# 1 Introduction

The idea of a space station, i.e. a permanently habitable orbital structure, has existed since the very early ideas of spaceflight itself were conceived. As early as 1903 the "father of cosmonautics", Konstantin Tsiolkovsky from Russia, dealt with inhabited stations in space close to Earth, with an autonomous power supply and bioregenerative life support systems. While he summarized his ideas in the book "Raketa v mezhplanetnoe prostranstvo" ("The Rocket into Interplanetary Space"), two other great space flight pioneers, Robert Goddard and Hermann Oberth, had already developed similar ideas as a result of their own work. In his book "Die Rakete zu den Planetenräumen" ("The Rocket into Interplanetary Space") published in 1923, Hermann Oberth was the first to mention the expression "Raumstation" (German for "space station"), and in the third edition of his book, published only shortly after the first two, he described the space station as the engineering project of the future and already mentioned nearly all the areas of application which are of interest today. Space stations challenged engineers, scientists and journalists to deal with concepts, sometimes rather unusual ones, for the realization of differing areas of application. It was not until 1952 that the subject attracted more public attention thanks to Wernher von Braun's study "Across the Space Frontier", in which he described a large, wheel-shaped space station.

The historical development of space activities can be outlined very clearly. The real beginning of space flight was the launch of the satellite "Sputnik" in 1957 and only four years later the first manned vehicle was launched into orbit, and after a further eight years, the first lunar landing took place. These events were followed by the first missions of space probes to other planets, with some of these even landing on the planets' surfaces. The first space station "Salyut 1" was launched in 1971 by the former Soviet Union and two years later, the USA placed its space station "Skylab" in orbit and this relied mainly on existing Apollo hardware. The first commercial communication satellites followed; for the first time, satellites were repaired on orbit and the first series of experiments was run as part of the newly developed discipline of "microgravity research". The latter was particularly supported by "Spacelab" as the European contribution to the US Space Shuttle program. All of these factors were important steps on the way to exploring the space environment, experiencing work and research in space and gaining an idea of how the space close to Earth could be used effectively. Under the leadership of the USA, these preparatory steps lead to plans for the (initially US with Western partners only) Space Station Freedom and, after the end of the Cold War with the integration of Russia into the project, plans for a truly global International Space Station.

Orbital stations have always stood their ground as far as plans for a future in space are concerned – from the first fantastic visions of space flight pioneers, through the idea's temporary stagnation during the race to the Moon, until today's large-scale program for a space station. Leading nations involved in spaceflight have become aware of a space station being an inevitable milestone of the long-term, well-founded evolution of research and development of and for humankind.

How does a space station differ from other space systems placed in orbit, such as satellites and platforms? To help answer this question we can introduce four main characteristics:

A space station is

- an orbiting system,
- large and usually to be assembled on orbit,
- intended to serve long-duration multi-user missions, and
- a crewed system.

Being an *orbiting system*, a space station must be robust enough to withstand the stresses of launch and still perform its functions in space. It must be equipped with a remote control system, a communication system for ground contact, a propulsion system, an attitude and orbit control system (AOCS), etc.

Given that a *large* space station will usually exceed the payload capacity of a single space transport vehicle, it will be necessary to design several space station modules and assemble them directly on orbit. Extensive dimensions also pose dynamic problems, which are typical of such large structures: a problem which does not occur when dealing with relatively compact capsules or satellites.

Compared to a transportation system or satellite, a space station is usually intended to serve many and different users for *long-duration missions*. That means, its subsystems and components are not only to operate continuously over a certain period of time: they must also be repaired or exchanged easily and quickly in case of malfunctions or nominal degradation. Moreover, space stations depend on the resupply of goods and sustaining operational and structural expenses that do not occur when dealing with satellite systems.

Finally, a space station is *inhabited by a crew*, either permanently or temporarily (otherwise it would be called a space platform). This is probably the most demanding feature for the design of the station. The crew needs a pressurized environment and a life support system, which in turn determines the amount of logistics supplies. The crew must also be provided with corresponding safety measures, which often require additional constructions such as shields to protect the crew against radiation and meteoroids, and/or additional procedures. In the case of an emergency, rapid return-to-Earth transportation is needed, e.g. by special crew rescue vehicles.

What makes the construction of a space station such a challenge for engineers? A space station of a considerable size is one of the most complex technical systems known today. Its interdisciplinary design and construction require a knowledge covering most of the disciplines in science and technology, e.g. mechanics, statics, thermodynamics, process engineering, electrical engineering, telecommunications, computer science, medical science, psychology, and systems engineering – only to mention the most important ones.

Due to this manifold range of disciplines, the effective cooperation and co-ordination of experts is inevitable. This is exactly the reason why the subject presents such a challenge for engineers, economists and political leaders, as well as for all those who plan and construct a space station, ensure its operation and, as a consequence, have to justify all decisions taken in the course of the project's life cycle. Considering the size and complexity of the corresponding tasks, one can easily imagine that the management of a space station sometimes develops a certain dynamics of its own.

When being confronted with the engineering problem “space station” for the first time, it is a good idea to categorize the overall problem. At the top level, two different views are clear: overall system design and subsystem design. Table 1.1 presents these two views and identifies the relevant chapters of this book where an elaboration can be found.

**Table 1.1.** Two Different Views of the Engineering Problem “Space Station”

| **Overall System Design** | **Subsystem Design** | **Chapter** |
|---|---|---|
| Crew<br>(Safety, Ergonomics, and Habitability) | Environmental Control and<br>Life Support System | 4, 11 |
| Energy Balance | Power and Thermal Control System | 3, 5 |
| Attitude and Orbit Control Strategy | Attitude and Orbit Control System | 6 |
| Utilization Aspects | Payload Systems | 7, 8 |
| Layout and Mass Distribution | Mechanisms | 9, 10 |
| Systems Integration | Structures | 9 |
| Logistics and Maintenance | EVA Systems, Robotics | 12, 13 |
| Command, Control, and<br>Communication Architecture | Flight Operation and Ground Support<br>System, Communication and<br>Data Management System | 12, 13 |

When designing a subsystem and its components, technology that is already known and available has to be combined within the given framework of specifications.

At system level, assessments are necessary to find out whether a space station consisting of different subsystems is able to perform all the tasks of the mission objectives. This will not be the case in the early design stages, and changes in mission requirements and thus new specifications for the subsystems will have to be defined.

During this iterative process of designing a space station, it is impossible to independently deal with overall system aspects and subsystem design as they are not completely isolated from one another. Both sides depend on each other and only their successful interaction will yield a useful concept and product.

One example for such an interaction is the choice of an appropriate propulsion system. Before choosing a technology for its realization, several questions must be answered, such as the following:

- What are the propulsive requirements (determined by mass distribution, aerodynamic drag and further parameters)?
- Are there any additional restrictive conditions such as maximum allowable acceleration (microgravity), or the exclusion of certain propellants due to safety precautions or compatibility with the environment, that have to be observed?

Being aware of such conditions, the subsystem engineers will be in a position to design an appropriate propulsion system. They may arrive at a point where there are two technologies as viable options. In this case, the subsystem engineers have to consult the system level engineers. The system level engineers may have to decide whether, for example, to choose an electrical propulsion system (due to its smaller propellant requirement), or an $H_2/O_2$ engine (which could receive part of its fuels from the life support system). In the end, all such aspects have to be weighed against one another until either a solution is found and accepted by all sides involved, or, when some new framework conditions (e.g. cost reduction) arise, the whole process begins anew.

Why do we need a space station at all? As already mentioned earlier in this introduction, the idea of a space station evolved in connection with the theoretical option of crewed spaceflight. Hermann Oberth, for instance, thought as early as 1925 about a space station to be used as a platform for Earth observation, or as a communications platform or as a mirror to illuminate the Earth's surface. Space stations as possible means intended to solve specific (i.e. technical and scientific) problems did not receive attention until the real beginning of the space age. Basically, four areas of application can be characterized for a space station today:

- A permanently available, multidisciplinary research facility in a low Earth orbit for basic and applied research
- A test facility for new technologies in the space environment
- A platform for the observation of the Earth environment, the solar system and the universe
- A starting point and traffic node for further space exploration and use, i.e. as a place of assembly, maintenance and resupply of space vehicles

Of course, the prioritization of these areas of application has not always been viewed equally throughout history. As a consequence, in most of the cases it is possible to derive underlying application scenarios from the different space station designs of the past decades or vice versa. Other reasons usually offered for building a space station – potential scientific payoff, high-tech employment, educational motivation, foreign policy benefits – have not been compelling, but together they have created enough support for the programs to survive. Though seldom clearly articulated and perhaps not fully understood, the essential foundation is the belief that sustained human activity, both in Earth orbit and beyond, has significant tangible payoffs.

In order to improve the understanding of these historical contexts and their significant influences on future concepts, Chapter 2 introduces a chronology of concepts, plans and projects for space stations and their applications: from the very first ideas of living in space up to the very detailed project of the International Space Station. Since the space station's architecture and applications always depend on the station's orbit and its physical conditions, the space environment close to Earth (i.e. at an altitude of some 100 km) is described in Chapter 3.

Chapters 4 to 6 introduce the main subsystems of the space station. Unlike other spaceflight systems, space stations are mainly characterized by the permanent presence of a crew, as already mentioned above. Therefore, it seems logical to describe the different systems in order of their importance: "Environmental Control and Life Support System" (Chapter 4); "Power and Thermal Control System" (Chapter 5); "Attitude and Orbit Control System" (Chapter 6). Chapters 7 and 8 titled "Utilization" and "Microgravity" cover the different areas of applications and their characteristics, especially for research in weightlessness. Only by considering these application areas can the required mission objectives be deduced from the space station's design or vice versa. This is one of the main objectives of this book: enabling the advanced reader to design his or her "own" space station according to a defined framework of requirements, e.g. mission profile, crew size, possible space transportation vehicles, logistic scenarios, etc. This iterative design process is described in Chapter 9 "System Design" and shows that the amount of supply goods from Earth can assume immense proportions. In order to minimize supply, future space stations will make use of synergistic effects resulting from different subsystems linked to one another. This process, as described in Chapter 10 "Synergisms", will help to achieve nearly closed regenerative process cycles.

Chapters 11 "Human Factors" and 12 "Logistics, Communications and Operation" address components and subjects which are certainly important, but which do not dominate the space station design, such as human factors, operation and maintenance of space stations, current space transportation vehicles (to handle logistics), communications and data systems, automation and maintenance. In conclusion, Chapter 13 describes "The International Space Station" with its utilization peculiarities, layout and general aspects of access and operation. At the end of the book, a detailed bibliography and an index are included.