2 History and Current Development

Long before scientists and engineers in our century began to develop visions about space stations and their applications, authors from the end of the last century had already laid down their ideas in short stories and novels. This period will be shortly addressed in Section 2.1 " Visions, Concepts and Early Designs of Space Stations (1865–1957)" . At the dawn of the real "space age", i.e. in 1957 when the first artificial satellite Sputnik was launched, development in the field of space stations progressed in two different ways: the space programs of the USA on one hand and the space programs of the former Soviet Union on the other. Their efforts climaxed in the so-called "space race", when the achievements of both nations followed each other in rapid succession and so each aiming to be the first nation on the moon, resulting in considerable progress on both sides: The USA conducted a significant number of studies and developed concepts leading up to the Apollo vehicles and, as a follow-up program, the space station Skylab. In the former Soviet Union, a series of Salyut space stations was developed and successfully operated. These achievements are covered in Sections 2.2 and 2.3. Important scientific and technological expertise was acquired in Europe during the 1980's which can be attributed to the development and operation of Spacelab (which was launched by a Space Shuttle). The Spacelab program will be briefly introduced in Section 2.4 and continued in Chapter 7 where its application is characterized. It was not until the end of the Cold War and the subsequent dissolution of the Soviet Union that from 1990–1995 the idea of a joint project had evolved: building and operating the large International Space Station under the leadership of the USA, with important contributions from Russia as well as Europe, Japan and Canada. With the Russian space station Mir, the USA and its later partners of the International Space Station (ISS) learned to cooperate in the fields of science, technology and the joint use of a space station. This period of political change as well as the assembly and use of the International Space Station will be addressed in Section 2.5. The chapter will be concluded with a comparison of several space stations in Section 2.6.

2.1 Visions, Concepts and Early Designs of Space Stations (1865–1957)

Early science fiction authors were inspired by the idea of crewed Earth satellites and rockets. In 1869, the American clergyman and author Edward Everett Hale (1822–1909) of Boston was the first to write a novel published in the "Atlantic Monthly" describing a white painted "brick moon space station" serving as navigational aid for seafarers. This is how the story goes: During an earthquake, this spherical "satellite" built from fireclay begins to roll, eventually reaching the launch platform made from flywheels already in full operation. It is prematurely launched into an Earth orbit with the construction workers and their families on board. But the tragic accident takes a favorable turn as the "crew" makes its home aboard the satellite, and, while orbiting the Earth, this "seed" of extraterrestrial civilization, transmits messages to its home planet Earth.

Another imaginative author worth mentioning is the famous Jules Verne (1828–1905) from Nantes, France. In his books "De la Terre à la Lune" ("From the Earth to the Moon") and "Autour de la Lune" ("Round the Moon"), he already foresaw many details of the lunar landing the way it was to take place 100 years later [Verne, Walter 92]. He not only described concentrated and preservable nutrition, constant air purification and oxygen resupply in detail, but he also thought of observation windows, a library, tools and animals being aboard (Fig. 2.1). It is well known that many space pioneers of later times were inspired by his novels.

The third author to be mentioned as representative of the past century is the German teacher Kurd Laßwitz. In his book "Auf zwei Planeten" ("Two Planets") he presented a rather poetic and utopian view of a space station without taking its technical aspects into account.

The Russian mathematics teacher Konstantin Eduardovich Tsiolkovsky (1857–1935) was the first of three great space flight pioneers our century has seen. The father of the theoretical basis of space travel had already made plans for a "satellite rocket" around 1903, but it was not until 1911 that he thought of using it to transport human beings. In 1933, he published his work "Album of Space Travels" in which

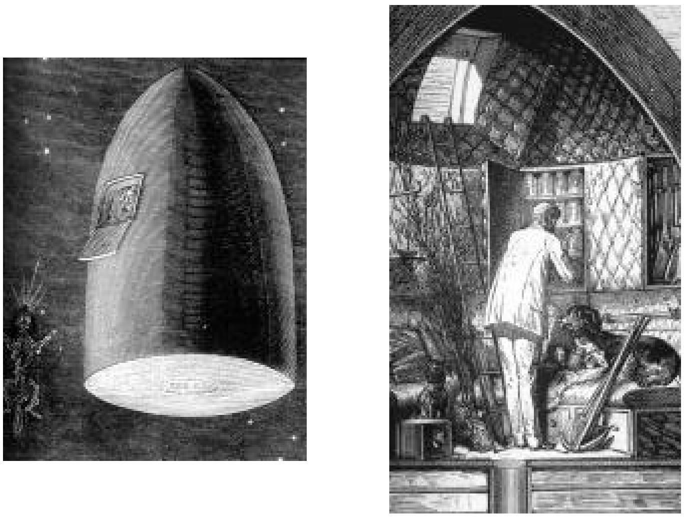

Fig. 2.1. Jules Verne's Vision of a Crewed Space Vehicle: Looking Back on Earth and Victorian Comfort on the Way to the Moon [Verne]

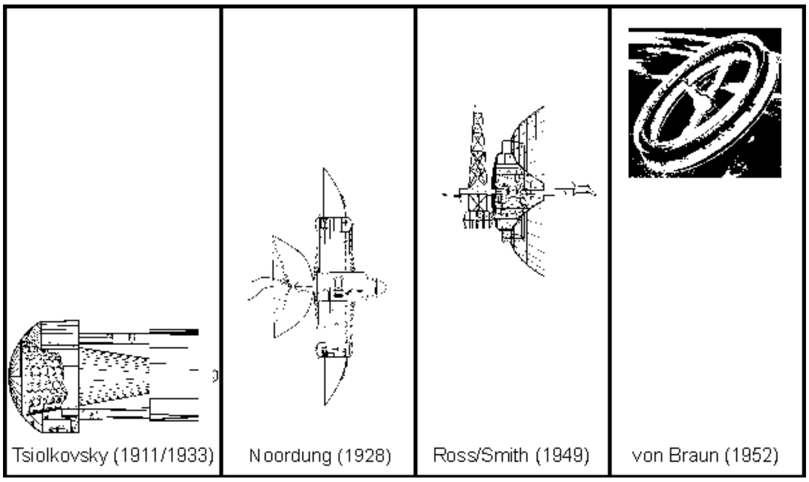

Fig. 2.2. Ideas of Space Stations from 1911–1952

he presented a concept of building a large habitation module in orbit (Fig. 2.2). Special attention should be paid to his theories of simulating gravity by rotating the station on its longitudinal axis and creating a park inside the station with vegetable beds and trees as an important part of a bioregenerative life support system. [Ordway 92, Puttkamer, Walter 92]

Around 1920, the second great space pioneer, the American Robert Goddard (1882–1945), described how our civilization could flee the dying solar system aboard a nuclear powered "ark" and suggested the use of extraterrestrial resources to manufacture the vehicle and its propellants. It is interesting to note certain parallels in Tsiolkowsky's and Goddard's work: on one hand, they both made valuable and detailed contributions to the scientific and technological development of space flight, but on the other hand many of their ideas turned out to be rather utopian. This is also true for the third space flight pioneer, the German Hermann Oberth (1894–1989). Yet, compared to Tsiolkovsky and Goddard, he was more interested in scientific principles and the applications of space stations in lower Earth orbits. Oberth suggested an (orbital) altitude of approximately 1000 km and pointed out the possibilities of an orbiting station for astronomical and Earth observation tasks. Additionally, he thought of a large solar mirror of 100 m in diameter for concentrating sunlight and solar heat and reflecting it back to the Earth. He also discussed the importance of a space station for several purposes: observation tasks in case of military conflicts, support of rescue operations, telegraphic or meteorological application, or even a space station as an "extraterrestrial refueling station" for interplanetary flights.

Early reflections on space stations were based on the assumption that when in orbit, humans would need "artificial gravity" to survive. Such simulated gravity obviously could be achieved by rotating a cylindrical or toroidal space station body. In this context, the works of two officers of the Austrian Imperial Army, Baron Guido von Pirquet and Hermann Noordung (pen name of Hermann Potocnik), published in 1928, are worth mentioning: In the journal "Die Rakete", Baron Guido von Pirquet presented three different concepts of a space station: the first for Earth observation in a 750 km-orbit, the second serving as a launching platform for interplanetary space vehicles in a 5000 km-orbit and the third a space station on an elliptical orbit intersecting the orbits of the first two stations. Hermann Noordung prepared a detailed study of a space station, consisting of three elements: a radial construction as habitation module, a power supply system (with solar collectors, evaporation and condenser tubes) and an observatory (cf. Fig. 2.2). He was the first to calculate a geostationary orbit in which the station was to revolve around the Earth and perform tasks like predicting the weather, military observation, warning ships of icebergs and mapping the Earth.

From 1930 until the end of World War II, rocket scientists and engineers concentrated mainly on developing missiles instead of space station ideas. Engineers of the large military development facility at the village of Peenemünde, located in northeastern Germany on the Baltic Sea, were the first to find a solution for problems concerning propulsion and navigation of a large rocket. The long-range ballistic missile A4 (meaning "Aggregat 4"), designated by the Propaganda Ministry as V-2 (meaning "Vengeance Weapon 2") was demonstrated for the first time in 1942 on the occasion of the rocket's initial flight. At the conclusion of World War II, the engineers from Peenemünde "moved" into Soviet and American projects of research and development (e.g. the US military operation called "Project Paperclip"). With the help of those engineers, substantial progress was made in rocket technology simultaneously in both the East and West. In addition to its military character, rocket technology came to civilian application, manifesting itself most clearly in the realization of space station concepts.

On the basis of the knowledge achieved by the middle of the century, Ross and Smith from Great Britain came to the conclusion that a massive space station could not be placed into orbit as a whole. Instead they advised to divide it into several separate discrete elements to be assembled in orbit. Inspired by Noordung's and Arthur C. Clarke's publications on the subject of geostationary orbits, H.E. Ross in January, 1949 wrote an article published in the Journal of the British Interplanetary Society describing the advantages of a space station revolving in such an orbit. For operation he suggested a 24-person crew. What is amusing is that this crew did not only include scientists and engineers, but, marked by the British-imperialist view at that time, two cooks and four orderlies as well!

In 1952, Wernher von Braun contributed greatly to the concept and creation of space stations by designing his famous wheel-shaped model, composed of several modules (Fig. 2.2 and Fig. 2.3). Von Braun's space station was to revolve in a polar orbit around the Earth at an altitude of 1600 km, accompanied by a free-flying astronomical telescope. Resupply was provided from the Earth by a winged reusable space transportation vehicle. The wheel-shaped structure of the space station was partially inflatable, had an outer diameter of about 85 m, and was triple-decked. Although Wernher von Braun considered his space station only a stage of development on his way to long-term exploration plans for Mars, he related a wide variety of fundamental technical ideas and principles which are still valid today. For example: the

Fig. 2.3. The Concept of Wernher von Braun (1952) [Pioneering 86]

use of a micrometeoroid shield and progressive methods of “Concurrent Engineering” as well as management of technically demanding projects.

However, the space age saw its true beginning with the launch of the first artificial satellite Sputnik on October 4, 1957. This event enabled the visions and speculations of space flight pioneers and engineers to evolve into realistic space station programs, that were government-funded in the East and the West.

2.2 US Space Station Studies (1957–1985) and Skylab

After the ground for other ideas on space stations had been laid by the pioneer concepts presented in the previous section, more concrete technical ideas became public shortly before 1960. But still, these new concepts and the previous ones had one thing in common: they were far from being realistic in terms of feasibility of transportation, assembly or long-term logistics. But a solution would not be long in coming.

Around 1960, NASA’s long-term plans considered the translunar flight and a crewed space station as parallel objectives to be realized around 1970. The Mercury program (at that time shortly before its initial flight) with its one-person-capsule was to serve as the basis of their development. This path was to start and finish in the 1970’s with either a permanently crewed platform or with a planetary landing (Fig. 2.4).

According to these plans, the National Aeronautics and Space Administration NASA (founded October 1, 1958) undertook studies for a crewed research laboratory, parallel to their crewed spaceflight program (later on the Apollo program) [Bekey 85].

During the 1960’s, all studies regarding space station concepts conducted by NASA field centers and associated enterprises were based on the assumption that large launch vehicles were available, i.e. Saturn V and its projected successor. This assumption manifests itself in their structural concept consisting of at least one element of the size of a Saturn V third stage as well as branched expansion modules.

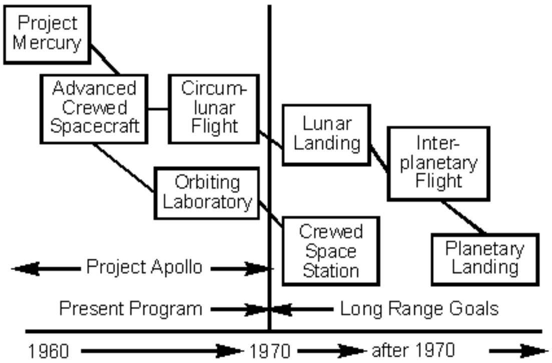

Fig. 2.4. NASA Crewed Space Flight Program Plans around 1960

An early, widely publicized concept had its origins in a survey of the newspaper "Daily Mail" in London. The survey was to address aerospace companies to solicit ideas and plans for a wooden mock-up of a space station for display at the London Home Show in 1959 on the subject "A Home in Space".

A concept of the Douglas Aircraft Company was selected with a crewed orbital observatory, consisting of the upper stage of a two-stage launch system. The idea was that, while on its way to a low Earth orbit, the launcher's second stage carried hydrogen and oxygen for the purpose of propulsion. Once the launcher reached its orbit, the four astronauts in a reentry capsule mounted on top of the launcher would convert the spent second stage into a space station. During this time, ideas ranging from live-in-tank concepts to crew restraint systems, equipment items and sleeping bunks (as they were later applied on Skylab) were born, as well as the perpetually revived discussion to use the numerous external tanks of the Space Shuttle to build large space stations.

On the occasion of a space station symposium in 1960, several enterprises presented their ideas including:

- Lockheed (modular design, launch by Saturn V)
- North American Aviation (rigid but self-deploying structure)
- Others (inflatable, partially launched by smaller rockets, partially driven by nuclear reactors)

At that time, it still was not clear whether priority would be given to a lunar landing or the construction of a space station.

This discussion was terminated in May 1961 with the famous words of the then US President John F. Kennedy: "I believe we should go to the Moon". NASA planners accepted the challenge choosing the lunar-orbit rendezvous technique as approach. Finally, the dream of a lunar landing came true in 1969. As a consequence, an Earth-orbiting space station as intermediate station for the lunar expedition "Apollo" was no longer necessary and this plan was abandoned in the 1960's. Remaining studies anticipated that a space station would be the logical post-Apollo program.

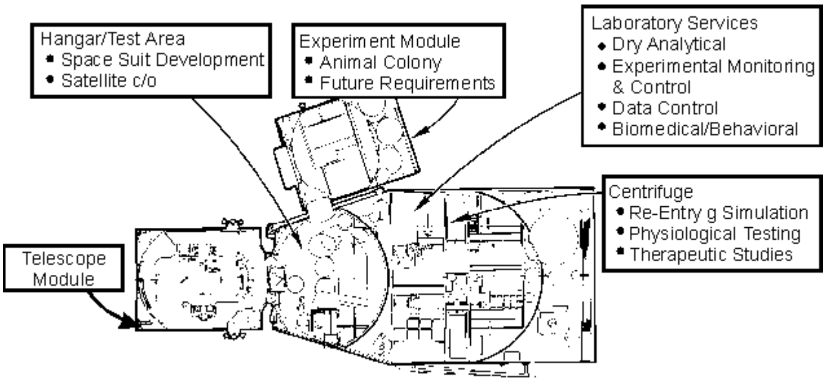

Fig. 2.5. Manned Orbiting Research Laboratory [Woodcock 86]

A joint study undertaken by NASA-Langley and contractors was further detailed by Douglas Aircraft from 1963–66 and lead up to a concept called Manned Orbiting Research Laboratory (MORL). The MORL was to have a crew of nine and revolve in an orbit at 300 km altitude and at 50° inclination. MORL was designed for biomedical experiments and was to serve as a telescope platform (Fig. 2.5). In the course of the studies, the MORL steadily became larger and more complex since no one had limited the logistics and consequently the costs either. This error was repeatedly committed in the course of the next two years. The Olympus studies undertaken by NASA-MSC Houston completed in 1962 on the basis of a two-stage Saturn V rocket suffered the same fate and ended up with a crew of 24 [Logsdon 85].

Douglas Aircraft was awarded a contract by the US Air Force to develop a similar concept MOL which had already taken into consideration the philosophy of the Apollo Applications Program conducted by NASA in 1965: components designed for the lunar landing should also be used for subsequent missions. It was not until then that the top levels of NASA management began to take up plans for a space station again and supported further internal studies during the years 1966–68, undertaken by groups headed by C. Donlan and E.Z. Gray. Again and again these groups had to deal with several conflicts between the different requirements of a space station such as:

- "Gravity simulated by rotation" vs. "Research in microgravity"
- "Astronomy (i.e. inertial flight mode)" vs. "Earth observation (i.e. gravity gradient stabilization)"
- "LEO servicing" vs. "Logistics for interplanetary flights"

Eventually, the "minimum station concept" resulting from this discussion was based on intermittent operation with changing flight modes, crewed (8–12 astronauts) or uncrewed, 320 km orbital altitude, 50° inclination and a 12 years design life.

Between 1969–70, NASA issued a statement of work for a space station "Definition" study (Phase B, cf. Chapter 9 "System Design"). Of the three firms who had submitted proposals, NASA awarded contracts to North American Rockwell and McDonnell Douglas. The space station was to be a cylinder, 10 m in diameter and 16 m in length, and it was supposed to be launched in 1977. Its design life was to be 10 years, and it was to be equipped with a photovoltaic or solardynamic isotope/ Brayton cycle system. The station was to be resupplied every 45 days, and rotation of the US crew was to take place every 90 days. Costs, at that time, were estimated at $ 8–15 billion (US). But even before NASA could issue a contract for the development of the station, the Saturn V program was "stopped" due to US congressional budget decisions. The only launch vehicle available now was the Space Shuttle. As a consequence, cylindrical space station modules of 10 m in diameter had to be reduced to the dimensions of the Shuttle's cargo bay, i.e. 4.5 m in diameter and 18 m maximum in length. The same restraints applied to other subsystems and components. Yet, even in this new situation, the contractors continued their study activities. However, in summer 1970 it had become obvious that after the Apollo mission there was to be only one large program, and this would be the Space Shuttle. Despite this development, studies were furthered until 1972 including the idea of a Shuttle based Sortie Lab. On the basis of this idea and in pursuance of it, the development of Spacelab was finally realized by the ESA, supported and operated by the NASA.

With the end of the Saturn V program and the decision to develop, from 1972 onwards, the Space Transportation System (STS, also called Space Shuttle) and to use it as the main transportation system, NASA altered its concepts of a space station. The changes now involved a modular design of the station so that any single component could be transported by the Space Shuttle. Rotating systems with large dimensions, assembled in space over thousands and thousands of crew-hours were, due to steadily increasing flight practice, replaced by smaller, zero gravity concepts for modules and stations which were designed rather with concern for their application than for human habitation.

During the second phase of US space flight development (cf. Fig. 2.6), sometime during the 1970's, concepts of large space stations existed more or less as marginal projects whereas the Space Shuttle program received full attention by NASA. The project of a space station remained interesting though, not with least thanks to the orbiting laboratory Skylab, which emerged from the Apollo Applications Program and was more or less assembled using parts from the Apollo Program. With a total of three crews, however, it turned out to be outstandingly successful [Skylab, Woodcock 86].

In the beginning, two alternatives were taken into consideration for the construction of Skylab: First, the so-called "Wet Workshop", launched with a Saturn IB. The Astronauts could enter the third stage after residual propellants had been purged and convert the spent stage into a space laboratory. Second, the "Dry Workshop" in which the third stage was to be outfitted on the ground before being launched by a Saturn V. During the first lunar landing in July 1969, the second alternative was selected and was to be brought into orbit with the last launch of a Saturn V rocket.

Figure 2.6 shows the chronology of American space station studies on their thorny way to the first American space station project Skylab. Two decades had passed since the studies of Wernher von Braun by Skylab's initial launch. And another two decades had yet to pass until the project to design a second space station with major US involvement was settled: the International Space Station.

	Douglas Aircraft, London Home Show	1959
Pioneer	Lockheed, Modular Concept	1961
Studies	NAA, Self-Deploying Ring	1961
	Olympus, NASA-MSC	1962
	MORL, NASA-Langley	1963-66
	MOL, Air Force	1966-69
Phase 1	NASA Phase-A Studies, after Apollo Program	1966
	Saturn V Abandoned, Space Shuttle Becomes Only Launch Vehicle	29-Jul-70
	NASA Phase-B Studies; Orientation Towards Modular Design	1970-72
	Only the Development of the Space Shuttle is not Affected by Budget Restraints	
	Skylab, not Permanently Crewed (Aroused a lot of Interest!)	1973
	MOSC, McD, Research Station	1975
Phase 2	SSSAS, JSC & McD, MSC & Grumman, Engineering Station	1976-77
	Development Station, McD	1981
	SOC, Boeing	1980-82
	NASA Task Force "Concept Development Group", Delta, Big T, e.a.	1983-84
	NASA Power Tower, Concept by Boeing 1983	1983
Phase 3	Reagan Issues Objectives for the Realization of a Space Station	25-Jan-84
	NASA Dual Keel	1986
	NASA Revised Baseline	1987

Fig. 2.6. Chronology of US Space Station Studies until 1990

Skylab was launched on May 14, 1973 into an orbit at 432 km altitude and 50° inclination. It was composed of a converted Saturn V third stage, the so-called "Orbital Workshop", a telescope mount, an airlock (from Gemini components) and a docking adapter (Fig. 2.7), respectively. Three crewed missions (28, 59 and 84 days in duration) were flown between May 25, 1973 and February 8, 1974, the three-person crews being transported by Apollo Command Modules. The first mission turned out to be an emergency repair service: During the launch of Skylab, the meteoroid shield failed due to aerodynamic forces and in turn damaged a solar panel and part of the thermal insulation. Additionally, the second solar panel could not be fully deployed. The first crew, however, succeeded in providing satisfactory operation of Skylab by carrying out several EVA's and installing an umbrella-like sunshade.

In terms of size and success, Skylab was a remarkable station, although it was not designed as a permanent system with provisions for resupply and therefore many did not accept it as a true space station. For example, the potable water for all three missions was stored in tanks aboard Skylab. Furthermore, Skylab had no propulsion system for reboost maneuvers. Due to the fact that there was no vehicle available (i.e. the Space Shuttle) for reboost maneuvers, Skylab could not stay in orbit. After having orbited the Earth for six years (with only about 171 days of true operation)