Chapter 3
Research and Design for Space Life

3.1 The Birth of a New Discipline in Space Design

To affirm with certainty and determination that Design for Space plays a fundamental and strategic role in human space exploration, it took me years of researches and projects that started from my Ph.D. in Industrial Design for Space at the Politecnico di Milano, after taking a degree in Architecture, at the same university, and becoming an architect.

When I started my Ph.D. researches in 1998—asking myself if an architect could have a role in Designing for Space, and which one—the Space field was the domain of scientists and engineers. Nobody was conscious of the importance of well-being to design proper environments and tools to facilitate life in Space and increase the comfort of human beings. No one even understood what Design was. Architecture was already something more familiar, even if in “Space language” architecture means the global plan of an engineering system, the structure of a whole Space program, and not the design of spaceships with expertise in habitability. But it was much worse for the Design field.

“Design” in English means “Project”, and despite the amount of literature on the topic that has tried to clarify, affirm and analyse the sense of the word “Design”, still today it is difficult to explain that Design is something more than working on the surface of an object; it’s not just designing something generically, it’s a discipline that embraces other disciplines, because the Design has a multidisciplinary nature.

The Design makes real ideas and gives shape to our world; it is the interpreter of the needs of people. Indeed, many times it is able to anticipate desires and to determine through objects and environments great changes in social behaviours and beliefs. Also, Design has a strategic approach. To this great misunderstanding about “Design”, I should have added the word “Space”.

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What “Space Design” could mean? How I could have explained my intent? Space Design could have become a discipline? The beginning was not very encouraging. But I decided that I would try.

### 3.1.1 A Space Architect and Designer Meets Engineers

I looked for interlocutors in the aerospace world, space agencies and industries, engineers and scientists to understand better how to face the hardware of the architecture, the habitation modules, the equipment and tools for living and working in Space; physicians and astronauts who could help me get close to the software concerning the human being and the effects suffered in confinement environment and in microgravity conditions. My aim was to begin to speak their languages and make them understand what contribution I could give being an architect, a designer and a researcher who had just started a Ph.D. on a new discipline in Space Design.

From the scientific literature concerning the Space field I found, the only discipline close to design was ergonomics, but applied with an engineering approach, which means considering the human being “something that must work”: astronauts had to adapt their selves to the machine, not vice versa.

Besides, astronauts have a lot of needs that machines do not have and that creates discontinuity and disruption in the development of the various activities and operations they have to perform on board: they have to sleep, they have to eat, they

![The International Space Station (ISS) at the final configuration stage. Credits by NASA](image)
must take care of their hygiene and physiological needs… robots are by far preferred to humans according to the engineering thought, although on several occasions it is still proven that humans can find creative solutions, such as the Apollo 13 mission\textsuperscript{1} and make the difference.

But I wanted to be positive and I thought that the coincidence of starting my Ph. D. in the same year in which the construction of the International Space Station (ISS) began might be considered a very exciting and promising point of start. In fact, it brought me luck and I was immediately rewarded for my efforts.

First, I realized that in Turin, just a hundred kilometres from Milan, Thales Alenia Space (in 1997 it was called Alenia Space) was designing and building over

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\textsuperscript{1}On 13 April 1970, Apollo 13 commander Jim Lovell told NASA headquarters: “Houston, we’ve had a problem” and began to explain the technical details of the failure. There was an explosion on board, and the ship was rapidly losing oxygen. I will begin for the crew and the whole of America, the odyssey of the difficult return to Earth, which should have been place 4 days later. All that remained was to abandon the objective of the Moon. The NASA control center in Houston decided for a passage around the Moon to push the Space Shuttle and make it take a route to Earth with a return trajectory “free”, i.e. driven manually. In the lunar module, the astronauts lived critical hours that the whole world followed with bated breath: three men for 4 days in a space designed to accommodate two people for 2 days. The energy reserves were scarce, and even the water, the heat decreased. The carbon dioxide filters were not enough for three people, but by making do with what they found on board and with the guidance of the control center, the astronauts built an adapter that they called “the mailbox”. Jim Lovell and Jeffrey Kluger then wrote a book about the mission, Lost Moon, which inspired the Ron Howard Apollo 13 film.
40% of the habitable pressurized modules of the entire ISS (Fig. 3.1), thanks to its extraordinary experience and technological know-how. Just think that today Thales Alenia Space—a joint venture between Thales (67%) and Leonardo (33%)—is the second industrial contractor of the orbital complex, after the American Boeing.

I contacted them immediately, and I got in touch with the Human Factors Engineering Department that it dealt with the aspects of habitability and usability of the equipment for the ISS. They were all engineers, apart from an architect and a designer, who, in order to survive and to integrate themselves, had adapted to the language of ergonomics, eliminating artistic ambitiousness like, for example, the importance of soft interventions as the use of colour and light to change the level of perceptual comfort of the environments, as well as the emotional aspects that impact directly on the performance quality of the astronauts’ activities.

The attention of the engineers was focussed on the human factors, and not on the human needs, treating the astronauts as a sum of parties that can be analysed and decomposed in singular pieces, like those of a car, without taking into consideration the whole person, that is something more than many body parts put together that have to work in some way. The holistic approach was completely absent.

### 3.1.2 The Ability to Predict Use and Gestures

When I arrived at Alenia Space, they were building the European Columbus Laboratory (Fig. 3.2) for the ISS, and they were testing in the pool a dimensional mock-up² to make experiments of the usability of the tools on the outside of the habitation module that covered various Extra-Vehicular Activities (EVA). I tried to learn their language to drive the concept that if the astronauts can live better, in a comfortable environment, considering in addition to the human factors also those

²The mock-up is a model with the same dimensions and weight as the real module, but it is not made of the same materials. There are four stages in the development of the mock-up, even if usually all four are never constructed for one single project.

The first model represents the shell, the environment and overall volume, and it permits verification of its dimensions, movements, illumination and colours.

The second, more approximate than the first because it is made of inexpensive materials, is more precise in terms of the internal configuration of the structure: complex details are verified and possible movement between the components is foreseen, and it can be tested underwater. This model is often substituted by an electronic mock-up for testing volumetric relationships, assembly and disassembly of the components, etc.

Real parts are added to the third mock-up, which is very similar to the second one: these are parts that actually work from a mechanical point of view, such as connectors, switches, lights, energy and interfaces. However, they are made of inexpensive materials.

The last mock-up has real equipment that is useful for training the crew such as the possibility of carrying out test procedures of the various instruments that the astronauts will find on board during the mission but there is no redundancy, there are no doubles of instruments foreseen in the real configuration. Furthermore, the functionality of the instruments on the fourth mock-up imitates the real situation, but not of the quality of the instruments in terms of safety and reliability.
related to the psychological and emotional sphere, their performances and the
results of the whole mission increase naturally.

Besides, I started to introduce a new methodology that I called *Use and Gesture
Design (UGD)* which put in a systemic view the human being and the movements,
the interactions and the gestures related to the equipment to use during scientific
and maintenance activities, or experiments, and the environments. I wanted to join
to the design process the analysis of use and gestures while imagining a new
product that will be used in microgravity and in confined spaces, an experience that
for all of us is unknown and it is not part of our daily life.³

*Designing for Space* was becoming for me something more defined, and as I
affirm also today, it means *starting anew, applying a different logic for a different
environment*, conceiving new instruments for uses and activities that Earth dwellers
have difficulty in envisaging, but which on the whole presuppose a different relation-
ship between our bodies, the objects and the surrounding space. Designing for
confined spaces and for microgravity conditions require the *ability to predict use
and gestures* that is to say foreseeing how an object will be used and in which ways,
to be able to imagine, for example, the actions and the movements of the crew in
relationship to the new Neutral Body Posture (NBP) that is assumed in micro-
gravity, and foresee the physiological, perceptive, ergonomic, psychological and
motorial requirements that will arise to the astronauts in conditions that are com-
pletely new and unknown to the human being (Dominoni 2002).

The most important and most interesting difference between *Designing for Space*
and *Designing for Earth* can therefore be identified in a new design process in
which it is introduced the capacity of use forecast, to visualizing gestures and
movements that interact with equipment and tools in extra-terrestrial environments
which cannot be compared to already known human experiences that can be amply
verified. Defining the boundaries of the *UGD* methodology for Space helped me to
expand and apply these principles also on Earth as a *spin-off of behaviours*, con-
cerning the use and gestures of the crew on board, as well as of technologies,
concerning the habitation modules and the whole architecture systems and
sub-systems in Space.⁴

³The *Use and Gesture Design (UGD)* methodology is explained in the first chapter of this book
and represents an innovation in approaching the development of the project, both on Earth then in
Space, looking at the behaviours and the movements of the human being while interacting with
tools and environments.

⁴If usually the *spin-off* term is used to describe a *technological transfer* from different fields of
application, I started from the beginning of my experience using spin-off (from Space to Earth) and
spin-in (from Earth to Space) to define *behaviours transfers*, because Design discipline concerns,
before all, the human being.
3.1.3  Turning Microgravity into an Advantage

A case study that could help the readers to better clarify this new design process that introduces the methodology of *Use and Gesture Design (UGD)* along with the ability to predict the uses of the object in the contest for which it is created—and that I had the opportunity to create and experiment concretely, coming into contact with Alenia Space in 1998—concerns the development of a system of tool-carrying containers, which Alenia Space asked me to design, and which I have called *Portable Caddy System* to be used as a toolset to support the routine maintenance of the European Columbus Laboratory of the International Space Station (ISS).

The project was part of a broader programme based on the development of concepts and Design solutions in order to increase the efficiency of systems to support movement, habitability and work in confined environments and in conditions of microgravity. As part of this research programme, the design of a tool holder system for routine maintenance of the ISS Columbus European Laboratory is located in the area of required equipment “Outfitting Complements” or prosthetic objects whose main purpose is to increase the efficiency of the crew’s activities.

Compared to the existing containers used at that time on the ISS that are as rigid toolboxes sized to be integrated into the racks\(^5\) room dedicated to storage, I studied a system of soft containers, made of fabric, that was portable, and also easily wearable by astronauts. The project follows the principle of *turning microgravity into an advantage*, not a limit, trying to exploit the new potential that can have weightless objects floating in space.

The idea was to imagine the containers close to the astronauts, as useful assistants, but independent, of the kind of *console* that could become rigid—if you had to lean and fix the tools that were not needed at that time, avoiding that they begin to float in the air, or that they were attached in a scattered way to the body of the astronauts with the Velcro®—and return soft, to be rolled, once used the tools and stored them in the *Portable Caddy System*, to occupy the minimum of space possible. My inspiration was the soft containers of fabric that are used to store jewellery, or those for cutlery, which are very similar in shape and use. I thought that instead of jewellery or cutlery, you could also imagine storing utensils, of different sizes for different uses, in the same way. Apart from the lightness and the saving of space, the project allowed—thanks to a flexible structure inside the fabric made of harmonic steel, to create the necessary rigidity, once unrolled the soft container, to take the form of a rigid console, a surface close to the astronaut, to support and fix the various tools, a sort of flying working plan.

The system included several pieces: in addition to the console, the largest piece, I had also proposed smaller pieces, wearables, for example, around the thigh, useful when astronauts were in confined and limited spaces that they could not use the

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\(^5\)The *rack* is a sort of modular cabinet which covers the walls of the habitable modules of the ISS. Its structure is conceived to host experiments, equipment and tools useful for the whole functioning and maintenance of the International Space Station (ISS).
console, or even if they need to use only a few pieces for certain operations, and not
the entire collection of tools. This was my first project in which to experiment with
the intuitions of the new methodology of Use and Gesture Design (UGD)—that is,
the analysis of the movements more suitable for the use of the soft toolboxes and
the tools punctuated by precise gestural sequences—and an extraordinary oppor-
tunity to increase my predictive use and gesture ability—to simulate the movements
of astronauts before on Earth, through a preventive verification of the possible uses
and gestures in relation to the body, objects, the activities to be carried out and the
Space environment—that has been articulated intertwining with the parallel
development of morphologic, functional and performance characteristics of the
Portable Caddy System.

The project for the Portable Caddy System can be traced back to the area of
research conducted by the Human Factors Engineering Department of Alenia Space
on the human performance in conditions of microgravity. Like the most projects of
equipment and objects supporting astronauts’ activities, they were taking on an
important role, although in Alenia Space they were reduced to an ergonomic
analysis by applying pre-constituted parameters and tables, without considering the
diversity of approach and behaviour between one astronaut and another, and
without applying innovative solutions: their principle was to proceed for small
steps, with incremental innovations, without thinking of new projects or new uses.

For this reason, I believe that my Portable Caddy System—created through a
new Design approach, which introduced the importance of combining the design of
the objects with that of its possible uses in an environment without weight—has
been welcomed with great interest by the Human Factors Engineering Department.

3.1.4 Design Research Methodologies for Space

The Portable Caddy System allows me to introduce instruments and methodologies
that belong to the Design discipline, as the Use and Gesture Design (UGD)
methodology that I created specifically for Space Design, hybridized with the
engineering approach of Task Analysis used by the Human Factors Engineering
Department of Alenia Space.

The starting point of this Design Research coincided with a predominantly
empirical survey to consider the experiences previously acquired in this field of
intervention evaluating the weaknesses and strengths of the system currently in use.
The goal was to re-think a system of containers designed specifically for Space,
avoiding adapting elements in use on Earth with the limits that derive from this
setting. This approach required a Design Research methodology based on an in-
separable connection between theory and practice, where practice means the ability
to simulate results through the prior verification of uses and gestures in relation to
objects and the environment. In the meantime, I involved Usag, an Italian company
specialized in producing tools and utensils, to support me to develop the project and
realized the prototypes of the Portable Caddy System.
The following are the main points of investigation that I defined together with Alenia Space in order to improve the quality and the efficiency of the already used equipment for the same functions:

1. Analysis of the movements and the human activities carried out within the habitable volumes, applying the *Use and Gesture Design (UGD)* methodology, and provided for the ordinary maintenance of the module to get to define the design requirements of the Portable Caddy System.

2. Study of available spaces and existing anchoring systems to facilitate movements and human activities for routine maintenance carried out within the habitable volumes, with particular reference to those planned for the International Space Station and the European Columbus Laboratory.

3. Analysis and identification of the advantages and disadvantages encountered by comparing the different anchoring systems in use.

4. Analysis and identification of areas requiring anchorages for the Portable Caddy System containers and the tools contained.

5. Study of the system currently in use and analysis of the advantages and disadvantages encountered on board the International Space Station.

6. Identification of the design requirements indicated by NASA as required (Ref. NASA-STD-3000 and ESA-RQ-013): number of tools and their type, number of procedures provided with listed in sequence the tools needed for each operation, number of postures required for the various routine maintenance operations and their type, suitable materials for the environment, functionality, comfort and freedom of movement.

7. Development of a new system of portable and wearable tool containers for routine maintenance called Portable Caddy System and based on the innovative concept of taking advantage of the peculiarities of the environment and microgravity conditions, considering until now the greatest limit of living and working in Space.

8. Realization of the first prototypes by Usag on the basis of the design brief.

9. Verification of requirements and design assumptions through testing of dry and water Portable Caddy System prototypes.

10. Realization of subsequent prototypes by Usag based on test results.

11. Verification of requirements and design hypotheses through experimentation and tests with parabolic flights.

Analysing the state of the art I focussed on the system currently in use, a Tool Box, developed by Alenia Space and DMR for the Italian Space Agency (ASI) and tested during two missions on the Russian Orbiting Space Station MIR: Euromir '94 and Euromir '95. Tool Box was designed to support crew members in the study and development of the “On-Orbit Testing of Crew Support Equipment Study” (Musso et al. 1996). It consists of a 2-mm-thick opaque anodized aluminium container to which Velcro® strips and elastic belts have been applied on the outer surface to provide temporary attachment of the tools and other necessary objects. The inside of the container is intended for tools. These were selected taking into account the offer on the market, and the consequent adaptations of the individual parts to the
conditions required by the space environment were reduced to a minimum. The list of tools provided for the container is generic: the selection was made considering a generic use of the container for routine maintenance operations and for emergency situations. Each tool has a ring attached to which is tied a rope that is fixed by Velcro® to the belt or wrist of the operator to prevent the tools from getting out of hand and start to navigate in Space. The total weight of the fully equipped tool container is 2.7 kg. The overall analysis to evaluate the efficiency and validity of the Tool Box has given rise to some considerations that have served to detect the major limits of this system:

- poor visibility of tools;
- poor solution of fixing tools inside the container;
- poor solution of attaching tools to the operator because the ropes tangle around the body limiting movements;
- high weight.

The state of the art included also a document NASA—Boeing which collected various equipment for astronauts including Equipment Bag Assembly (EBA): it was a container consisting of a large expandable central space with small external and internal pockets and an outer band to carry it on the shoulder. The fabric was made of a semi-transparent mesh held at the corners by hinges and Velcro®.

My Design Research would try to overcome the limits found in the Tool Box system by transforming them into project objectives-requirements. The innovation points of my Portable Caddy System were given by the objectives I put as results of the state-of-the-art’s survey:

1. The main objective identified was to provide permanent storage of tools in the racks of the International Space Station (ISS) and at the same time to provide temporary support to tools and equipment used for ordinary activities on board maintenance. This was the first innovation: to provide a system of containers able to perform the two functions, permanent storage and temporary use of tools. Until now, in fact, systems have been designed separately for the permanent storage of equipment in racks (Ref. Boeing Soft Stowage Human Space Logistic System, Catalogue Issue 1) and portable containers for the temporary use of the same equipment. A system of containers that performs both functions results in a saving in volume, weight and a consequent reduction in equipment.

2. A further step forward has been the study of container supports that allow to be transported with ease and positioned in different ways and angles adaptable to the different areas, often poorly accessible, of the ISS. This is the second innovation: to provide a system of portable and wearable containers able to guarantee flexibility in use and immediate availability of tools.

3. The third objective was to try to solve and overcome the limitations of the system currently in use by making the tools visible from the outside of the containers. This is the third innovation: to provide a system of semi-transparent containers able to make tools visible (Fig. 3.3).
4. The fourth objective has been to try to solve and overcome the limits of the system currently in use (Ref. APM IVA Tool List Maintenance, Technical Note, Columbus Team, Alenia Space Division, 29.09.99) allowing the operator to carry out the various activities without losing the tools or being limited by the fixing system of the same. These are the fourth innovation: *to provide a system of containers able to ensure an effective attachment of the same tools to the support and the operator.*

These four innovations gave rise to other more specific objectives that contributed to increase the comfort, the efficiency and the usability of the Portable Caddy System in Space:

- the reduction of the volume and specific weight of containers compared to those currently in use;
- flexibility to adapt to different spaces and maintenance operations;
- easy access to tools by the operator;
- the wearability of containers to facilitate their transport in orbit during various activities (Fig. 3.4);
- the softness of the material to fit the body and the different spaces available.

Considering the set of objectives and requirements defined above, this Design Research has made it possible to define a system of portable main containers
rollable and closable which, once opened, can be completely stretched, or only partially, flat and in every direction, thanks to two bands of harmonic steel with return of shape inserted in the fabric. The harmonic steel bands have the task of stiffening the support and transforming it from a portable container to a work surface during use: this solution allows the container to be fixed to the internal structure of the module and at the same time to adapt to the limited and sometimes difficult to reach spaces of the intervention areas inside the European Columbus Laboratory (Ref. Boeing, *Flight Crew Support and Integration (FCS&I)*, Section of the *Space Station Operations Data Book (SSODB)*, December 1997).

The main containers have inner pockets semi-transparent made with a net to divide the various tools and ensure the total visibility and accessibility of the tools during use. The internal pockets have flexible and standardized dimensions to accommodate different tools. The accessibility of the tools through the pockets is resolved with elastic bands that facilitate the extraction of the tools but at the same time prevent their escape. There are also external pockets to place small accessories. The attachment of the container system to the internal structure of the module is through Velcro® belts that roll up by self.

Fig. 3.4 Two prototypes of wearable containers of the *Portable Caddy System* designed by the author facilitate tools transport during operations on ISS. Credits by the author
The portable and wearable containers (Ref. NASA-STD-3000) have a semi-rigid shape, pre-formed and rounded at the sides, with a hinged opening on three sides. The stiffening system with harmonic steel bands, also present in the main containers, allows the wearable container, once opened, to become a small console with the tools well visible and close at hand.

Concerning the operator-object relationship, the portable and wearable containers have been studied and designed to be positioned adherent to the thigh, at the waist and transversally (shoulder-waist), compatible with the type of operation to be carried out. The possibility of placing them on the arm and on the leg was ruled out due to poor visibility of access to the tools. The fastening to the body is through Velcro® belts that roll up self-sealing. The fabric used for the Portable Caddy System is composed of Betacloth and Nomex fibres. There is also an antibacterial finishing on the tissue.

3.1.5 To Verify Prototypes with Dry and Underwater Tests

Alenia Space was interested in developing study models and prototypes of the Portable Caddy System to verify the usability (at that time the term usability was not widespread and they used ergonomics) and the effectiveness of the new system of fabric containers, soft and wearable. As usual in developing projects and as already explained before, I decided to involve a terrestrial company, specialized in the production of tools, Usag, for the realization of prototypes of the soft bags.

I led first dry tests, so-called in Space language to describe the tests that can be done on Earth and that are useful for small objects or equipment, as a rack interface, in which the interaction with the human being does not change a lot when in microgravity. Dry tests are the last procedure that is carried out on the ground before performing tests underwater or in parabolic flights is referred to as a dry test. It is very useful for defining in detail the operations to be carried out, such as screwing and unscrewing components and structural parts, in order to verify that everything is functioning correctly and to avoid jeopardizing the verification possibilities offered by the other tests.

Then, I had the chance to led underwater tests in the big swimming pool of Alenia Space called the Neutral Buoyancy Facility (NBF) the best place on Earth for simulating weightlessness, in which a mock-up of the European Columbus Laboratory has been built, to test astronauts operation during Extra-Vehicular Activities (EVA). There are several peculiarities that are characteristic of tests carried out underwater which are important to point out and that concern the relation between the body, the gestures and the movements and a good playground to apply the Use and Gesture Design (UGD) methodology:
if the equilibration of the subject is appropriate in relation to the depth, the simulation of the absence of gravity is very realistic;

- the friction of the water influences rapid movement in a significant manner; contrary to parabolic flights, gravity is not completely absent, so all the objects that are not balanced “fall” to the bottom of the swimming pool if they are not appropriately tied, instead of “floating away” as happens in orbit;

- the duration of the tests can be lengthy, with no limitation on the simulation procedures, which instead are strictly limited in the case of parabolic flights;

- there are no problems of “airsickness” typical of parabolic flights, which limit the productivity of the subjects and therefore the percentage of the success of the tests.

There are some limits, however, regarding the configuration and the design of the simulators to be introduced into the swimming pool: it is not possible to use electric apparatuses, and therefore the operation of the flight system or of electric tools cannot be simulated; metal structures must be able to resist corrosion and allow adequate water flow, in order to minimize the hydrodynamic inertia; materials must be waterproof and may not vary in performance once immersed in water.

Apart from the possibility to experiment the microgravity in the same way, the simulation of the Space environment in water is in fact rather approximate: there is no real sensation of microgravity; the subjects involved in the tests essentially cannot communicate very well with each other; the lighting level is very different from the real one and it can be difficult to see well when performing activities; the conditions of movement are altered by the tendency— inherent in the subjects—to “swim”.

This kind of underwater simulation is, however, particularly useful for the tests involving the crew activities and equipment characterized by significant volumes as well as complex sequences of operations, for instance: large apparatuses to be transported, assembled and removed, assembled, long and complex procedures, to be evaluated in an integrated manner; activities requiring the involvement of several subjects; Extra-Vehicular Activities (EVA), or when it is useful to have a mock-up of several elements, or sections of elements, of the International Space Station (ISS); accessibility to equipment whose location cannot be simulated in parabolic flights, also for reasons of safety.

Coming back to my project, after this digression on the validation systems useful for testing new Space products, the prototypes of the Portable Caddy System have had several opportunities to be used and verified during the experiments as support to the planned activities of Alenia Space. The first results commented by the test

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6The parabolic flights are currently the simulation system that most closely imitates the effective conditions of microgravity experienced in orbit, but for very short intervals of time, approximately 30 s of microgravity each parabola with an Airbus A300. The bigger limit is the need to subdivide the operative procedures into many separate sequences of operations lasting no more than the period of one parabola. A standard flight campaign lasts 3 days, with 30 to 40 parabolas carried out on each day, considering that between two successive parabolas they pass from 2 to about 4 min.
subjects provided interesting input for further development of the *Portable Caddy System* according to its future use in conditions of microgravity.

The tests conducted in the laboratories of Alenia Spazio, *dry* and *underwater* (Figs. 3.5 and 3.6), have demonstrated the effectiveness of the system during use and, in particular, have been extremely functional, in both portable main containers and wearable containers, the following activities related to the *Use and Gesture Design (UGD)* methodology:

1. portable main containers:
   - opening and unrolling, securing the *Portable Caddy System* inside the module (even if in water, in horizontal position, the stiffening system with harmonic steel bands meets too much resistance and is therefore not reliable), closing and rolling, the fastening of the *Portable Caddy System* inside the module by Velcro® (rather than with elastic clamp), the repositioning of the tools in the *Portable Caddy System*;

2. portable and wearable containers:
   - the opening, the adhesion to the leg, the accessibility to the tools, the repositioning of the tools in the wearable *Portable Caddy System*, the closing.

Fig. 3.5  I took these photos during the tests of comfort, efficiency and usability of the *Portable Caddy System* conducted underwater inside the Neutral Buoyancy Facility (NBF) of Alenia Space in Turin. Credits by the author
In both portable main and wearable containers (1. and 2.), the choice to use soft material such as fabric instead of metal or plastic was successful for the extreme ease of opening and closing and for the best adaptability to body shapes when it has to be worn (Fig. 3.6).

### 3.1.6 Co-design with Astronauts

It was a great new experience for me to have the opportunity to receive feedback from astronauts testing my Portable Caddy Tools System, even though I did not receive, as I thought, useful guidance for improving or modifying prototypes.

The **briefings** and **de-briefings** I led with them\(^7\) provided for me to create very specific questionnaires that left no room for dialogue. The open questions I had

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\(^7\)The *briefing* and the *de-briefing* are activities that involve astronauts to check the products during the design process, before the realization of the prototypes (briefing activities) and after to have conducted tests of usability (de-briefing activities) in order to give opinions and suggestions to improve the performative qualities of the project.
prepared didn’t give me answers that would help me better understand their needs, and in this particular case, to understand if my system was working. I had to go back to my ability to imagine how it could have been if I had lived in Space, without gravity. Later, I would find that, with a few exceptions, astronauts are trained to perform very complex and detailed procedures that do not require their participation in the design process. Today, we would have called it a co-design process. For them, creative skills are not contemplated, although I still believe that designing for and together with our users, especially astronauts who experience what it’s like to live and work in Space, is important, if not indispensable.

We will see later in this same chapter how the first Space architects and designers, from the design of the Soyuz to the Skylab up to the International Space Station, had a different feedback from the crew, certainly more participation and enthusiasm from cosmonauts than astronauts, that perhaps for training and prove-nance are closer to a military approach that is based on orders that must be executed quickly and that often do not include an active and proactive contribution.

3.1.7 Disruptive Feasibility Studies with Design Companies

For the moment, we continue with my experience that in the same year 1998 is enriched with other opportunities for Space Design: the Italian Space Agency (ASI) launched the first Call for the Technological Utilization of the Space Station (which will be unfortunately also the last until today). I participated with two proposals to develop feasibility studies of new products to be used by astronauts in Space in which I had involved for the technological part, some Italian industrial partners considered leaders in their respective fields, and above all that they had a strong vocation to do research and innovate their products, and for the spatialization\(^8\) of the prototypes Alenia Space. The objective of the ASI was to select the most innovative feasibility studies that would become, through standard procedures, experiments to be tested on board the International Space Station (ISS). At the end of the selection’s procedure, I was very happy to discover that both my proposals had been accepted and financed. It was the first time that in the field of Space were involved terrestrial companies, and overall design-oriented, to participate to a Space programme that would have required the realization of prototypes to be tested on board the ISS, and in ASI they were very curious to see the results involving private companies that did not belong to the Space field like all the others who did not belong to the space sector like all the others who usually participated in the calls.

\(^8\)We utilize to call in Space jargon spatialization the sum of all the procedures referred to NASA Technical Standard 3000, specific for human space flights, and tests that make a product ready to be launched in Space respecting requirements of human factors, habitability and environmental health.
The first proposal, in which I involved Benetton Group—the Italian company very famous to have launched during the 1980s the sweaters round neck with lots of colour gradations—was a feasibility study that I called VEST. Integrated Clothing System for Intra-Vehicular Activities (IVA) is used by the astronauts on board the International Space Station (ISS). The project was made of different typologies of clothing focused from one hand, on the characteristics of comfort and wearability of the garments, and from the other hand, on new smart textiles researches, in particular related to the thermoregulating and antibacterial properties of the fibres, to increase the well-being of the crew during human space flights (Dominoni 2005).

Also, the project foresaw the integration of a system of sensors into the garments to monitor the biomedical parameters without being invasive for the astronauts and require their active participation. The project VEST will be treated as a case study in this book in chapter 4 Space Design Between Research, Project and Education.

The second proposal, in which I involved TechnoGym—a worldwide Italian company leader in designing fitness machines and defining wellness scenarios—was a feasibility study that I called AGILE, Attrezzi Ginici LEggeri for Intra-Vehicular Activities (IVA) to be used by the astronauts on board the International Space Station (ISS). The project was made of a system of fitness machines, more light and friendly of the existing ones at that moment (a VELO cyclo ergometer and a trade mill) and aimed to increase the efficiency of the physical exercise, reduce the time of training, and also make easier and pleasant the two mandatory hours per day dedicated to maintain muscle mass and bone structure. AGILE implied many studies and researches on physiology specific for microgravity environment in which appropriate physical exercises become for astronauts one of the most efficacy countermeasures to the loss of muscle mass and bone decalcification that astronauts encounter living in Space.

3.1.8 Space Design is Multidisciplinary

For me, of course, starting to devote myself to projects that had an almost immediate effective response was a great joy and the beginning of a series of new and exciting activities, in which as project leader and Principal Investigator I found myself interacting with experts in the various disciplinary fields, who had different backgrounds and languages, and who often had difficulty understanding each other. For the designer, accustomed to dealing with traditional production realities, and above all terrestrial ones, the Design Research in the Space field is only possible with the presence and constant participation of agencies and industries specialized in the Space sector that are able to provide you with all the necessary information to address the project assignments from time to time.

I soon discovered that a fundamental feature of the Design discipline is its multidisciplinary nature, the ability to speak different languages, to relate to the scientific community of reference, to collect data and requirements to translate them into solutions and to act as a bridge between the project and the human sciences,
using the group as an accelerator to the creative process. This topic will be exploited later on in this same chapter in the paragraph Designer’s Perception at ESA.

Taking into account that the Design embraces the entire world of artifacts, I would have found myself soon designing, after the experience of the toolboxes, Portable Caddy System, a clothing support system, VEST, a fitness system equipment and machines, AGILE, as well as a washing machines that it is assumed to be able to wash without water, systems for the preparation, the consumption and the conservation of the food, systems for the illumination and the personal hygiene, and all items and tools regarding the whole habitability in the Space.

3.1.9 Crossing Space Knowledge Through Design

The identification of the new areas of research presupposed for me, from the lens of Design, scrupulous analysis of the Space environment and the specificities that most affected everyday life, as the activities the crew carried out, or they could have performed in the future, on board the International Space Station (ISS).

Along with the scientific literature, unfortunately very poor as regards the contribution of Design discipline in the development of real projects that could be tested by astronauts, I was looking for information on ongoing research programmes that involved human space missions to identify strategic development lines that could have been crucial in the design process, with the aim to find possible areas of convergence with Design. I was trying to complete the puzzle on the state of the art of a sector, the Space, still too small and young to be able to count on reliable statistics conducted on the astronauts’ behaviours and experiences in confined environments and in microgravity conditions.

The experience gathered by the soviet and American human space missions in half a century of activity had not produced enough data to be formalized and translated into shared scientific knowledge; indeed, I found vague information, and sometimes even contradictory, because of the subjectivity of every astronaut. For example, I was struck by the fact that in Space, sight could become less acute—30% of astronauts, even after short-term missions, reported a decrease in visual capacity—but above all that some reported seeing even the faintest colours, in pastel tones. The causes of this phenomenon are not yet entirely clear but, according to the physicians and medicals, it could be triggered by the absence of gravity that makes the body fluids concentrate in the lower limbs and the head, thus reducing the pressure of the retina. So, which colours should you choose for microgravity environments? Very bright shades to be perceived as “normal” compared to earthly experience? Or soft colours to favour calm and relaxation? How much does colour affect the environment of the ISS to support the activities of astronauts, to promote concentration as well as sleep? No study so far has been tested aboard the International Space Station on the power of light and colour to facilitate the performance of astronauts on board.
The lack of reliability of the experience acquired and the little knowledge of the Space environment with its effects on man was due to the small number of human space missions and astronauts involved—the Space conquest is still in a pioneering phase—and, in part, to the duration of the same missions which, except for rare occasions of some continuous months of stay on board, apart from the Russian cosmonauts (Gadzenko et al. 1982), in most cases did not exceed 2 weeks. I’m talking about the early 2000s when the scientific experiments to be conducted on the International Space Station (ISS) could count on a 7/8 day of human space missions called Taxi Flight for the brevity of the period. Today, the astronauts’ missions last approximately 6 months, and in some cases have even exceeded a year. The scientific researches have also made progresses and now we know more about the effects of the Space environment on the human being (Wichman and Donaldson 1996).

The most comprehensive study of long-term microgravity permanence remains the one conducted on Scott Kelly’s body during and after the One Year Mission between 2015 and 2016 (one consecutive year in orbit on ISS) and that of his twin remained on Earth. If, on the one hand, the data reveal unexpected details about the adaptability of our organism, on the other hand, there are still many unknowns and it is difficult to generalize. Much of the information that emerges may relate to the specific way Scott Kelly’s body reacted, and it may not be true for all astronauts, nor for the general population. It is difficult to say if the results can be extended to the next human space missions to the Moon and Mars, well beyond the 400 km distance from the ISS home, where you can enjoy all the protective effects of the Earth’s magnetic field.

For the designer, the knowledge of the Space environment and its effects on the human being is essential to be able to identify the requirements to generate ideas that can offer the crew the actual benefits in terms of comfort and efficiency in the performance of the activities on board.

The exploration of a new area such as Space, in which I could enter with the role of researcher and designer, was complex and innovative both from the technological than the sociological point of view. This implied the presence of people who had devoted their lives to study and training, hoping to be chosen, at least once, to participate in human space missions that would have taken them beyond Earth, out of our planet, and to face risks still little known to the scientific community. I am not thinking only of the most extreme experiences, in which the entire crew has lost their lives, but I would like to recall that even today very little is known about the harmful effects of cosmic radiation and cell degeneration in the absence of gravity, especially in the medium and long terms (Moore et al. 1996).

I also discovered that Designing for Space required the industrial designer to commit, just as important as designing, which concerned the strategic organization of the new scenarios that were on the horizon (Dominoni 2002). And I was increasingly convinced that Space would have a decisive influence in the near future on people’s lives and behaviours, enhancing health as wellness. I needed to dedicate an equally important commitment to that of designing which concerned the organization of new scenarios and the management of contacts necessary to relate
to the relevant scientific community. The identification of new areas of research
requires a thorough analysis of the Space environment, its peculiarities and the
consequent influences on life and all the various activities that the astronauts carry
out and could carry out on board, not to mention the ability to imagine spin-offs
through new applications on Earth.

The first action I considered essential was to integrate to the scientific literature—
at that time the only book available that could be close to my interests was Living
Aloft (Connors et al. 1985)—and papers, and information on the state of the art of
the field with the research programmes in progress trying to maintain a direct contact
with the space agencies and identify the strategic lines of development of the human
space flight’s exploration that could have given me decisive suggestions to Design
for Space, and perhaps even inspirations on what might have been the possible areas
of convergence with the Industrial Design discipline. It is not enough to have many
new ideas if they cannot be tested directly with astronauts. It is essential to be known
and to make clear what are the potentials of Design in the Space field.

In order to be able to work as a researcher and designer of Space equipment and
environment, it is therefore essential for the designer that the scientific and
industrial Space community is constantly informed about nature and the role of
Design, to know the potential and possible applications of this discipline in con-
fined environments and microgravity conditions. In this regard, a path that I would
have immediately pursued is to participate in symposia, calls for competitions and
workshops, organized by national and international space agencies, to disseminate
the results achieved and research developments, and progressively gain credibility
and interest in Space scientific community, consisting of agencies, research and
development centres, product certification and validation bodies, and Space
industries. Very often, the correct identification of the interlocutor can determine
the quality of the project results (Dominoni 2015).

At the International Workshop ESA ExploSpace. Space Exploration and
Resources Exploitation, organized by European Space Agency (ESA) and led from
20 to 22 of October 1998 in Sardinia, I presented my first paper9 IVA Clothing
Support System concerning the first results of a Clothing Support System
designed for the crew of the International Space Station (ISS), able to improve the comfort of
living and working on board through the wearability of garments, aesthetics,
thermal stability and body hygiene (Dominoni 1998). I was the only woman pre-
senting a scientific paper and the only designer among many engineers and
physicists among which Carlo Rubbia (Nobel Prize in Physics 1984) just before me.
My presentation was noted with curiousness and interest and for me was a fantastic
occasion to meet a lot of extraordinary people and start to build my network of
academic and scientist coming from Space field.

9The Paper IVA Clothing Support System received the Scientific Award for Young Researchers by
the European Space Agency (ESA): In appreciation of Annalisa Dominoni scientific value pre-
senting the paper “IVA Clothing Support System” at ESA ExploSpace Workshop, Space
Exploration and Resources Exploitation, Cagliari, Sardinia.
After that lucky episode other projects began, such as the *Feasibility Study of Habitability on board the ISS* commissioned by the Italian Space Agency (ASI) that asked me to imagine a new scenario with equipment and tools thought specifically for the Space environment, including various activities as the preparation, consumption and conservation of food, the body care and personal hygiene, the entertainment activities during the free time on board, the physical exercises, the possibility to grow plants in microgravity together with living, working and sleeping main activities on ISS. It was a big work of designing and forecasting use and gestures in a confined environment and microgravity conditions which led me to gain more and more experience in Space Design.

Then, the more exciting work for Space was to become Principal Investigator of two experiments on board the ISS, *VEST, Clothing Support System for the International Space Station*, during the *Marco Polo Mission* in April 2002, and *GOAL, Garments for Orbital Activities in weightLessness*, during the *Eneide Mission* in April 2005, both performed by the astronaut Roberto Vittori. I do not want here to describe more the experience because it is presented as the case study in chapter 4 of this book *Space Design Between Research, Project and Education*. After these two experiments, other projects of research and design have followed each other but now I would like to stop here with my personal experience that gave me the opportunity to introduce approaches, principles and methodologies of the new discipline in Space Design, and expand my gaze beyond time and history to retrace some milestones of Space Design.

### 3.2 Space Design Was Born by a Woman

 Few know that was a woman who had the value to give shape to the human space flights for the first time in the world, an architect, a designer who took care of well-being of the cosmonauts introducing in her projects’ harmony, beauty, colour and semiotic languages balancing with human needs, functions and technology. During the *Space Race* in the 1950s and 1960s, the task of designing the look of the soviet union’s booster rockets and orbital laboratories fell to one woman: Galina Balashova. For the budding architect in the midst of a militarized rush into Space, the work was also a chance to bring the principles of architecture and design into places they had never been before.

This woman defined the style of the whole soviet space program, from its logos to its satellites. Her delicate and rich watercolour and pencil illustrations of habitation modules, interiors, furniture, control panels, ergonomic studies and the vast paraphernalia which embraced everything from badges and logos to stationery and satellites are testaments to functionality, and have served multiple generations of Russian spacecrafts up to the present: from the design for the Soyuz capsule to the Salut and the Mir space stations, including the Buran programme and the soviet
reusable spacecraft. But they are also gorgeous works of art, like relics from a nearly forgotten future. Her work, much of it once top secret, has itself nearly been forgotten, even within Russia.

Galina Balashova, born in 1931, began her career as an architect by stripping off the decorations from Stalinist buildings that had fallen foul of the Khrushchev reforms. The classical language of socialist realism was firmly out by the mid-1950s when she started, but the designs still had to get built. She finished her career in the early 1990s as the pre-eminent architect of human space exploration. Balashova began working for OKB-1, the soviet space agency, designing residential buildings for the scientists and engineers working on the soviet space program. As the only architect in the team, she was then poached to work on the interiors of the manned spacecraft that came in the wake of Yuri Gagarin’s first brief space flight in 1961. Recently, in 2015, an exhibition at Deutsches Architektur museum (DAM) in Frankfurt/Main named Design for the Soviet Space Program. The Architect Galina Balashova enlightened her great work and underline the importance of Design in Space (Meuser 2015). What is surprising is the sheer range of her architect’s work. From interiors and Space furniture to the graphics on the sides of spaceships (Fig. 3.7) and on the inevitable soviet space programme medals, her hand is everywhere. Her impeccable watercolour renders completely defined the image of the soviet space program, both in Space and on Earth, and on stationery. She used
to say that a good architecture always depends on the same rules, and it doesn’t matter whether it’s about a house or a spaceship. And I would add, it doesn’t matter whether it’s about an object, or a tool, a garment or a fitness machine.

As architect and designer, her projects give shape to the whole Space Nathan Rogers’ From the Spoon to a City in which the Milanese architect and critic intended to express the breadth of the territory to express the breadth of the territory project of our profession, which allows acting simultaneously on different scales of complexity concerning the human being.

3.2.1 The Language of Semiotic and Colour in Space

There are some striking insights into Space Design for zero gravity. It was thought, for instance, that in zero-gravity conditions, cosmonauts wouldn’t bother about orientation in the Spacecraft, but Galina Balashova realized it mattered and, in a semiotic coding, introduced colours schemes (Fig. 3.8) that ensured floors were always dark coloured and ceilings light, so cosmonauts could have reference points to orient themselves. Furniture was designed to look domestic rather than Space Age. While product designers were playing with aluminium and moulded plastics shaping a world inspired by Space scenario as sci-fi movies, she designed
glass-fronted sideboards, integrated beds that could have come from nautical design, and radiogram-style control panels. We could say today that her functional and visual attitude was attributable to minimal design in contrast with the Space Age formal excesses. The complex interiors of the first Mir Space Station—launched in 1986 to serve as mankind’s first permanent presence in Space—with their ingenious vertical sleeping capsules, were, for instance, meticulously planned by her. She went further.

When the Soviet Space Program team realized that there was no decoration on the spaceship walls, Balashova was invited to paint a series of pictures and she responded by painting the remembered landscapes of her childhood, watercolours depicting Russian countryside, which she thought would be a reminder of home memory to the cosmonauts. “These pictures” she related “no longer exist, since they were incinerated with those parts of the Soyuz Capsule that burn up during landing”.

The only reason her remarkable drawings survived is that, as there was no architecture and design department, except for Balashova herself, there was no architecture and design archive. So, despite their classified nature, she was allowed to take them all home. An interesting topic that emerges, reading an interview she released to the press during the exhibition, is the confusion of the engineers who manage the human space missions in distinguishing the role of Art from that of Design, or Architecture: One day, Konstantin Petrovich Feoktistov asked me to do a sketch for the interior of the living module for a spaceship. Actually, Feoktistov first asked artist Viktor Petrovich Dyumin, because he thought that this was a task for artists. Dyumin pointed out that designing interiors was something architects did. And so, one weekend I found myself working away drawing a sketch.

The living module that Galina Balashova faced when she started her engagement was composed of a drawn with two red boxes in the plans. She wanted to look at the cosmonauts needs to make sure they felt at home in the small capsules creating a harmonious small room around them that could be sweet, functional and easy to use. The room needed to be outfitted just as if it were an apartment: with a bed, a table, chairs, a toilet and a shower.

In Space, we do not have any references regarding top and bottom, and it is very difficult to orientate. Balashova drew up two proposals. In the first one, the case in the Soyuz Capsules, she gave the space a floor and a ceiling. The floor was in green, the ceiling bright blue and the walls’ sides bright yellow. In the other proposal, the case of a project she made for the Lunar Orbital Craft LOK, it was not to distinguish clearly between top and bottom, but to structure the Spacecraft by means of different volumes. The Soyuz Capsule variant won because it is easier to work in rooms that had a clearly defined top and bottom, and it is easier to train cosmonauts flew into Space in identical, true-to-scale mock-up. In some of her drawings, there are pictures on the spaceship walls, maybe pretty superfluous in space travel, where

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10 https://www.iconeye.com/opinion/review/item/12306-galina-balashova.
11 https://www.stylepark.com/en/news/only-the-watercolors-burned-to-nothing.
every added gram and every extra centimetres of space counts, and overall, where functional and security aspects are predominant of all the other choice.

3.2.2 Balancing Human Needs and Functionality with Beauty

In Space, there is microgravity, and the human body reacts differently than on Earth, and there is a confined environment, but we can anyway to check the dimensions and the proportions of an interior of a spaceship through a mock-up analysing the relation of interface between human beings, available spaces and objects. As today we use to test with analogues the feasibility degree of a project, Galina Balashova as well faced with the interior of a submarine to have an idea of a confined environment in which people live for long time, without natural light and environmental stimuli, without privacy and the possibility to go out. “Another challenge was how to fasten documents and equipment in place: in zero gravity everything simply floats around otherwise. So, we clad the inside surfaces and all objects with Velcro® fasteners. The coloured wall cladding, the floor and the ceiling, it was all made of Velcro®. That way, you could attach objects simply anywhere, and just as easily detach them again. Only the chair and bed covers were made of normal fabric—the cosmonauts fastened themselves in place using belts. Their suits would have been damaged far too quickly under the permanent strain of Velcro® fasteners”.12 The use of Velcro® is still currently the most efficient and the least invasive system useful to fix objects and tools to the interior surfaces of the spaceship, or to the bodies of the astronauts, mainly thanks to its simplicity and its minimum volume and weight. As well as considering functional aspects, she asserted that the most important skill for an architect or a designer is a good taste. That means “To find the right proportions in the balance of humans, space and architecture. And that you can always reconcile function and beauty—he’d cribbed the latter from Palladio” (Meuser 2015).

In this book, I drive the idea that Design approach can add an aesthetic value to ergonomic and technology requirements, and the projects of Galina Balashova are very good case studies that show how to conciliate the world of engineering with the world of beauty, which is so important for the human being’s harmony. Balashova was gratified by the cosmonauts who liked the interior design of the Soyuz and the Mir. Only once did one request brighter colours: he said it was a little too dark in the Space Station, because to save weight, only the bare minimum of lighting had been provided. So, she installed more lamps. Not only she was satisfied by the cosmonauts’ appreciation, but her success was transferred in orbit to the

12https://www.stylepark.com/en/news/only-the-watercolors-burned-to-nothing.
astronauts: “After the Apollo-Soyuz Program, our cosmonauts said the american astronauts really liked our interior design because it was so comfortable. The American section was evidently far more tech and less homely. That made me feel proud, as engineers don’t think of the architecture only of the technical side to things. The best thing about my work was the freedom I had: No one told me I had to take this or that colour, do that this way, and whatever. I was able to take the decision I thought were the right ones as nobody was in the slightest interested in what I did”.13

3.3 A Designer to Create the Skylab

When inside NASA, for the first time, the question of habitability was being asked designing the Skylab laboratory, the only one that would have items designed specifically for this unique space mission, Raymond Loewy, was already a famous designer and was chosen for this task. Loewy worked on functional styling for a variety of mass-produced products for 40 years, besides designing stores, shopping centres and office buildings. He gave shape to the bottle of Coca-Cola, the packaging of Lucky Strike, but also the Air Force One for President John F. Kennedy and the Greyhound bus, according to its streamline’s philosophy and the ability to face the project in different scales.

Skylab was the United States’ first space station14 launched by NASA, a complex and complete orbiting home and scientific laboratory, an exciting adventure with all the drama that could be packed into its three manned flights, for about 24 weeks between May 1973 and February 1974. Major operations included an orbital workshop, a solar observatory, Earth observation and hundreds of experiments. It was conquest, of human-made hardware, a difficult and challenging environment, and even of ideas, and it was a severe test of man’s capability to analyse, solve problems and make innovative repairs in a hostile and unforgiving environment. Skylab was ingenuity but also innovation. The programme was initiated with hardware developed for other programmes, modified for this Space odyssey, and supplemented by items designed specifically for the conduct of its unique mission, many of them concerning habitability, like the first and unique “shower” made to be used in Space.

13idem.
14https://www.nasa.gov/mission_pages/skylab/missions/skylab_manned.html.
3.3.1 From Functional to Comfortable Spacecraft

Habitability is, as one NASA designer remarked, “a nebulous term at best”, one “not usually found in the engineer’s vocabulary”. Besides factors within the engineer’s usual responsibilities, such as the composition and temperature of the atmosphere and the levels of light and noise, habitability also encompasses the ease of keeping house, the convenience of attending to personal hygiene, and the provision for exercise and off-duty relaxation. Experience and intuition both suggested that these factors would become more important as missions grew longer. Looking ahead to space stations, NASA designers needed basic information on these problems of living in Space (Johnson 1974).

Early Spacecraft had been designed to be operated, not lived in. Weight and volume limitation in the Mercury and Gemini Capsules—the epithet, though despised by crews, was apt—meant that only the bare requirements for protecting and sustaining life could be provided. Michael Collins, the pilot on Gemini 10, compared the two-man Gemini craft to the front seats of a Volkswagen. That tiny space was home for Frank Borman and James Lowell for 14 days on Gemini 7.

The Apollo command module, though just over twice the volume of Gemini, was still primarily a functional spacecraft. Some improvements made it a bit more pleasant—hot water, for example—and its extra space gave the crew of three astronauts some freedom to move around and exercise stiff muscles; but few concessions were made to mere comfort. For the most part, “astronauts accepted whatever discomforts were inherent in their spacecraft, unless they interfered with performances, what mattered was accomplishing the missions”.

When early planners looked ahead to orbiting space stations, their attention was devoted to problems much more pressing than crew comfort. Of 41 papers presented at a Space Station Symposium in 1960, only one addressed the question of making the “space station a pleasant place to live”. This paper (Payne 1960) noted that operating an orbiting station would be much like keeping a lighthouse and discussed some of the factors that would have to be improved so that people could be induced to go into Space. Some of these factors were intangible, said the author, but they were no less important for that. Nine years later, the situation had changed little. Spacecraft technology still occupied the engineers’ attention, while the questions of everyday living were left for someone else to look after (Compton and Benson 1983).

Raymond Loewy was the first industrial designer called by NASA at Marshall Space Center (MSC)—which was involved in an experiment entitled Habitability Crew Quarters having the objective of obtaining design criteria for advanced spacecraft and long-term space stations—to give some reasonable degree of creature comfort. He produced a formal report in February 1968, Habitability Study A. A. P. Program, citing many faults in the existing layout and suggesting a number of improvements.
The interior of the Skylab laboratory was poorly planned, while Loewy thought that a working area should be simple, with enclosed and open *areas flowing smoothly as integrated elements against neutral backgrounds*. While he found a certain honesty in the straightforward treatment of interior space, the overall impression was nonetheless forbidding. The basic cylindrical structure clashed with rectangular elements and with the harsh pattern of triangular grid work liberally spread throughout the laboratory. It served to separate the habitation module in three principal parts, and also for anchorage through special outer soles on astronauts’ footwear. The visual environment was badly cluttered. Lights were scattered apparently at random over the ceiling, and colours were much too dark. This *depressing habitat could, however, be much improved simply by organized use of colour and illumination*. He recommended (Loewy 1981) a neutral background of pale yellow, with brighter accents for variety and for identifying crew aids, experiment equipment and personal kits. Lighting should be localized at work areas, and lights with a warmer spectral range substituted for the cold fluorescents used in the mock-up.

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**Fig. 3.9** Raymond Loewy designed a flexible layout for the *Habitability Crew Quarter* of the Skylab improving the colour organization and lighting to change the perception of space. Credits by Raymond Loewy Foundation
3.3.2 Improving Habitability and Recreational Values

Loewy proposed to create a wardroom, a space for eating, relaxing and handling routine office work, better yet, the floor plan should be made flexible by the use of movable panels, so that different arrangements could be tested (Fig. 3.9). These suggestions were received at MSC with a certain amount of perplexity (Belew 1977). And since none of the astronauts who had examined the mock-ups had attached any importance to such things. They cared less about styling and appearance than efficiency, and they wanted a Spacecraft in which they could do their jobs without a lot of petty annoyances. They were, in fact, somewhat disdainful of the attention given to such amenities as interior colour schemes.

In June 1968, a new principal investigator was appointed to work on habitability issues, Caldwell Johnson, Chief of Spacecraft Design in the Advanced Spacecraft Technology Division at MSC. He first looked at the Skylab laboratory convinced Johnson that habitability had been given no thought at all. In the course of their work, he and his colleagues had built up a store of information on design factors for all kinds of crew activities under circumstances of confinement and isolation, but their data might as well not have existed. So, he translated habitability from testing
different design concepts to create an operational system that would reduce the chores of daily living to a level entirely incidental to human space flight operations. He proposed to deal with nine major components of habitability: environment, architecture, mobility and restraint, food and water, clothing, personal hygiene, housekeeping, communication within the spacecraft, and off-duty activity. By systematizing the man spacecraft relationship, Johnson hoped to bring some engineering rigour into an otherwise chaotic field (Johnson 1974).

As it happens in all the projects, at the end the final result is a compromise between the proposal of designers and the resistance of the commitment: some habitability recommendations of both Raymond Loewy and Caldwell Johnson were accepted, and had a great impact of the Skylab laboratory structure, like the rearrangement of the floor plan to provide a wardroom, and the addition of a large window (Fig. 3.10) to allow the crew to enjoy the view from orbit, because its recreational value alone would be worth its cost on a long space mission.

Also, the clothing system changed: Johnson had to persuade the crews that the test pilot’s traditional one-piece flight coveralls were not suited to long-term living in the workshop. In this, they acquiesced, but they would not give up the pockets on the lower trouser leg, ideal for a pilot strapped into an airplane cockpit, but as Johnson believed, a useless impediment to moving around freely in zero-g. Johnson designed a three-piece uniform to which a matching jacket could be added; it was practical and attractive, but he was disappointed when the crews spoiled the effect by covering the shirt and jacket with name tags and badges.

When it came to matters of purely personal preference, such as off-duty relaxation and entertainment, Johnson was content to let the crew have their choice. He proposed an entertainment centre in the wardroom, equipped to show movies, or provide music, but it drew no enthusiastic response. Considering that the Skylab was the first space station in which human beings could experiment the condition of freedom to be weightlessness, the main entertainment interest of the astronauts was living the microgravity and look at the Earth’s magic beauty.

Skylab’s crewmen found that, within the roomy laboratory, and without the impediment of gravity’s pull, they could perform feats that even the most talented acrobats on Earth could not duplicate. “Mobility around here is super—Conrad reported—nobody has any motion sickness. Every kid in the United States would have a blast up here”. The cavernous workshop, 8.2 m long and 6.7 m in diameter, invited exploration. In Space, they soared around their home, embellishing their flights with flips, cartwheels and inventive gymnastic exercises (Belew 1977). So even if Skylab designers had provided recreational equipment to vary the routine of long hours in Space—there were dart sets, without sharp points, playing cards, balls, books, exercise equipment and a tape player—much of this went unused. Crew preferences tended strongly towards reading and recorded music—provided everyone could have his own private tape player; musical tastes were quite disparate (Compton and Benson 1983) and Earth gazing during orbital daylight and star watching during orbital night became principal diversions.

Thinking at the efforts of both designers of Skylab—Loewy and Johnson, respectively, outside and inside NASA, to create an environment more comfortable
and beautiful to increase the well-being of astronauts—I can only feel close to their frustration that it is not just the feeling of to be considered superfluous and not indispensable, as engineers are. The disappointment is that some astronauts, fortunately not all, who are our users, were completely indifferent to Loewy and Johnson’s efforts to improve their comfort. An opposite reaction is to the cosmonauts that appreciated all the design proposals of Galina Balashova to make the Space environment more harmonious and comfortable.

### 3.4 International Space Station: Design Versus Engineering

The project of the International Space Station (ISS) did not involve a designer or an architect from outside, as was the case for the Soyuz Capsules, the Salyut and Mir Space Stations, and the Skylab laboratory. The entire design of the habitable modules of the ISS was done within the engineering departments of space agencies, mainly NASA and ESA, in collaboration with the aerospace industry, of which the major contractors are Boeing and Thales Alenia Space.

The reasons for this change can be traced back to the fact that the ISS is an international project of the United States, Russia, Canada, Japan and the Space Agencies of 11 member countries of the European Community, in which each country has contributed, independently, to realize different pieces of the International Space Station, in a different time. The assembling of the ISS in orbit began in 1998, with the launch of the Russian cargo block Zarya—which in Russian means dawn and became one of the cornerstones of the ISS—and started from two central pressurized modules made by Russia and USA providing the ISS with energy, propulsion and space during the early stages of its assembly.

The ISS remains uninhabited for 2 years, and it is necessary to wait for the year 2000 to assume the form (or at least the functions) of a Space house. In July of that year, the launch of the Russian Zvezda module takes place, which hooks to Zarya and Unity. Zvezda integrates the rooms of the base which is now equipped with kitchen, toilets, dormitories, oxygen generators and carbon dioxide recycling plants, equipment for the training of astronauts and for the transmission of data. Everything is ready for the arrival of the first crew (Fig. 3.11).

Both Russia and the United States (US) space habitation modules are different in equipment layout and capabilities: launch, docking and modular systems. In the beginning, the US module was a sort of plug-in to the Russian module (without windows), which was self-sufficient about energy, limited resources, but sufficient. The US instead has a different concept: all the habitable modules need to be together to function as they are not autonomous spacecrafts. The European Columbus Laboratory, jointed in 2008, recalls the US internal layout that is organized per modular approach: bays, racks and drawers.
Looking at these first examples of configurations adopted by the international partners to build the ISS, it would have been difficult to imagine one commitment to a single designer to give shape and identity to the entire space station. But maybe, the right reason, and probably the main one, is the spread of a common thought that still considers Space still a pioneer sector, and in which the development of the habitation modules is the domain of engineering.

The designer still fails to emerge as a key figure necessary from the early stages of the project development, because the engineers do not consider priority aspects related to habitability, as we saw in the case study of the Skylab laboratory, in which although there was a part of NASA that was opening up to the concepts of comfort, the internal resistances to the various departments regarding the proposals of Raymond Loewy were still many, like wondering what a window was for, even if then, in the end, they realized. Even if the International Space Station today has the Cupola, developed and built in Italy by Thales Alenia Space, after more than 30 years from the Skylab, we are far from the regular involvement of Design competences in Space even if it is much bigger than the window of the Skylab. The Cupola (Fig. 3.12) is a spectacular robotic control room that transported to the International Space Station (ISS) with the STS-130 mission aboard the Endeavour, which was launched on 7 February 2010. The glass if 15 cm of thickness, no distortion or refraction, a work of art and technology. The Cupola lets astronauts see and work through seven windows, with a 360º view all around the ISS that allows to see the Earth, and also check the robotic arm. It has been hooked to the Node 3
Tranquillity, also developed by Thales Alenia Space, and is used as a quite spectacular Flight Control Center of the ISS during spacewalks, spacecraft manoeuvres or works that require the use of the robotic arm of the ISS. Everything is ruled from ground, there are no pilots on board and astronauts are scientist as in a laboratory.

The purpose of the present space programmes is to provide an environment where the space travellers of the present and the future can live and work efficiently and effectively forever longer continuous periods, also in anticipation of future interplanetary journeys, as a result, we are moving towards habitable systems that are self-sufficient and autonomous complements from land supplies. But, on the subject of habitability, however, the vision of Design is quite different from that of engineering, especially concerning the meaning of habitability and wellness.

### 3.4.1 Industrial Design at NASA

I had the chance recently to interview Marc Cohen who started working at NASA as architect before the beginning of the International Space Station Program and was able to give real contributions to increase the habitability in Space. His testimony confirms my thesis of the dichotomy between Architecture and Design versus Engineering. He was the second Space architect in NASA’s Ames Research Center experimenting the opportunity to offer ideas, after Maynard Dalton at Johnson
Space Center (JSC), who started at the beginning of the Apollo programme around 1963. Here I report part of my interview to him completed during the month of June of this year 2020 that starts with his experience in NASA at the beginning of 1980s. “I always thought that any other professional architect in my job could make comparable contributions. When I think about that time in the 1980s and early 1990s, it was the most exciting time in my life, the perfect job for me in the best organization in the world at Ames. However, I become exhausted just remembering how hard I fought to implement my ideas into the program.

The International Space Station was really the last NASA space programme that was wide open at the beginning and allowed for real architectural design creativity. In contrast, unfortunately, the Orion allowed very little opportunity for architectural or human factors creativity besides the controls and displays because the NASA administrator at the time it started thought that replicating the Apollo command module was the best way to go. Orion has twice the pressurized volume and is rated for up to about 30 days in Space, with all new electronics and ECLSS are new, but otherwise it is much the same idea. The Artemis lunar Gateway has even less openness because NASA head quarter decided to build it with predetermined non-competitive contracts for existing hardware”. Along his projects that were realized and flew in Space or achieved serious hardware prototyping, he drafted the original fabrication drawings for what became the first ISS equipment racks during a

Fig. 3.13 The Suitport EVA access facility mock-up during field tests, designed in the early phase of the ISS advanced development programme faces the important needs regarding the transition between inside and outside the pressurized habitation modules. Credits by NASA
week at Marshall Space Flight Center (MSFC). The MSFC people built a whole module full of them for the US lab mock-up that became the Destiny lab module.

But the more interesting project in which we can see the contribution of Design in Space field is the Suitport Extra-Vehicular Activity (EVA) access facility (Fig. 3.13) originated during the early phase of the International Space Station (ISS) advanced development program. It grew from a recognition that the construction and operation of Space Station Freedom (SSF) would require several thousand hours of EVA time. To make the best use of SSF crew time, it will become necessary to make the entire space suit donning and doffing, and airlock egress/ingress as safe, rapid and efficient as possible (Cohen 1995). The Suitport found its first practical use as a terrestrial application in the NASA Ames Hazmat vehicle for the clean-up of hazardous and toxic materials. In the Hazmat application, the Suitport offers substantial improvements over conventional hazard suits, by eliminating the necessity to decontaminate before doffing the suit. In the EVA access facility procedures using the Suitport, we can see an example of the Use and Gesture Design (UGD) methodology in which the transition from inside of the ISS and outside of the extreme environment is designed and predicted in all the possible movements performed by the astronauts (Fig. 3.14).

Confirming the trend of the International Space Station (ISS), in which industrial design’s contribution of the habitable modules was an activity developed inside the engineering departments of space agencies in collaboration with the space industry,
the Habitability Design Center (HDC) introduced at NASA around 2005 is a conceptual human-centred design studio. It was born initially to solve secondary small ergonomic issues, then progressively increased its involvement in the design of actual products destined to pressurized lunar rovers or the ISS itself (Taylor 2008) gathering together expertise in industrial design, architecture, and system engineering. The HDC\textsuperscript{15} comes from NASA human space flight with a design approach focussed on the human factors as a design tool to develop products, systems, and architecture for Space. The team is comprised of professionals with direct knowledge on Human Centered Design (HCD) methodology, industrial design, architecture, and systems engineering. This team uses advanced Spacecraft concepts, rapid prototyping, and mock-up fabrication techniques to solve the unique challenges of living and working in extreme environments. The HDC provides advanced concepts for habitats and spacecraft interiors while keeping the needs of the human first and foremost.

At first view, in the online presentation of the HDC, it seems that the skills of designers which are considered most significant by NASA, which is made mostly by the engineers, are the capacities to visualize quickly ideas and concepts that can result very useful to attract customers: “Using an iterative process, the team takes an idea through the stages of artist sketches, to blueprinting, computer models, scaled prototypes and finally full-size mock-up fabrication. This process allows for stakeholders to provide feedback early in the design process and to gather critical usability assessments”.

Deepen the topic it appears clear that the HDC was an integral partner in the design of a vast number of products ranging from dining tables for the ISS to ergonomic seats for the Orion and Space Exploration Vehicle (SEV). Leveraging their expertise in human factors, HDC designers are often called upon to evaluate hardware to improve usability. Typical design questions include, can an astronaut easily reach all the critical controls if they are in casual clothing or fully suited? Does a seat conform to an astronaut regardless of their height and body size? Can a crew member anchor themselves in microgravity to easily eat at a galley table? Addressing these challenges early on in the design phase speeds, and often results, in a better product. The HDC team is often called upon to help oversee field tests of vehicle prototypes as they are evaluated in analogues like the Desert Research and Technology Studies (RATS).

If HDC came from the NASA human space flight world, confronting always with real requirements and projects that can evolve in products on board the International Space Station or other Space vehicles, another trend flows in the opposite direction, that regards the intellectual reflection of alternative Design concepts. It is represented by the so-called Space Architecture group, which involves both architects and designers intending to challenge themselves on uncommon grounds.

\textsuperscript{15}https://www.nasa.gov/feature/habitability-design.
Following the 1st International Space Architecture Symposium—held by a group of architects and designers, among which also the author, at the World Space Congress in Huston, 2002, according to the Millennium Charter, the manifesto which we created in that occasion—the definition of Space Architecture has been acknowledged as *the theory and practice of designing and building inhabited environments in outer space* with the motivation of responding to the deep human drive to explore and occupy new places. “Architecture organizes and integrates the creation and enrichment of built environments. *Designing for Space* requires specialized knowledge of orbital mechanics, propulsion, weightlessness, hard vacuum, psychology of hermetic environments, and other topics. Space Architecture has complementary relationships with diverse fields such as aerospace engineering, terrestrial architecture, transportation design, medicine, human factors, space science, law, and art”.

The idea behind is that Space Architecture is nothing more than an extension of terrestrial architecture. The goal is the same: to provide a shelter that protects and supports good quality of life for the inhabitants. And as in any architectural project, the designer needs to research and learn all about the environment in which the product is placed. What really changes are therefore the conditions and characteristics of such environment. But when we embrace outer space, the limit of Space Architecture group is to feed a discussion on concept design proposals that not have opportunities to be built as real habitation modules or products for astronauts. The scientific activity is oriented to write papers and books and to organize symposia. Being part of the creation of the Space Architecture group, I presented two papers at the 1st International Space Architecture Symposium in Huston titled *Designing for Space* and *Space Architecture Education in Milan*, the latter on the experience of a new Master of Science in Space Design that I created and led at the Politecnico di Milano at the end of my Ph.D., over the years 2001 and 2002 and I maintained the relations with the whole group until now. The positive aspect is that the Space Architecture group has increased a network of Space enthusiasts’ researchers and professionals aimed to *Design for Space*.

3.4.2 Designer’s Perception at ESA

In recent years we saw, there has been a growing evolution in the Space field, triggered by future planned human space missions, which once again propose the desire for exploration as the main engine, now driven principally by the private sector which looks at *space tourism* as a propellant to increase interest and budget. With a permanent settlement on the Moon and a manned landing on Mars as goals to support pioneer ambitions and efforts, a great boost is given to the research, in order to fill the gaps that still make these perspectives impracticable. Following a trend already widespread in several industrial sectors, space agencies are turning to the adoption of *cross-disciplinary teams* as a tool to stimulate innovation.
The group is, indeed, a natural amplifier and accelerator of the creative process, which serves as a collective brain, with much higher potential of the single individual brain (Dominoni 2009). Having analysed in depth the group dynamics in the past, I can affirm that the context of cross-disciplinary innovation teams is particularly interesting as a slightly more open door for designers to step in the Space Industry. Recently, I followed the development of a thesis conducted by a student of mine who has participated at the Course of Space Design, Space4Inspiraction (S4I)—inside the Master of Science in Integrated Product Design, School of Design, Politecnico di Milano—that had the skill, and the good fortune of being chosen as the first and only designer for an internship at the Spaceship EAC cross-disciplinary team of the European Astronaut Centre (EAC) in Cologne, a project initially directed by the Italian astronaut Samantha Cristoforetti, after her mission Future conducted on board the International Space Station.

The thesis, A Year in Space: Reflections about the Integration of a Product Designer in Collaborative Space Projects, was based on the know-how acquired, thanks to my research in 20 years of publications and design for the Space to verify the changes taking place in the light of a methodological aspect that has been taking shape for several years and that concerns the increase of the importance of cross-disciplinary to generate innovation. In particular, this thesis focuses on an interesting setting for the introduction of the diverse perspective of Design in commonly strictly engineering workplaces.

3.4.2.1 The Contamination of Design and Space Exploration

Considering the strong partnership, we consolidated with the European Space Agency (ESA) during these years, overall the last four, developing projects, researches and new educational programmes of Design and Fashion, in which we involved also companies for both Space and private sectors, crossing multidisciplinary teams, we wondered if it was possible to measure what was the level of contamination today between the world of Industrial Design and that of space exploration, because of the increasing importance of the human being in long-term missions, and also the development of private industry aimed at elite space tourism.

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16A Year in Space: Reflections about the Integration of a Product Designer in Collaborative Space Projects, is a thesis by Emilia Rosselli Del Turco; Supervisors proff. Annalisa Dominoni and Benedetto Quaquaro, School of Design, Politecnico di Milano; Co-Supervisors: prof. Paolo Fino, Politecnico di Torino, dr. Aidan Cowley, European Astronaut Centre (EAC).

17Space4InspirAction (S4I), which will be treated in this book as a case study, is the first and unique “Space Design” Course in the world recognized and supported by the European Space Agency (ESA) with experts and scientists who suggest and then deepen the project themes, chosen every year together with us, in line with the main objectives of the space agencies and industries’ strategic interplanetary programs. S4I was created in 2017 by me together with the architect/designer and professor Benedetto Quaquaro, at the School of Design, Politecnico di Milano, inside the Master of Science in Integrated Product Design. While I’m writing we are leading the 4th edition Space4InspirAction 2020 in distance, according to the rules for the Covid-19 pandemic.
And overall, I was curious to verify the impact of the contribution of a designer in a multidisciplinary team working for Space and understand what the situation is today in ESA and how the role of the designer in Space scientific environment is interpreted. The thesis aims to discuss the potential benefits unleashed by the introduction of the discipline of design within these cross-disciplinary efforts of the space sector. In particular, a product development of the project named Flexrack carried out during the internship at Spaceship is used as a discussion ground to reflect on the challenges, the methodologies and skills provided by the work of a product designer in this field as project owner and technical support. Finally, a series of semi-structured interviews makes it possible to compare the views of the industry itself and to formulate some considerations for the future. The conclusions focus in particular on the vision of an ideal collaboration for Design in Space, which aims to make most of the different points of view involved, and on the obstacles identified to its implementation.

We tried to build a state-of-the-art tailored to designer point of view in which best practices useful for our purpose could converge: to bring out the importance of Design as a discipline inside cross-disciplinary teams for the Space industry. This approach has been recognized and appreciated by ESA teams in various topics, especially in comparison with an engineering approach, and allowed a redefinition of important topics for Design methodologies and innovation as a crossroads of different perspectives.

The interviews provide some recommendations for strategic actions in order to overcome the aforementioned obstacles. A large effort was dedicated to extracting the thematic connected to the overall notion and opinion in the respect of the profession of designer in order to lay the groundwork to analyse potential critical points that would jeopardize any present and future collaborative work.

In general, there is a lack of a precise idea of what are the approach and the outputs of a designer when coming to technological products. Words used are often generic and redundant, but some topics are recognizable. Among them, none had the experience of actual interdisciplinary collaboration with creative professions, besides short university workshops. Even in these cases, contributions were often separated, and the relationship did not have the time to overcome the initial difference and miscomprehension. One of the respondent’s reports of having had courses from industrial designers in the context of the International Space University (ISU) Master. Another one, instead, remembers in his answers a previous multidisciplinary collaboration within the automotive industry, where engineers were mainly called to provide feasibility constraints to the vision of Design.

### 3.4.2.2 A Misunderstanding of the Design Role

The results of the interviews show that the human factors have recognized a domain of designer, but a clear definition has not given; at the same, the designer is considered able to manage qualitative factors, but it is no evidence of what they are and their impact on the project. The relation between the human being and the
object is missed, as well as the use of the storyboard to analyse the gesture and the interface dynamics, in order to discover topics not related to the structure or the mechanic but connected with a requirement of flexibility and usability. For example, some modifications of the shelter of the Flexrack project that are strongly related to the usability improvement of the product are poorly understood.

The usability term when quoted is not connected to the figure of the designer but begins to grow the more generic theme of efficiency. However, during the interviews, it turns out that many errors and problems on the International Space Station (ISS) are attributable to usability problems. The results of this study pushed us to list recommendations to fill the gap of Design in Space inviting to make known the Design and its benefits within this industry. The use of comprehensible language, adopting systems and modes of reasoning, and based on complete case studies and that they have quantitative as well as qualitative assessments it is suggested.

3.4.2.3 Designer Contribution in the Space Industry

A collaborative environment is the most promising context for the introduction of designers in the Space Industry. Nevertheless, collaboration is a hard achievement when coming to the combination of natural scientists, especially engineers, and other disciplines. Design particularly has a set of fundamental differences in terms of methodology and epistemology which makes it difficult for engineering backgrounds to have a clear understanding of its outcomes and processes.

In particular, Design opposes Engineering with an unstructured process, an un-standardized result, a broad approach, a deep analysis of the problem, a focus on the qualitative factors and a freest relation with reality’s constraints. The latter jeopardizes mutual respect of the expertise which further reduces the openness to actual exchange. Exactly for this reason, though, collaboration is foreseen, in order to ground the designer more on constraints by providing the needed technical knowledge, and to assure a more integrated and diverse perspective next to the engineer’s one, to reduce the risk of blind spots and increase the operational functionality.

The designer’s role would occur especially in the early phases and with a broad mandate, to influence a variety of projects before their implementation. The major obstacles for this to happen are identified in a general conservatism within the Space Industry, in the narrow focus on the most striking and substantial requirements, that makes difficult changes on hyper-tested systems, and in the cultural distance of the engineering system between strongly different Design thinking settings, which makes it difficult to have a conscious appreciation of the possibilities offered by a designer in this field. Also, the management of public money on strict priorities, still connected to pure survival and security of a human space mission make it difficult to introduce new ones related to the well-being of the crew.
3.5 To a New Space Era by Design

If the Habitability Design Center (HDC) has the advantage of suggesting, for experience, how the professionalism of the designer is fundamental from the early stages of the design process, because it contributes with its strategic skills to improve the quality of the project, has the big limit of having self-confined to be the progressive evolution of the human factors approach applied within space agencies and industries by design engineering, without passion and creativity, with a human-centred design attitude that, however, does not integrate the deepest needs of the human being and not even beauty. Also, the complex and multidisciplinary approach, typic of a designer, is here reduced at someone who can visualize ideas to show to customers, a sort of draftsman. In the HDC design process, there no sign of human needs, comfort and wellness. All the effort of the NASA designers seems to dedicate to improve usability, which is a direct derivation from the traditional human factors, and that identify the methodological approach of engineers to solve topics related to Habitability in Space.

The interest to increase the quality of life, considering also emotional and psychological factors—like Raymond Loewy did convincing NASA to introduce a window to look at the Earth underlining the importance of the entertainment in the Skylab laboratory—and overall, the important role of the beauty to enhance the value of such environments in which humans would live and work in balance—like Galina Balashova use to do through wonderful drawings—seem to be not contemplated. The idea of habitat for NASA corresponds to an aseptic environment, in which prevail smooth surfaces of aluminium easy to clean, covered by racks that contain equipment useful for the maintenance of the station, experiments to be conducted, food and medical supplies for the crew.

Life planned in orbit is made of planned activities, nothing is left to improvise, astronauts follow to the letter very detailed procedures, they do physical exercise not for leisure, but as a necessary countermeasure to counter the negative effects of microgravity, they eat terrible food and perform personal hygiene in extreme conditions, with great difficulty and discomfort, because nothing is designed really for Space, but the majority of the equipment and tools they use are terrestrial, re-adapted for the Space environment.

It is incredible to see how in the most pioneering phase of human space exploration the Russian and American space agencies and Industries felt the need to involve architects and designers in the Design of space stations, including disruptive ideas, like the language of semiotic and colour in Space, the balance between human needs, function and beauty, or the importance of the recreational values for the well-being of the crew. And after more than 50 years of design developments, in which different experiences and data of the various human space missions have been collected, they take a step back, losing these first precious cases that demonstrate the fundamental role of Design discipline in creating habitats in Space, for humans, and not for robots!
Departing from the Shuttle programme and the construction of the International Space Station (ISS), I tried to describe the little consideration of the *habitability* issues, due in part to the lack of understanding by engineering the meaning of Design. I hope that with the setting of the cis-lunar orbital station Gateway and Mars as the next goal in the space exploration roadmap, the competences of Design will be integrated into the whole design process.

Despite last decades saw an incremental attention towards space manned missions, and their requirements with the final aim of really enabling a permanent human presence in Space, the involvement of Design approach in Space is far to be completed. The need for long-term travels and, consequently, separation from Earth placed the focus on the dynamics triggered by humans’ involvement in a mission’s design to start to learn more about how these would behave and interact in such scenarios.\(^{18}\) Furthermore, the progressive enlargement of the group of people having the possibility to experience Space to scientists, researchers and even tourists, over long-time trained astronauts, opens to the need of reconsidering the habitability issues related to life in Space environments.

In the light of the above, in the Space field, the necessity appeared to go beyond the pure technical approach led by engineering team and slowly open to other competencies. Design, among them, represents a point of interest, thanks to its experience with the integration of users’ needs and behaviours with the productive and technical worlds.

### 3.5.1 An “Italian Design Style” Spaceship

Design becomes indispensable to create new environments and objects designed specifically for Space that can *turn the limit, as is the microgravity, into an opportunity*. And perhaps, it would be advisable to think also of environments for the amusement and the entertainment of the crew, like we have been asked by Thales Alenia Space (TAS) which has commissioned us a recent project for a new spaceship looking at a *recreational space*, with more room for astronauts’ entertainment. The assignment concerned *Innovative Concept Design Solutions aimed to Emphasize the Italian Style by Design* supporting the programme for a *New Orbital Infrastructure Recreational/Habitable Configurations* and specifically for *Window Design in Pressurized Modules* (task 1) and *Recreational/Habitable Module Interior Design* (task 2) introducing also proposals of fashion and products design elements in the interiors habitat under definition of TAS in Italy.\(^{19}\) We applied

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\(^{18}\)Evan Twyford in the video *Industrial Design for the Outer Space*, Vice Media 2012, NASA Archives.

\(^{19}\)I led and developed the project of the new spaceship together with Benedetto Quaquaro identifying, according to Thales Alenia Space, *Preliminary Design Solutions for the Support to New Orbital Infrastructure Recreational/Habitable Configuration* inside our Space4InspirAction Lab at the Design Department of Politecnico di Milano.
design methodologies as User-Centred Design (UCD) and Use and Gesture Design (UGD), together with ergonomics aspects, to increase the comfort and the efficiency of the crew in confined environment and microgravity condition optimizing crew space usability and subsystem arrangement through flexibility and re-configuration. Our proposals concerning Concept Design Solutions for both external and internal configurations and volumes of a new Space Station were focussed on the two tasks given: Window Design and Recreational/Habitable Module.

Concerning the task 1, our purpose was to design various solutions injecting style elements to the existing technical solution conceived by TAS to build a strong identity of the new Spaceship focussing on recognisability (also from outside the Spaceship) modifying panes alternative shapes and colours according to the materials’ requirements. The goal we wanted to achieve was to transform the Spaceship in a precious object, a Jewel in Space, in the dark sky, designing a new configuration alternating round and oval windows as precious stones creating a “ring” to highlight the window light stands out against the dark sky, if black, or the aluminium modules softly, if gold, or strongly, if red.

Concerning the task 2, the study of the internal accommodation of the recreational/habitable areas was focussed on four topics: re-configurability, free room optimization, illumination adaptability, stowable functional furniture (e.g. working/lunch desk, restraints); the innovative design solutions related to fashion and products design elements in the interior habitat explored various possibilities among which relaxing couch, privacy feeling enhancement (e.g. isolation, including acoustic noise), handrails, foot restraints and stowage solutions focusing on aspect of technical feasibility and in compliance with the constraints/requirements given by the preliminary concept provided by TAS. Imagining the Jewel in Space from inside, it reveals an immersive experience into the dark Space, the feeling we want to transmit was entering the window, surrounded by glass—sliding into the interspace created by the round window—and “looking at the stars lying on the sofa”.

We have re-designed completely both the exterior skin, including the windows, that alternate different shapes and create the idea of a transparent and continue surface, and the interior of the habitation module: an acoustic textile padding able to reduce noise and increase acoustic isolation covers the structure of the windows, as well as the interior of the module, creating sofa rings and giving a smooth feeling like a hug.

The project of a New Orbital Infrastructure Recreational/Habitable Configurations was related to the request of Thales Alenia Space to find “Innovative Concept Design Solutions aimed to Emphasize the Italian Style by Design”. The inspiration which has driven this not easy task was made by three keywords: Italian Design—Sixties—Space Age.

“Re-configurability” was the key to gain more internal space and flexibility. The racks on the International Space Station (ISS) are replaced by easily removable cylindrical volumes that can slide and transform themselves into “tailored chaises longue” for a free room optimization (Fig. 3.15). The cylinders run on tracks serving as soft surfaces of support, as well as shelves, or removable containers. The internal space of cylinders it is foreseen for stowage of equipment and tools.
Flexible restraints to maintain softly the body posture on the cylinders/chaises longue are foreseen, as well as accessories for working, having lunch, resting and so on. Female Velcro® shapes are distributed along the whole soft surface to allow crew moving or maintaining the body posture thanks to male Velcro® socks.

The re-configuration of the internal spaces has been given to gain more free volume and flexibility according to the different activities and needs of the astronauts: working, relaxing, gathering, reading, playing and listening to music, resting, looking outside the windows, organizing meeting and lunchtime.

Light changes intensity and colour following circadian rhythms with the aim to change the perception of the environment according to the various activities, while the overall feeling is of relaxation and wellness (Fig. 3.15).

We put wellness as focal point of the whole project creating a sensorial environment in which all senses were stimulated, to contrast the lack of natural stimuli in Space. In order to reach the illumination adaptability, we imagine LED Rings for diffused light that change intensity and colour in relation to the various activities on board and integrating circadian rhythm system with chromotherapy: for examples, white-gold light during daily life activity, white-blue light when a relaxing

Fig. 3.15 Preliminary Design Solutions for the Support to New Orbital Infrastructure Recreational/Habitable Configuration designed by Annalisa Dominoni and Benedetto Quaquaro for Thales Alenia Space: the racks of ISS are replaced by easily removable cylindrical volumes, while light changes intensity and colour following circadian rhythms with the aim to change the perception of the environment according to the various activities and create a space of relaxation and wellness. Credits by the authors.
environment is required, gold light for gathering, recreational activities and eating together or orange light for fitness activity that implies to be very active and energetic. Removable personal lights to be fixed where needed inside the space station were also foreseen. In addition, we propose to introduce light walls to divide virtually the interior space of the module introducing the use of Artificial Reality (AR) for fitness activities and immersive experience into nature.

The whole project has foreseen the design of the environment and the proposal of specific crew system/outfitting items and tools to be integrated into the interior of the New Orbital Infrastructure Recreational/Habitable Configuration, designed by Annalisa Dominoni and Benedetto Quaquaro for Thales Alenia Space, there is a collapsible textile partition inspired by the gennaker snuffer used in sail competitions, with the aim to enhance space re-configuration for crew privacy and socialization purpose, and a foldable relaxing chaise longe to provide a support for rest of the activities. Credits by the authors

Fig. 3.16 Among which specific crew system/outfitting items and tools to be integrated into the interior of the New Orbital Infrastructure Recreational/Habitable Configuration, designed by Annalisa Dominoni and Benedetto Quaquaro for Thales Alenia Space, there is a collapsible textile partition inspired by the gennaker snuffer used in sail competitions, with the aim to enhance space re-configuration for crew privacy and socialization purpose, and a foldable relaxing chaise longe to provide a support for rest of the activities. Credits by the authors.
3.5.2 Space Design Drives the Private Space Industry

On 30 May 2020, I was able to attend the launch of the SpaceX’s Crew Dragon Spaceship and the docking on 31 May, after about 19 h of travel to the International Space Station (ISS). A great success for America that returns after 9 years in Space with a new launcher, Dragon 9, which replaced the Shuttle. SpaceX developed Crew Dragon in partnership with NASA’s Commercial Crew Program. In 2015, NASA selected SpaceX to pursue crewed commercial flight to and from the International Space Station. This was the agency’s first mission order for SpaceX to launch astronauts from the United States. SpaceX, the private aerospace company of Elon Musk, is known to be very attentive to the futuristic Design of its vehicles: the interior of the Crew Dragon looks like it came straight out of a science fiction film. The black-and-white ultramodern design of the capsule is visually stunning. Aside from its seven seats, which are made from carbon fibre and the Italian Alcantara textile, the interior of the capsule has a number of key features. SpaceX wanted a voyage in Crew Dragon to be an enjoyable experience for its passengers. It has four windows and a sleek digital display that will show information ranging from where the craft is in Space to information about the environment inside the capsule. Crew members can monitor the interior environment with an environmental control and life support system, setting the on board temperature between 18 and 27 °C. The private Space enterprise has also designed spacecraft to be fully autonomous, though astronauts on board will be able to monitor and control the craft using facilities on board the Crew Dragon. The same focus on Design has been placed on spacesuits for astronauts, designed by Hollywood costume designer Jose Fernandez, who combine aesthetics and technology. His specialization in superhero wardrobe has certainly influenced the development of suits for SpaceX, in which the alternation between white and dark grey, ovoid helmets, high boots and geometric lines that define the details give life to a comfortable and futuristic silhouette.

It is therefore clear that Design takes on strategic importance when dealing directly with the private space industry, especially if guided by visionaries who are not content to ensure security and technological reliability of the vehicles, but they want to transform the experience of the human space flight’s into something magical and unforgettable, they want to give shape to a dream.

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