13 The International Space Station

As a complement to the previous chapters, this chapter on the International Space Station (ISS) will describe the special characteristics relevant to the mission, planned laboratory facilities, and user support as well as important technical and programmatic aspects of the station's operation.

Previous chapters have already dealt with the assembly of ISS, its most important components and parameters (Sections 2.5–2.6) and the station's orbital environment and subsystems (Chapters 3–6). Important aspects of utilization have been discussed in Chapters 7 ("Utilization"), 8 ("Microgravity") and 12 ("Logistics, Communications and Operation"). As this chapter is the conclusion of this book, supplemental information and an overview of the current space station plans will be given, thus it may also serve as a guide for users that are planning experiments for research and technology demonstration [ESA-Guide 96, ESA-Guide 98, NASA-Guide 98].

13.1 Station and Mission Elements

This first section deals with those characteristics of ISS, and the entire mission, which are of interest especially to users. These characteristics will help us realize the vast possibilities of ISS in terms of multilateral cooperation based on concerted action and bartering. ISS draws upon the resources and scientific and technological expertise of at least 16 nations and will provide unprecedented access to a crewed, long-duration space research facility. The governments of the United States, Canada, Europe, Japan and Russia are named "International Partners", in short "Partners". Each Partner can establish its own bi-lateral agreements with other countries to supply portions of the partner's contribution, often in exchange for research access to the station once it is operational. The United States, for example, has additional agreements with Brazil and Italy to this end.

Each partner nation is allocated a share of station resources in accordance with its contribution to the program. The partners use their own internal mechanisms to apportion space and research capability to their scientific, technological, and commercial interests. To coordinate their research, the partners have established bi- and multilateral working groups. The United States will have the use of the US laboratory module in addition to 46.7% of the European and Japanese pressurized laboratory space. Not including the Russian laboratory space, this constitutes over 75% of available station research accommodations. Thus, the Partner's share, at present, is NASA (75.3%), Italy (0.85%), Brazil (0.45%), Japan (12.8%), ESA (8.3%) and Canada (2.3%) [NASA-Guide 98]. The utilization and distribution of these accommodations and resource capabilities is achieved at the International Partner level rather than at a specific laboratory or attached site level. This approach provides each International Partner with broader opportunities for planning to accomplish its specific payload mission objectives.

13.1.1 Characteristics of ISS

The International Space Station will be assembled from several basic components: modules, nodes, truss structures, solar arrays, and thermal radiators. Modules are pressurized cylinders and represent habitable space onboard the space station. Modules may contain research facilities, living quarters, and any vehicle operation stations and equipment to which the astronaut may need access. Nodes connect modules to each other and offer external space station access for purposes such as docking, EVA access, and pressurized payload access. Truss structures are the erector-set-like girders that link the modules, the main solar power arrays, and the thermal radiators. Together, the truss elements form the Integrated Truss Structure. Solar arrays collect solar energy for conversion into electricity for the operation of ISS and its payloads. Thermal radiators bleed off excess heat into the vacuum and cold of space.

Once its assembly has reached completion, ISS will feature eight solar arrays and two large radiators mounted on the 108 m long truss structure. The US modules will be directly connected to the center segment of the truss; behind them there will be the Russian modules and the vertical truss including the solar arrays. The European COF and the Japanese JEM module will be situated at the “front” of the station (with respect to its flight direction) in front of the US Laboratory module (cf. Fig. 13.1).

The Canadian manipulator system SSRMS can move along the truss between the first (inner) pair of solar arrays. The station’s dimensions are 108 m x 74 m and it will have a total mass of 415 tons. Moreover, 110 kW of electrical power will be generated aboard ISS, of which 47 kW are allocated for research purposes. After the first phase of assembly, three astronauts will live and work aboard the station. The number will be increased to six or seven after completion of assembly. Each crew member will stay in orbit for at least three months – this is the minimum period possible, corresponding to the length of the intervals between two Space Shuttle flights to ISS.

The attitude and orbit control strategies defining the station’s flight direction, altitude and attitude were covered in Sect. 6.2. Perturbations aboard the station in the form of quasi-static microgravity levels and g-fluctuations (g-jitter) were explained in Sect. 8.4, whereas the self-induced environment around the station (mainly influencing external sensors and observation instruments) was covered in Sect. 3.9.

The International Space Station will include the following orbital elements (the acronyms in parentheses designate the corresponding parts shown in Fig. 13.1, see also Table 2.8 and Fig. 2.27):

- The functional and payload module “FGB” (acronym derived from Russian designation): The FGB, also named Zarya (Russian for “dawn”) is manufactured in Russia and financed by the USA. It is an autonomous space vehicle including

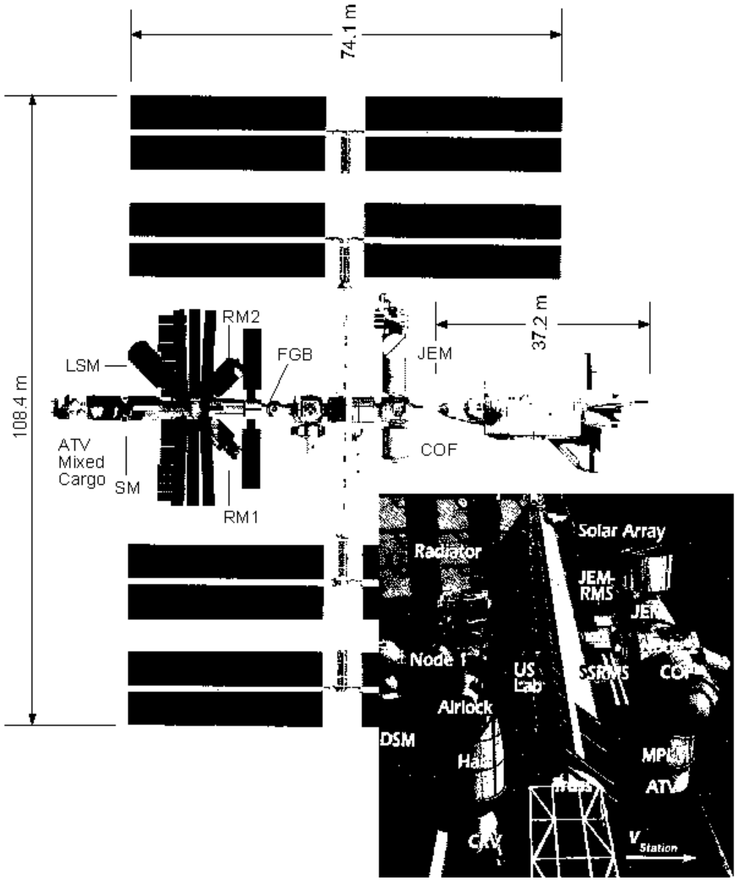

Fig. 13.1. The view from above shows, with respect to flight direction, the rear part of the station (on the left) with the fundamental elements of the Russian Segment and a European Automated Transfer Vehicle (ATV) docked at the Russian Service Module (SM) and carrying Mixed Cargo. The forward part of ISS (in the lower right corner) comprises the European laboratory module COF with an ATV docked to it, with the ATV carrying an MPLM (Mini Pressurized Logistic Module) [ESA-Fakten 96, DARA-ISS 96].

power supply and thermal control as well as navigation, propulsion, and communication equipment.

- The Service Module (SM), provided by the Russian Space Agency (RKA): It includes habitation, work and sleep compartments for up to three crew members and complements the propulsion and attitude control functions of the FGB. At the rear part of the SM there is a docking port for uncrewed Russian Progress vehicles. The Mixed Cargo-version of the European Automated Transfer Vehicle (ATV) also can dock at this port.
- Six pressurized laboratory modules for scientific research:
  - A laboratory module (US Lab) from NASA

  - A US-contributed Centrifuge Accommodation Module (CAM)
  - Two Research Modules (RM1, RM2) from the Russian Space Agency RKA
  - A Japanese Experiment Module (JEM) from the Japanese Science and Technology Administration (STA)
  - A European laboratory module, the "Columbus Orbital Facility" (COF), from the European Space Agency (ESA)
- Various unpressurized accommodation sites on the US, Russian and Japanese elements for installation of scientific and technological external payloads
- A habitation module (Hab) from NASA, offering space for four crew members
- A Life Support Module (LSM) from RKA, complementing the life support functions of the Service Module (SM)
- The Russian Universal Docking Module (UDM), where the Russian research modules RM1 and RM2, the LSM, and the docking segment will be mounted (the UDM also being used for docking with Russian transportation vehicles)
- The Russian Docking and Stowage Module (DSM), an additional docking possibility for Russian space transportation vehicles
- The Russian Docking Compartment (DC), also serving as an air lock for the crew during EVAs
- The US air lock
- The Node 1 and the Node 2 as well as adapters between the various pressurized modules
- A docking port for the US Space Shuttle at Node 2 and at the nadir end of the US Habitation Module (US Hab)
- The Crew Return Vehicle (CRV) which is permanently docked at the station, a crewed reentry vehicle serving as "life boat" for the station, thus ensuring the safe return of the crew to Earth in case of emergency (as yet undecided as to which of the International Partners will furnish the CRV.
- The following three manipulator systems will be available outside the station:
  - The Canadian remotely operated space station manipulator system (SSRMS)
  - The European Robotic Arm (ERA), moving along the Russian "Science Power Platform" (SPP)
  - The Japanese remotely controlled manipulator system (JEM-RMS), mounted on the JEM
- Two large support structures: One truss from NASA and the SPP from Russia, together comprising the structure that links the different station elements.
- Photovoltaic solar arrays, radiators for temperature control, attitude control systems, communication equipment, and corresponding distribution systems for power supply and communications.

13.1.2 The Gradual Assembly of ISS

The first element of ISS is the FGB module, launched on November 20, 1998 by a Russian Proton rocket. During the following six months, three further flights by the US Space Shuttle and Russian launch vehicles are to take place, transporting Node 1 (manufactured in the USA, launched December 4, 1998), two adapters and the Russian Service Module (SM) into space. All these components together make a “core station”, which can be permanently crewed from July 1999 onwards with a crew of three, who is to live and work in the Russian Service Module (cf. Table 2.8).

The subsequent installation of the first segments of the US truss and the Russian SPP, as well as that of the solar arrays, radiators and communications equipment which are to be mounted onto them, considerably increases the resources this “core station” is able to offer. The European Robotic Arm (ERA) plays an important role in the assembly process of the Russian SPP and the different Russian modules.

In late 1999 or early 2000, the US Lab, the Airlock and the Russian Docking Compartment are to be added. Over the years 2000–2003, the scientific capacities will be gradually expanded by launching and installing the two Russian research modules RM1 and RM2, the Japanese Experiment Module (JEM), and the European Columbus Orbital Facility (COF). The outfitting of the research modules with racks (ISPRs) and other equipment is done during intermediate Space Shuttle flights.

Assembly of the station will be complete in 2004. From this point onwards, the total number of astronauts aboard the station can be increased to six or seven, since the US habitation module (Hab) to be launched in January 2004 can accommodate up to four persons.

13.1.3 Mission Characteristics

After the Assembly Phase, the Utilization Phase will begin in 2004. This phase is projected to last 10 years, and it is divided into sections of three months each. At the beginning or end (depending on the point of view) of such a section, a Space Shuttle flight to ISS will take place; the crew, parts of payload elements, and equipment will be exchanged. Moreover, the Space Shuttle will deliver supplies to the station and return experimental test items to Earth. After each Shuttle “visit”, the station will be lifted by a reboost in order to compensate for the loss of altitude during the preceding three months caused by the decelerating effect of the residual atmosphere. Each reboost maneuver will increase the station’s altitude by about 10-40 km, the exact altitude increment being dependent on the influence the solar cycle has on the atmosphere.

ISS will be operated in several different modes. The primary modes of operation for research are “Microgravity” mode and “Standard” mode. Other modes of operation include Shuttle docking, Extra-Vehicular Activity (EVA), and orbital reboost (see Sect. 6.3.2 “Orbit Control Strategies” and Sect. 8.4 “Perturbation Compensation and Levitation”). The crew time available for research is 120 h/week for six astronauts, a seventh astronaut would add another 40 h/week. When fully operational, ISS will provide 26 kW minimum continuous and 30 kW average power and thermal conditioning to payloads during standard and microgravity modes of operation. During various other ISS operating modes, a minimum of 6.5 kW of continuous power is provided to the integrated set of payloads.

The nominal atmospheric pressure onboard ISS is maintained between 97.9–102.7 kPa, with a minimum of 95.8 kPa. Carbon dioxide levels are maintained below 0.7% to ensure the medical safety of the crew. The relative humidity is maintained between 25% and 70%. To support specific biological research, agreements have been reached to reduce the atmospheric carbon-dioxide content to 0.37% (with the goal of reaching 0.3%) for two 90-day periods each year. This is accomplished by running several carbon dioxide removal assemblies simultaneously. The oxygen partial pressure is maintained in the range of 19.5–21.1 kPa. Potable water for payloads and experiments is provided at a rate of 5.5 kg per day.

Continuous operation and supply cycles require great effort on ground. For example, all activities related to the launch of the first payload have to be repeated for all subsequent payloads, sometimes even overlapping one another. At the end of the first phase of experiment selection (and coordination on the ISS Partner level), and in the case of the subsequent selection phases alike, a "Partner Utilization Plan" (PUP) is agreed upon for each year of the steady-state station utilization. The composition of the payload and the sequence of the scientific schedule for each increment have been coordinated and fixed far in advance by the "Space Station Strategic and Tactical Planning Process". If this planning includes an exchange of payload elements, the "Payload Integration and Operations Preparation Process" will have to be started in time. For the European COF operation, for example, this process has to be continued quasi-permanently in order to continually " move" the payload through all the different phases of preparation up until launch.

Payload flight operations, firstly, comprise the new payload's onboard installation, testing and verification. The next steps are the scientific tasks that the payload is to perform, its maintenance and repair (if necessary) and finally, its removal and return to Earth. In the case of payloads situated in one of the pressurized parts of the station, astronauts will perform installation on rack or drawer level. Usually, this requires a connection with standard elements such as screws, latches and joints as well as electrical, fluid-mechanical and vacuum tube connectors. External payloads are installed with the help of the SSRMS robotic system which is controlled by the astronauts. Small payloads like the Express Pallet Adapters are installed with the help of the small Special Purpose Dextrous Manipulator (SPDM), which, for this task, is mounted at the end of the larger SSRMS robotic arm. After successfully checking the complete installation, all internal or external payloads are cleared for routine operation. Either astronauts, autonomous control and robotic units, or ground control (or a combination of all three) will operate the payloads and intervene, if necessary. Inside each research module, astronauts can control the payloads either by means of laptops, (which are connected to the Local Area Network (LAN)) or directly by means of switches, displays and experiment computers. Procedures which have to be processed automatically, are usually monitored by the experiment computer; alternatively, this can be performed by the Payload Control Unit (PLCU).

An experiment can also be controlled by the original Payload Investigator (PI). In this context, resources must not be exceeded (electrical power, cooling, data systems and astronaut time are available only for a limited period of time); this is laid out in a short-term plan on the basis of commands which were validated before the flight. As a consequence, the scientist can monitor all relevant experiment and housekeeping data and intervene, if necessary. The scientist, in turn, is supervised by the Control Centers (CC) and Payload Operations Interface Control (POIC) (cf. Fig. 13.2), but they will only intervene if the User Home Base (UHB) operation turns out to have any negative influence on the crew, on other payloads, or on re-

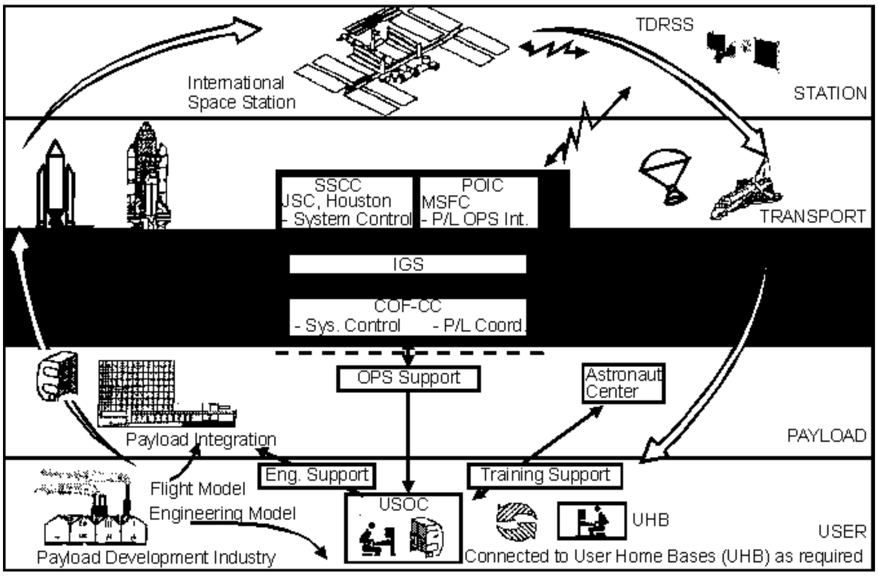

Fig. 13.2. Schematic Representation of the Onboard/Ground Operation with the Different Control Centers

sources not assigned to the PI, or if the previously defined operational window is exceeded or has to be limited.

All the different ways of transmitting commands, voice or video between space station and ground via TDRSS or other relay satellites are described in Sect. 12.2. At present, the uplink data rate is rather small (72 kbit/s); the downlink data rate of 43 Mbit/s is likely to be increased to 150 Mbit/s by adding further satellite transponders (TDRSS, Artemis, other DRS capacities). For payload data, the MIL-STD-1553B is applied where the LAN protocol corresponds to the IEEE 802.3 convention.

13.2 Pressurized Modules and Payload Structures

Seven pressurized station elements are planned as laboratories or can be used for experiment operations: the laboratory modules US Lab, JEM, COF, RM1 and RM2 mentioned before, and the modules US Hab and US Centrifuge. These modules and their utilization will be described in the following sections. Facility descriptions may vary in level of detail dependent upon the level of definition and stage of development of a particular facility at the time of the writing of this book.