Appendix D

THE INTERNATIONAL SPACE STATION

This appendix presents an review of the International Space Station Program and the facilities that are or will be available for research. First, the appendix reviews the objectives of the ISS and the identified research directions for the station. Next, it presents an overview of all the ISS components. That is followed by a more in depth review of the components which directly support research aboard the ISS. The appendix ends with a presentation of the identified challenges of the ISS and expected upgrades to the program to overcome these challenges. Chapter 2 utilizes this review to identify the most important resources provided by the ISS.

D.1 Objectives and Research Directions

The objectives of the ISS as stated in the ISS Familiarization Manual developed by NASA are:

> "The purpose of the ISS is to provide an "Earth orbiting facility that houses experiment payloads, distributes resource utilities, and supports permanent human habitation for conducting research and science experiments in a microgravity environment." (ISSA IDR no. 1, Reference Guide, March 29, 1995)
>
> "This overall purpose leads directly into the following specific objectives of the ISS program:
>
> - Develop a world-class orbiting laboratory for conducting high-value scientific research

- Provide access to microgravity resources as early as possible in the assembly sequence
- Develop ability to live and work in space for extended periods
- Develop effective international cooperation
- Provide a testbed for developing 21st Century technology."

[NASA, 1998]

After creating these objectives, NASA worked to further detail the research objectives of the ISS. To this purpose, NASA has created an ongoing program to determine the "research directions" of the ISS. During the development of these directions, NASA first defined the ISS as a special type of laboratory, one which has three special purposes:

- "an *advanced testbed* for technology and human exploration;
- a *world-class research facility*; and
- a *commercial platform* for space research and development." [NASA, 2000]

As of January 2000 the NASA Office of Life and Microgravity Science Applications had identified a number of research fields which can directly use the resources provided by the ISS to advanced human knowledge and provide benefits to the people in the ground. The identified fields include (adapted from [NASA, 2000]):

- **Biomedical research and countermeasures / Advanced human support technology** - what knowledge and technology are necessary for humans to live and function productively beyond the Earth's surface.
- **Biotechnology -** produces and characterizes biological molecules and assemblies important to basic and clinical research.
- **Combustion science** - the basic mechanisms of combustion can be more easily studied in microgravity, where scientists can make observations and measurements of combustion and the systems and processes it enables.
- **Fluid physics** - the universal nature of fluid phenomena, which affect everything from transport dynamics in the human body to the mixing characteristics of the atmosphere, makes this research fundamental to all areas of science and engineering.
- **Fundamental physics** - microgravity enables the development of uniform samples, the free suspension of objects, and the lack of mechanical disturbance on experimental subjects to test the fundamental physical laws.

- **Gravitational biology and ecology** - studies in gravitational biology and ecology seek to advance our understanding of how the ubiquitous force of gravity affects the many stages of plant and animal life.
- **Materials science** - the ISS gives researchers to study the relationships between the structure, properties, and processing of materials without buoyancy-induced convection, sedimentation, or hydrostatic pressure. Microgravity also provides the chance to investigate "containerless processing".
- **Space science** - from its orbital position, the ISS affords researchers a long-term "window on the universe" from which to study the structure and evolution of the cosmos.
- **Engineering research and technology development** - advances in engineering research and technology development (ERTD) can help reduce costs and improve the performance of future government and commercial activity in space, and enhance the quality of life on Earth. ISS research helps validate the technologies for long-duration space exploration, power generation and storage, robotic manipulation capabilities, automatic maintenance, and spacecraft control. New applications, processes, and technologies promise to benefit the telecommunications, water and power, construction, and other industries on Earth.
- **Space product development** - commercial researchers will springboard off of basic science and engineering to use the knowledge gained from the ISS research to create new products and processes to benefit the medical and pharmaceutical fields, the electronics and chemical industries, and the engineering community, among others.
- **Earth science** - the orbit of the ISS will cover about 85% of our planet's surface, making it a useful platform for ongoing Earth science research to assess the global trends such as: atmospheric and climate change; weather patterns; vegetation and land use patterns; and food, water, and mineral resource use.

D.2 Components of the ISS

Figure D.1 shows the expected configuration of the ISS at US Core Complete, as of July 23, 2004. Once this configuration is achieved, the ISS will be composed of the following major modules (the following descriptions were adapted from [NASA, 1998] to reflect US Core Complete):

- **Node** - The Node is a U.S. element that provides six docking ports (four radial and two axial) for the attachment of other modules. It also provides

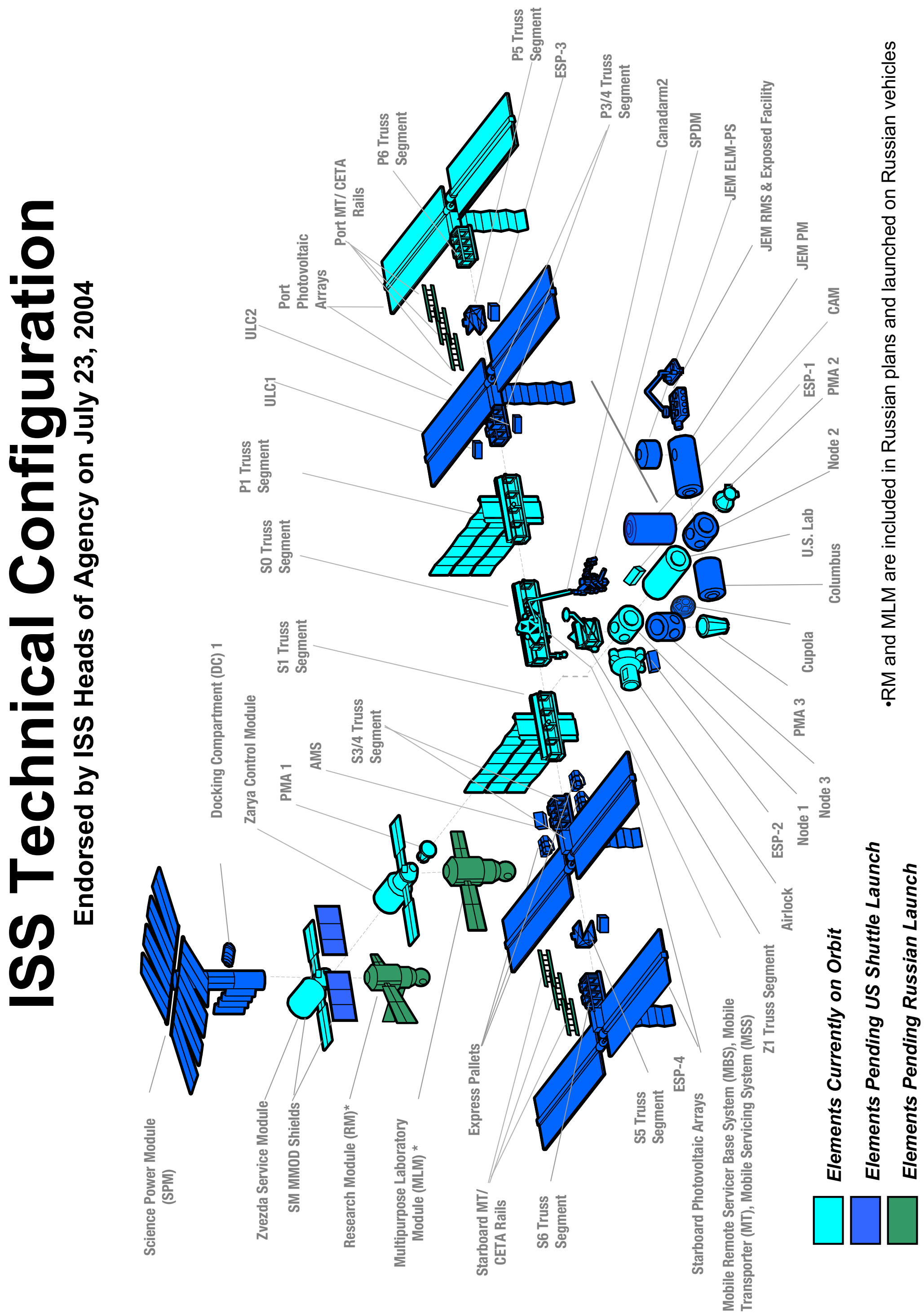

Figure D.1 The ISS at US Core Complete external attachment points for the truss. The Node provides internal storage and pressurized access between modules. There are three Nodes.

- **Service Module** - The Service Module (SM) provides the Station living quarters, life support system, communication system, electrical power distribution, data processing system, flight control system, and propulsion system. Living accommodations on the Service Module include personal sleeping quarters for the crew; a toilet and hygiene facilities; a galley with a refrigerator/freezer; and a table for securing meals while eating. Spacewalks using Russian Orlan-M spacesuits can be performed from the SM by using the Transfer Compartment as an airlock.
- **Soyuz** - Besides being an Earth-to-Orbit Vehicle (ETOV) used for crew rotations, Soyuz is the Russian element that provides the crew emergency return ("lifeboat") capability. As such, there is always a Soyuz docked to the Station whenever the Station crew is onboard. At least every 6 months, the docked Soyuz is replaced with a "fresh" Soyuz.
- **Laboratory** - The Lab is a U.S. element that provides equipment for research and technology development. It also houses all the necessary systems to support a laboratory environment and control of the U.S. Segment.
- **Multi-Purpose Logistics Module** - The MPLM allows transfer of pressurized cargo and payloads. It is launched on the Shuttle and berthed to the Node, where supplies are off-loaded and finished experiments are loaded. The MPLM is then re-berthed in the Shuttle for return to Earth.
- **Joint Airlock** - The Joint Airlock is a U.S. element that provides Station-based Extravehicular Activity (EVA) capability using either a U.S. Extravehicular Mobility Unit (EMU) or Russian Orlon EVA suits.
- **Docking Compartment** - The Russian element Docking Compartment (DC) is used during the assembly sequence to provide egress/ingress capability for Russian-based EVAs and additional docking ports.
- **Truss** - Built over numerous flights, the truss is a U.S. element that provides the ISS "backbone" and attachment points for modules, payloads, and systems equipment. It also houses umbilicals, radiators, external payloads, and batteries.
- **Science Power Platform** - The Science Power Platform (SPP) is a Russian element that is brought up by the Shuttle to provide additional power and roll axis attitude control capability.
- **Japanese Experiment Module** - The Japanese Experiment Module (JEM) is a Japanese element that provides laboratory facilities for Japanese material processing and life science research. It also contains an external platform, airlock, and robotic manipulator for in-space ("exposed") experiments and a separate logistics module to transport JEM experiments.

- **Cupola** - The Cupola is a U.S. element that provides direct viewing for robotic operations and Shuttle payload bay viewing.
- **Research Module** - The Research Module (RM) is a Russian element that provides facilities for the Russian experiments and research. It is analogous to the U.S. Lab.
- **Columbus Orbital Facility, Also Known as the Attached Pressurized Module** - The Columbus Orbital Facility (COF) is an European Space Agency (ESA) element that provides facilities for the ESA experiments and research. It is analogous to the U.S. Lab.
- **Centrifuge Accommodations Module** - The Centrifuge Accommodation Module (CAM) is a U.S. element that provides centrifuge facilities for science and research. It also houses additional payload racks.
- **Logistics Vehicles** - Logistics flights are required throughout the life of the ISS and will be accomplished using a variety of vehicles.
  - The Shuttle will be used to bring water, and pressurized cargo. When the Mini-Pressurized Logistics Module (MPLM) is used, the Shuttle can bring nearly 9 metric tons of pressurized cargo to ISS. The Shuttle is also the only means for returning items intact from ISS.
  - The Progress M1 is provided by RSA and used to accomplish three primary tasks: orbital reboost, attitude control fuel resupply, and pressurized cargo resupply. It will be launched on a Soyuz booster. Pressurized cargo includes oxygen, nitrogen, food, clothing, personal articles, and water. The Progress is filled with trash as its stores are consumed, and when exhausted, undocks, deorbits, and re-enters the atmosphere over the Pacific Ocean.
  - The Autonomous Transfer Vehicle (ATV) is provided by ESA and is scheduled to be completed in 2006. It will be launched on an Ariane V launch vehicle. It is roughly three times as large as the Progress M1, but is functionally the same as described above.
  - The H-2 Transfer Vehicle (HTV) will be provided by National Space Development Agency of Japan (NASDA) and is under design. It will launch on a H-2A launch vehicle. Its purpose is to carry pressurized cargo only. Unlike the Progress M1 and ATV, the HTV doesn't carry resupply fuel, and it doesn't dock. It rendezvous to the forward end of the Station and is grappled by a robotic arm and berthed.

D.3 ISS Facilities for Research

The previous section presented an overview of all the components that compose the International Space Station. Several of those elements have been designed specifically to support research aboard the ISS to fulfill the research directions listed in Section D.1. This section describes the special elements of the ISS which support research, summarizes their capabilities, and lists the available resources for scientists. The section first presents further description of the modules; then the section describes the resources available to scientists.

D.3.1 ISS Modules for Research

The following summaries of the research modules were adapted from [NASA, 2000b]

- **US Destiny Laboratory -** The U.S. laboratory, named Destiny, is the module where a significant portion of the pressurized U.S. research will take place. The module overview is presented in Figure D.2 [NASA, 2000b]. Destiny will accommodate up to 13 ISPR research racks. Destiny is the first research module installed on the Station. The side of Destiny that faces Earth for the majority of possible ISS flight attitudes contains a circular window of very high optical quality design where the Window Observational Research Facility (WORF, see below) will reside.
- **US Centrifuge Accommodation Module (CAM) -** The CAM (pictures in Figure D.3 [NASA, 2000b]) is a laboratory dedicated to U.S. and cooperative international gravitational biology research. It houses a 2.5m diameter centrifuge, which is the essential component of a larger complement (multi-user facilities) of research equipment dedicated to gravitational biology. In addition, 9 locations are provided for passive stowage racks.
- **US Integrated Truss Attachments** - There are four dedicated sites on the starboard side of the ISS truss where external payloads can be attached. The general location of these attach points is indicated in Figure D.4 [NASA, 2000b]. There are two attachment points on the nadir, or Earth-facing, side of the truss, and two on the opposite, or zenith, side of the truss. Physically the attach points consist of a system of three guide vanes and a capture latch used to secure the payload, as well as an umbilical assembly to mate utilities and connections. Resources are given for a single payload occupying an entire truss-site; an EXPRESS pallet, which occupies an entire truss site, provides an equally sub-divided surface for up to six individual payloads with standardized interfaces for payload integration.

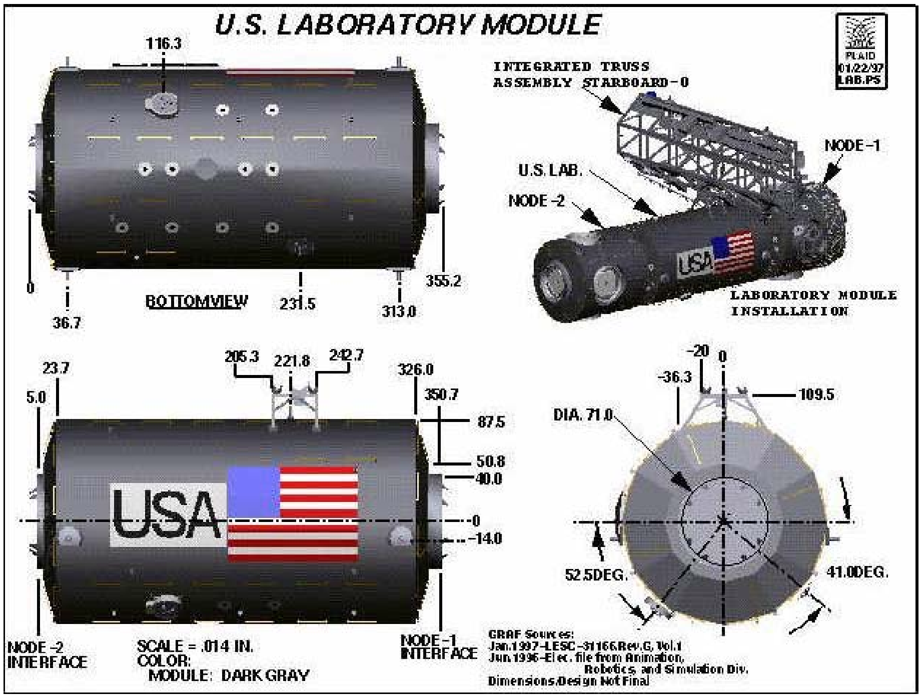

Figure D.2 US Destiny laboratory

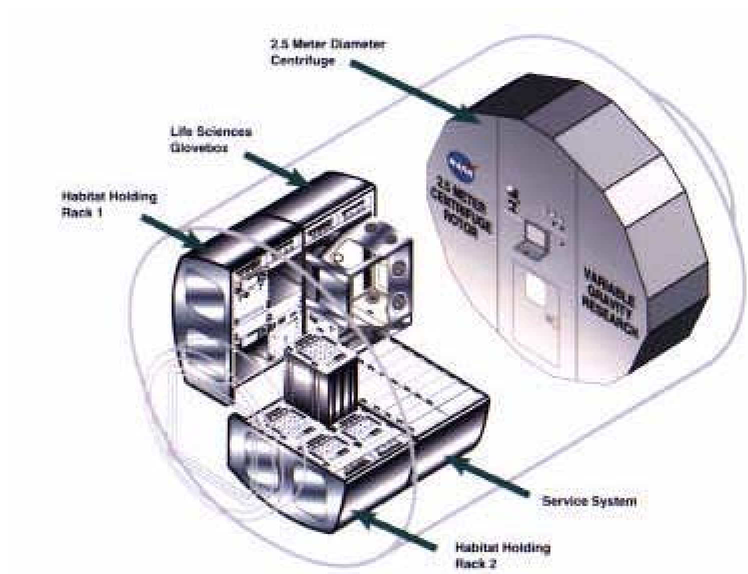

Figure D.3 US Centrifuge Accommodation Module

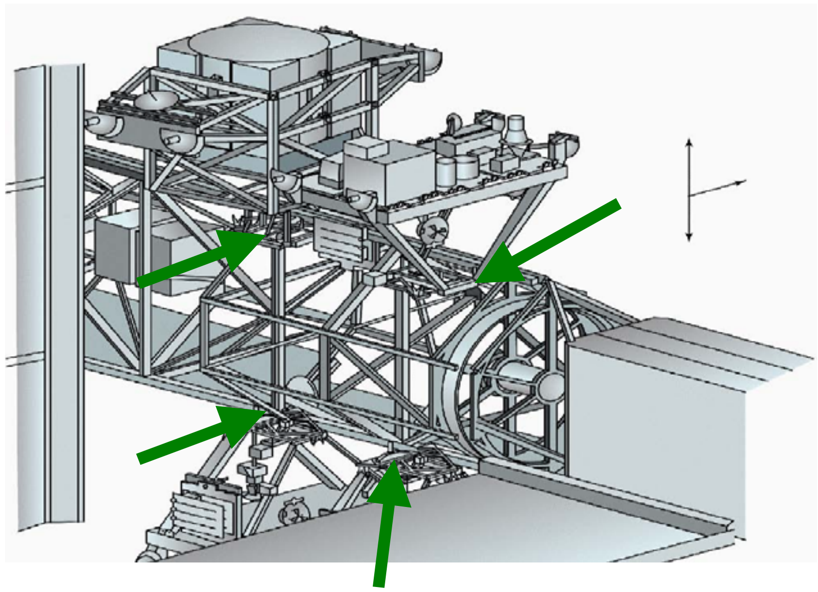

Figure D.4 US Truss Attachment Points (4)

- **Japanese Experiment Module (JEM)** - The Japanese Experiment Module (JEM), also known by the name Kibo, is the segment of ISS developed by the National Space Development Agency (NASDA) of Japan for the purpose of supporting research and development experiments in Earth orbit. Figure D.5 [NASA, 2000b] shows the several major systems of the JEM:
  - JEM Pressurized Module (JEM-PM) is a laboratory for experimental research in areas such as space medicine, life sciences, materials processing, and biotechnologies. It contains an airlock to transfer experiments. The module provides 10 ISPRs for research payloads.
  - JEM Exposed Facility (JEM-EF) is an un-pressurized pallet structure exposed to the environments of space to support user payloads for the purpose of experimental research in areas such as communications, space science, engineering, materials processing, and earth observation. A total of 10 payload sites are provided
  - The Pressurized Section (ELM-PS) and Exposed Section (ELM-ES) serve as a pressurized and exposed passive storage, respectively.
- **Colombus Module -** The European Space Agency (ESA) Columbus module, pictured in Figure D.6 [NASA, 2000b], provides 10 ISPRs for research payloads. Columbus is designed as a general-purpose laboratory to support ESA-defined scientific disciplines in the areas of materials and fluid sciences, life sciences and technology development. An Exposed Payload

Facility with two separate support structures attached is expected to be added to the Columbus Pressurized Module.

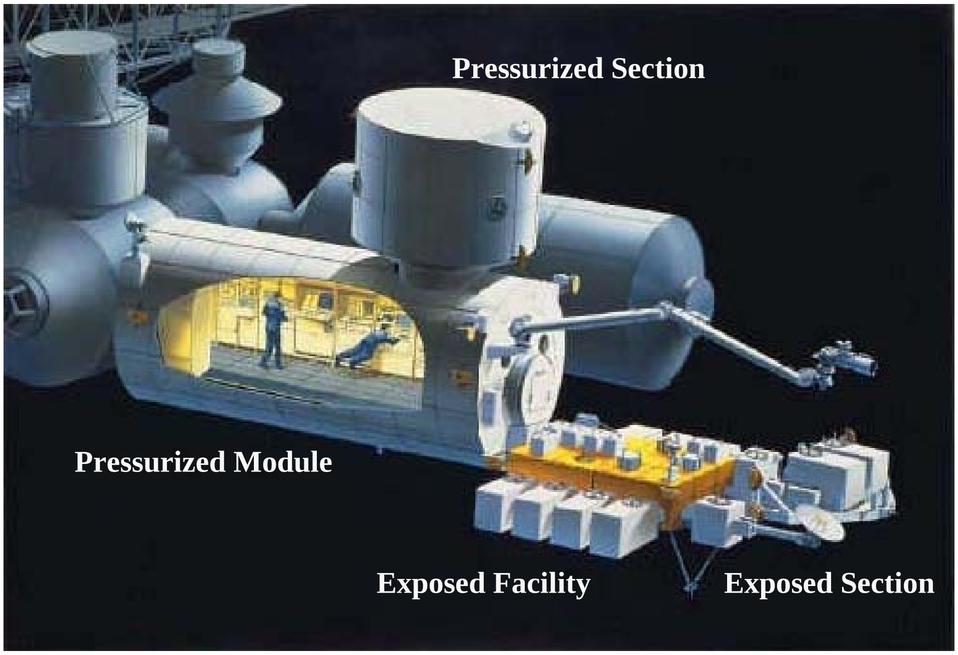

Figure D.5 Japanese Experiment Module

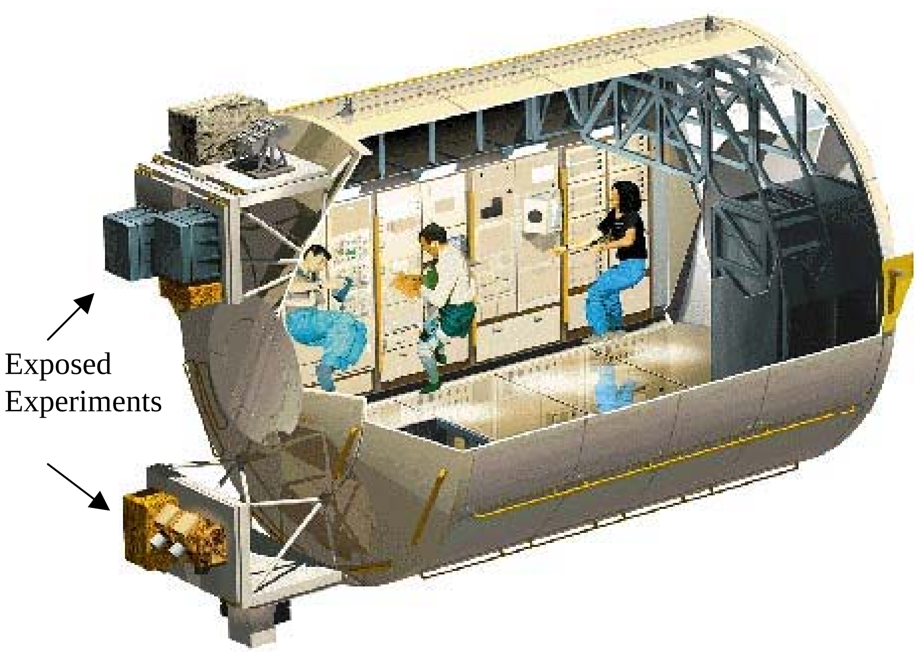

Figure D.6 Columbus Module

- **Russian Segment** - The Russian segment is slated to have two research modules to support research payloads generated by Russian researchers. The segment will have power, data, and other systems separate from the rest of the ISS.

D.3.2 ISS Resources for Research

The following resources are available to scientists at one or more of the research modules provided for research. While some resources are specifically intended for operations in the pressurized area of the modules, several are also available to exposed experiments.

- **Controlled environment** - the ISS operates an altitude of 350-460km and an inclination of 51.6° to the equator. It flies over 85% of the globe and 95% of the Earth's population. Steady state accelerations are maintained between 1-2μg during standard operations in the laboratory modules; vibration is controlled in the 0.01-300Hz frequency range, with a maximum RMS of 1mg at 300Hz. The pressure, air composition, relative humidity, and temperature are also controlled and monitored. The ISS also provides multiple sensors to monitor the external environment as well as controls to prevent contamination of the "exposed" experiments.
- **Power** - At US Core Complete the ISS will provide 26 kW minimum continuous and 30 kW average power during Standard and Microgravity modes.
- **Payload Data Handling and Communication** - A 72 kbps S-band forward link is used to send commands for payloads, while a 150 Mbps Ku-band system is used for the payload downlink. Three types of connections are available for this distribution: 1) a MIL-STD- 1553B Payload Bus, 2) an 802.3 Ethernet, or 3) a fiber-optic High-Rate Data Link (HRDL). Included in the data rate are four compressed channels of video downlink, and three channels of video uplink. The Payload Multiplexer/Demultiplexer provides 300 megabytes of nonvolatile mass storage for payloads.
- **Thermal Management** - Thermal radiators are positioned on the Integrated Truss Structure. Using H_2O internally, the radiators pick up heat from the ISS through the environmental control system, which then transfers that heat to the radiators using NH_4 as the active heat transfer fluid.
- **Cryofreezer System** - the Cryogenic Freezer System will maintain samples at or below -183 °C (-297.4 °F) throughout a mission life cycle. It will be used to preserve plant and animal cell fine anatomy, ultra structure and genetic material. The 35-liter (1.2 ft^3) internal volume of the storage freezer will accommodate 1000 or more 2- to 5- ml (0.1- to 0.3- in^3) sample vials.

- **Minus Eighty-degree Laboratory Freezer** (MELFI) - The Minus Eighty-degree Laboratory Freezer for ISS will maintain samples below -68 °C for experiments which all biochemical action to be stopped but do not require cryogenic temperatures. Cell culture media, bulk plant material, and blood, urine and fecal samples are examples of the types of items that will be stored in the MELFI.
- **Payload Stowage** - The majority of stowage on ISS is accommodated by International Standard Payload Rack (ISPR)-size racks that provide compartmentalized storage. The types of stowage racks currently being developed are the Resupply Stowage Rack (RSR, $1.1m^3$) for storage of miscellaneous items on individual storage trays; the Zero-G Stowage Rack (ZSR, $1.2m^3$), which uses a collapsible shell and a fabric insert to store things within the ISS only, but not for transport; and the Resupply Stowage Platform (RSP, $1.2m^3$) to transport cargo using the fabric shells of the ZSR. The ISPR racks provide a number of resources to scientists:
  - 1.6 m3 (55.5 ft^3) of internal volume to accommodate up to 700kg of equipment.
  - Support of half-sized payloads, such as the Spacelab Standard Interface Rack (SIR) and the Space Shuttle Middeck Locker.
  - A 3 kW power feed and a 1.2 kW auxiliary feed for the payloads at 120 Vdc/25A average. Selected locations provide 6kW and 12kW power capability.
  - A moderate-temperature water loop is provided at an inlet temperature range of 16-24 °C (61-75 °F).
  - A MIL-STD-1553B Payload Bus provides command and data processing capabilities at each ISPR location.
  - EIA-RS-170A optical pulse frequency modulated video signals are available in the US and ESA modules; the JEM distributes video using twisted shielded wire pairs. Seven video recorders and multiple video monitors can be connected to the ISPR signals.
  - All of the laboratory modules support a waste gas exhaust system that is vented to space via a 2.5 cm gas line.
  - Selected locations provide a 2.5 cm vacuum resource line.
  - A 0.95 cm nitrogen line is provided as a standard service
  - Carbon dioxide, argon, and helium are provided to selected locations in the JEM.
  - The Active Rack Isolation System (ARIS) is designed to isolate payload racks from vibration such that the on-rack environment will meet the sys-

tem vibratory specifications. Currently, eleven ARIS-equipped racks are planned for investigator use.

- Sub-Rack Accommodations and EXPRESS Rack - Scientists can use the standard stowage presented above, or build their own equipment based on a Middeck Locker Equivalent (MLE). The EXpedite the Processing of Experiments (EXPRESS) rack concept allows quick integration of sub-rack payloads to the ISS resources described above ($0.06m^3$, 2kW @ 28Vdc, 2kW head rejection, some with ARIS).

D.3.3 Multi-user Facilities

The ISS program originally planned for the development of a wide variety of multi-user facilities. Multi-user facilities provide general equipment for research on a specific area, but are not individual experiments on their own. They are intended to form a key part of the ISS infrastructure, providing scientists with basic equipment for use in their experiments. The design of these facilities is modular, such that individual scientists can design components uniquely suited for their experiment needs which attach to the ISS provided facilities. Table D.1 [NASA, 2000b] presents the original list of multi-user facilities intended for the ISS. While some of the following facilities are no longer expected to be deployed, it is relevant to list all of the concepts developed by NASA and its international partners originally, as it showcases the need to develop multi-user facilities for a wide range of scientific fields.

It is interesting to see that out of the 22 multi-user facilities originally planned for the ISS, only one is for the advancement of space technology (AHSTF). Further, that facility is directly related to the life of humans in space, and not to the advancement of space technology outside of the human physiology. This thesis will study the creation of multi-user facilities for space technology, rather than the biological and physical sciences; the planning of the multi-user facilities for the biological and physical sciences in the ISS is a positive reinforcement to the idea of multi-user facilities for space technology.

TABLE D.1 Originally planned multi-user facilities for the ISS

Facility Name	Sponsor	Description
Human Research Facility	NASA	Physical and physiological changes in humans due to space flight.
Gravitational Biology Facility	NASA	Effect of space environment on biological systems.
Biotechnology Research Facility	NASA	Mammalian cell culture, tissue engineering, biochemical separations, and protein crystal growth.
Fluids and Combustion Facility	NASA	Fluid physics and combustion science research.
Microgravity Sciences Glovebox	NASA/ESA	Crew-manipulated investigations for a variety of experiments.
Materials Science Research Facility	NASA	Solidification of metals and alloys, thermophysical properties, polymers, crystal growth, and ceramics.
Window Observational Research Facility	NASA	Geologic, climatologic, atmospheric, and geographic research.
X-Ray Crystallography Facility	NASA	Protein crystal analysis facility for macromolecular crystals.
Advanced Human Support Technology Facility	NASA	Research on technology to sustain human life during long duration space missions.
Low-Temperature Microgravity Physics Facility	NASA	Low temperature exposed laboratory to study fundamental physics in space.
Fluid Science Laboratory	ESA	Study dynamic phenomena of fluid media.
European Physiology Modules	ESA	Respiratory, cardiovascular, hormonal, body fluids and bone conditions, as well as neuroscience.
Gradient Heating Furnace	NASDA	High temperature (up to 1600°C) zone-type furnace with vacuum.
Advanced Furnace for Microgravity Experiments with X-ray Radiography	NASDA	In-situ observation with X-ray radiography of heated/melted samples.
Electrostatic Levitation Furnace	NASDA	Study containerless sample processing.
Isothermal Furnace	NASDA	Solidification and diffusion of samples with uniform temperature profile.
Cell Biology Experiment Facility	NASDA	Controlled environment for research on small plants, animals, cells, tissues, and microorganisms
Clean Bench	NASDA	Closed workspace for aseptic operations with life sciences and biotechnology.
Fluid Physics Experiment Facility	NASDA	Support fluid physics experiments.
Solution/Protein Crystal Growth Facility	NASDA	Protein crystal growth in ground and microgravity.
Image Processing Unit	NASDA	Image capture for other experiment facilities.
Aquatic Animal Experiment Facility	NASDA	Accommodates freshwater and saltwater organisms in microgravity.

D.4 Engineering and Operational Challenges of the ISS

In order to better understand the resources available in the ISS, and more specifically to identify those resources which set it apart from other types of microgravity facilities, it is useful to understand which issues have been identified as the most important limiting factors to the correct utilization of the ISS for research purposes. Reports by NASA ([Durham, 2004], [O'Neill, 1999]) and the NRC ([NRC, 2000], [NRC, 2001], [NRC, 2002]) have identified specific issues related to the ISS which directly affect research. The resources identified by these issues can greatly benefit research aboard the ISS; limitations on the availability of these resources limit research opportunities. Because of this direct relationship, these resources are of special importance to make the best use of the ISS for research.

The major challenges and issues identified over the past years, directly related to conducting research on the ISS and listed as recommendations within the mentioned reports, are:

- Communications:
  - Increase of communications bandwidth
  - Enable video communications
  - Establish continuous communications
  - Allow crew to communicate directly with principal investigators (PI's)
  - Provide PI's with direct electronic access to their experimental data
  - Develop better communications tools and interaction processes to support the multi-national, multi-time-zone utilization of the ISS
- Facilities
  - Refine payload computing architectures continuously
- Crew
  - Reassess the crew's activities; allow the crew to take part of daily timeline development
  - Reconsider the use of payload-specialists for ISS missions
  - Reconsider the posibility to use some components of the ISS as a "safe-haven" to enable the return of a crew of seven

  - Use robotics to increase crew availability
- Approach to Research
  - Pursue revolutionary approaches to develop new EVA technologies
  - Create an inter-disciplinary research prioritization plan
  - Utilize Space Shuttle missions to maintain interest by the science community until the ISS is ready for operations
  - Expand cooperation with international partners to maintain their interest

The recommendations are grouped into four main areas: communications, facilities, crew, and approach to research. The emphasis on communications and crew among the several reports is of importance to this thesis, since it indicates that those two special features of the ISS are relevant to a wide range of ISS users and NASA itself. It is interesting to see that the recommendations on communications are guided towards creating a stronger and more direct presence of the investigators in the everyday operations of experiments aboard the ISS. The recommendations call for the use of real-time video for the PI to be virtually present in the ISS; they also intend to make data more available to scientists.

The recommendations also put emphasis on the crew availability and expertise. One of the reports ([NRC, 2002]) goes as far as to argue that NASA reassess the ability to support seven astronauts, even without a crew return vehicle. Two reports call for the re-evaluation of payload-specialists to become part of ISS crews (when the crew size was expected to be seven astronauts). All the reports argue that the crew should have an important role in deciding daily timelines to maximize their productivity. As a whole, the reports put heavy emphasis on utilizing the crew as best as possible. Minimizing their involvement in repetitive tasks should be automated, so as to maximize their time involved in conducting science. It is important to note the difference between simply minimizing the astronaut time needed for an experiment and minimizing time involved in repetitive tasks. The reports do not call for the automation of all experiments, rather they call to maximize the crew time availability to perform productive research.

The recommendation to "pursue revolutionary approaches to develop new EVA technologies" also stands out. Through this recommendation, a large number of important scientists not only push for research, they call for the ISS to become a laboratory where technology matures substantially. The recommendation argues that the experiments conducted aboard the ISS must help to substantially advance the scientific knowledge and technological capabilities of space flight. As related to the TRLs presented in Chapter 1, this recommendation calls for technology maturation up to TRLs 6/7/8, demonstrating full technologies, ready for deployment to their final missions.

Lastly, we can look at the upgrades that NASA has planned for the ISS after the US Core Complete assembly changes have been decided. In [Durham, 2004] members of the ISS Payloads Office list the latest infrastructure upgrades to the ISS; a summary of these upgrades is presented in Table D.2 [Durham, 2004].

Once again, we note that the intended upgrades to the ISS concentrate on the areas of communications and crew. The projects stress the need to transfer data better, both within the ISS and to ground; increases in bandwidth of up to 30 times are expected. Some of these upgrades are to help the crew to improve their interfaces with ISS equipment and with ground personnel, ultimately maximizing their useful time to perform research and minimizing the time they need to perform procedural tasks.

TABLE D.2 ISS Infrastructure Upgrades

Project	Description	Current Constraint	Upgrade Goal
Integrated Station LAN (ISL)	Replace the existing three separate networks in the ISS into a single "all-ISS" network to enhance data delivery to ground and enable astronaut access from all modules.	Data rates & Limited Connectivity	Flexible 1Gbps network
Timeliner	Develop a procedural and logical scripting tool to automate execution of procedures aboard the ISS with three levels of crew intervention (manual, crew-controlled, and automatic).	Manual procedures execution	Automated procedure execution
ISS Downlink Enhancement Architecture (IDEA)	Remove the ground-based and DOMSAT bottlenecks which restrict the Ku band downlink to 50Mbps and implement a high bandwidth WAN.	50Mbps downlink	150Mbps downlink
Mission Operational Voice Enhancement (MOVE)	Standardize voice communications among all NASA centers and the ISS with the option to add features such as video teleconference and multiple site support.	Obsolete/non-maintainable voice communications	Common all-NASA mission communications systems
Ku→Ka Band Transition	Initial study to increase the downlink bandwidth of the ISS to a higher-frequency band.	Ku band capacity & int’l use agreements	Ka band data capacity > 1.5Gpbs