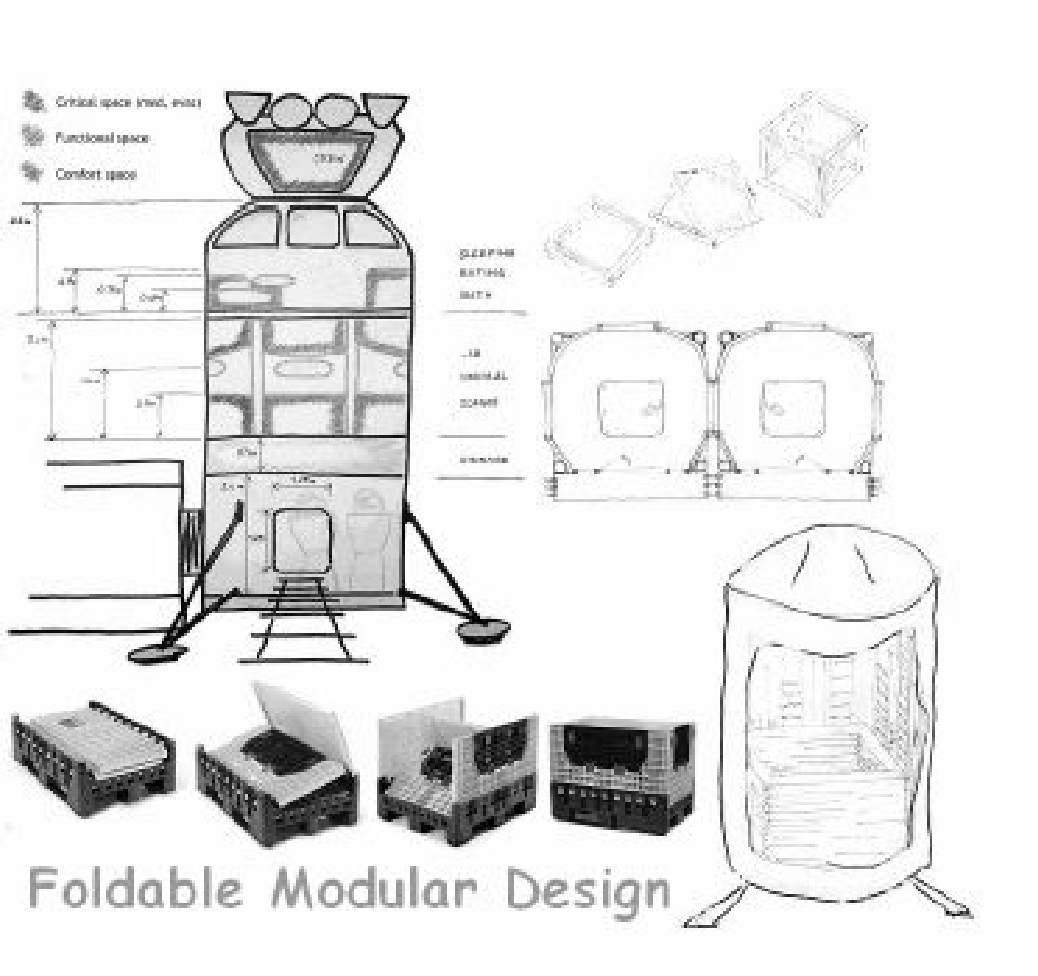

Fig.3 Moon Group 2: Nils Pokrupa, Rachel Beth Tullet, Emanuele Tracino, Serena Oliva, Mehmet Cevdet Erek, Horst Philipp

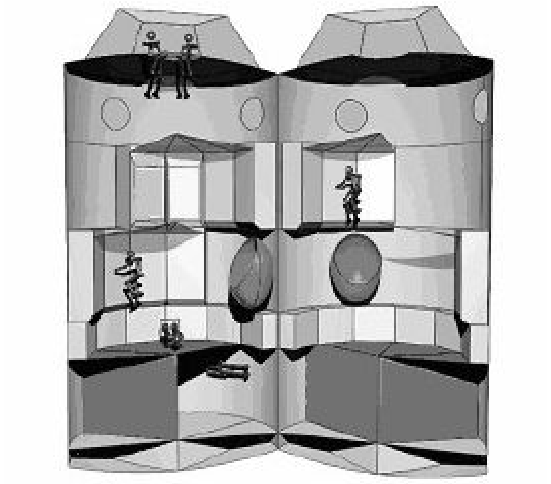

Fig. 4 Phobos Group: Lars Jonas Jonsson, Laura Parker, Van de Steen Gaëlle, René Waclavicek, Irene Slacht, Luis Daniel Gomes

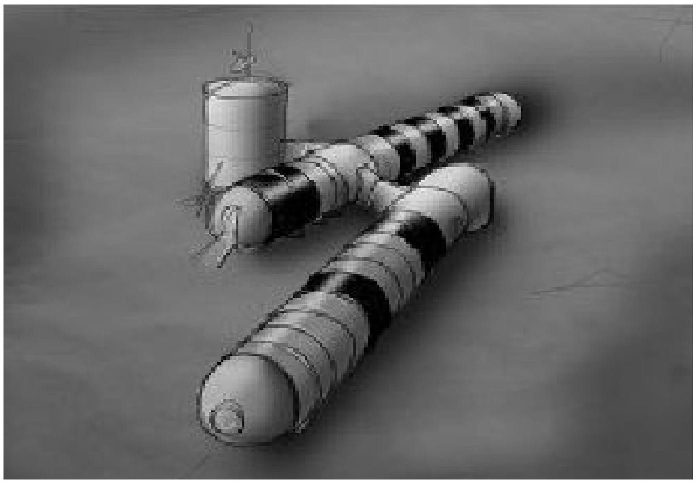

Fig. 5 Mars Group 1:Bas Lansdorp, Eirik Sønneland, Maria Gunter, Guy Michael Murphy, Kristian von Bengtson, Olathe Jean Clark

SpaceLab of Politecnico di Milano is carrying out projects on Moon habitat module called BLU (Basic Lunar Unit). [13]

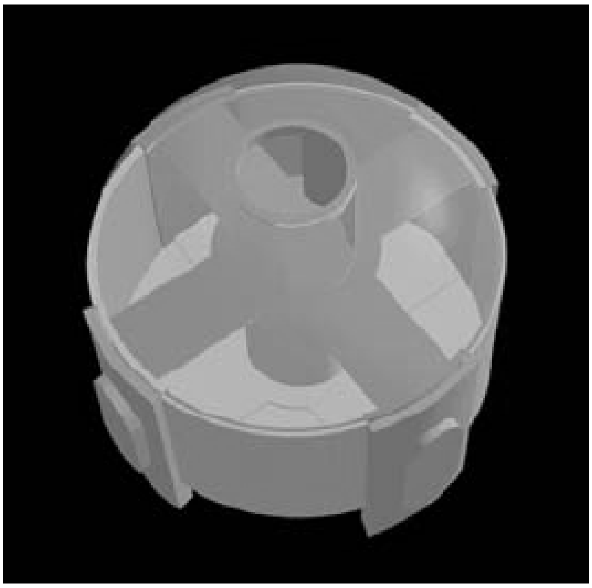

Fig.6 BLU Module axonometric view

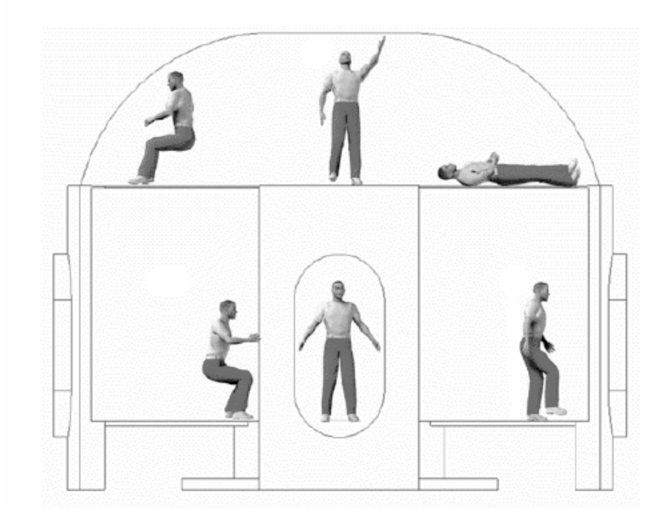

Fig.7 BLU Module section

Considerations related to phase A

Concurrent design approach has been successfully used for satellite and ISS modules. However the main parties involved in this process were engineers. 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 habitat design because experts supporting human needs cannot be involved later, after the main architecture has been defined, but they can contribute from the earlier phases in the habitat definition. 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. The human being is a complex system and to manage this complexity requires many experts focussed on different fields. Having expertise in life support systems alone is not enough to support all the human needs during a mission. 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 scientists, architects, industrial designers, human factor experts, doctors and psychologists to name but a few.

Examples of involvement on phase B

Politecnico di Milano was called by ASI (Italian Space Agency) for a “Habitability ISS” study in 2000 and for the “VEST Project” in 2001. VEST (Fig. 8) is a IVA shirt with sensors for physiological monitoring worn by the Italian astronaut Roberto Vittori during the Marco Polo Mission.[14]

Fig. 9 shows a project for a personal hygiene zone build inside a rack on the ISS.

Fig 10 shows an image from “Ops Study for MEEMM”. The aim of this study was to define the optimal configuration to carry out the physiological experiments on board the ISS in microgravity condition. Fig 11 shows the study that lead to the definition of a smart container for items used during MEEMM experiment.

Fig. 8 Image from VEST projects

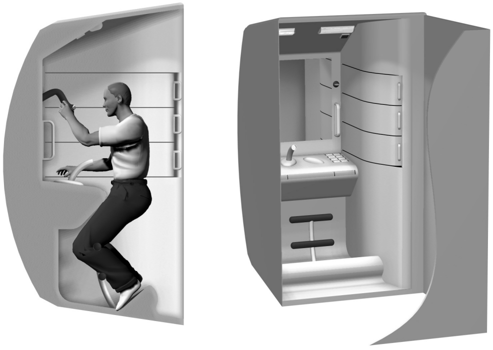

Fig. 9 Hygiene cabin for ISS

Fig. 10 Image from “Ops study for MEEM”

Fig. 11 Smart container restrained on ISS

Considerations related to phase B

Time and innovation: often industrial designers work on saturated and changeable market contexts. To develop Human Mission means having a stable context and a long process that can take between 5 to 10 years depending on the mission. This means that each design must consider the gap between concept definition and effective time to launch of the system. For this reason the relation between development of new technologies and development of mission phases must be considered and projects should have a minimum standardization level to allow updates.

Outguess and flexibility design actions for innovation: Adaptability is an important characteristic of design for space. Know-how related to space is continuously growing and aspects or technologies that are not well know in the time of preliminary concept definition may be better defined in following phases. Those variations in the context do not have to invalidate the project but there needs to be enough adaptability to fit new knowledge. The context changes can be due to new technology or new political or economical issues that force the mission development in a new direction.

Reliability and innovation: while creativity is frequently considered as a positive in the design of new products, in the space sector it is generally difficult to bring innovation because in a trade-off between efficient options, the flight-validated or proven solution will be more easily chosen. This is due to the fact that testing a new technology or system is a process that requires long times and investments that can significantly impact on the whole mission costs and duration.

Design for lightness and redundancy: A common feature of space products is that when they are launched (with a few exceptions) they must be working. Resorting to human maintenance in the case of failure is a critical or unavailable issue. Low tolerance to failure in the space field is also due to extreme environments. For this reasons robust design strategies comprise over dimensioning and redundancy of structures and subsystems. At the same time, strategies of design for lightness must always be followed because lightness is a fundamental requirement for space products optimization and cost reduction.

Conclusions

This paper has described past and current contribute of industrial designer discipline in space field, and it has highlighted the points of contact between the current of design practice and the issued related to space field. Process used by space agencies during mission design and problems related to habitat design have been introduced and explained. The current status of design context has been described providing practical examples of approaches to the complexity and multidisciplinary projects developed for current markets. Based on this evidence this paper has shown that the architects and industrial designer efforts are suitable in phase A and B of the Life Cycle Mission Design. Examples of the presence of design in both phases has been shown. Finally, a series of considerations of design practice in the space field has been justified.

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