

International Space Station

User's Guide

Table of Contents

Table of Contents	2
List of Figures	3
List of Tables	3
1. Introduction	5
1.1 Document Purpose and Structure.....	6
1.2 ISS History and Overview	6
1.3 NASA Research Coordination and Advisory Committees	7
2. ISS Development	7
2.1 Assembly Sequence	7
2.2 Build-up of Resources and Early Utilization.....	8
3. ISS Research Elements.....	8
3.1 A Module Named "Destiny": The U.S. Laboratory Module	9
3.2 U.S. Centrifuge Accommodation Module (CAM)	10
3.3 U.S. Integrated Truss Attachments.....	10
3.4 Japanese Experiment Module (JEM).....	11
3.5 Columbus Module	12
3.6 Russian Segment.....	12
4. The ISS Environment.....	12
4.1 Orbital Parameters and Modes of Operation	12
4.2 Microgravity	14
4.2.1 Quasi-steady Requirements	14
4.2.2 Vibratory Requirements	15
4.2.3 Microgravity Acceleration Measurement.....	16
4.3 Internal Environment Control and Monitoring	16
4.4 External Environment Control and Monitoring	16
5. Accommodations for Research on ISS.....	16
5.1 Resource Allocation	16
5.2 Station-wide Resources	17
5.2.1 Power.....	17
5.2.2 Payload Data Handling and Communication	17
5.2.3 Thermal Management.....	18
5.2.4 Payload Stowage	18
5.2.5 Crew Resources	18
5.2.6 Crew Health Care System	19
5.3 Generic NASA Accommodations for Research Payloads	19
5.3.1 International Standard Payload Rack	19
5.3.2 Active Rack Isolation System.....	21
5.3.3 Sub-Rack Accommodations and EXPRESS Rack	21
5.3.4 Nadir Research Window	22
5.3.5 Laboratory and Station Support Equipment.....	23
5.3.6 U.S. Truss Site Payload Accommodations and EXPRESS Pallet.....	24
5.3.7 JEM and Columbus Exposed Facility Payload Accommodations	25
5.4 Multi-User Facilities: The Facility-Class Payload Concept	26
5.4.1 Human Research Facility.....	28
5.4.2 Gravitational Biology Facility.....	28
5.4.3 Biotechnology Research Facility.....	29
5.4.4 Fluids And Combustion Facility.....	30
5.4.5 Microgravity Sciences Glovebox.....	30
5.4.6 Materials Science Research Facility	31
5.4.7 Window Observational Research Facility	31
5.4.8 X-Ray Crystallography Facility.....	32
5.4.9 Advanced Human Support Technology Facility.....	32

5.4.10	Low-Temperature Microgravity Physics Facility	32
5.5	International Partner Research Accommodations	33
5.5.1	ESA Accommodations	33
5.5.2	NASDA Accommodations	34
6.	Payload Operations	35
6.1	User Autonomy.....	35
6.2	Payload Ground Command and Control.....	36
6.3	Operational Flexibility.....	36
7.	Getting On Board: NASA Research and ISS.....	36
7.1	Life Sciences.....	37
7.2	Microgravity Sciences	37
7.2.1	Microgravity Science Experiment Selection.....	37
7.2.2	Microgravity Sciences Experiment Definition and Development	38
7.3	Space Sciences	38
7.4	Earth Sciences	38
7.5	Engineering Research and Technology.....	39
7.6	Commercial Payloads	39
	Appendix A. Related Documents.....	40
	Appendix B. Related Websites	41
	Appendix C. Station Assembly Flights.....	44
	Appendix D. Commercial Space Centers	46
	Appendix E. Acronym List	48

List of Figures

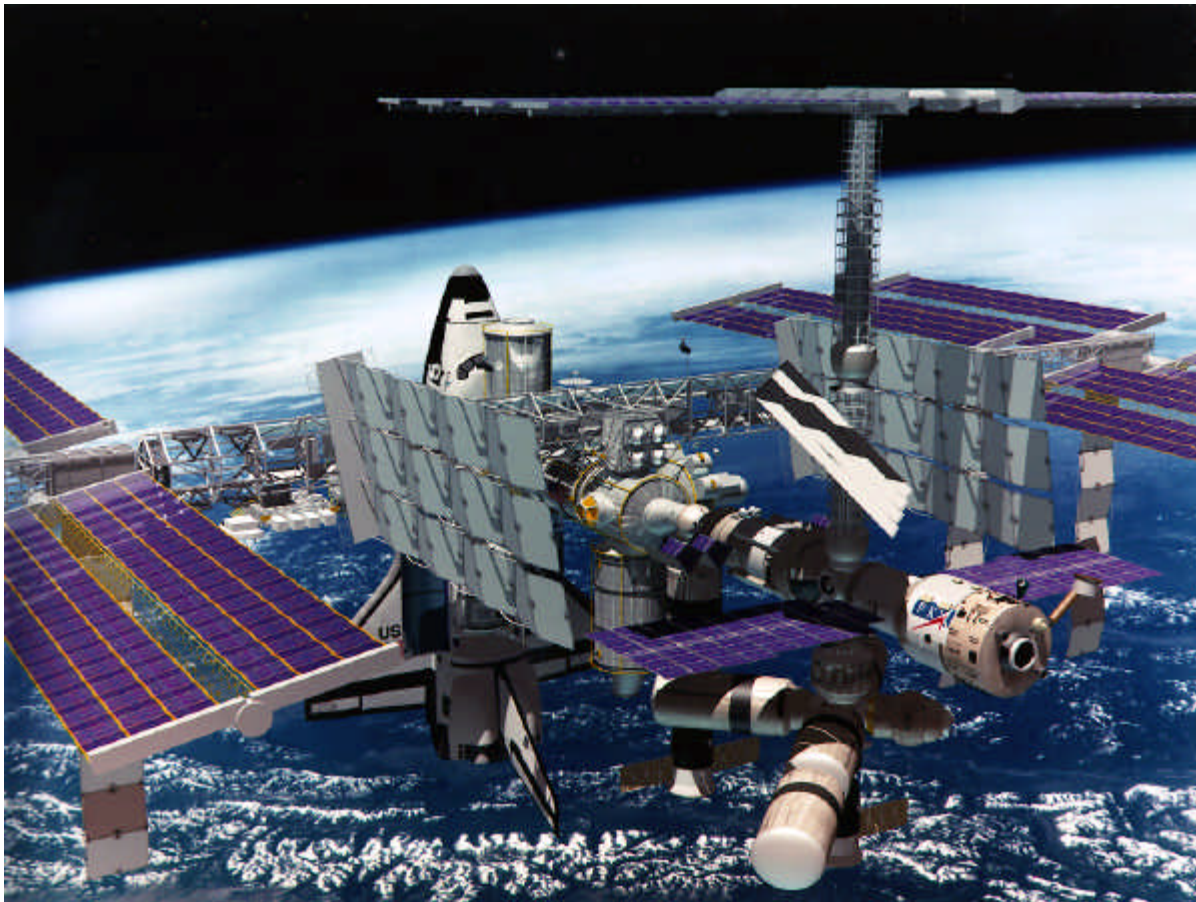
3.-1.	ISS Assembly Complete configuration	8
3.-2.	ISS Module and ISPR geometry.....	9
3.1-1.	U.S. Laboratory module ("Destiny") views	10
3.2-1.	Centrifuge Accommodation Module.....	10
3.3-1.	U.S Exposed-Payload Attachment Sites on Starboard Truss	11
3.4-1.	Japanese Experiment Module (Kibo).....	11
3.5-1.	Columbus Orbital Facility	12
4.1-1.	ISS orbital inclination and groundtrack	13
4.1-2.	Space Station Reference Coordinate System	13
4.2.1-1.	ISS quasi-steady microgravity environment	15
4.2.2-1.	ISS vibratory microgravity requirements.....	15
5.3-1.	(a) ARIS components attached to an ISPR; (b) EXPRESS rack with 8 Mid-Deck Lockers	21
5.3.4-1.	Nadir Window Cross-Sectional View	22
5.3.6-1.	EXPRESS Pallet	24
5.3.6-2.	EXPRESS Pallet Adapter (ExPA) Payload Envelope.....	25
5.3.7-1.	JEM-EF Configuration and JEM-EF Experiment Payload-Attached Locations	25
5.4-1.	HRF Rack 1.....	28
5.4.2-1.	GBF centrifuge.....	29

List of Tables

3.-1.	ISS Research Module Data	9
4.1-1.	ISS Modes of Operation.....	14
5.1-1.	ISS Partner Allocation.....	17
5.3.5-1	Laboratory and Station Support Equipment.....	23
5.3.6-1.	U.S. Attached Payload Resource Accommodations	24

5.3.7-1. Non-U.S. International Partner Attached Payload Resource Accommodations.....	26
5.4-1. ISS Facility-Class Payloads	27

International Space Station User's Guide



1. Introduction

Assembly of the International Space Station (ISS) began in late 1998 and will continue until completion sometime around the year 2004. During its assembly and over its nominal 10-year lifetime, the ISS will serve as an orbital platform for the United States and its International Partners to make advances in microgravity, space, life, and earth sciences, as well as in engineering research and technology and commercial product development. All of these activities will aid in understanding the basic biological, chemical, and physical processes that affect our daily lives, our home planet, our exploration of space, and our most fundamental

concepts about the universe. The utilization of the ISS for creating knowledge and technology is an enterprise that not only requires the construction of a safe and viable orbiting laboratory, but also requires that ISS Users provide the best complement of research and technology payloads possible for flight on the ISS. The ISS Users, as defined in this document, comprise any and all members of the diverse community of scientific, engineering, technical and commercial organizations and individuals whose objectives may benefit from use of the ISS. The ISS Program realizes that ISS Users already associated with the program and, more importantly, Users who may potentially be interested in using ISS in the future, need an information source that is directed specifically at the working research community. The

International Space Station User's Guide was designed and developed to be this source.

1.1 Document Purpose and Structure

The *International Space Station User's Guide* is an introductory guide to the research capabilities of the ISS. It is designed to provide a top-level overview of the ISS research program, the available research hardware on ISS, and the necessary steps for getting experiments on board the Station. By reading the *User's Guide*, the external researcher should be able to determine whether the ISS might be a viable platform for their research, where in the NASA research organization they might fit, and how to go about getting into the ISS research program.

By outlining the Station operational parameters and hardware that working researchers may use to accomplish their objectives, the *Guide* is the practical accompaniment to the *NASA Research Plan Overview* and *Executive Summary*. The *Overview* and *Executive Summary* describe, in layperson terms, the rationale, likely content, and anticipated benefits of a variety of research fields for the ISS. An additional document, the *Science and Technology Research Directions for the International Space Station*, outlines the major research topics and thematic research questions that ISS will address in the area of Life and Microgravity sciences. Further descriptions of ISS systems and procedures appear in the *ISS Familiarization Manual*, a NASA training document at a technical level suitable for potential ISS researchers. The latter two documents are available to the public via the Internet, see Appendix A-Related Documents. Other documents that relate to the *Guide* are also compiled in Appendix A.

In Appendix B-Related Websites, an outline of the *Guide's* subject headings are mapped against the present structure of ISS-related websites associated with NASA and its International Partners. This map is intended to largely supplant citation of websites within the body of the *Guide*, although the *Guide* text does contain some references to sites with particularly relevant supplemental information.

1.2 ISS History and Overview



In his State of the Union Message to Congress in January 1984, President Ronald Reagan officially established the goal of developing a permanently inhabited station in

orbit. Invitations were issued to Canada, Europe and Japan to join in the effort and agreements with the Canadian Space Agency (CSA) and the European Space Agency (ESA) were reached in September 1988, and with the Government of Japan in March 1989. A rapidly expanding cooperative relationship in human spaceflight between the U.S. and Russia resulted in several agreements that ultimately led to the incorporation of Russia into the International Space Station program in December of 1993. The Russian addition resulted in several design modifications that are now part of the present ISS configuration.

Today, the structure of the ISS Program as a cooperative international effort is based on a multi-lateral Intergovernmental Agreement between all of the involved governments, and on bilateral Memoranda of Understanding between NASA and the International Partner (IP) space agencies that represent these governments. The management structure spelled out in these agreements specifies that each of the IPs will make certain hardware contributions and have certain responsibilities inside a framework in which the U.S. has leading management and integration roles. Complicating the picture is the possibility for bilateral "barter" agreements, in which two partners make trades based on their respective capabilities.

Although the ISS Program has some similar aspects to large engineering testbed or "big science" projects with which a working researcher may be familiar from their own particular fields, it has other aspects that make it unique. Unlike a particle accelerator or multi-user astronomical telescope facility, the ISS is designed to meet a number of human goals in the areas of exploration and international relations that augment its goals for research *per se*. This multi-faceted aspect of ISS results in a complex program structure that is outlined as follows.

Whereas the overall management responsibility for NASA resides with the NASA Administrator and Associate Administrators at NASA Headquarters (HQ) in Washington, D.C., day-to-day management

of a major NASA project such as the ISS is usually handled at one of the many NASA field centers distributed across the U.S. These so-called Lead Centers then distribute tasks to contractors or other NASA centers as needed. For ISS the lead center is NASA Johnson Space Center (JSC) in Houston, TX. At JSC the ISS Program is managed by the Space Station Program Office (SSPO, NASA Johnson Space Center, Mail Code OA, Houston, TX, 77058).

To handle its broad range of responsibilities, the SSPO is in turn sub-divided into several offices that include the Vehicle office (Mail Code OB), which oversees vehicle construction and assembly, and Payloads (Mail Code OZ), which is in charge of development and integration of payloads.

For the ISS User who wants to pursue research on the Station, the SSPO can play an informational role initially. It does not, however, come into direct involvement until a User's project is funded, authorized for flight, and under development. Actual selection and funding of ISS research is the responsibility of science, engineering and commercialization program offices at NASA Headquarters. These program offices are organizationally separate within NASA from the SSPO. They are responsible for all of NASA research, not just investigations to be done on the ISS. It is these Headquarters programs that will in most cases be the first point of contact between a potential ISS User and the ISS program. Further information on these programs is covered below in Section 7 - Getting on Board.

1.3 NASA Research Coordination and Advisory Committees

ISS research is coordinated through NASA internal organizations as well as through external advisory councils and committees whose purpose is to aid NASA's decision-making in a variety of long term and short term areas. The councils and committees are generally drawn from academia, government and industry. The highest NASA advisory group is the **NASA Advisory Council (NAC)**. The NAC, its committees and subcommittees provide their advice and counsel directly to the NASA Administrator. Among its seven standing committees the NAC includes the **Advisory Committee on the International Space Station (ACISS)**, which answers to the NASA Office of Space Flight. There is a particularly important subcommittee called the **Space Station Utilization Advisory Subcommittee (SSUAS)**. The membership of SSUAS consists of 10 to 15 individuals drawn from academia, industry, and government.

Twice each year, in the winter and summer, the full SSUAS meets with ISS Program representatives for briefings on a variety of topics. A smaller group of SSUAS members also meet with ISS Program representatives each month. The SSUAS evaluates information it receives in these briefings, makes findings and issues recommendations to ACISS and the ISS Program. These findings and recommendations have a great influence on ISS development, especially in regard to the optimization of research capability.

The internal NASA team that supports ISS research utilization is comprised of various organizations, each of which contributes in a coordinated way to meeting the needs of the research community. The research capabilities of the ISS are formally managed by incorporating the needs of the research community into the ISS technical requirements that the SSPO has direct responsibility for and the prime contractor, Boeing, is obligated to meet. To this end the SSPO maintains civil service and contractor staff whose sole purpose is to manage the science requirements and interact with NASA science and research organizations, as well as external advisory committees, to achieve research utilization of the Space Station that is as broad as possible.

2. ISS Development

2.1 Assembly Sequence

ISS development is progressing through three designated phases. ISS Phase I took place before assembly and consisted of a series of cooperative research flights between the United States and the ISS partners. Most notably, this involved a series of rendezvous flights between the Space Shuttle and the Russian space station *Mir*, cosmonaut flights on the Space Shuttle, and U.S. astronaut stays and research on *Mir*. In ISS Phase II, the knowledge gained from Phase I operations is applied to the on-orbit assembly of the ISS. ISS Phase II concludes with the successful assembly of the U.S. and Russian components of the ISS that are necessary to begin Station research. ISS Phase III development consists of the final research outfitting of the ISS, as the European, Japanese, and Canadian elements are transported to orbit and the Station becomes fully operational.

Contained within Development Phases II and III are steps in the overall ISS Assembly Sequence. The Sequence lists events in the assembly of ISS, based on the flights bringing elements, personnel and equipment to the Station. The flights may be on the

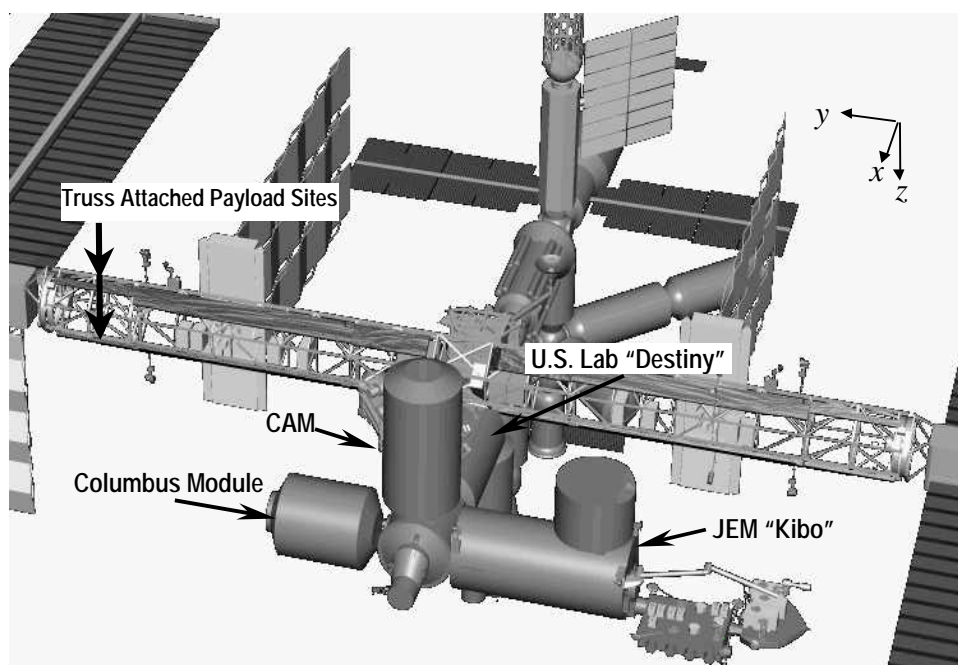


Figure 3.-1 ISS Assembly Complete configuration

U.S. Shuttle (STS), or Russian crewed (Soyuz) and un-crewed (Service Module, Progress) vehicles. The Assembly Sequence is considered a working schedule and subject to adjustment as programmatic needs arise. For this reason the *Guide* provides only a sequential list of Assembly flights, minus flight dates, as a conceptual guide to the reader in Appendix C. For the full ISS Assembly Sequence the reader is referred to the ISS Assembly website (Appendix B).

2.2 Build-up of Resources and Early Utilization

On-orbit assembly of ISS will take about five years. Because this is a lengthy time to wait to begin research activities, so-called Early Utilization of the ISS will begin at flight 5A.1, during the Assembly phase. The sequence of availability of resources for the conduct of research prior to Assembly Complete is complex and fluid making it impractical to specify the resource availability sequence as part of the *Guide*. For this reason, the *Guide* is organized around a depiction of ISS capabilities and resources as they will exist at Assembly Complete. Information on pre-Assembly Complete resources is, however, available through the SSPO for individuals that need it.

3. ISS Research Elements

The ISS is divided into *segments* that are defined in most cases along the lines of responsibility of the International Partners. Segments

are in turn constructed from one or more functional *elements* that include modules, nodes, truss structures, solar arrays, and thermal radiators. Modules are pressurized cylinders that will provide most of the habitable space on board the Station. They may contain research facilities, living quarters, and any vehicle operational systems and equipment to which the astronauts may need access. Nodes connect modules to each other and offer external Station access for purposes such as docking, ExtraVehicular Activity (EVA) access, and unpressurized payload access. Trusses are erector-set-like girders that link the modules with the main solar power arrays and thermal radiators. Together, the truss elements form the Integrated Truss Structure. Solar arrays collect solar energy and convert it into electricity for the operation of the Station and its payloads. Thermal radiators radiate excess thermal energy into space.

The configuration of ISS at Assembly Complete is shown in Figure 3.-1. ISS research requiring pressurized conditions will be conducted primarily in the U.S. Laboratory *Destiny*, the European *Columbus* module, the Japanese Experiment Module (JEM) *Kibo*, and the U.S.-contributed Centrifuge Accommodation Module, or CAM. Designs and plans for additional research modules contributed by the Russian Space Agency (RSA) are not yet finalized.

Basic data such as length, diameter and mass for the ISS research modules are summarized in Table 3.-1. The interior of all of the research modules, like the ISS interior as a whole, will be a “shirt-sleeve” environment, with an oxygen-nitrogen atmosphere and

Table 3.-1. ISS Research Module Data¹

	U.S. Lab, <i>Destiny</i>	U.S. CAM	Columbus Module	JEM-PM
Length, exterior, m [ft]	8.8 [28.8]	8.3 [27.1]	6.5 [21.5]	11.2 [36.8]
Length, minus end cones, m [ft]	7.7 [25.2]	7.75 [25.3]	5.0 [16.4]	8.9 [29.1]
Diameter, exterior, m [ft]	4.4 [14.6]	4.4 [14.6]	4.5 [14.8]	5.0 [16.2]
Mass, on orbit AC ² , kg [lbm]	26,771 [58,896]	14,352 [31,574]	16,568 [36,449]	43,566 [95,845]
Rack locations along length	6	4	4	6
Total rack locations	24	15	16	23
Research racks, total number	13	4	10	10
Research racks, U.S. share	13	4	5	5

¹Dimension and mass data from *International Space Station On-Orbit Assembly, Modeling, and Mass Properties Data Book, Rev. J, August 1999*

²Assembly complete (AC), includes full systems complement (including robotic arms, attached payload sites etc.)

temperature and humidity conditions similar to Earth-bound laboratories. Experiments within the research modules will have access to power, cooling, communication, vacuum, exhaust, gaseous nitrogen and microgravity measurement resources. Details on all of these are described below in Section 5 - Accommodations for Research.

For investigations wishing to have experiments exposed to space, various attachment sites are provided at ISS exterior locations, including the starboard side of the ISS truss (Fig. 3.-1), the JEM Exposed Facility (JEM-EF), and the end-cone of the *Columbus* module. Section 5 also provides details on the payload accommodations at these locations.

Within the U.S., European and Japanese laboratory modules, the internal space allocated for payloads is configured around a system of uniformly-sized (with some slight variations) equipment racks called Inter-

national Standard Payload Racks (ISPRs). These racks, which are approximately the size of a large refrigerator, are designed to be extremely versatile with respect to the type and configuration of equipment they can accommodate. A diagram of the basic ISPR geometry and its relation to a module is shown in Figure 3.-2. Table 3.-1 lists the total number of ISPR locations for each module.

The backs of the ISPRs have a radius of curvature just slightly less than the modules to efficiently fill all available space. The resulting module cross-sectional geometry has the racks arranged in quadrants around an interior workspace with a square cross-section (Figure 3.-2). The workspace is in turn lined with racks along all four “walls” with the number of racks depending on the length of the module (Fig. 3.-2, Table 3.-1). Additional details on ISPR design are covered in Section 5.3.1. The rack system used in the Russian segment modules is presently under design.

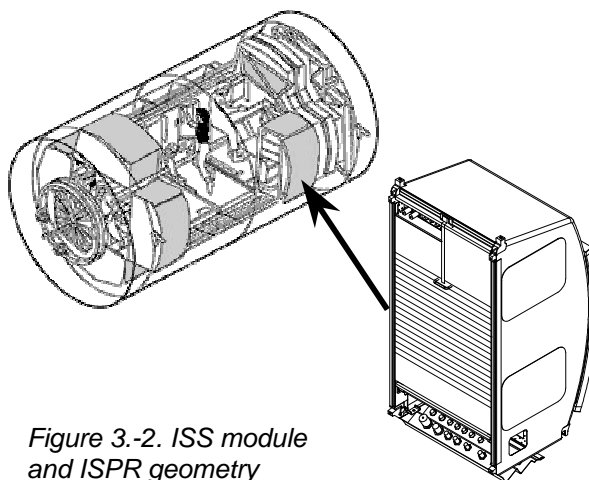


Figure 3.-2. ISS module and ISPR geometry

3.1 A Module Named “Destiny”: The U.S. Laboratory Module

The U.S. Lab, named *Destiny*, is the module where a significant portion of the pressurized U.S. research will take place. Several exterior views are shown in Figure 3.1-1. *Destiny* will have internal interfaces to accommodate the resource requirements of 24 equipment racks. Thirteen of these are ISPR research racks and the rest are for other uses, such as controlling ISS systems. *Destiny* will be the first research module installed on the Station (see Appendix C-Station Assembly Flights) and as such will be the site of the earliest research projects. The side of *Destiny* that faces Earth for the majority of possible ISS flight

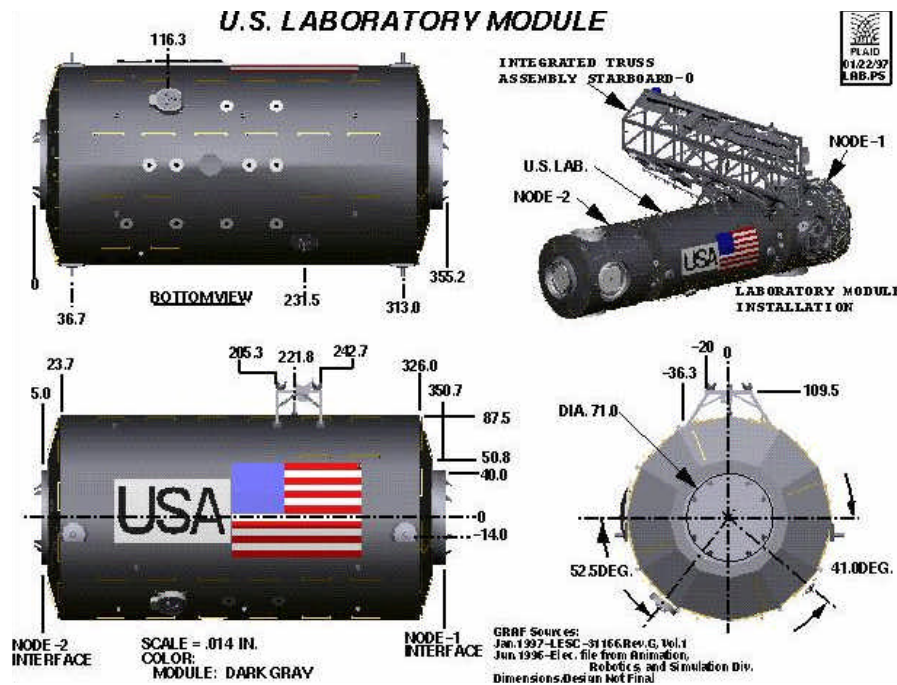


Figure 3.1-1. U.S. Laboratory module ("Destiny") views

As shown in Figure 3.2-1, it houses a 2.5 m (8.2 ft) diameter centrifuge, which is the essential component of a larger complement of research equipment dedicated to gravitational biology. The complement will include a Life Sciences Glovebox, two Habitat Holding Racks and a Cryo-Freezer. In addition, 9 locations are provided for passive stowage racks; one for a passive service system rack for gravitational biology research, and the other 8 to be allocated for all Users' passive stowage as required on a mission-to-mission basis.

3.3 U.S. 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 3.1 and a more detailed view, with the actual attach points indicated by arrows, is provided in Figure 3.3-1. There are two attach 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. For illustration purposes on the two zenith attach points Figure 3.3-1 depicts a single truss-site payload of larger size next to a smaller standardized EXPRESS (EXpedite the PRocessing of Experiments to the Space Station) pallet carrying multiple payloads. The details on size, mass, power, data and other resources for both of these

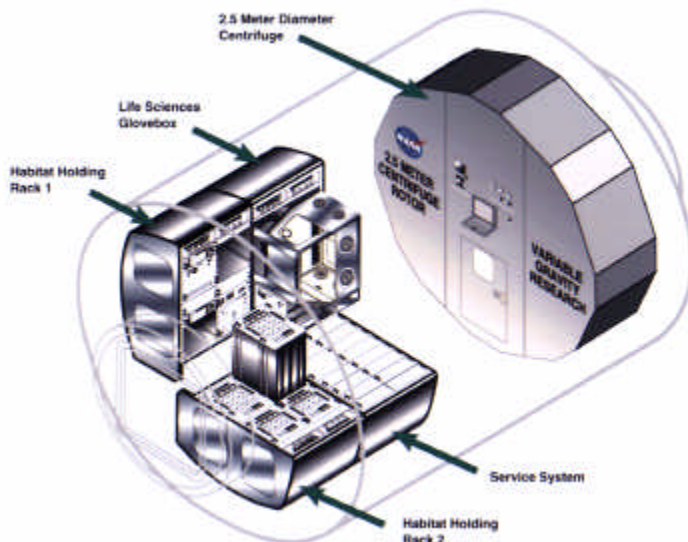


Figure 3.2-1. Centrifuge Accommodations Module (CAM)

attitudes contains a circular window of very high optical quality design. In the module interior this window will be located beneath a single rack location where the Window Observational Research Facility (WORF, see Section 5.4.7) will reside.

3.2 U.S. Centrifuge Accommodation Module (CAM)

The CAM is a laboratory dedicated to U.S. and cooperative international gravitational biology research.

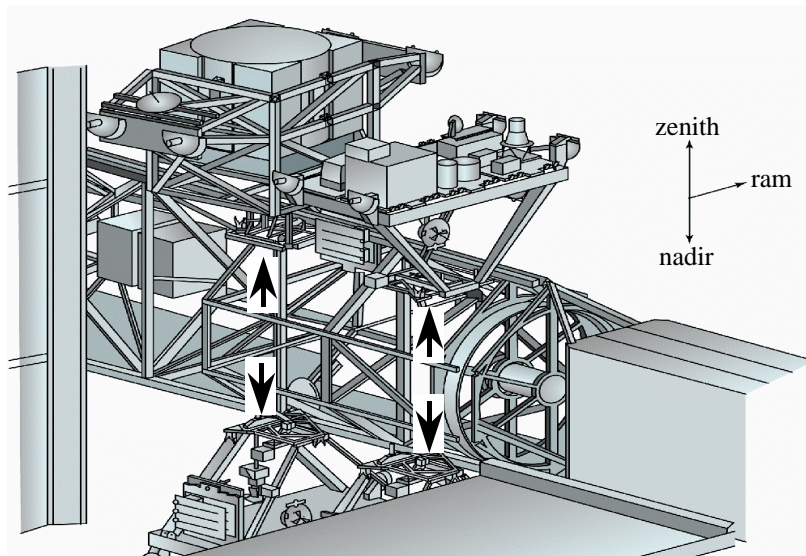


Figure 3.3-1. U.S. exposed-payload attachment sites on starboard truss.

types of attached payload accommodations are discussed below in Section 5.3.6.

3.4 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. As shown in Figure 3.4-1, the JEM consists of several major systems that are assembled on orbit:

The JEM Pressurized Module (JEM-PM) is a laboratory for experimental research in areas such as space medicine, life sciences, materials processing, and biotechnologies. The JEM-PM can also transfer

equipment to and from the vacuum of space through an airlock chamber without having to depressurize the entire laboratory. The JEM-PM supports a total of 10 ISPRs for research payloads, of which 5 are allocated to NASA under NASA-NASDA resource-sharing agreements. (See Section 5.1 below for details on ISS resource sharing).

The JEM Exposed Facility (JEM-EF, Fig. 3.4-1) 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, and under resource-sharing provisions a total of 5 of these sites are allocated to NASA. Additional details on the structural

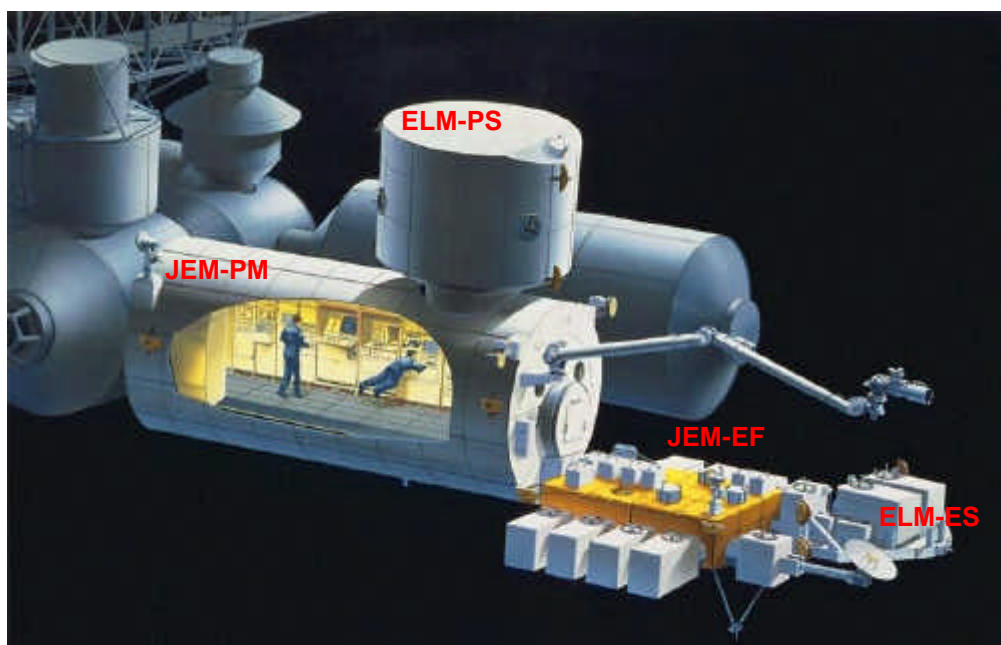


Figure 3.4-1 Japanese Experiment Module (*Kibo*)

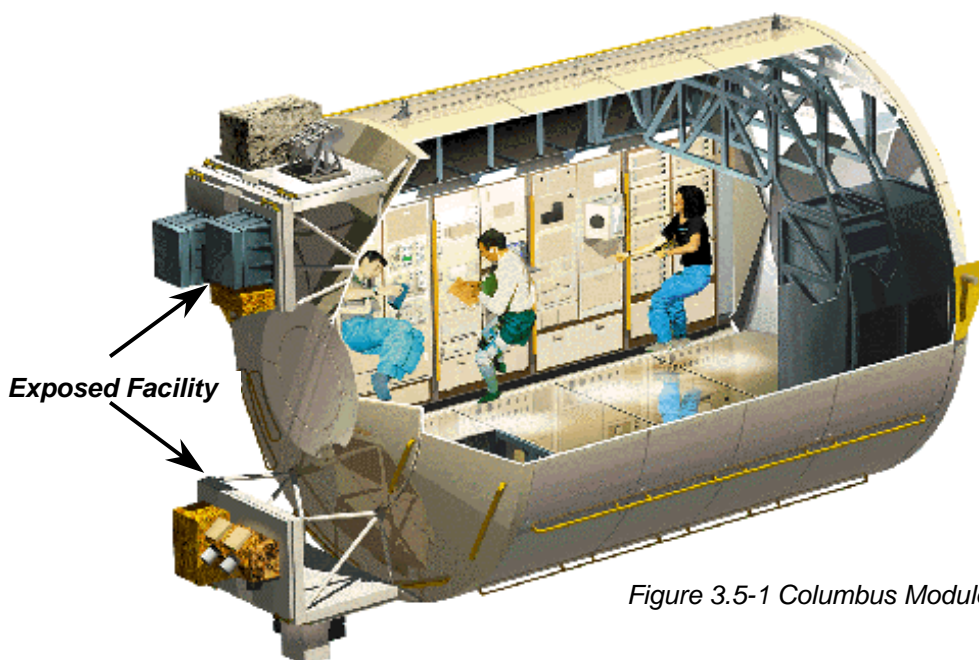


Figure 3.5-1 Columbus Module

support, thermal conditioning, power, video, data services and other accommodations provided for JEM-EF payloads are covered below in Section 5.3.7.

In addition to the PM and EF, the JEM has an Experiment Logistics Module-Pressurized Section (ELM-PS) to serve as a pressurized passive storage and carrier module for stowage of research supplies, spare hardware and internal user payloads. There is also the un-pressurized Experiment Logistics Module-Exposed Section (ELM-ES) which is a storage and carrier module for spare external hardware and user payloads.

3.5 Columbus Module

The *Columbus* module will be contributed to ISS by ESA (Figure 3.5-1). Its internal configuration provides for a total of 10 ISPRs for research payloads with 5 ISPRs allocated to NASA under NASA-ESA resource sharing agreements. To achieve cost benefits the basic *Columbus* design is based on the Multi-Purpose Logistics Module (MPLM), a transport module provided to the ISS program by Agenzia Spaziale Italiana (ASI), the Italian Space Agency.

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. As part of its Micro-gravity Facilities for *Columbus* Program, ESA is developing five multi-user laboratories in the fields of Biology, Human Physiology, Materials, and Fluid Science that will be provided to European scientists.

These facilities are nominally slated to occupy ESA's space in *Columbus*, but location swaps with facilities in the modules belonging to the other International Partners, particularly the U.S., may occur in response to operational considerations.

An Exposed Payload Facility is planned for *Columbus*. It will consist of two separate support structures attached to the *Columbus* Pressurized Module end cone in the zenith and nadir positions (Fig. 3.5-1). NASA-ESA resource sharing agreements allocate 50% of the resources at these locations to NASA, and additional details on the payload accommodations at these sites are given in Section 5.3.7.

3.6 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.

4. The ISS Environment

4.1 Orbital Parameters and Modes of Operation

The ISS has a nearly circular orbit with an altitude range of 350-460 km (189-248 n mi) and an inclination of 51.6° to the equator. As shown in Figure 4.1-1, the Station's orbit causes it to reach a maximum of

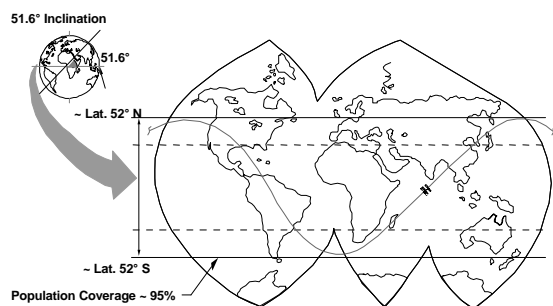


Figure 4.1-1. ISS orbital inclination and groundtrack

52° in north and south latitude, such that it flies over 85% of the globe and 95% of the Earth's population.

The description of the Station's flight attitude (orientation relative to the plane of its orbit) is referenced to local-vertical/local-horizontal (LVLH) axes that are fixed with respect to the Station's near-circular orbit (i.e., *not* to the physical Station). The LVLH origin is at the Station's center-of-mass; the z-axis points radially toward the Earth's center (or toward the *nadir* direction), the x-axis points along the orbital velocity vector (the *ram* direction, with *wake* being opposite), and the y-axis completes the right-handed triad. The flight attitude of the Station is then described using a second, Station-fixed, coordinate system whose orientation relative to LVLH is specified using the Eulerian angles of yaw, pitch and roll. Several Station-fixed coordination systems are defined. The most widely used is the Space Station Reference Coordinate System, shown in Figure 4.1-2, in which the positive x-axis points along the axis of the U.S. Lab away from the Zarya and Service Modules; the positive y-axis points starboard along the main truss, and positive z completes a right-handed coordinate system.

Between flight 5A, when payloads will first be carried, and flight 12A, there are two main flight atti-

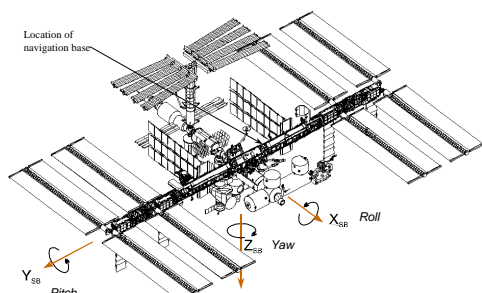


Figure 4.1-2. Space Station Reference Coordinate System

tudes for ISS: normal XVV (station x-axis toward the velocity vector) and XPOP (station x-axis perpendicular to the orbit plane). The XVV mode is airplane-like, x forward, z down, and y ("right wing") level. For integrated systems design reasons (thermal, power, communications, etc.) XVV is required to be $\pm 15^\circ$ roll/yaw, and +10 to -20° pitch with respect to LVLH.

Until flight 12A, when additional solar arrays are installed, there is insufficient power generation in XVV when the sun β angle (angle between the sun-line and the orbit normal) exceeds either 37° or 52° (depending on the stage of assembly), making it necessary to fly in the XPOP orientation. The ISS orbit plane regresses about the earth's rotational pole at about $6^\circ/\text{day}$ relative to the sun, so the station alternates between a couple weeks in XVV and a couple of weeks in XPOP for almost two years, until flight 12A finally makes that unnecessary.

The ISS will be operated according to a number of specific modes, each of which has a specified set of conditions and capabilities (Table 4.1-1). Some familiarity of the ISS User with these modes is important because, although most modes support research payload operations at some level, there are others for which payload operations may be sharply curtailed or discontinued. Among the modes summarized in Table 4.1-1 are Microgravity and Standard modes, which are the primary modes of operation for research. During Microgravity mode the Station must be operated so as to meet a stringent set of requirements for its microgravity environment. This partly involves maintaining an XVV attitude by non-propulsive means, along with other operational constraints. More details on ISS microgravity requirements are provided in the next section. Standard mode has many identical capabilities to Microgravity mode, and provides full support for research payloads. However, Standard mode allows a number of activities that could result in the microgravity environment specifications being exceeded, such as control of the Station attitude by propulsive means.

In addition to Microgravity and Standard modes, Reboost mode is necessary because the Station's large cross-section and low altitude causes its orbit to decay due to atmospheric drag at an average rate of 0.2 km/day (0.1 n mi/day). Thus, a periodic reboost using on-board thrusters must be carried out approximately every 10 to 45 days. The Reboost period itself requires 1-2 orbits (1.5 - 3 hours) and represents an assured, but temporary, interruption in the maintenance of the Station's microgravity specification.

Table 4.1-1. ISS Modes of Operation

Standard	<ul style="list-style-type: none"> Represents core operations when tended or preparing to support human presence Provides "shirt sleeve" environment Internal and external operations supported, monitored and controlled
Reboost	<ul style="list-style-type: none"> Used to obtain additional altitude while maintaining a habitable environment <i>and</i> supporting internal and external user payload operations Altitude controlled propulsively
Microgravity	<ul style="list-style-type: none"> Consists of capabilities required for microgravity research by user payloads in a habitable environment <i>Does not</i> include effects of crew activity, but <i>does</i> include effects of crew equipment (e.g., exercise devices)
Survival	<ul style="list-style-type: none"> Initiated upon command or when a warning of imminent threat (e.g., loss of attitude control, loss of thermal conditioning, available power out-of-range) is not acknowledged by the on-orbit crew, the Orbiter crew, or the ground Autonomously attempts to correct the threatening condition and provides keep-alive utilities to Station's crew/core systems <i>Precludes support or commanding of external or internal operations</i>
Proximity Operations	<ul style="list-style-type: none"> Provides capabilities related to supporting safe operations with other vehicles while maintaining a habitable environment and supporting internal and external user payload operations Vehicle is actively determining and controlling attitude nonpropulsively
Assured Safe Crew Return	<ul style="list-style-type: none"> Provides mitigation capability for life threatening illness, unrecoverable loss of Station habitability, or extended problem requiring resupply/servicing, which is prevented from occurring due to launch problems Consists of actions, operations and functions necessary to safely populate the Crew Return Vehicle (CRV), separate the CRV, return the CRV to earth, and egress the CRV upon recovery on the ground
External Operations	<ul style="list-style-type: none"> Utilizes functionality related to supporting Station-based external operations while maintaining a habitable environment and supporting internal and external payload operations Vehicle actively determining and controlling its attitude non-propulsively

4.2 Microgravity

Inside an orbiting spacecraft a "microgravity" environment exists in which the acceleration of objects and persons relative to their surroundings is reduced

to the level of micro g's ($9.8 \times 10^{-6} \text{ m s}^{-2}$). The acceleration environment is "microgravity" and not "zero gravity" due to two principal classes of residual accelerations. The first of these is quasi-steady acceleration, whose magnitude and direction varies relatively slowly, on the timescale of greater than 100 seconds, and whose cause lies largely in the very small aerodynamic drag experienced by the spacecraft as well in gravity gradient effects. On top of quasi-steady accelerations, the structural and acoustic vibrations due to the mechanical systems in the spacecraft produce vibratory accelerations, whose magnitudes and directions are oscillatory over a spectrum of frequencies from 0.01 to 300 Hz.

The levels of both quasi-steady and vibratory accelerations on ISS are of interest to microgravity researchers whose investigations cover the effects of reduced gravity on a large range of physical, chemical and biological phenomena. For this reason, the ISS has been designed, is being built, and will be operated to meet a set of requirements for both its quasi-steady and vibratory microgravity environment. The requirements specify not only allowable levels of acceleration, but also where on the Station and for how long such acceleration limits must be obeyed.

4.2.1 Quasi-steady Requirements

Accelerations are considered quasi-steady if at least 95% of their power lies below 0.01 Hz as measured over a 5400-second period (the approximate time of one orbit). Quasi-steady acceleration is present largely for two reasons. The first is aerodynamic drag that the Station experiences due to the residual atmosphere at low earth orbit. This drag causes the Station to lose altitude, and somewhat paradoxically, causes it to accelerate along its orbital velocity vector. The second contribution comes from gravity gradient: the fact that any point not exactly at the Station's center mass wants to follow its own orbit. Such points, however, because they are physically part of the Station are subject to accelerations from the structural forces that keep them attached to the Station as it orbits.

The drag, gravity gradient and other secondary effects can be incorporated into calculations that reveal the quasi-steady acceleration magnitude as a function of coordinate position relative to the Station's center of mass. The results take the form of coaxial elliptical cylinders of equal acceleration that are aligned along the Station's orbital velocity vector. Figure 4.2.1-1 is a view along the y axis in the Space Station Reference Coordinate System, showing where the various

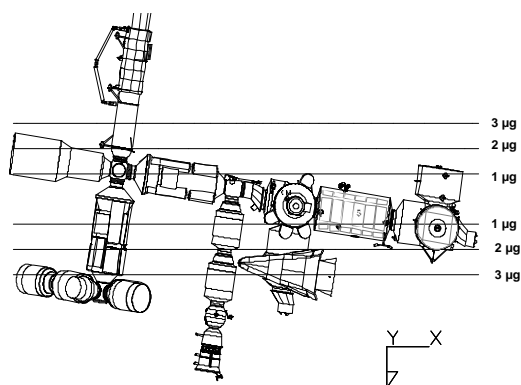


Figure 4.2.1-1. ISS quasi-steady microgravity environment

Station elements lie relative to a planar section through the cylinders for flight in XVV attitude. Note that the U.S. Lab lies principally within the 1 μg contours, with some racks between the 1 and 2 μg contours.

The calculations for the ISS quasi-steady acceleration environment can be compared to a set of formal design requirements which state that *50 percent of the ISPR locations within the U.S. Lab, Columbus and the JEM must have quasi-steady accelerations below 1 μg for periods of 30 continuous days a total of 6 times per year.* The operation of the Station in Microgravity Mode is designed to produce these 30-day intervals. The quasi-steady acceleration vector has an additional directional stability requirement stating that the *component perpendicular to the vector's orbital average must be less than or equal to 0.2 μg .* To meet this requirement the Station's attitude must be controlled during orbit so that it maintains a constant position relative to the LVLH axes.

4.2.2 Vibratory Requirements

The requirements for the vibratory microgravity environment on ISS are defined in terms of a "spectrum" of allowed root-mean-square (RMS) acceleration as a function of vibrational frequency from 0.01 Hz to 300 Hz. The total vibrational level experienced by the station arises from the combined effects of the payload and vehicle systems. The vibratory microgravity requirements are therefore defined using an RMS acceleration vs. frequency curve for the allowed contribution to the total system vibration by the vehicle alone, with a separate curve for the allowed contribution by the entire complement of payload systems. These two curves are shown in Figure 4.2.2-1. The total allowed system vibration is the root-sum-square of the payload and vehicle values and at the scale of

Figure 4.2.2-1 would plot just slightly above the vehicle curve.

Similar to the quasi-steady microgravity regime, the vibratory acceleration levels given by Figure 4.2.2-1 must apply at 50 percent of the ISPR locations within the U.S. Lab, Columbus and the JEM, for at least 30 continuous days, 6 times per year (i.e., during Microgravity Mode).

During ISS development the contribution of the ISS vehicle systems, without payloads, to the total system vibration is assessed analytically using a computationally intensive set of finite-element and statistical energy models. A fundamental aspect of the results of these models has been to show that, without some type of mechanically active vibration-damping system, the vibration levels at all ISPR locations would exceed the Figure 4.2.2-1 requirements. As a result an Active Rack Isolation System (ARIS) was designed to isolate selected ISPRs from Station vibrations while at the same time holding them in place in their rack bays. Additional details on the ARIS are provided in Section 5.3.2 below.

Calculation and modeling of the contribution of payload systems to the total system vibratory environment is also being implemented, but is at a technically less-advanced stage. Nevertheless, the fact that a payload complement vibratory requirement exists at all should be noted by any investigator considering developing a payload for ISS, because the requirement has implications for placing constraints on how much vibration an individual payload can produce. A scheme to manage the vibration contributions of individual payloads so that the total payload complement does not exceed the requirement is presently under development

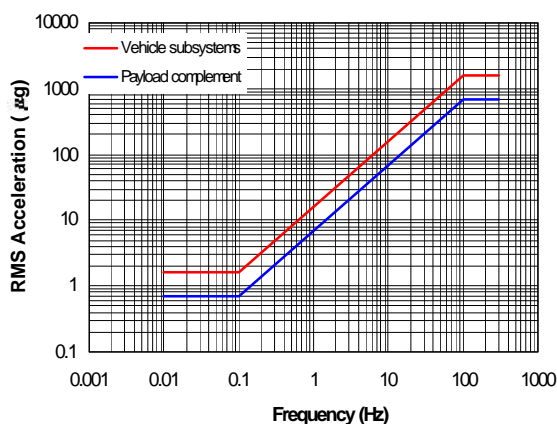


Figure 4.2.2-1 ISS Vibratory Microgravity Requirements

4.2.3 Microgravity Acceleration Measurement

The Space Acceleration Measurement System-II (SAMS-II) and the Microgravity Acceleration Measurement System (MAMS) will measure the quasi-steady (MAMS) and vibratory (MAMS and SAMS-II) microgravity environment on board ISS. The data will assist ISS Users with correlating microgravity-sensitive experimental results with the ISS microgravity environment. The Principal Investigator Microgravity Services (PIMS) project at NASA's Glenn Research Center will analyze the SAMS and MAMS data and provide the results to principal investigators, the ISS program and other investigators. Further information on PIMS and ISS microgravity measurement can be found on the PIMS website (Appendix B).

4.3 Internal Environment Control and Monitoring

The nominal atmosphere onboard the ISS is an Earth-normal 101.4 kPa (14.7 psia) with 21% oxygen and 78% nitrogen. Pressure is maintained between 97.9 – 102.7 kPa (14.2 - 14.9 psia), with a minimum pressure of 95.8 kPa (13.9 psia). Oxygen partial pressure is maintained in the range of 19.3 - 23.4 kPa (2.8 - 3.4 psia). The relative humidity is maintained between 25% and 70%. The medical operations requirement, and the ISS specification, for CO₂ level is a 24-hour average of 0.7% or less, although a 24-hour average exposure as high as 1% is allowable during crew exchanges. The ISS program has agreed to maintain the cabin CO₂ level to 0.37% (with the goal of reaching 0.3%) for two 90-day periods each year. Modeling has shown that with two U.S.- and one Russian-segment CO₂ scrubbers a level closer to 0.2% can be expected.

4.4 External Environment Control and Monitoring

The ISS external environment is the space natural environment as modified by the presence of the ISS and its related operations. The natural environment is defined as that which would exist if the ISS were not in orbit. The natural environment includes neutral atmosphere, plasma, charged particle radiation, electromagnetic radiation, meteoroids, space debris, magnetic field, and gravitational field.

The ISS itself produces a variety of modifications to its external environment. Among these are changes to the gaseous and particulate environment, which are of concern because they can result in surface con-

tamination and change the environment for imaging and sensing space and the earth. Controls on these effects for the ISS Program include the specification that ISS contamination sources will contribute no more than 1×10^{14} molecular-cm⁻² to the molecular column density along any unobstructed line of sight, and produce no more than 1×10^{-6} g-cm⁻²-yr⁻¹ total deposition on sampling surfaces at 300°K. Contamination requirements directed specifically at effects on attached payloads and the ISS vehicle by other attached payloads specify that an attached payload shall not deposit material at a rate greater than 5×10^{-15} gm/cm²/sec on other attached payloads and 1×10^{-15} gm/cm²/sec on ISS vehicle elements. There will be instruments attached at or near external payload sites to monitor these contamination rates.

5. Accommodations for Research on ISS

This section provides a detailed overview of the general and specific resources for research payloads on ISS. This includes station-wide resources such as power and data that affect all users, whether associated with the U.S. or non-U.S. IP communities. For specific research facilities, however, the discussion covers in detail only those areas of ISS to which U.S. investigators will have direct access. Indirect access to facilities controlled by the IP research communities is possible if U.S. researchers are part of co-investigator teams with IP researchers. For this reason a brief outline of the IP facilities is also provided.

5.1 Resource Allocation

Each of the ISS International Partners is allocated a share of Station resources in proportion to their contribution to the program. The resulting allocation scheme is detailed in Table 5.1-1. Within this overall allocation framework additional shifting of resources can occur based on bilateral agreements that allow IPs and countries to trade resources and responsibilities. Internally, IPs use their own mechanisms to apportion space and research capability to their scientific, technological, and commercial interests. To coordinate their research and resources trades, the IPs have established bi- and multilateral working groups.

In exchange for providing the bulk of the Station infra-structure and lift capability, the United States is allocated 97.7% of the space in its own U.S. Lab module plus 46.7% of the European *Columbus* and

Japanese JEM pressurized laboratory space. This is equivalent to 13 ISPRs in the U.S. Lab, and 5 ISPRs each in both the JEM and *Columbus*. The CAM holds 4 ISPRs also allocated to the U.S., yielding a Station-wide number of 27 ISPRs for U.S. research, 5 for the Europeans and 5 for Japan. In addition to its four attached payload sites on the ISS truss, the U.S. program will have use of 50% of the external attached payload space being provided on the JEM-EF and *Columbus*. No allocation of resources for the Russian Space Agency is included in Table 5.1-1 because with the exception of crew time, RSA retains 100% of the resources and accommodations it provides.

In addition to outright trading of resources and responsibilities, cooperative development agreements are also possible, whereby a facility or piece of equipment is developed jointly by two (or more) IPs with the understanding that both will share access to the final product. A significant fraction of the research-specific facilities and equipment described below, which are under nominal access to U.S. researchers, are being developed in this way.

5.2 Station-wide Resources

5.2.1 Power

Station power at assembly complete will be generated from four sets of solar arrays on the Integrated Truss Structure. The arrays rotate on two axes to track the sun. The lack of a third axis does reduce power generation during high solar β angles as discussed above, but this does not cause operational limitations to payloads after flight 12A. At assembly complete 26 kW minimum continuous and 30 kW average power and thermal conditioning will be provided to payloads during Standard and Microgravity modes. An additional 2.5 kW of power is provided to operate ISS systems that support payload operations. During various other operating modes, payloads receive a minimum of 6.5 kW of continuous power.

5.2.2 Payload Data Handling and Communication

To transfer research data and video to the ISS User, the Station provides an onboard command and data distribution network associated with a forward and return antenna 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. Data onboard are distributed from the payloads to an automated payload switch (APS).

Table 5.1-1. ISS Partner Allocation	NASA	CSA	ESA	NASDA
	Percent (%)			
Utilization Capabilities / User Accommodations				
NASA Lab Module <i>Destiny</i> - Annual Avg Rack Locations (DRE)	97.7	2.3		
NASA CAM - Annual Avg Rack Locations (DRE)	97.7	2.3		
NASA Truss Payload Accommodations - Annual Avg Truss Attach Points (AP)	97.7	2.3		
ESA Columbus Module - Annual Avg Rack Locations (DRE) - Annual Avg COF Attach Points (AP)	46.7	2.3	51.0	
Japanese Experiment Module (JEM) - Annual Avg Rack Locations (DRE) - Annual Avg JEM-EF Attach Points (AP)	46.7	2.3		51.0
Utilization Resources				
Resources: - Annual Avg Power (kW) - Annual Total Crew Time (hours) (non-Russian)	76.6	2.3	8.3	12.8
Rights to Purchase Supporting Services				
Space Station Launch & Return Services - Press/Unpress Upmass (kg) - Press/Unpress Downmass (kg) - Press Volume/ Press Down Volume (DRE)	76.6	2.3	8.3	12.8
Communications Data Transmission Capacity - Annual Avg Downlink (Mbps)	76.6	2.3	8.3	12.8

DRE = Double Rack Equivalent

Three types of connections are available for this distribution, either directly or indirectly: 1) a MIL-STD-1553B Payload Bus (through a Payload Multiplexer/Demultiplexer), 2) an 802.3 Ethernet, or 3) a fiber-optic High-Rate Data Link (HRDL). The APS distributes the data to a high rate modem for distribution to the Ku-band system. The Assembly Complete orbital coverage for the Ku-band system is approximately 45%. However, several initiatives are in place to increase this orbital coverage to continuous availability. Included in the data rate at Assembly Complete 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. A 216-gigabit communications outage recorder is provided to record research data during loss of signal with the communication system. Video onboard is distributed from the payload to one of several switches. Each switch routes the signal to a recorder or monitor, or distributes it to the downlink. Three video compression units will be on board (one each in the U.S. Lab, JEM, and *Columbus*) to allow video to be downlinked simultaneously with the research data.

5.2.3 Thermal Management

Thermal radiators are positioned on the Integrated Truss Structure. These radiators are oriented using rotary joints to keep them parallel to the sun's rays so as to keep them from receiving external heat inputs, and to keep them oriented toward space to allow radiation of heat. Using H₂O internally, the radiators pick up heat from the ISS through the environmental control system, which then transfers that heat to the radiators using NH₄ as the active heat transfer fluid.

5.2.4 Payload Stowage

Whereas the major items of hardware planned for orbital flight on the ISS can be specifically "slotted" at uniquely suitable locations on the vehicle, generic stowage space is required for the small, loose pieces of hardware and consumables that must support a crewed space vehicle. Stowage considerations encompass not just time on orbit, but transport to and from orbit as well. Because stowage is optimized for the entire Station system, instances may result in which research stowage is not immediately adjacent to a User's experiment.

The majority of stowage on ISS is accommodated by ISPR-size racks that provide compartmentalized storage. The types of stowage racks currently being de-

veloped are the Resupply Stowage Rack (RSR), the Zero-G Stowage Rack (ZSR), and the Resupply Stowage Platform (RSP). The RSR has a capacity of 1.1 m³ (37.5 ft³) and stows miscellaneous small items or loose cargo by means of a group of lockers of various sizes. These locker assemblies, made with doors and latches, are configured to accept individual stowage trays, and are bolted into the rack structure. Stowage trays are the basic containers for transportation to orbit and for on-orbit stowage of internal cargo for the ISS. If a given RSR is used only in the transportation phase, contents of the trays may be removed and stowed in the appropriate modules. The stowage trays are modular and interchangeable to support a variety of cargo types.

The ZSR is a lightweight, on-orbit stowage restraint system. The ZSR comprises two elements: a collapsible shell and a fabric insert. The shell is an aluminum frame that provides a standardized interface to the insert. The fabric inserts can be configured to carry sub-containers that include the stowage trays mentioned above, as well as various types and sizes of soft-sided cargo bags. The 1.2 m³ (42.8 ft³) ZSR is not designed to transport cargo during launch and landing phases.

The RSP is a re-supply/stowage carrier system for transporting ambient pressurized cargo to and from the ISS. It can transport the same types of soft-sided cargo bags and other sub-containers as the ZSR.

5.2.5 Crew Resources

When assembly is complete, the crew will work an 8-hour day Monday through Friday, and a 4-hour day on Saturday. Sundays are planned as crew rest days, although required essential payload maintenance activities, such as care and feeding of biological specimens, will take place. A total of 160 crew-hours per week will be available for research purposes at Assembly Complete. This number assumes the nominal crew size of seven. These hours must be apportioned among all science, technology, and commercial investigations on board the Station. The remaining crew hours will be devoted to Station maintenance, EVA, command and control, and other Station vehicle housekeeping functions as necessary. Additional hours for payload operations may be available, based on the burden of ISS vehicle requirements.

5.2.6 Crew Health Care System

To support the medical needs of crewmembers during ISS assembly and operations, NASA has developed the Crew Health Care System (CHeCS). CHeCS consists of three primary elements: 1) the Health Maintenance System for providing medical care, 2) the Environmental Health System for monitoring the internal environment of the ISS, and 3) the Countermeasures System, which provides hardware and procedures for crew member exercise to minimize the effects of spaceflight on the body.

The Health Maintenance System includes a defibrillator, an ambulatory medical pack, a respiratory support pack, an advanced life support pack, a crew medical restraint system, and a crew containment protection kit.

The Environmental Health System will assess toxicology, water quality, microbiology, and the radiation environments. To accomplish this, the toxicology system includes a volatile organic analyzer, a compound-specific analyzer for combustion products, and a compound-specific analyzer for hydrazine. A water sampler and archiver and total organic carbon analyzer will enable crewmembers to assess water quality. A surface sampler kit, a water microbiology kit, and a microbial air sampler will enable microbiology assessments. Finally, the radiation environment will be monitored with an extravehicular/intravehicular charged particle directional spectrometer, a tissue equivalent proportional counter, and a variety of dosimeters placed throughout the Station.

The Countermeasures System will consist initially of a treadmill equipped with a vibration isolation and stabilization system and a medical computer.

The primary purpose of CHeCS is to provide for and monitor the well being of the astronauts while in orbit but components of CHeCS occasionally may be used to support life sciences research on ISS if that use does not interfere with CHeCS' primary purpose. Similarly, CHeCS may require occasional use of research equipment for periodic assessment of crew health.

5.3 Generic NASA Accommodations for Research Payloads

5.3.1 International Standard Payload Rack

To support efficient integration and interchangeability of payload hardware — and to maximize joint research among investigators using this multinational

facility — the ISS program has adopted the International Standard Payload Rack (ISPR). The 37 ISPR slots for science payloads on ISS provide a common set of interfaces regardless of location. Nonstandard services are also provided at selected locations to support specific payload requirements.

Each NASA ISPR provides 1.6 m³ (55.5 ft³) of internal volume. The rack weighs 104 kg (230 lbm) and can accommodate an additional 700 kg (1543 lbm) of payload equipment. The rack has internal mounting provisions to allow attachment of secondary structure. The ISPRs will be outfitted with a thin center post to accommodate sub-rack-sized payloads, such as the 48.3 cm (19 in) Spacelab Standard Interface Rack (SIR) Drawer or the Space Shuttle Middeck Locker. Utility pass-through ports are located on each side to allow cables to be run between Racks. Module attachment points are provided at the top of the rack and via pivot points at the bottom of the Rack. The pivot points support installation and maintenance. Tracks on the exterior front posts allow mounting of payload equipment and laptop computers. Additional adapters on the ISPRs are provided for ground handling. Japan has developed an ISPR with interfaces and capabilities that are nearly identical to NASA's.

Power. The standard power interfaces for the 37 ISPRs consist of a 3 kW power feed and a 1.2 kW auxiliary feed. The power interface voltage will range from 114.5 to 126 Vdc. Prime power is fed to the ISPRs via 8-gauge wiring. The modules provide the switching and circuit protection using 25-A remote power controllers. The auxiliary power feed is distributed on 12-gauge lines. At selected ISPR locations (5 in *Destiny*, 5 in *Columbus*, and 4 in the JEM), a 6 kW power capability is distributed on 4 gauge wiring along with 1.2 kW auxiliary feed. At three locations within the U.S. Lab, prime and redundant 6 kW power feeds are provided to support operation of 12 kW payloads

Thermal Management. A moderate-temperature water loop is provided via a 1.3 cm (0.5 in) line with a quick-disconnect to each ISPR at an inlet temperature range of 16-24 °C (61-75 °F). The water is circulated through heat exchangers and stainless steel cold plates to allow thermal conditioning of the internal payload hardware. The water flow is controlled within the U.S. Lab and the JEM to optimize the heat rejection efficiencies of the system. The maximum return water temperature is 49 °C (120 °F). Inside a payload rack, an avionics air/heat exchanger assembly can be connected to the loop to remove up to 1200 W by circulating air. At selected locations in the U.S. Lab (9 ISPRs) and the JEM (5 ISPRs), a

low-temperature water loop (0.6-10 °C or 33-50 °F) is provided via a 1.3 cm (0.5 in) line with a quick-disconnect. The maximum return temperature on this loop is 21 °C (70 °F). A pressure drop of 40 kPa (5.8 psid) is allowed across the inlet and outlet of both water loop interfaces. Payloads can also dissipate small amounts of heat into the cabin air. Depending on the temperature conditions set by the crew, a minimum of 500 W can be dissipated into both the U.S. Lab and *Columbus* (complement of all payloads within the module). Negotiations are underway with Japan on the allowable heat dissipation into the JEM.

Command and Data Handling. The standard interfaces to the ISPRs include a MIL-STD-1553B Payload Bus that uses twisted shielded wire pairs and a high rate data link via optical fibers. Commands to the payloads from the ground, crew, and onboard automated procedures are delivered via this 1553B connection as are health, status, safety, and ancillary data types. Each payload location is allowed one remote terminal on the bus. Payload display and controls via 12 laptop ports are supported in the three modules (4 in the U.S. Lab, 4 in the *Columbus*, and 4 in the JEM). A timing signal is available to the payloads at 1 Hz with an accuracy of ± 5.0 ms with respect to the onboard time source over the 1553 bus.

Each ISPR is provided 2 fibers that connect to an input and output port on the APS for distribution of up to 100 Mbps of data between racks or for downlinking via the Ku-band system. Within the JEM, two additional fibers support downlinking research data through the JEM Interorbit Communication System (ICS). An 802.3 Ethernet local area network is distributed to the ISPR locations within the U.S. Lab, JEM, and *Columbus* for telemetry, file transfer, and laptop communications. The Ethernet's 10Base-T architecture allows up to 10 Mbps of data transfer to multiple ISPR locations. The Ethernet commonality of this interface across the 37 ISPRs is presently under definition.

Video. The standard video interface to the ISPRs within the U.S. Lab and *Columbus* is comprised of fiber optic lines using an EIA-RS-170A optical pulse frequency modulated video signal. Fibers are used to support video to and from the ISPR payload. A synchronization and control signal is also provided to the ISPR in accordance with EIA-RS-170A. The video distribution to the JEM is via twisted shielded wire pairs. A video card can be used inside the payload racks to convert the optical video/sync signals to electrical baseband NTSC EIA-RS-170A video/sync. The video signals from the ISPRs are sent to switches that allow distribution to onboard monitors, one of

seven video tape recorders, or to the video baseband signal processor to allow distribution to the ground via the Ku-band.

Vacuum Exhaust System (Waste Gas). All of the laboratory modules contain the plumbing to support a waste gas exhaust system that is vented to space. A 2.5 cm (1 in) diameter gas line connected to this exhaust system is provided at each of the ISPR locations. The pressure allowed into the waste gas line is 275.8 kPa (40 psia). The temperature of the exhaust waste gas is allowed to be between 15.6-45 °C (60-113 °F). The waste gas system can reach pressures of 1×10^{-3} torr (1.9×10^{-5} psia) in less than two hours for a single payload volume of 100 liters (3.5 ft³) at an initial pressure of 101.4 kPa (14.7 psia). The waste gas system is a shared and scheduled resource that can only be operated at one ISPR location within each module at a time. This requirement is to prevent cross contamination of payloads and incompatible mixtures of waste gas constituents. The types of waste gas constituents allowed must be compatible with the wetted materials of the module waste gas system.

Vacuum Resource. At selected locations within the U.S. Lab (9 ISPRs), JEM-PM (4 ISPRs), and *Columbus* (8 ISPRs), a 2.5 cm (1 in) vacuum resource line is provide via a quick-disconnect for those payloads requiring a vacuum environment. Each module contains the plumbing to produce this vacuum resource by connection to space. The vacuum is provided at a pressure of 10^{-3} torr (1.9×10^{-5} psia). Multiple payload locations may be connected to the vacuum resource at a time.

Nitrogen. A 0.95 cm (0.375 in) nitrogen line via a quick disconnect is provided as a standard service to all 37 ISPRs. The nitrogen is provided between 15.6-45 °C (60-113 °F) at a pressure of 517-827 kPa (75-120 psia). The flow rates to payloads will be up to 0.9 kg (0.2 lbm) per minute. Each payload will incorporate a valve to control the flow of nitrogen.

Carbon Dioxide, Argon, and Helium. As a non-standard interface, carbon dioxide, argon, and helium are provided to selected ISPR locations in the JEM. These gases are provided via a 0.95 cm (0.375 in) line with a quick-disconnect. The nominal pressure range of these gases is 517-786 kPa (75-114 psia) when a single ISPR is being operated. The maximum design pressure of the line is 1379 kPa (200 psia).

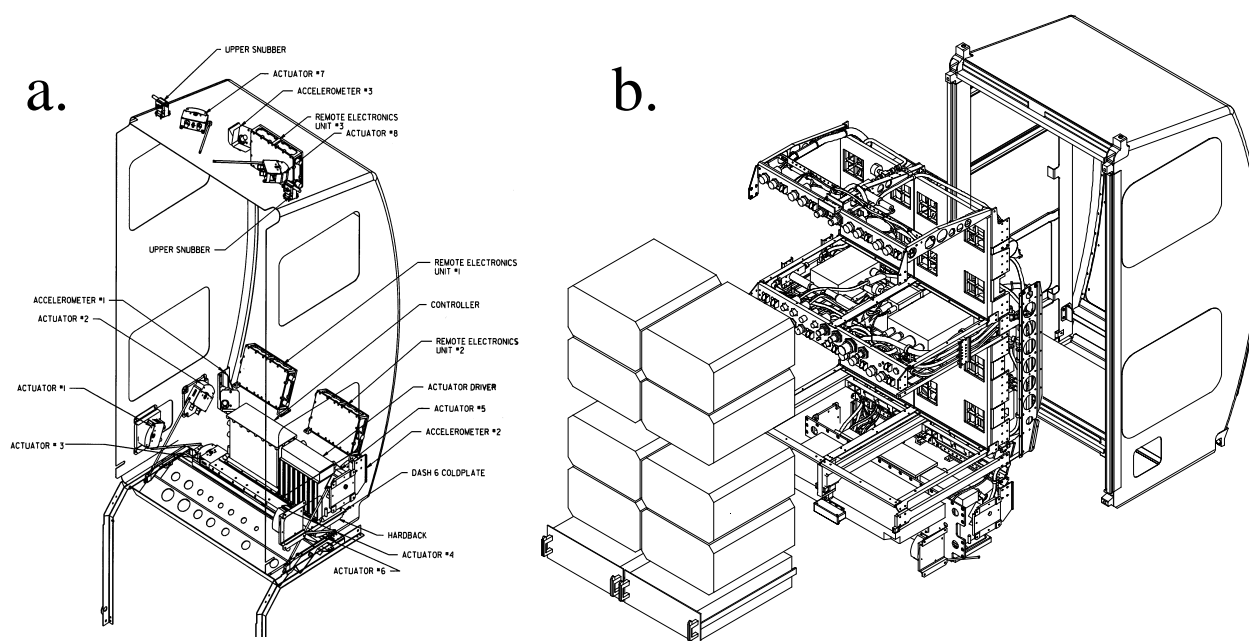


Figure 5.3-1. (a) ARIS components attached to an ISPR, (b) EXPRESS rack with 8 Mid-Deck Lockers

5.3.2 Active Rack Isolation System

The Active Rack Isolation System (ARIS) is designed to isolate payload racks from vibration such that the on-rack environment will meet the system vibratory specifications shown in Figure 4.2.2-1. The ARIS is an active electromechanical damping system attached to an ISPR that senses the vibratory environment with accelerometers, then damps it by introducing a compensating force. The ARIS components reside both inside and outside the ISPR (Fig. 5.3-1a).

Currently, eleven ARIS-equipped racks are planned for investigator use and several locations in *Destiny* and *Columbus* accommodate ARIS-equipped racks. The ARIS is currently under development and its system capabilities will be determined as part of an on-orbit ISS microgravity characterization experiment during the 6A-7A.1 time interval.

5.3.3 Sub-Rack Accommodations and EXPRESS Rack

The accommodations for research on ISS are designed to give a User the option of using what amount to “central facilities” for conducting their research, or developing their own experimental equipment from scratch. The central facilities option is discussed below in Section 5.4, which covers Facility-Class Payloads. If no central facility meets a given investigator’s requirements, they can consider building “investigation-specific” equipment that is unique to their needs. Such equipment will typically be allocated a sub-portion of an ISPR based on a unit

of space called a Mid-deck Locker Equivalent (MLE). This unit has dimensions roughly based on the Space Shuttle’s Mid-deck Storage Locker (MDL), which has an internal 0.06 m^3 (2.0 ft^3) volume and approximate dimensions of 43.2 cm (17 in) width \times 50.8 cm (20 in) depth \times 25.4 cm (10 in) height. Equipment that is built around the MLE size-concept is typically referred to as a sub-rack payload.

In designing ISS to accommodate sub-rack payloads it became apparent that several advantages would be obtained if investigators building MLE-based equipment were provided with host racks with a standardized set of interfaces. Based on this the EXPRESS rack concept was born. EXPRESS stands for EXpedite the PROCESSing of Experiments to the Space Station. The purpose of the EXPRESS Rack is to allow quick (i.e., less than one year) and simple integration of payloads into the ISS. The EXPRESS Rack contains standard interfaces within an ISPR configuration to allow payloads quick and standard access to ISS resources. The EXPRESS Rack offers structural support hardware, power conversion and distribution equipment, data and video equipment, nitrogen and vacuum exhaust distribution hardware, and thermal support equipment.

Whereas an EXPRESS Rack can be accommodated at any ISPR location on the ISS, it typically will be installed in a 3-kW ISPR location. The EXPRESS Rack configuration shown in Figure 5.3-1b accommodates eight MLE-payloads in two areas of four lockers each, and two 4-Panel Unit (PU) drawers. This layout can accommodate single or multiple MLE-style lockers.

MLE payloads are bolted to the EXPRESS Rack backplate, which is attached to the rear posts of the ISPR. MLE payloads interface to resources (power, commands/telemetry, water cooling, waste gas venting, and GN₂) via connection on the front face of the payload. Cooling is provided via passive radiation and heat exchange to the cabin environment, forced avionics air cooling via rear interfaces with the Rack avionics air loop, or water cooling. Drawer payloads interface at the rear for power, data, and avionics air.

The payload complement within an EXPRESS Rack receives a combined total of 2 kW at 28 Vdc for power and 2 kW heat rejection (air and water cooling combined). The EXPRESS Rack includes an Avionics Air Assembly (AAA) to provide forced air cooling. This assembly has a limited capability that must be shared by all payloads within the rack. Adequate air flow rate should be provided by the payload developer with an internal fan or equivalent. Use of cabin air cooling is restricted for EXPRESS Rack payloads due to Fire Detection and Suppression concerns and restricted heat dissipation allocation for racks in the ISS. The EXPRESS Rack interface to the moderate temperature water loop and the forced air cooling are common/shared resources and must be evaluated as an integrated subsystem to ensure that the heat loads are equally accommodated by the particular system. Each EXPRESS Rack includes one payload connection for vacuum exhaust and one connection for nitrogen distribution.

Some EXPRESS Racks will use ARIS to reduce acceleration disturbance. The EXPRESS Rack with ARIS has two connectors on the lower connector panel where second generation Space Acceleration Measurement System (SAMS-II) Remote Triaxial Sensors can be connected for the purpose of measuring the acceleration environment within the EXPRESS Rack.

A sub-rack payload destined for an EXPRESS Rack (an EXPRESS payload) can be transported to the ISS in the orbiter middeck, in an inactive EXPRESS Rack in the Multi-Purpose Logistics Module (MPLM), or in an EXPRESS transportation rack in the MPLM. Passive EXPRESS payloads are transported to the ISS in the MPLM, either in an inactive EXPRESS Rack or in an inactive EXPRESS transportation rack. An EXPRESS payload that must be active during ascent/descent or must have late or early access may be integrated into the space shuttle orbiter mid-deck. An EXPRESS rack payload can be transported from the ISS to the ground with the same options for launch.

5.3.4 Nadir Research Window

The Nadir Research Window is positioned in the U.S. Lab module such that in normal XVV attitude it will point toward nadir. The window design has a three-pane configuration, with an outer 1 cm (0.38 in) thick debris pane, a 3.2 cm (1.25 in) redundant pressure pane, and a 3.2 cm (1.25 in) primary pressure pane (see Figure 5.3.4-1). In addition, in the U.S. Lab interior a removable scratch pane will be mounted over the primary pressure pane to protect the pane from debris within the window volume prior to the installation of the Window Observational Research Facility (WORF). The debris and pressure panes are made out of fused silica, with a 50.8 cm clear aperture, and will have an optical wavefront error of 1/10 of a wave over 12.7 cm, with a reference wavelength of 632.8 nm. Using this window, it will be possible to use up to 20-cm optics without image degradation from window-induced wavefront error. Although ground resolution is difficult to estimate because of differing conditions of target contrast, atmospheric haze and shimmering, and spacecraft motion, the 20-cm optics used in the WORF may, under optimum conditions, be able to distinguish ground objects as small as 1-3 m (3.3-9.8 ft). The window panes will have an anti-reflection coating designed to minimize signal loss due to reflections between adjacent panes. This coating provides a wavelength transmittance through the window that favors the visible wavelengths, although it has reasonable transmittance in the near UV and infrared.

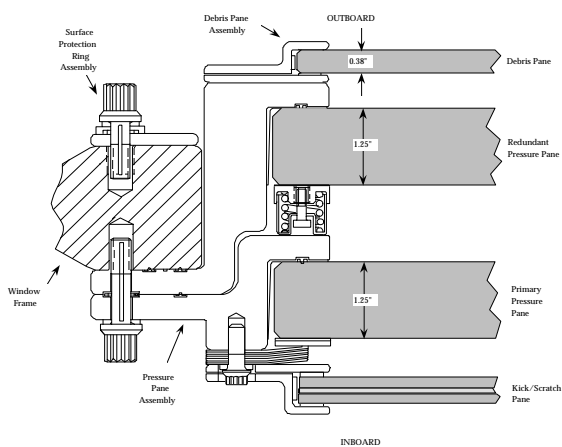


Figure 5.3.4-1. Nadir window cross-sectional view

Table 5.3.5-1. Laboratory and Station Support Equipment

Laboratory Support Equipment	
Description	Flight Available
Refrigerated Centrifuge	Post AC
Digital Thermometer	UF-1
Incubator	UF-3
Micro Mass Measurement Device	UF-5
Small Mass Measurement Device	UF-5
Compound Microscope	UF-3
Dissecting Microscope	UF-3
Passive Dosimeter	5A.1
Quick/Snap Freezer	UF-7
Cryo Storage Freezer	UF-7
Minus Eighty-degree Laboratory Freezer (MELFI)	UF-1
Station Support Equipment	
Bar Code Reader	UF-1
Battery Charger	UF-1
ISS General Purpose Video Camera	TBD
Film Still Cameras	7A.1
Digital Still Camera	7A.1
Cleaning Equipment	6A
DC Power Supply	UF-1
Digital Recording Oscilloscope, Digital Multimeter, pH Meter, and Digital Thermometer (Combined)	7A.1
Function/Sweep Generator	UF-1
General Purpose IVA Tools	2A
Maintenance Work Area	7A.1
Portable Utility Light	TBD
Crew Refrigerator/Freezer	UF-1
Restraints and Mobility Aids	UF-1
Utility Outlet Panel	TBD
Fluid System Servicer	TBD

5.3.5 Laboratory and Station Support Equipment

Lab Support Equipment (LSE) and Station Support Equipment (SSE) comprise the general-purpose equipment and tool items developed to support ISS maintenance and payload operations. (The distinction between LSE and SSE relates mainly to where the equipment originates from within the ISS Program.) A significant fraction of this equipment exists to support research, and consists of the sorts of basic equipment such as pH meters and microscopes that

would be found in a typical ground-based research lab. The availability of specific pieces of LSE and SSE is linked to the assembly sequence such that pieces will become available to researchers at different stages of Station assembly. A list of the LSE and SEE items and the flight after which they will be available is provided in Table 5.3.5-1. The laboratory freezer systems provided as part of the LSE complement are of particular interest to the Life Sciences researchers and are described separately below.

Cryofreezer System. The Cryogenic Freezer System will consist of two complementary units, the Cryogenic Storage Freezer and the Quick/Snap Freezer. The Cryogenic Storage Freezer 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, ultrastructure and genetic material. It will provide a cryogenic storage environment both on orbit and during transport to and from the ground. When used with appropriate ground-support equipment, it will allow samples to be maintained at cryogenic temperatures during transport from the home laboratory on the ground to the Space Station and from the Space Station back to the ground lab. The 35-liter (1.2 ft³) internal volume of the storage freezer will accommodate 1000 or more 2- to 5- ml (0.1- to 0.3- in³) sample vials.

The Quick/Snap Freezer is a portable unit to be operated in conjunction with the Cryogenic Storage Freezer. The Quick/Snap Freezer will be used to cool all samples before they are inserted into the storage freezer and will also provide a means to transport cooled samples between the Life Sciences Glovebox, the X-ray Crystallography Facility, and the Cryogenic Storage Freezer. It will “quick freeze” 2 ml (0.1 in³) and 5 ml (0.3 in³) contained samples and ultra-rapidly freeze (“snap freeze”) small (1 × 2 × 1 mm or 0.04 × 0.08 × 0.04 in) tissue samples. The unit will be accessible from within the work volume of the Life Science Glovebox.

Minus Eighty-degree Laboratory Freezer

(MELFI). The Minus Eighty-degree Laboratory Freezer for ISS (MELFI) is a low temperature sample cooling and storage unit that will maintain samples below -68 °C (-90.4 °F) throughout a mission life cycle. The MELFI will provide a temperature-controlled volume of not less than 300 liters (10.6 ft³) in four Dewar-type modules (vacuum-insulated containers). Each Dewar will have a capacity of not less than 75 liters (2.6 ft³) of internal storage volume. The MELFI is designed to operate optimally at -80 °C (-112 °F), but will have independent activation/deactivation and temperature control for each

Table 5.3.6-1. U.S. Attached Payload Resource Accommodations

U.S. Truss Site (allocation per site)	
Operational Envelope	ref. SSP 57003-Attached Payload Interface Requirements Document
Maximum Payload Height	3.1 m (10 ft) ¹
Mass	4990 kg (11,000 lbm) ¹
Power	3 kW at 113-126 Vdc (shared) ²
Thermal	passive only
Low Rate Data	by 1553B, <100 kbps (shared) ²
High-Rate Data	by fiber optic High-Rate Data Link, 95 Mbps (shared) ²
U.S. EXPRESS Pallet (allocation per pallet)	
Mounting platform dimensions	394 x 229 cm (155 x 90 in)
Total payload mass	1361 kg (3000 lbm)
U.S. EXPRESS Pallet Adapter (per adapter)	
Adapter dimensions and operational envelope	(see Fig. 5.3.6-2)
Payload mass	227 kg (500 lbm)
Power	2.5 kW at 113 Vdc/500 W at 28 Vdc (shared) ²
Thermal	passive only
Low Rate Experiment Data, Command, Control and Telemetry	by 1553B, < 100 kbps (shared) ²
High Rate Experiment Data	by fiber optic High-Rate Data Link, 6 Mbps (shared) ²

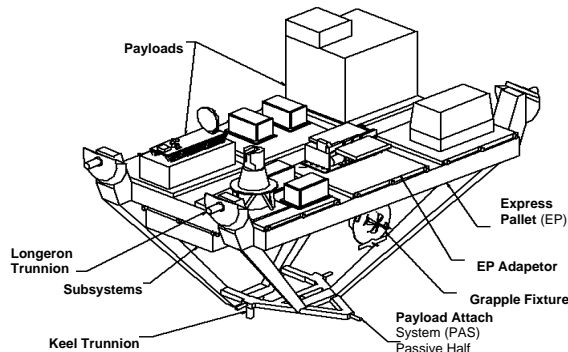
¹Subject to enveloping formulas

²Maximum value, represents allocation shared among several payloads.

Dewar, allowing one Dewar to be set at +4 °C (39 °F) and one at -26 °C (-14.8 °F). It will preserve samples that require 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. The four Dewars will accommodate a wide variety of sample container sizes and shapes.

5.3.6 U.S. Truss Site Payload Accommodations and EXPRESS Pallet

The available resources and accommodations for U.S. truss-site payloads are summarized in Table 5.3.6-1. Resources are given for a single payload oc-

**Figure 5.3.6-1. EXPRESS Pallet**

cupying an entire truss-site, which is one option for an ISS User, and also for payload accommodated on an EXPRESS pallet, which is the other option. An EXPRESS pallet occupies an entire truss site using the truss payload attach system. It provides an equally sub-divided attachment surface that will accommodate up to 6 individual payloads (Figure 5.3.6-1). Similar to the EXPRESS rack for internal payloads, the accommodations at each of the 6 payload locations are standardized to provide quick and straightforward payload integration. This is accomplished using a standard EXPRESS Pallet Adapter (ExPA) plate to which the payload is permanently mated prior to launch and which is subsequently locked into place on the pallet by the Special Purpose Dexterous Manipulator on the Station's robotic arm. Power and data distribution to each of the six ExPAs is then provided via blind-mate connectors to the integrated pallet.

The enveloping parameters for the allowed dimensions for payload hardware occupying one entire truss site are somewhat complex and are diagrammed in NASA document SSP 57003-*Attached Payloads Interface Requirements Document*. The allowed payload mass and center of gravity are also enveloped in SSP 57003 and the values in Table 5.3.6-1 are provided as one example of an inter-related set of parameters. For individual EXPRESS pallet adapter payloads the dimensional envelope is diagrammed in Figure 5.3.6-2.

The power and data resources supplied to individual attached payloads are subject to sharing with other payloads. Table 5.3.6-1 therefore specifies the maximum power and data resources that an individual payload could receive assuming there were no demands from other attached payloads. Because this is an ideal situation the actual resource is subject to availability and likely to be less than the values listed.

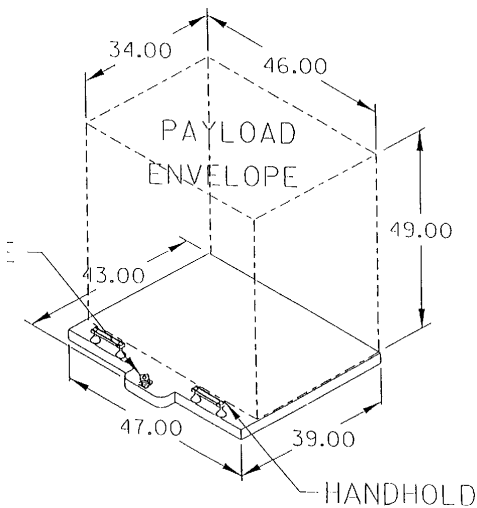


Figure 5.3.6-2. EXPRESS Pallet Adapter (ExPA) payload envelope (dimensions in inches).

Power to individual truss sites is provided by prime and redundant power feeds and is switched and circuit-protected by a 25 A remote power controller. An individual EXPRESS pallet receives all of the power and data resource allocated for its truss-site.

Each truss site is provided one remote terminal on the payload MIL-STD-1553B bus from the payload Multiplexer/De-Multiplexer (MDM) in the U.S. Lab. The bus is used for command, control, system health, and status data. Data downlinks or on-board display can be achieved through connections to the payload MDM. Two high-rate fiber optic data links are provided at each site. The fibers are connected directly into the automated payload switch within the U.S.

Lab to allow research data to be downlinked via the Ku-band system or switched to another payload.

For individual ExPA payloads a pallet controller will provide a MIL-STD-1553B bus, RS 422/485 and analog interfaces. It will transmit and receive high rate data on fiber optic interfaces.

For attached payloads whose missions are based on astronomical imaging or Earth remote sensing a knowledge of ISS orbital position, flight attitude and view fields is a consideration. Data on orbital position and flight attitude will be provided to payloads as Broadcast Auxiliary Data on the 1553B bus. Position will be known to within 3000 ft (RMS of x , y and z axes.). Attitude knowledge will be within 3° per axis of roll, pitch and yaw. The fields of view for attached payloads are dependent on payload type and location, with full truss-site payloads having greater latitude in viewing than ExPA payloads. Viewing in the zenith direction for payloads on nadir-pointing truss sites is not generally possible and vice versa. Viewfields for ExPA payloads depend on the payload's position on the pallet and the relative height of adjacent payloads. Positions provide various combinations of viewing in the nadir, zenith, ram, wake, and Earth-limb directions.

5.3.7 JEM and Columbus Exposed Facility Payload Accommodations

Payload dimension envelopes, masses, fields of view and other resource data for the JEM-EF and the *Columbus* Exposed Payload Facility are listed in Table 5.3.7-1. As shown in Figure 5.3.7-1, the JEM-EF

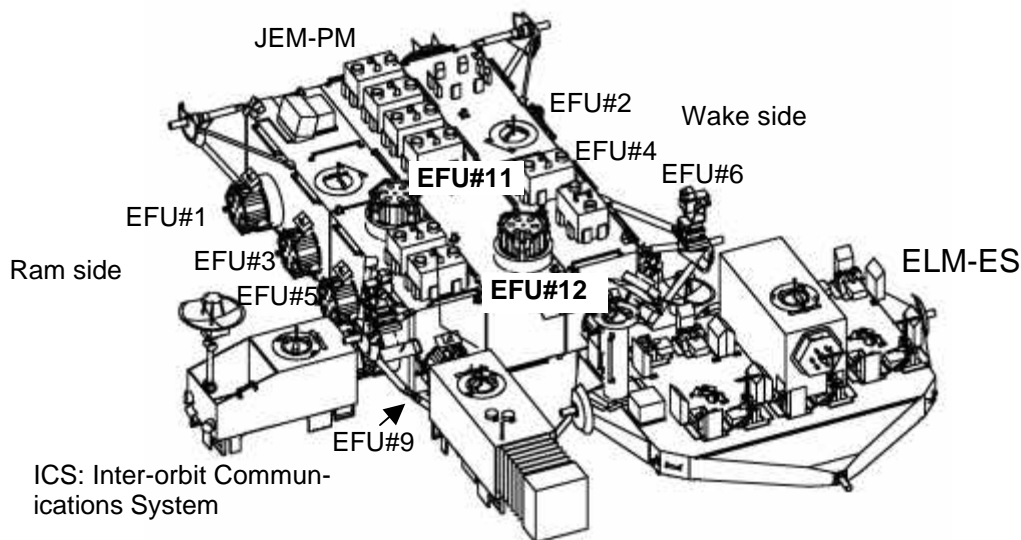


Figure 5.3.7-1 JEM-EF Configuration and JEM-EF Experiment Payload-attached Locations

provides a total of 12 attachment ports called Exposed Facility Units (EFUs) to which space-exposed hardware may be mated using a standard Payload Interface Unit (PIU). It is through the PIU that payloads receive all utilities. A total of 10 EFUs are available for User payloads, the other two being allocated to the ELM-ES, which transports payloads to orbit and stores them when they are not active, and the Interorbit Communication System (ICS). Five of the 10 available EFUs are available for NASA payloads.

In addition to a PIU, each JEM-EF payload must have a Space Shuttle-compatible Grapple Fixture to allow handling of the payload by the JEM Remote Manipulator System (JEM-RMS), a robotic arm system used for the transport and positioning of external user payloads. The JEM-RMS has both a main arm and a fine arm for robotics manipulation and is operated by the crew from within the JEM-PM with the aid of a viewing port. A central capability of the JEM system is the ability to use the airlock in the JEM-PM to robotically transfer payload hardware between the JEM-PM, the EF and the ELM-ES. Due to airlock size constraints this capability is limited to research samples or hardware sub-parts of payloads but does not include entire payloads.

The availability of these resources is not equal at all EFUs. For example, higher masses of 2500 kg can be accommodated at two EFU locations, one on the wake and the other on the port side of the EF. The listed mass values are maximums per site. Power is switched and circuit protected. Each site is provided a moderate temperature non-water fluid (fluorinert) loop for heat rejection. The data and video services are connected back to the U.S. Lab for downlinking and distribution to the Ku-band system or to the ICS.

Columbus Exposed Facility payloads are accommodated on two support structures attached to the outboard end-cone of the module (see Fig. 3.5-1). Payloads will be interfaced to these support structures using ExPAs. Each support structure accommodates one starboard-pointing and either one nadir-pointing or one zenith-pointing ExPA, for a total of four on the module (Fig. 3.5-1). The payload accommodations and resources provided to the *Columbus* Exposed Facility ExPAs are summarized in Table 5.3.7-1.

5.4 Multi-User Facilities: The Facility-Class Payload Concept

The ISS central research facilities are being developed and managed as a special category of payloads

Table 5.3.7-1. Non-U.S. International Partner Attached Payload Resource Accommodations

JEM Exposed Facility (per EFU)	
Dimension envelope	1.8 x 0.8 x 1.0 m (6 x 2.6 x 3.3 ft)
Mass	500 kg (1,100 lbm)/2500 kg (5500 lbm)
Power (main)	3 kW at 113-126 Vdc (shared) ¹
Power (keep alive)	100 W feed
Thermal (active)	by circulating fluid (fluorinert) loop, 3 kW
Thermal (passive)	by conduction through PIU, 7 kW
Low Rate Experiment Data, Command, Control and Telemetry	by 1553B bus, < 100 kbps (shared) ¹
High Rate Experiment Data	by FDDI optical fibers, 43 Mbps
Ethernet	by 802.3 protocol, 10 Mbps (shared) ¹
Experiment Video	by twin-axial cable, using EIA-RS-170A protocol.
Fields of view	zenith-ram-wake-port (2 sites); zenith-nadir-ram (3); zenith-nadir-ram-port (1); zenith-nadir-wake (4)
Columbus EXPRESS Pallet Adapters (per adapter)	
Payload dimension envelope	(see Fig. 5.3.6-2)
Payload mass	227 kg (500 lbm)
Power	2.5 kW at 120 Vdc (shared) ¹
Thermal	passive only
Low rate experiment data, command, control and telemetry	by 1553B bus, <100 kbps (shared) ¹
High-rate data	by extension of Columbus video/data link, 32 Mbps
Ethernet	by 802.3 protocol, 10 Mbps (shared) ¹
Fields of view	all except nadir (1); all except zenith (1); all except port with partial nadir/zenith (2)

¹Maximum value, represents allocation shared among other payloads.

Table 5.4-1. ISS Facility-Class Payloads

Facility Name	Facility Type, (Rack Number) Research Function	Research Organization	Developing Organization (Location)	Location on ISS	Integration Flight(s)
HRF	Rack-level, (2), +stowed equipment Effects of microgravity on humans	OLMSA, Life Sciences Division	NASA Life Sciences RPO (JSC)	Columbus	5A.1, 12A.1
GBF	Rack-level, (3), +centrifuge rotor Effects of gravity on biological systems	OLMSA, Life Sciences Division	NASA Space Station Biological Research Project (NASA ARC)	CAM	UF-7
BRF	Rack-level, (1) Protein crystallization, cell culture and biochemical studies	OLMSA, Microgravity Research Division	NASA MRPO Biotechnology Science Discipline	JEM-PM	AC
MSRF	Rack-level, (3) Materials science and materials processing investigations	OLMSA, Microgravity Research Division	NASA/ESA MRPO Materials Science Discipline	U.S. Lab	UF-3, AC
FCF	Rack-level, (3) Combustion science and fluid physics investigations	OLMSA, Microgravity Research Division	NASA MRPO Fluids/Combustion Science Disciplines	U.S. Lab	UF-3, UF-5, AC
LTMPF	Exposed facility Low-temperature physics investigations under microgravity	OLMSA, Microgravity Research Division	NASA MRPO Fundamental Physics Discipline (NASA JPL)	JEM-EF	HTV2
MSG	Rack-level, (1) Enclosed volume for chemical and biological studies under microgravity	OLMSA, Microgravity Research Division	NASA/ESA MRPO Glovebox Program	Columbus	UF-1
XCF	Rack-level, (1) Single crystal growth and structure determination	OLMSA, Space Utilization & Product Development	NASA MRPO Space Product Development	U.S. Lab	UF-5
AHSTF	Rack-level, (1) Test-bed for supporting technologies for long duration human spaceflight	OLMSA/Office of Spaceflight (joint)	NASA Microgravity/ Spaceflight (Code U/M)	JEM	16A
WORF	Rack-level, (1), uses nadir window Earth observation by various imaging systems	OLMSA, Offices of Spaceflight, Earth Sciences, and other government agencies	ISS Payloads Office (JSC-OZ)	U.S. Lab	UF-2
APCF	Sub-rack, single MLE Protein screening under temperature-controlled conditions		ESA/NASA	Columbus	7A.1
EMCS	Sub-rack Plant growth and development studies under variable gravity	OLMSA, Microgravity Research Division	ESA/NASA	U.S. Lab	UF-3

known as facility-class payloads, which are intended to form a key part of the Station's research infrastructure. Facility-class payloads are fundamentally multi-user in nature. Rather than originating with an individual investigator, facility-class payloads are being designed and developed by several NASA organizations, in some cases under cooperative development and barter agreements with IP organizations. Funding and oversight of the ISS facility-class payload program is managed through the ISS Payloads Office at JSC.

In keeping with promoting experimental flexibility for the ISS, a number of facility-class payloads have modular designs that allow investigators to design investigation-specific components uniquely suited to a particular experimental need. Access to the ISS facility-class research infrastructure is open to the U.S. and International Partner scientific community through competition.

Table 5.4-1 summarizes the array of facility-class payloads currently under development for ISS. The Table designates a facility type as "rack-level" if it

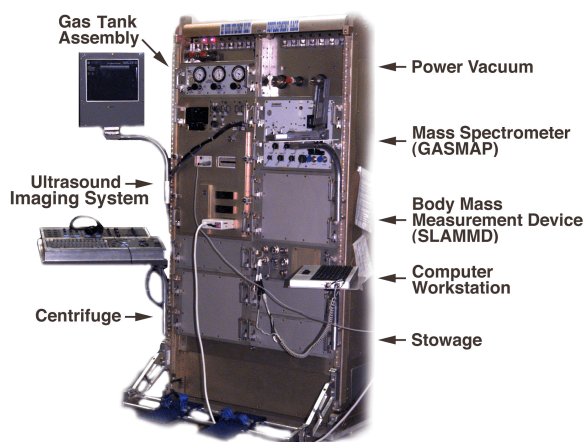


Figure 5.4-1 HRF Rack 1

consists of one or more fully integrated racks. Basic information is included on the NASA or IP research and support organizations to which the facilities are linked. The Integration Flight column lists the flights that will bring major components of the facility to the Station. (In this column the AC designation denotes a facility that will be available at Assembly Complete, but whose actual integration flight is too late in the Assembly Sequence to define at this time.)

Many facility-class payload projects have associated websites and these are listed in Appendix B.

5.4.1 Human Research Facility

The Human Research Facility (HRF) supports life sciences investigations on ISS that seek to understand the physiological and psychological changes in humans due to space flight. Investigations will be of two broad types: basic research that uses microgravity and other unique aspects of the ISS environment to address fundamental scientific questions regarding human physiology, and strategic research defined by NASA to solve problems associated with human adaptation to spaceflight. The latter may involve, for example, developing countermeasures to mitigate the detrimental effects of long-term exposure to microgravity.

HRF will consist of items mounted on two racks based on the EXPRESS design (HRF Racks 1 and 2), as well as separate equipment kept in stowage and brought out as needed. A photographic diagram of HRF Rack 1, highlighting the type and location of its major components, is shown in Figure 5.4-1. HRF Rack 1 will be the first of the facility-class payloads launched to ISS, on flight 5A.1. HRF Rack 2 will be added later, sometime around flight 12A.1. An im-

portant feature of both racks is that they are outfitted with Standard Interface Rack (SIR) interfaces for individual subrack components of research equipment. The SIR interface provides standardized slides and slide guides for the mechanical interface between a subrack unit and the HRF rack. It provides blind mating of power and data connectors when a subrack unit is slid into the HRF rack. The SIR interface permits simple installation of a SIR-equipped drawer in any position in the HRF rack, exchange of one drawer for another and movement from one rack to another.

The major pieces of research equipment in HRF Rack 1 are an Ultrasound/Doppler system, a metabolic gas analyzer system, a portable computer and a computer workstation for data processing and data communications. A suite of experiment-unique radiation dosimetry equipment will also be stowed in the HRF rack. An extensive list of additional HRF research equipment can be found at:

✓ <http://slife.jsc.nasa.gov/>

Investigators using HRF will also have access to the complement of equipment in CHeCS, even though the latter is technically part of the vehicle systems and not a research payload. As an example, the ergometer and treadmill, developed by CHeCS for countermeasures, may be utilized in HRF exercise experiments.

Investigations that will use the HRF are selected through an established process that includes international solicitation, review and selection via an annual NASA Research Announcement (NRA). The first NRA which included ISS research opportunities was distributed in February 1996 with the result that initial investigators were under contract in 1997. The human research program on ISS uses an experiment definition and development process similar to that used on the Shuttle program and subsequently modified on the NASA/Mir program. In addition to HRF capabilities, the investigators in the program use their own unique hardware, other flight facilities, ancillary flight information and ground systems to accomplish their research objectives.

5.4.2 Gravitational Biology Facility

The ISS will house a suite of biological research specimen support equipment that collectively will constitute the Gravitational Biology Facility (GBF). Housed within the CAM, the GBF supports research on how the space environment affects a broad range of biological systems. The centerpiece of the GBF is

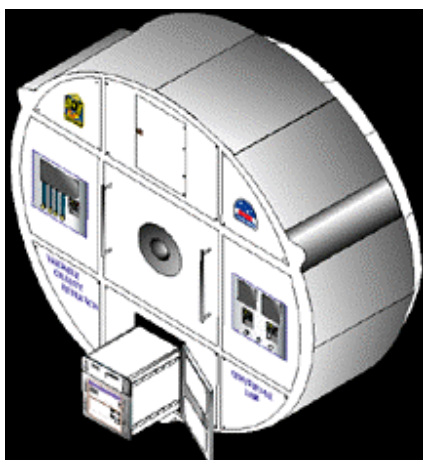


Figure 5.4.2-1. GBF centrifuge

a 2.5 m (8.2 ft) diameter centrifuge, shown in Fig. 5.4.2-1, that accommodates eight biological habitats for maintaining a variety of biospecimen types, from cells to rodents to large plants. To monitor and provide utilities for the habitats when they are outside of the centrifuge, the GBF provides Habitat Holding Racks (HHRs), as well as a Life Sciences Glovebox for transferring specimens without exposing them to the cabin environment.

As the Centrifuge rotates, artificial gravitational forces are produced upon the attached habitats that house various biological specimens. To create a 1.0 g acceleration the centrifuge rotates at 28.4 revolutions per minute. Slower rotations produce lower levels of artificial gravity; faster rotations produce higher levels of gravity. Accelerations ranging from 0.01 g to 2.0 g will permit scientists to compare how differing gravity levels affect the biology of organisms housed in habitats under otherwise identical conditions, thus separating the effects of gravity from other factors in the space environment.

The centrifuge will provide life support resources and electrical power to the habitats as well as data transfer links to ISS systems and to the ground. The hub, or center, around which the Centrifuge rotates provides structural support for the rotating part of the centrifuge, and it provides life support to the specimen habitats.

The Life Science Glovebox will provide a sealed work area in which crew members can perform experimental procedures. Habitats and other science equipment will be attached to the Life Sciences Glovebox in a manner that prevents any exchange of biological material between the cabin and Glovebox or habitat when biospecimens are being transferred into or out of the glovebox. Two crew members will

be able to use the Glovebox work volume at the same time by means of gloves that extend into the work volume. The enclosed volume of the Glovebox will be about one half cubic meter (approximately 16 cubic feet). As air circulates through the work space, activated charcoal filters will clean it continuously by adsorbing chemicals that may be present. In addition, a high efficiency air filter will remove particles and aerosols.

Two HHRs provide the structural, mechanical, environmental, and communications support for the biospecimen habitats. The HHRs will provide life support resources and electrical power to the habitats and other scientific equipment, as well as data links to ISS systems and to the ground. Each HHR, as well as the Life Sciences Glovebox and the centrifuge rotor, is outfitted to accommodate SIR drawer payloads. Each habitat, in turn, is outfitted as a SIR drawer, permitting simple one-step installation and removal of habitats and other science equipment. Thus, a habitat may quickly and simply be exchanged from one HHR to another or transferred to and from the Life Sciences Glovebox or the centrifuge rotor. Experiment data can be transferred from the Station to NASA's Ames Research Center and then relayed to scientists at their institutions and laboratories. The data links also make it possible for operators on the ground or astronauts on the Space Station to send commands to the laboratory equipment. This will allow researchers on the ground to monitor and control the environmental and experimental parameters inside the habitats.

Habitats which will be available to researchers include: a Cell Culture Unit for cell and tissue cultures; a Plant Research Unit for small plants; an Egg Incubator for studies in development; an Insect Habitat; an Aquatic Habitat; and an Advanced Animal Habitat for rats and mice. The habitats provide food, water, light, air, humidity and temperature control, and waste management for their inhabitants. In addition to environmental capabilities, the habitats collect, transmit, and receive operational, engineering, and scientific data through their host systems: the Centrifuge, the Life Sciences Glovebox, and the HHRs. In addition to the Habitats the GBF will have an Incubator to provide the capability to grow cells and tissue cultures.

5.4.3 Biotechnology Research Facility

The Biotechnology Research Facility (BRF) will be the primary scientific facility for conducting mammalian cell culture, tissue engineering, biochemical

separations and protein crystal growth on ISS. The BRF consists of one rack that provides support services for a variety of sub-rack payload experiments developed by investigators. Facility services include power, thermal management, video signal switching and processing, distribution of research quality gases and bulk 37° C incubation. The BRF will provide a centralized command and data handling interface to the Space Station, as well as some data and video storage.

5.4.4 *Fluids And Combustion Facility*

The ISS Fluids and Combustion Facility (FCF) is one modular, multi-user, facility designed to accommodate the research needs of the fluid physics and combustion science research communities. The FCF will occupy three powered racks and one stowage rack. The powered racks are called the Fluids Integrated Rack (FIR), Combustion Integrated Rack (CIR), and Shared Accommodations Rack (SAR). The combustion and fluids disciplines share racks and mutually necessary hardware within FCF to dramatically reduce cost and effectively use ISS resources.

The FCF Level 1 performance requirement stipulates that 10 high-quality, complex, fluids and combustion experiments be performed annually within nominal NASA budgetary and ISS resource constraints. It further stipulates that FCF be able to support 80 percent of the fluids and combustion experiments likely to be proposed. FCF can also accommodate up to 20 additional high-quality experiments sponsored by commercial entities and IPs; however, those sponsors must provide the additional funding and ISS resource allocations. Owing to the flexibility of FCF, experiments from disciplines outside of fluids and combustion can also be supported.

FCF incorporates several very advanced imaging systems capable of microscopic to macroscopic imaging at low to very high frame rates and over ultraviolet to infrared wavelengths. Some of these are intensified systems for low light imaging. Some are capable of intelligent, automatic target acquisition, tracking, focusing, and zoom. Payloads located in the FIR, CIR, and SAR can use them. By design, after SAR is on-orbit, other US Lab facilities and payloads can also use them. Other facilities and payloads can share the FCF image storage, analysis, and transmission capabilities (located in the FCF racks) via a small-diameter, temporary, fiber-optic interface cable from the FCF rack to an FCF-provided camera mounted in their rack (their rack must provide 28Volt power to the camera). Up to six FCF cameras can be

concurrently operational. Owing to the modular design, users can develop their own unique camera and lens systems relatively cheaply, if necessary, and connect them to the FCF data storage and communication sub-system.

The FIR features a large user-configurable volume for experiments. The volume resembles a laboratory optics bench. An experiment can be built up on the bench from components, or it can be attached as a self-contained package, or a combination. The FIR provides data acquisition and control, sensor interfaces, laser and white light sources, advanced imaging capabilities, power, cooling, and other resources. Equipment can be quickly mounted by astronauts with final positioning by remote control from the FCF Telescience Support Center (TSC, see Section 6.) or from the Principal Investigator (PI) home institution. FIR is designed to be adaptable to nearly any kind of fluids experiment.

The CIR features a 100-liter combustion chamber surrounded by optical and other diagnostic packages including a gas chromatograph. Experiments are conducted in the chamber by remote control from the TSC or PI home institution. The CIR is the only rack on ISS dedicated to combustion experimentation.

The SAR contains shared data storage and computational capabilities. Among other things these allow the PI to analyze large volumes of image data between data point runs to optimize science return. The SAR provides powered storage for scientific samples needing that capability. It provides a sample preparation and FCF maintenance area, as well as active storage of fluids and gases needed for certain types of fluids and combustion experiments. When not being used for the forgoing, it provides a significant volume and optics bench that is configurable for experiments – including mid-deck locker type experiments. These experiments will have the full FCF capability for data acquisition, control, and imaging available to them; hence, they can be less expensive to produce. Experiments are conducted by remote control from the TSC or PI home institution.

5.4.5 *Microgravity Sciences Glovebox*

The Microgravity Science Glovebox (MSG) is a joint development project between NASA and the European Space Agency (ESA). The double rack unit is a versatile research facility designed to permit the flexibility of crew-manipulated investigations. Its configuration has been planned around the concept of an experimental workstation where a variety of experiments can be installed and operated in a fashion

very similar to their operation in a ground-based laboratory. This approach has provided a work area with a comprehensive set of readily accessible laboratory resources to support an investigator-supplied experimental apparatus. Specifically, the facility provides a large enclosed work volume, power, video, photography, vacuum connections, heat rejection, stowage, filtered air, gaseous nitrogen, lighting, airlock access, physical positioning and hold-down attachments, and computer data acquisition and control capabilities.

In consideration of the ambient microgravity operational environment, the work area is enclosed and sealed by a large window, designed to contain potential liquid spillage, loose hardware, or gaseous by-products generated as a result of the experiment's performance. Crew access to the volume and operational manipulation of the experiments is through sealed glove ports. To enhance the value of the crew operation, the communication utilities to the facility have been designed to enable real-time visual and data monitoring of the experimentation by a ground based scientist, along with limited computer control by this scientist. As ISS utilization evolves, the MSG is scheduled to become a major pathfinder for developing and exploiting the scientific advantages of truly enabling the coupling of experimentation in space with an evaluative response from the crew and investigators.

5.4.6 Materials Science Research Facility

The Materials Science Research Facility (MSRF) is a facility to accommodate the current and evolving cadre of peer-reviewed Materials Science investigations which include solidification of metals and alloys, thermophysical properties, polymers, crystal growth studies of semiconductor materials, and research in ceramics and glasses. The facility will provide the apparatus for satisfying near-term and long-range Materials Science Discipline goals and objectives to be accomplished in the microgravity environment of the U.S. Laboratory on the ISS. The types of materials processing that will be accommodated include Bridgman-type directional solidification, solidification and quench, physical vapor transport, solution undercooling, solution crystal growth, and containerless processing.

The MSRF consists of three modular autonomous Materials Science Research Racks (MSRR-1, MSRR-2, and MSRR-3) which will be deployed in phases and will accommodate materials processing furnaces and common subsystems and interfaces required to

operate the furnaces. Each MSRR is a stand-alone rack that will use ARIS. Each will be comprised of either on-orbit replaceable Experiment Modules (EMs), Module Inserts (MIs), Investigation-unique Apparatus, and/or Multi-user generic processing apparatus, and will support a wide variety of scientific investigations.

The European Space Agency, the international partner for MSRR-1, will provide the Materials Science Laboratory and associated infrastructure for mounting it inside the ISPR. Materials science capabilities will be accommodated with Module Inserts (MI) to be installed in the MSL. Single sample processing is accomplished using manual sample exchange by a crewmember. A number of Module Inserts, which are on-orbit replaceable, are currently being developed both by NASA and ESA. These MIs will accommodate near-term scientific investigations for the Materials Science Research Program.

MSRR-2/3 configurations will have enhanced capabilities to provide a variety of additional hardware features to meet the current and future anticipated science processing requirements. These capabilities include, but are not limited to, high temperature processing, in-situ optical imaging, real time video, magnetic damping, sample resistance measurement, X-Ray imaging, and Seebeck measurements. The design of the EMs for MSRR-2/3 will be consistent with the developing rack architecture and will incorporate optimum flexibility to support on-orbit maintenance and change-out of key components. The EMs for each of these rack will be designed to be "smart" furnaces and will be comprised of the Furnace Module, Avionics, Control, Support Subsystems, and Automated Multiple Sample Exchange mechanism.

5.4.7 Window Observational Research Facility

Installed over the Nadir Research Window, the Window Observational Research Facility (WORF) provides a means of deploying a variety of payloads for conducting geologic, climatologic, atmospheric, and geographic research. As shown in Figure 4.1-1, the ISS flies over ~85% of the Earth's surface (up to 95% of the Earth's human population), and flies over a given location approximately every three days, with an identical lighting condition every three months. This pattern will provide a tremendous opportunity to observe changes in Earth's surface, oceans and atmosphere on a regular basis.

The WORF design will use existing EXPRESS Rack hardware to minimize both development time and

schedule risk. Common EXPRESS hardware will include a Rack Interface Controller box for power and data connection, Avionics Air Assembly fan for air circulation within the rack, rack fire detection, and appropriate avionics to communicate with the ISS data network. The WOLF rack will provide mounting for payloads, with access to power at 120 or 28 Vdc, uplink and downlink commands at low and medium data rates, and moderate temperature cooling capability for payloads. The WOLF will also include a means of removing condensation from the interior surface of the window and a variety of shields to protect the interior window surface from the impacts from loose tools and hardware being used in the payload area. These shields will still have sufficient optical performance to allow the crew member to see out the window during their use. The interior of the WOLF will provide for a non-reflective, light-tight environment both to minimize glare off the window, and to allow use of payloads that will be sensitive to extremely low energy phenomena such as auroras. A shroud attached to the hatch at the front of the rack will allow crew members to work in the WOLF without the problems of glare from the U.S. Lab interior.

The payload volume of the WOLF is sized to allow the mounting of payloads up to 53.3 cm x 50.8 cm x 76.2 cm (21 in x 20 in x 30 in) with a mass of up to 136.1 kg (300 lbf). This allows the crew to operate up to three instruments in the window at once. The payload volume will provide a standard set of mounting points for payloads to mount instruments and supporting avionics. At present, the WOLF will not provide specialized tracking mounts for individual payloads. Investigators requiring special instrument mounts will need to provide them. The WOLF will provide mounts for small, hand-held payloads such as film cameras, electronic still cameras and camcorders. This mount will provide for stable mounting for the purposes of crew Earth observations photography. Lastly, the WOLF will provide secure stowage for the scratch pane, as well as limited payload stowage.

5.4.8 X-Ray Crystallography Facility

The X-ray Crystallography Facility (XCF) is a comprehensive protein crystal analysis facility that incorporates necessary elements for analyzing complex macromolecular crystals in the microgravity environment. The XCF supports the preparation of crystals for visual evaluation and mounting, sample freezing, and collection of X-ray diffraction data on selected crystals. As part of its resource allocation the XCF will have crystal growth facilities housed in an

associated EXPRESS Rack, enabling commercial researchers to grow crystals as well as determine their structures. The integrated capabilities of the XCF enable commercial researchers and scientists to grow samples and obtain structural data on those samples prior to subjecting the crystals to re-entry stress and time-related degradation. Without crew intervention for nominal operations, the proposed system robotically downlinks video of crystal formation to the awaiting scientist. The researcher commands which crystals are to be harvested and prepared for freezing and the X-ray diffraction analysis. The information is stored on board as well as transmitted to the researcher on Earth. The downlinking allows the scientist to review the results and uplink any modifications to the data collection process. An astronaut crew member can provide assistance on a scheduled or 'as available' basis. Data privacy for principal investigators can be provided.

5.4.9 Advanced Human Support Technology Facility

The Advanced Human Support Technology Facility (AHSTF) will serve as a research and development testbed for enabling technologies required by NASA to sustain human life during long duration and deep space missions. Technologies to be developed will support the following fields: Advanced Life Support; Advanced Environmental Monitoring and Control; and Space Human Factors Engineering.

The AHSTF is anticipated to feature the first ISS suite of hardware in support of advanced life support and environmental monitoring. The AHSTF will provide an on-orbit test bed for supporting technologies that enable development of a closed environment life support system applicable to long-duration exploration flights. Nanominiaturization technologies will probably be extensively utilized during this early period of ISS human support technology research, particularly to enhance environmental sensor systems. Detailed hardware parameters for the AHSTF are under development.

5.4.10 Low-Temperature Microgravity Physics Facility

The Low Temperature Microgravity Physics Facility is the first laboratory developed by NASA from the *Fundamental Physics in Space Roadmap* (JPL 400-808, 4/99). The LTMPF Facility Class Payload is a complete low temperature laboratory to be attached to the JEM-EF. There will be two identical facilities, each weighing 500 Kg or less and each supporting

two experiments in parallel operations. An advanced superfluid helium Dewar maintains a base temperature pre-selected at between 1.6K to 2.0K for a period of approximately five months.

The Dewar insert is configured to best accommodate two experiments. Typically it consists of two sets of thermal-mechanical platforms called the probes. Attached to each probe are the cells and sensors for each experiment. Each probe can have several stages of isolation platforms with separate temperature regulations on each stage to provide the maximum temperature stability. The total volume for both probes and experiment hardware occupy a cylindrical volume of 19 cm (7.5 in) in diameter and 70 cm (27.6 in) long. The total allocated weight for both sets of experiment hardware attached to the probes (but excluding the probe mass) is 12 Kg or less. Electronics are built on the modular VME chassis with up to 42 slots for standard or custom-built electronic boards that can be reconfigured for each flight. Ultra high-resolution temperature and pressure sensors have been developed based on SQUID (Super-conducting Quantum Interference Devices) magnetometers. There are up to 12 SQUIDS shared between the two experiments. The high-resolution thermometers have demonstrated sub-nano-Kelvin temperature resolution in past space experiments. Other existing measurement techniques include resistance thermometers, precision heaters, capacitance bridges, precision clocks and frequency counters, modular gas handling systems, and optical access capability. An onboard flight computer controls all facility and instrument electronics, all ISS interfaces, command, telemetry, and data storage during on-orbit operations.

Most LTMPF experiments are sensitive to random vibrations, charged particles, and stray magnetic fields. The level of random vibrations at low frequency (< 0.1 Hz) is several micro g rms. A passive vibration isolation system attenuates higher frequency (> 1 Hz) vibration inputs from the ISS to below 500 micro g rms. Several layers of magnetic shielding are built into the instrument probe to protect the experiments from on-orbit variations in the magnetic field environment. Vibration and radiation monitors will provide experimenters near real-time data.

The responsibility for developing and testing the experiment hardware and software rests on the principal investigator, who may also choose to delegate the responsibility to a more experienced party including the LTMPF project staff located at NASA's Jet Propulsion Laboratory (JPL). In addition to general management and science support, JPL will also be

responsible for the final integration of experiment hardware to the facility and the engineering activities thereafter. Once on ISS, the experiments simultaneously take data for approximately five months. After cryogen depletion, LTMPF may continue to monitor environments on board the ISS while it awaits return by the Shuttle. Upon return to Earth, the experiments undergo de-integration and inspection at JPL. The facility and some of the experiment hardware are then refurbished for the next set of experiments. Each facility is designed to survive five cycles of testing, launch and landing. Taking turns to launch one facility ever 16 months will provide for up to twenty years of service to experiments that demand an environment of long duration microgravity at low temperature.

5.5 International Partner Research Accommodations

All of the previously described research accommodations, whether developed solely by the U.S. or under cooperative/barter agreements between the U.S. and the other IPs, are directly accessible to U.S.-based researchers. The following sections provide a summary of multi-user research facilities whose programmatic origin gives priority access to researchers based in non-U.S. IP countries.

5.5.1 ESA Accommodations

A complete description of the research accommodations being contributed to ISS by ESA are to be found in the ESA document *The International Space Station: A Guide for European Users* (ESA Publication BR-137). The resources allocated to European users are based on 5 ISPRs in the *Columbus* module and 2 Express Pallet Adapters on the *Columbus* external payload facility. Beyond this allocation, European researchers can gain access to whatever additional resources are being developed under barter or cooperative development agreements between ESA and other IPs.

European multi-user external research facilities for the *Columbus* Exposed Facility remain to be defined. The 5 ISPR locations allocated to ESA inside *Columbus* will be used to support the following facilities:

Biolab. *Biolab* is a single-rack multi-user facility that will support biological research on small plants, small invertebrates, microorganisms, animal cells, and tissue cultures. It will include an incubator equipped with centrifuges in which the preceding

experimental subjects can be subjected to controlled levels of accelerations.

Fluid Science Laboratory. This is a single-rack multi-user facility in which it will be possible to study dynamic phenomena of fluid media in micro-gravity.

European Physiology Modules. The *European Physiology Module* is a single-rack multi-user facility that will support investigations of respiratory and cardiovascular conditions, hormonal and body fluid shift, bone demineralization and neuroscience. The facility is based on a modular design concept to support diverse experiments.

European Drawer Rack. The *European Drawer Rack* is an ISPR-based holding rack designed to accommodate up to 8 independently-operating sub-rack payloads. The payloads have the option of being accommodated in Middeck Lockers or slightly larger Standard Experiment Drawers.

European Stowage Rack. This is a modular stowage rack designed to accommodate payload equipment and samples in Standard Experiment Drawers and Middeck Lockers. Power, data and thermal control resources are not provided to the stowed items.

5.5.2 NASDA Accommodations

The NASDA research accommodations are summarized in the NASDA publication *Space Station Japanese Experiment Module Multiuser Experiment Facilities Catalog*. The accommodations for Japanese users are based on 5 ISPRs in the JEM pressurized module, and 5 ports on the JEM-EF. Multi-user facilities for Japanese users on the EF remain to be defined, however. The 5 ISPR spaces will consist of three Materials Science Racks and two Life Sciences Racks. Some of the individual multi-user research facilities being developed for these racks are of sub-rack size, so that an individual ISPR may contain more than one facility.

The multi-user research facilities currently under development for Japanese users are as follows:

Gradient Heating Furnace (GHF). The GHF is allocated the entire resources of Materials Science Rack 1 and consists of the Material Processing Unit and Sample Cartridge Automatic Exchange Mechanism. The Material Processing Unit is a zone-type 1600°C (2912 °F) furnace with vacuum capabilities that accepts cartridge-type samples. In order to conserve crew resources on orbit, the sample cartridge is

automatically exchanged by the Sample Cartridge Automatic Exchange Mechanism.

Advanced Furnace for microgravity Experiment with X-ray radiography (AFEX). A multi-user image furnace with the capability for in-situ observation using X-ray radiography. A sample placed in the focus of a gold-plated ellipsoidal mirror is heated and melted by radiation from a 1500 W halogen lamp. Alternatively, isothermal heating of samples can be carried out using ceramic heaters placed around the sample. AFEX is allocated the entire resources of Materials Science Rack 2.

Electrostatic Levitation Furnace (ELF). The ELF is a materials research facility that uses electrostatic levitation for containerless sample processing. Laser heating provides for sample heating to temperatures of up to 2000°C (3632 °F) in a gas atmosphere or under vacuum. Observation is provided by a pyrometer, a thermal imaging system and a video camera. The ELF will occupy a sub-rack portion of an ISPR.

Isothermal Furnace (ITF). The ITF is a multipurpose furnace for forming materials and conducting research on solidification and diffusion of melting samples with a uniform temperature profile. Two locations are provided in this facility for addition of user-unique equipment. The ITF will occupy a sub-rack portion of an ISPR.

Cell Biology Experiment Facility (CBEF). The CBEF provides a controlled temperature, humidity and CO₂-level environment for fundamental life sciences research on small plants, animals, cells, tissues and microorganisms. A rotating table can provide g-levels from 0.1 to 2 g for specimens. The CBEF is a sub-rack payload currently slated to share rack space with the Clean Bench.

Clean Bench (CB). Provides a closed workspace for aseptic (glovebox) operations with life sciences and biotechnology materials. All materials entering and leaving the work volume pass through a pretreatment chamber for sterilization if required. The CB is currently paired in an ISPR with the CBEF.

Fluid Physics Experiment Facility (FPEF). Intended to support fluid physics experiments involving phenomena such as Marangoni convection, bubble generation, heat transfer, liquid wettability, combustion and bubble behavior in a moderate temperature environment. The FPEF is currently scheduled to share rack space with the Solution/Protein Crystal Growth Facility and the Image Processing Unit.

Solution/Protein Crystal Growth Facility (SPCF).

The SPCF has two major components, the protein Crystal Research Facility, for growing large, high-quality protein crystals for analysis on the ground, and the Solution Crystallization Observation Facility, for microscopic examination of the crystals on orbit. The two units can be operated independently. The SPCF will share rack space with the FPEF and the Image Processing Unit.

Image Processing Unit (IPU). The IPU receives experiment imagery from the experiment facilities and encodes the data either for downlink or storage on removable media. It has the capability to receive and compress four video signals simultaneously and to record the signals on four VCRs.

Minus Eighty-degree Laboratory Freezer for ISS (MELFI). This is a second unit of the MELFI described in Section 5.3.5 above.

Aquatic Animal Experiment Facility (AAEF). The AAEF is a sub-rack facility that will accommodate freshwater and saltwater organisms (such as Medaka fish) inside the JEM environment. The facility will be designed to accommodate experiments for up to 90 days, making it possible to conduct research ranging from early development and differentiation to individual responses in the microgravity environment.

6. Payload Operations

ISS Payload Operations include both the advanced planning for on-orbit research and the actual real-time operations for using on-board ISS laboratories. The advanced payload operations planning includes all the preparation activities in which the investigator's research objectives are defined and coordinated with other research payloads and the ISS system operations. Real-time operations are those activities that occur during the actual on-orbit conduct of the scientists' research protocols. These activities include conducting the experiment procedures, operating the experiment hardware, and gathering the experiment's data and samples.

The three goals of ISS Payload Operations are: 1) to give researchers some autonomy to manage and operate their research payloads; 2) to distribute operations capabilities; and 3) to provide researchers with operational flexibility.

6.1 User Autonomy

Unlike previous U.S. space vehicles, the ISS will operate continuously over several years, and will allow change-out and upgrade of payloads during that time. Planning for payload operations will allow new payloads to be added or permit the return of on-orbit payloads as part of the normal change process. Planning expertise will be geographically distributed at control centers and user sites around the world. ISS payload operations will be multidisciplinary and will include a broad range of crew-attended, unattended, automated, and telescience operations. NASA will provide Payload Operation Integration (POI) for ISS Payloads. POI is the assessment and management of interactions between multiple payloads, payload facilities, and Station systems, including interactions between hardware, software and operations. The NASA POI process involves developing integrated payload operations requirements, plans, and processes and ensures their compatibility with the flight system. This effort includes Station-wide payload operations management and integration, integrated payload planning and operations, and payload crew and ground personnel training and safety. Safety, operational effectiveness, and system-to-payload performance are the primary goals. The NASA POI process will integrate all U.S. users, regardless of the payload's location on orbit.

Researchers will have the choice of where their ground operations will be based. Whether located in a Telescience Support Center (TSC) at one of NASA's Field Centers, in the mission control center of an International Partner, or in a remote site such as a university research laboratory, researchers will be able to manage and operate their research. A TSC is a NASA facility equipped to conduct telescience operations on board ISS. A remote site is a non-NASA facility such as a Commercial Space Center, university, private industry, or non-NASA government agency. "Telescience" is defined as the acquisition of information through remote experimentation and observation. From laboratory desktop computers, Telescience will maximize the ability of researchers to communicate with the crew, to direct the "commanding" of their research hardware and software, and to manage the receipt, processing, and analysis of their research data. To support researchers in remote locations, NASA has developed the Telescience Resource Kit (TReK). TReK is a PC-based telemetry and command system which will give researchers access to their payload on board the ISS in addition to ground-based planning and information management systems (see TReK website, Appendix B).

Researchers will define their science planning requirements and provide their science expertise on payload and experiment operations. Investigators will develop the detailed operations plans for their experiments, will participate in training the crew, and will help develop the procedures the crew will use while in space. Researchers' planning inputs will also be used to develop an operational schedule for on-board activities.

6.2 Payload Ground Command and Control

ISS payload command and control is designed to give an ISS User maximum flexibility in choosing the location and method for controlling a given payload. The most simple option available is to control the payload by a payload operator who maintains personnel at the Huntsville Operations Support Center (HOSC) at the Marshall Space Flight Center. Within the HOSC is the Payload Operations and Integration Center (POIC) that will provide 24 hour, real-time monitoring of payloads. The POIC manages the execution of on-orbit ISS payloads and payload support systems in coordination/unison with distributed IP payload control centers, TSCs and payload unique-remote facilities. Through the POIC Users have several operational options for controlling their payloads, including the use of TrEK through a TSC or directly into the POIC as well as several others. Details on these options can be found on the POIC Webpage (Appendix B).

At each optional level, payload command and control data will be routed through the POIC to the Space Station Control Center at JSC, and then onto the White Sands Complex in New Mexico for uplink to ISS. Each command is uplinked through the Tracking and Data Relay Satellite System (TDRSS) to ISS with an expected round-trip latency of <4 seconds. ISS Users that are operating at or through a TSC will have that additional link in the payload command chain, but the latency will still be <4 seconds. Down-linked payload data will come from ISS through TDRSS to the White Sands Complex, and then directly to the HOSC for distribution to the payload operations sites, either a TSC or the payload developer's home institution.

6.3 Operational Flexibility

Because the ISS vehicle is designed for extensive communications, including voice, video, telemetry, and downloads of real-time and stored data, researchers will easily be able to assess the success or shortcomings of their on-orbit research protocols. Investi-

gators will be able to discuss problem areas with mission planners and will be better able to devise new procedures. For example, a procedure that resulted in a limited sample yield could be modified to improve future test results. ISS operations are designed to give scientists the flexibility to modify or enhance their experiment operations as long as they remain within their resource constraints. Detailed payload operations plans will be developed one week in advance, thus allowing researchers time to review previous data and revise their research approach, thereby improving the quality of data collection on later experiment runs.

7. Getting On Board: NASA Research and ISS

For potential ISS investigators located within the U.S., and for certain cases potential investigators outside the U.S., the selection, funding, and logistic support of research to be performed on board ISS is managed through the interaction between the ISS Program, and science, commercial and engineering Offices based at NASA Headquarters. The Offices manage a large range of research programs, of which research to be performed on ISS is only a subset. The Offices are as follows:

The Office of Life and Microgravity Sciences and Applications (OLMSA or Code U). OLMSA is divided into three Divisions: Life Sciences, Microgravity Research, and Space Utilization and Product Development. Life Sciences deals with the majority of life sciences and human research supported by NASA. The Microgravity Research Division (MRD) manages microgravity research involving the life and physical science. Space Utilization and Product Development is concerned with commercial projects related to either life sciences or microgravity sciences.

In addition to being responsible for solicitation, selection and funding of research within their respective disciplines, the Divisions also in certain cases set program requirement for development of the facility-class payloads that fall within their areas.

The Office of Space Science (OSS or Code S). OSS manages NASA research in the astronomical, planetary, and space sciences.

The Office of Earth Science (OES or Code Y). OES manages NASA's program in Earth observation and remote sensing.

The Office of Space Flight (OSF or Code M). OSF manages NASA's human space flight program and is responsible for the development of engineering innovations for next-generation spacecraft. Code M is involved in engineering research on the Station.

A concept of central importance to the potential ISS User is that each of these Offices has their own procedures for soliciting, selecting, and funding research to be done on ISS. To provide logistical and development support for research projects once they are funded, the Offices have implemented Research Project Offices (RPOs) at NASA Field Centers. The RPOs serve as the interface between research projects and the ISS Program, and perform other oversight and development tasks related to their disciplines.

At the present time, research funding for ISS is under distributed management between the Headquarters Offices and the ISS Payloads Office at Johnson Space Center (JSC Code OZ). The funding for investigator support and associated research costs is provided by the Headquarters Offices. The ISS Payloads Office manages the budget allocated for building the array of multi-user, facility-class and EXPRESS payloads that form the principal Space Station research infrastructure. While under this arrangement the majority of an ISS research investigator's budget resource will probably originate from the Headquarters Offices, a sub-set of additional resources may also flow from ISS Payloads. The degree of this subdivision depends on the type of project and the Headquarters Office program with which it is associated.

7.1 Life Sciences

The Life Sciences Division of OLMSA supports ISS flight experiments which are implemented through three programs: Biomedical Research and Countermeasures (BR&C), Fundamental Biology (FB), and Advanced Human Support Technology. Investigations for these programs are solicited primarily through an annual NASA Research Announcement (NRA).

In the areas of BR&C and FB, the NRA is coordinated with research announcements of the member agencies of the International Space Life Sciences Working Group (ISLSWG). Proposers responding to these announcements can utilize the capabilities for Life Sciences Research provided on ISS by all of the ISLSWG agencies. Review and selection of the proposals is coordinated by the ISLSWG agencies.

Selected proposals first enter a definition phase during which the technical feasibility is verified. Ex-

periments which successfully complete this phase then enter a development and operations cycle and are manifested to be performed on the ISS.

Details on the review and selection process may be found by downloading the most recent Life Sciences NRA from the following internet site:

✓ <http://peer1.idi.usra.edu/>

7.2 Microgravity Sciences

NASA supports research in microgravity sciences through the Microgravity Research Program managed by the Microgravity Research Division (MRD) of OLMSA. The mission of MRD is to "Obtain new knowledge and increase the understanding of gravity dependent phenomena obscured by the effects of gravity in biological, chemical and physical systems, and where feasible, to facilitate the application of that knowledge to academic and commercially viable products and processes." The support of MRD for microgravity research is allocated across five specific disciplines: Biotechnology, Combustion Science, Fluid Physics, Fundamental Physics, and Materials Science. NRAs describing funding opportunities for each of these disciplines are released by MRD on a projected cycle of 2 years.

The latest NRAs for microgravity science are available at:

✓ <http://peer1.idi.usra.edu/>

Proposals for microgravity science flight investigations first undergo a selection process, during which they are evaluated for initial funding based on scientific and technical merits. If an experiment is selected, it then enters into a multi-phase flight definition and development cycle.

7.2.1 Microgravity Science Experiment Selection

Microgravity Science flight experiment proposals will undergo a series of three reviews.

- 1) Scientific peer review for selection recommendation,
- 2) Science peer review for scientific feasibility,
- 3) Science and Engineering review for definition of requirements .

Criteria related to the scientific relevance, significance, quality, and necessity of using the space flight environment are included in the scientific peer review. The relevance of the experiment to programmatic priorities, scientific merit as evaluated by the

scientific peer review, technical risk as determined by the technical evaluation, funding availability and projection of future flight opportunities are also considered in the reviews. The PI must pass all 3 reviews before proceeding to flight. NASA HQ will make final selections.

7.2.2 *Microgravity Sciences Experiment Definition and Development*

Once a project is funded, its overall requirements for hardware development and access to NASA ground-based or flight facilities are coordinated by the Microgravity Research Program Office (MRPO) at NASA's lead center for microgravity research, Marshall Space Flight Center (MSFC). MRPO also conducts oversight of management and support tasks performed at other NASA centers for the specific microgravity science disciplines described above. A funded project that advances to flight status on ISS will generally have some aspects of its support, hardware development for example, assigned to the NASA center best suited to the project's microgravity discipline area. It is also the responsibility of the MRPO to be the bridge between an investigator and their first point of contact with the ISS program, which is the International Space Station Payloads Office at JSC.

In addition to the MRPO support role for specific microgravity research projects whether they ultimately fly on ISS or not, the MRPO monitors the development and implementation of the microgravity performance accommodations on the ISS, keeping the interests of the microgravity research community and potential microgravity investigators in mind.

7.3 Space Sciences

Research activities in the Space Sciences are funded through the Office of Space Science (OSS or Code S) at NASA Headquarters. The mission statement of the OSS is, "From origins to destiny, chart the evolution of the Universe and understand its galaxies, stars, planets, and life." The OSS supports four fundamental areas of research:

- the Search for Origins,
- the Structure and Evolution of the Universe,
- the Exploration of the Solar System, and
- the Sun-Earth Connection.

Space science research will be conducted on ISS primarily through the use of attached payloads. In

addition to opportunities for EXPRESS Pallet Adapter, JEM-EF, and *Columbus* Exposed Payload Facility payloads, OSS is investigating full truss site payloads with their greater capacity for mass and volume. This type of payload is ideal for investigations such as cosmic ray research, which require a large viewing area and large mass with tolerant pointing requirements. Astrobiology research will be conducted in conjunction with Code U using their selection and funding processes.

The OSS uses NASA Announcements of Opportunity (AOs) to fund flight missions. At this time, the OSS does not have a specific AO for ISS payloads. Instead, the Missions of Opportunity (MoO) class under the Explorer Program AOs will provide the opportunity to propose ISS payloads. The MoOs are available in all Explorer AOs, including Medium-class Explorers (MIDEX), Small Explorers (SMEX), and University-class Explorers (UNEX).

Space science ISS payloads selected under the Explorers AOs will be funded and managed through the Explorers Program. The Program will provide a mission manager for each selected payload. The primary interface between all potential and selected payloads and the SSPO is the OSS RPO located at Goddard Space Flight Center in Greenbelt, MD.

7.4 Earth Sciences

NASA supports research and development activities in the Earth Sciences through the Office of Earth Science (OES) at NASA Headquarters. The mission of OES is "to develop understanding of the total Earth system and the effects of natural and human-induced changes on the global environment". OES research is expected to encompass the areas of science and applications. Opportunities will exist for attached payloads, as well as pressurized payloads in the WOLF. Due to the global coverage of the ISS orbit, ISS payloads are appropriate for most of the Earth science disciplines.

The OES uses both AOs and NASA Research Announcements to fund research. At this time, the OES does not have a specific AO for ISS payloads. Opportunities for both attached payloads and WOLF payloads will be offered under the Earth System Science Pathfinder (ESSP) and University Earth System Science (UnESS) AOs. WOLF payloads may also be selected by NRAs.

Earth science ISS payloads selected under the ESSP Project and UnESS Project AOs will be funded and managed through these associated Projects. ESSP and

UnESS will provide mission managers for each selected payload. The primary interface between all potential and selected payloads and the SSPO is the OES RPO located at Goddard Space Flight Center in Greenbelt, MD.

7.5 Engineering Research and Technology

The Space Station Payloads Office funds Engineering Research and Technology (ERT) payloads that use the Station as a testbed and which develop, test and demonstrate technologies that can improve the ISS systems or payloads capabilities, lower the costs of maintenance or operations, and reduce power or crew time requirements. ISS also funds the Commercial Space Center (CSC) for Engineering that facilitates industry's use of the ISS for engineering research and technology development.

New technologies are flown as demonstration payloads so that the capabilities and reliability of a new technology can be verified before committing that technology for use on the ISS. The ERT payloads are also used to demonstrate technologies that are important to exploration programs and commercial interests. Both pressurized and un-pressurized payloads are funded through this program.

The Space Station Payloads Office has designated the Johnson Space Center's Technology Planning Office (JSC/EX2) as the manager of the ERT Program Office. The ERT payload resource allocation on the ISS is part of the payload allocation for the NASA Office of Spaceflight (Code M).

7.6 Commercial Payloads

The commercial payload development (CPD) effort, precipitated by passing of the Federal Commercial Space Act of 1998, seeks to establish a marketplace and stimulate a national economy for space products and services in low Earth orbit, where both demand and supply are dominated by the private sector. In the short term, the program will begin the transition to private investment and offset a share of the public cost for operating the Space Shuttle fleet and the ISS through commercial enterprise in open markets. Basic and applied research in science and technology,

both in space and on the ground, is expected to continue in the tradition of the government-sponsored space program.

Several parties inside and outside NASA are cooperating in the planning and execution of CPD. OLMSA (Code U) and the Office of Space Flight (Code M), both at NASA Headquarters, jointly hold broad program definition, initiation, facilitation, and monitoring responsibilities for the overall CPD Program.

A joint Headquarters-ISS commercial offer process is evaluating pathfinder projects, working to remove barriers to feasible projects, and referring feasible offers to the appropriate NASA field centers for further evaluation. As promising pathfinder projects are implemented, the lessons learned will be applied to complete NASA's overall ISS commercialization policy, leading to eventual establishment of routine commercial research operations on the ISS.

OLMSA, through its Space Utilization and Product Development Division (Code UM) at NASA Headquarters, facilitates participation and investment in space-linked commercial goods and services in order to benefit U.S. industry and the economy as a whole. Funding for payload hardware to support the commercial and technology experiments planned for the ISS is included under the ISS Research Program managed by the ISS Payloads Office (Code OZ) at JSC. Program management for Space Utilization and Product Development is carried out by the Space Utilization and Product Development Office at Marshall Space Flight Center in Huntsville, Alabama, and the Space Technology and Engineering Applications Program at JSC.

To accomplish orbital commercial research and to develop industry partnerships, the Space Utilization and Product Development program uses Commercial Space Centers (CSCs) which are non-profit organizations based at universities, or other non-profit centers. The CSCs provide support and expertise to encourage industry to conduct space research in areas such as biotechnology, agribusiness, and materials. A company that wants to become involved in space research can begin by establishing a partnership with a CSC that emphasizes the appropriate technical research area. A list of CSCs is provided in Appendix D.

Appendix A. Related Documents

The following documents contain supplemental information to guide the user in the application of this document. These reference documents may or may not be specifically cited within the text of the *Guide*.

Document No.	Title	Type, source
SSP 52000-PAH-PRP, Rev. A	ISS Payload Accommodations Handbook for Pressurized Payloads	Multilateral-ISS Internal
SSP 52000-PAH-ERP, Draft	ISS Payload Accommodations Handbook, EXpedite the PROcessing of Experiments to Space Station (EXPRESS) Rack Payloads	Multilateral-ISS Internal
SSP 57003	Attached Payload Interface Requirements Document	NASA-ISS Internal
SSP 57021	Attached Payloads Accommodation Handbook	NASA-ISS Internal
NP-1998-02-232-HQ, Rev 1	Improving Life on Earth and in Space: The NASA Research Plan, an Overview	NASA Internal
No Number	Science and Technology Research Directions for the International Space Station	NASA Internal, available at: http://www.hq.nasa.gov/office/olmsa/
JPL 400-808, 4/99	Fundamental Physics in Space Roadmap	NASA Internal
No Number	Space Station Japanese Experiment Module Multiuser Experiment Facilities Catalog	NASDA Internal
No Number	Centrifuge	NASDA Internal
No Number	Space Station Integration & Promotion Center: The Base for Japan's International Space Station Program	NASDA Internal
JBX-98079	Introductory Guidebook for JEM Exposed Facility Potential Users	NASDA Internal
BR-137, February 1999	The International Space Station: A Guide for European Users	ESA Internal, available at: http://esapub.esrin.esa.it
No Number	International Space Station	NASDA Internal
No Number	International Space Station Fact Book, July 1999	NASA Internal
TD9702A	ISS Familiarization Manual	NASA Internal, available at: http://spaceflight.nasa.gov/station/reference/index.html
LS71001	Functional Requirements Document for the Human Research Facility	NASA Internal
AIAA 99-0312	Low Temperature Microgravity Physics Facility	AIAA Publication
AIAA 99-0314	X-ray Crystallography Facility for the International Space Station	AIAA Publication
AIAA 99-0313	EXPRESS Rack Overview	AIAA Publication

Appendix B. Related Websites

Official NASA external websites are organized below according to the sections and sub-sections of the *Guide* for which they are relevant. An official NASA-site search engine is available at:

✓ <http://www.nasa.gov/search/index.html>

1. Introduction

✓ NASA Human Space-ISS Home <http://spaceflight.nasa.gov/station/index.html>

1.1 Document Purpose and Structure

1.2 ISS History and Overview

✓ NASA Homepage <http://www.nasa.gov>
 ✓ NASA Headquarters Homepage <http://www.hq.nasa.gov/>
 ✓ NASA Field Centers <http://www.nasa.gov/nasaorgs/index.html>
 ✓ NASA Human Space-ISS Home <http://spaceflight.nasa.gov/station/index.html>
 ✓ Spaceflight History <http://spaceflight.nasa.gov/history/>
 ✓ JSC Homepage <http://www.jsc.nasa.gov/>
 ✓ ISS IPs, IP Homepages <http://spaceflight.nasa.gov/station/reference/partners/index.html>
 ✓ ISS Partners Sign Agreements http://spaceflight.nasa.gov/station/reference/partners/special/iss_aggrements/index.html
 ✓ RSA Homepage <http://www.rka.ru/english/eindex.htm>
 ✓ ESA Homepage <http://www.esa.int/>
 ✓ NASDA Homepage http://www.nasda.go.jp/index_e.html
 ✓ ISS Multilateral Agreement <http://www.hq.nasa.gov/office/codei/>

1.3 NASA Research Coordination and Advisory Committees

2. ISS Development

2.1 Assembly Sequence

✓ Phase I Shuttle-Mir <http://spaceflight.nasa.gov/history/>
 ✓ ISS Assembly Website <http://spaceflight.nasa.gov/station/assembly/index.html>

2.2 Build-up of Resources and Early Utilization

✓ Evolution of Resources <http://spaceflight.nasa.gov/station/assembly/elements/uslab/evolut.htm>

3. ISS Research Elements

✓ ISS Graphical Overview-PLAID Lab <http://spaceflight.nasa.gov/station/assembly/plaid/>
 ✓ ISS Virtual Tour <http://spaceflight.nasa.gov/gallery/vtour/index.html>

3.1 A Module Named “Destiny”: The U.S. Laboratory Module

✓ U.S. Lab PLAID view <http://spaceflight.nasa.gov/station/assembly/plaid/lab.jpg>
 ✓ U.S. Laboratory Module <http://spaceflight.nasa.gov/station/assembly/elements/uslab/>

3.2 U.S. Centrifuge Accommodations Module (CAM)

✓ CAM PLAID view <http://spaceflight.nasa.gov/station/assembly/plaid/cen.jpg>
 ✓ ISS Biological Research Project http://spaceprojects.arc.nasa.gov/Space_Projects/SSBRP/index.html

3.3 U.S. Integrated Truss Attachments

3.4 Japanese Experiment Module (JEM)

✓ NASDA ISS Home Page http://jem.tksc.nasda.go.jp/index_e.html
 ✓ NASDA JEM Website http://jem.tksc.nasda.go.jp/iss_jem/index_e.html

3.5 Columbus Module

✓ ESA Columbus Website <http://www.estec.esa.nl/spaceflight/incolab.htm>

3.6 Russian Segment

✓ Russian Space Agency Website <http://www.rka.ru/english/eindex.htm>

4. The ISS Environment

4.1 Orbital Parameters and Models of Operation

✓ ISS Orbit and Tracking <http://spaceflight.nasa.gov/realdata/tracking/index.html>

4.2 Microgravity

✓ OLMSA-MG Research Div. <http://microgravity.hq.nasa.gov/>
 ✓ OLMSA-Understanding Microgravity <http://mgnews.msfc.nasa.gov/db/understanding Ug/understanding Ug.html>
 ✓ MSFC-What is Microgravity? <http://www1.msfc.nasa.gov/NEWMSC/slgl.html>
 ✓ MSFC-MRPO <http://microgravity.nasa.gov/index.html>

4.2.1 Quasi-steady Requirements

4.2.2 Vibratory Requirements

4.2.3 Microgravity Acceleration Measurement

✓ Microgravity measurement http://microgravity.grc.nasa.gov/MSD/MSD_htmls/mmap.html
 ✓ PI Microgravity Services http://microgravity.grc.nasa.gov/MSD/MSD_htmls/PIMS.html

4.4 Internal Environment Control and Monitoring**4.5 External Environment Control and Monitoring****5. Accommodations for Research on ISS****5.1 Resource Allocation**

- ✓ ISS Multilateral Agreement <ftp://ftp.hq.nasa.gov/pub/pao/reports/lga.html>

5.2 Station-wide Resource

- 5.2.1 Power
- 5.2.2 Payload Data Handling and Communication
- 5.2.3 Thermal Management
- 5.2.4 Payload Stowage
- 5.2.5 Fluids and Gasses Available
- 5.2.6 Crew Resources
 - ✓ ISS Crew Information <http://spaceflight.nasa.gov/station/crew/index.html>
- 5.2.7 Crew Health Care System

5.3 Generic NASA Accommodations for Research Payloads

- 5.3.1 International Standard Payload Rack
- 5.3.2 Active Rack Isolation System
- 5.3.3 Sub-Rack Accommodations and EXPRESS Rack
- 5.3.4 Nadir Research Window
- 5.3.5 Laboratory and Station Support Equipment
 - ✓ Laboratory Support Equipment <http://floyd.msfc.nasa.gov/msg/investigations/develop/lse/lse.html>
- 5.3.6 U.S. Truss Site Payload Accommodations and EXPRESS Pallet
- 5.3.7 JEM and Columbus Exposed Facility Payload Accommodations
 - ✓ ESA ISS Multi-User Facilities <http://www.estec.esa.nl/spaceflight/index.htm>
 - ✓ NASDA ISS Multi-User Facilities <http://jem.tksc.nasda.go.jp/JEM/jemmefc/english/index.html>

5.4 Multi-User Facilities: The Facility-Class Payload Concept

- 5.4.1 Human Research Facility
 - ✓ HRF Homepage <http://lslife.jsc.nasa.gov/>
- 5.4.2 Gravitational Biology Facility
 - ✓ Space Station Bio Research Fac http://spaceprojects.arc.nasa.gov/Space_Projects/SSBRP/index.html
 - ✓ Fundamental Biology (Grav Bio) <http://spaceflight.nasa.gov/station/science/disciplines/life/index.html>
 - ✓ Grav. Bio RPO-Ames <http://www.gravbio.nasa.gov/>
- 5.4.3 Biotechnology Research Facility
 - ✓ MRPO Biotech Program <http://microgravity.nasa.gov/Biot.html>
 - ✓ Biotechnology Facility Catalog <http://microgravity.nasa.gov/mf.html>
- 5.4.4 Fluids and Combustion Facility
 - ✓ FCF Homepage <http://zeta.lerc.nasa.gov/fcfwww/index.htm>
 - ✓ MRPO Combustion Program <http://microgravity.nasa.gov/Combustion.html>
 - ✓ MRPO Fluids Program <http://microgravity.nasa.gov/FFTP.html>
- 5.4.5 Microgravity Sciences Glovebox
 - ✓ MSG Homepage <http://floyd.msfc.nasa.gov/msg/msg.html>
 - ✓ MRPO Glovebox Program <http://microgravity.nasa.gov/Glov.html>
- 5.4.6 Materials Science Research Facility
 - ✓ MSRF "on the rack" <http://spaceflight.nasa.gov/station/science/features/Experimenters/index.html>
 - ✓ MSRF Catalog (preliminary) <http://microgravity.nasa.gov/mf.html>
- 5.4.7 Window Observational Research Facility
- 5.4.8 X-ray Crystallography Facility
- 5.4.9 Advanced Human Support Technology Facility
 - ✓ OLMSA AHST Program <http://www.hq.nasa.gov/office/olmsa/lifesci/advhuman.htm>
- 5.4.10 Low-Temperature Microgravity Physics Facility
 - ✓ LTMPF Homepage <http://ltmpe.jpl.nasa.gov/>
 - ✓ MRPO Fmtl. Physics Program <http://microgravity.nasa.gov/FundaPhy.html>

5.5 International Partner Research Accommodations

- 5.5.1 ESA Accommodations
 - ✓ ESA ISS Multi-User Facilities <http://www.estec.esa.nl/spaceflight/index.htm>
- 5.5.2 NASDA Accommodations
 - ✓ NASDA ISS Multi-User Facilities <http://jem.tksc.nasda.go.jp/JEM/jemmefc/english/index.html>

6. Payload Operations**6.1 User Autonomy****6.2 Payload Ground Command and Control**

- ✓ Huntsville Operations Sup. Center <http://www1.msfc.nasa.gov/NEWSROOM/background/facts/hosc.htm>
- ✓ TReK Homepage <http://mole.msfc.nasa.gov/trek/welcome.htm>
- ✓ POIC Homepage <http://mole.msfc.nasa.gov/trek/poic.htm>

6.3 Operational Flexibility

7. Getting On Board: NASA Research and ISS

- ✓ OLMSA-Code U Homepage <http://www.hq.nasa.gov/office/olmsa/index.htm>
- ✓ Office of Space Science-Code S <http://spacescience.nasa.gov/>
- ✓ Office of Earth Science-Code Y <http://www.earth.nasa.gov/>
- ✓ Office Space Flight-Code M <http://spaceflight.nasa.gov/index-m.html>
- 7.1 Life Sciences**
 - ✓ OLMSA Life Sci. Division <http://www.hq.nasa.gov/office/olmsa/lifesci/index.htm>
 - ✓ Life Science Res. Opportunities <http://peer1.idi.usra.edu/>
 - ✓ Grav. Biology RPO at Ames <http://www.gravbio.nasa.gov/>
- 7.2 Microgravity Sciences**
 - ✓ OLMSA MG Research Division <http://microgravity.hq.nasa.gov/>
 - ✓ MG Science Res. Opportunities <http://peer1.idi.usra.edu/>
 - ✓ MRPO at Marshall SFC <http://microgravity.nasa.gov/index.html>
 - 7.2.1 *Microgravity Science Experiment Selection*
 - 7.2.2 *Microgravity Sciences Experiment Definition and Development*
- 7.3 Space Sciences**
 - ✓ Office of Space Science-Code S <http://spacescience.nasa.gov/>
- 7.4 Earth Sciences**
 - ✓ Office of Earth Science-Code Y <http://www.earth.nasa.gov/>
- 7.5 Engineering Research and Technology**
 - ✓ ERT Program <http://spaceflight.nasa.gov/station/science/disciplines/ert/index.html>
- 7.6 Commercial Payloads**
 - ✓ ISS Commercial Development <http://commercial.hq.nasa.gov/>
 - ✓ OLMSA SUPD <http://www.hq.nasa.gov/office/olmsa/spd/index.htm>
 - ✓ MRPO Space Product Develmt. <http://microgravity.nasa.gov/spd.html>
 - ✓ OLMSA Related Sites <http://www.hq.nasa.gov/office/olmsa/links/index.htm>
- Appendix A. Related Documents**
 - ✓ ESA Documents <http://esapub.esrin.esa.it>
 - ✓ NASA Scientific and Tech. Info. <http://www.sti.nasa.gov/>
- Appendix B. Related Websites**
- Appendix C. Station Assembly Flights**
 - ✓ ISS Assembly Website <http://spaceflight.nasa.gov/station/assembly/index.html>
- Appendix D. Commercial Space Centers**
 - ✓ OLMSA SUPD <http://www.hq.nasa.gov/office/olmsa/spd/index.htm>
- Appendix E. Acronym List**
 - ✓ NASA ISS Acronyms <http://spaceflight.nasa.gov/station/reference/index.html>

Appendix C. Station Assembly Flights

A list of ISS Assembly Flights is shown below. This is provided as a conceptual guide to the reader based on the sequence of flights in Revision E of the ISS Assembly Sequence, which was current as of December, 1999. For an up-datable more complete reference the reader should visit NASA's ISS Assembly webpage at:

✓ ISS Assembly Website <http://spaceflight.nasa.gov/station/assembly/index.html>

Flights that use the U.S. Space Shuttle have a corresponding STS number in the second column. Non-STS flights utilize Russian crewed *Soyuz* vehicles ("S" in flight name), or un-crewed *Progress* vehicles ("P" in flight name). Utilization of un-crewed European and Japanese vehicles will be added to the Sequence as these programs evolve.

Flight Name	STS No.	Delivered Elements
1A/R		FGB "Zarya"
2A	88	Node 1 (1 Stowage rack), PMA1, PMA2, 2 APFRs (on Side-walls)
2A.1	96	Spacehab Double Cargo Module; OTD, Strela Components(on ICC)
1R		Service Module (Launched on PROTON launcher)
1P		Progress-M1
2A.2	101	Spacehab Double Cargo Module; Strela Components (on ICC)
2P		Progress-M1
3A	92	Z1 truss, CMGs, Ku-band, S-band Equip; PMA3, EVAS (SLP); 2 Z1 DDCUs (Sidewall)
2R		Soyuz TM [3 person crew capability]
4A	97	P6, PV Array (6 battery sets) / EEATCS radiators, S-band Transponder
3P		Progress-M1
5A	98	P6, PV Array (6 battery sets) / EEATCS radiators, S-band Transponder
4P		Progress-M1
4R		Docking Compartment 1 (DC1), Strela
5A.1	102	Lab Outfitting (6 Sys racks, RSRs, RSPs, ISPR) (on MPLM); EAS, PFCS, LCA, and RU (on ICC)
5P		Progress-M
6A	100	Lab Outfitting (6 Sys racks, RSRs, RSPs, ISPR) (on MPLM); EAS, PFCS, LCA, and RU (on ICC) [microgravity capability]
2S		Soyuz – TM1
6P		Progress-M1
7A	104	Airlock, HP gas (2 O2, 2 N2) (on SLDP) [Phase 2 complete]
7A.1	105	RSRs, RSPs, ISPRs (on MPLM); OTD, APFR (on Sidewall)
UF-1	106	ISPRs, RSRs, RSPs, MELFI (on MPLM)
3S		Soyuz TMA
8A	109	S0, MT, GPS, Umbilicals, A/L Spur
UF2	110	ISPRs, 3 RSRs, RSPs (MPLM); MBS; PDGF (Sidewalls)
9A	112	S1 (3 rads), TCS, CETA (1), S-band
4S		Soyuz -TMA
11A	113	P1 (3 rads), TCS, CETA (1), UHF
9A.1	115	Science Power Platform w/4 solar arrays and ERA
5S		Soyuz TMA
12A	116	P3/4, PV Array (4 battery sets), 2 ULCAS
12A.1	118	ISPR, RSRs, RSPs (MPLM); P5 w/Radiator OSE
13A	119	S3/4, PV Array (4 battery sets), 4 PAS

Flight Name	STS No.	Delivered Elements
3R		Universal Docking Module (UDM)
5R		Docking Compartment 2 (DC2)
10A	121	Node 2 (4 DDCU racks); NTA (on Sidewall)
10A.1	122	Propulsion Module
1J/A	124	ELM PS (4 Sys, 3 ISPRs, 1 Stow); 2 SPP SA w/ truss, Conform. Shields (ULC)
1J	125	JEM PM (4 JEM Sys racks), JEM RMS
UF3	127	ISPRs, 1 JEM rack, RSPs, (on MPLM); Express Pallet w/ Payloads
UF4	128	Truss Attach Site P/L; Express Pallet w/ Payloads; ATA, SPDM (SLP)
2J/A	129	JEM EF, ELM-ES w/ Payloads and SFA; 4 PV battery sets (on SLP)
9R		Docking & Stowage Module (DSM) (FGB module type)
14A	131	2 SPP SA w/ truss, 4 SM MMOD Wings (ULC); Cupola (SLP); MT/CETA Port Rails (SLP)
UF5	132	ISPRs, RSPs (on MPLM); Express Pallet w/ Payloads
20A	134	Node 3 (2 Avionics, 2 ECLSS racks)
1E	135	Columbus Module (5 ISPRs)
8R		Research Module #1 (RM-1)
17A	136	1 Lab Sys, 4 Node 3 Sys, 2 CHeCS, RSPs, ISPRs (MPLM) - ©
18A	137	CRV #1, CRV adapter - (d)
19A	138	RSPs, 1 RSR, ISPRs, 4 Crew Qtrs. (on MPLM); S5 - (e)
15A	139	S6, PV Array (4 battery sets), Stbd MT/CETA rails
10R		Research Module #2 (RM-2)
UF7	140	Centrifuge Accommodations Module (CAM), ISPRs (TBD 3-1)
UF6	141	RSPs, ISPRs (on MPLM); 2 PV battery sets (SLP)
16A	142	Hab (6 Hab sys racks, 2 RSRs, ISPRs) - (f)

Appendix D. Commercial Space Centers

The following is a list of Commercial Space Centers (CSCs). Additional information is available on the OLMSA Space Product Development webpage at:

✓ <http://www.hq.nasa.gov/office/olmsa/spd/index.htm>

1. **Center for BioServe Space Technologies**, University of Colorado-Boulder, Department of Aerospace Engineering Sciences, Campus Box 429, Boulder, CO 80309. Established October 1, 1987. Director: Dr. Louis Stodieck, Tel: 303-492-4010, Fax: 303-492-8883, stodieck@colorado.edu, www.Colorado.EDU/engineering/BioServe/
2. **Center for Commercial Applications of Combustion in Space**, 1500 Illinois Street, Colorado School of Mines Golden, CO 80401. Established May 1, 1996. Director: Dr. Franklin D. Showengardt. Tel: 303-384-209, Fax: 303-384-2327, fschowen@mines.edu, www.physics.mines.edu/ccacs/
3. **Center for Biophysical Sciences and Engineering (Formerly Center for Macromolecular Crystallography)**, University of Alabama-Birmingham, MCLM 262, 1530 3rd Avenue South, Birmingham, AL 35294-0005. Established October 1, 1985. Director: Dr. Lawrence DeLucas, Tel: 205-934-5329, Fax: 205-934-0480, delucas@cmc.uab.edu, www.cmc.uab.edu/
4. **Solidification Design Center**, Auburn University, 201 Ross Hall, Auburn, AL 36849. Established: January 28, 1997, Director: Dr. Tony Overfelt, Tel: 334-844-5940, Fax: 334-884-3400 overfra@mail.auburn.edu
5. **Commercial Space Center for Engineering**, 223 Weisenbaker Engineering Research Center, Texas A&M University, College Station, TX 77843-3118. Established May 8, 1998, Director: Dr. David Boyle, Tel: 409-845-8768, Fax: 409-847-8857, dboyle@tamu.edu
6. **Consortium for Materials Development in Space**, University of Alabama – Huntsville, Research Institute Building/M-6517, 301 Sparkman Drive, Huntsville, AL 35899. Established October 1, 1985, Director: Dr. William Gathings, Tel: 256-890-6620, Fax: 256-890-6791, gathinw@email.uah.edu, www.smaplab.ri.uah.edu/~cmds/
7. **Center for Advanced Microgravity Materials Processing**, Northeastern University, 342 Snell Engineering Center, 260 Huntington Ave., Boston, MA 02155. Established June 16, 1997, Director: Dr. Albert Sacco, Jr., Tel: 617-373-2989, Fax: 617-373-2209, asacco@coe.neu.edu
8. **Space Vacuum Epitaxy Center**, University of Houston, Science and Research Building 1, 4800 Calhoun Road Houston, TX 77204 –5507, Established October 1, 1986, Director: Dr. Alex Ignatiev, Tel: 713-743-3621, Fax: 713-747-7724, ignatiev@uh.edu, www.svec.uh.edu/
9. **Wisconsin Center for Space Automation and Robotics**, 2348 Engineering Hall, 1415 Engineering Drive, College of Engineering, University of Wisconsin – Madison, Madison, WI 53706-1687, Established October 1, 1986, Director: Dr. Weijia Zhou, Tel: 608-262-5526, Fax: 608-262-9458, wzhou@facstaff.wisc.edu, www.engr.wisc.edu/centers/wcsar/
10. **Medical Informatics & Technology Application Center**, Department of Surgery, VCV Hospital - West Hospital, 1200 E. Broad Street - 16th Floor, Richmond, VA 23289, Established June 1, 1997, Director: Ronald C. Merrell, M.D., Phone: 804-828-1141, Fax: 804-827-1016, ronald.merrell@vcu.edu
11. **ITD ProVisions Technology Commercial Space Center**, Bldg. 1103, Suite 118, Stennis Space Center, MS 39529, Established: October 1, 1997 Director: Dr. George May, Tel: 228-688-2509, Fax: 228-688-2861 gmay@IFTD.org
12. **Life Sciences Division Food Technology Commercial Technology Space Center**, 194 Meat Lab, Iowa State University, Ames, Iowa 50011-3150, Established: August 4, 1999, Director: Dr. Dennis Olson, Tel: 515-294-1055, Fax: 515-294-6328, dgolson@iastate.edu

13. **Center for Space Power**, 223 Weisenbaker Engineering Research Center, Texas A & m University, College Station, TX 77843-3118, Established October 1, 1987, Director: Dr. Frederick Best, Tel: 409-845-8768, Fax: 409-847-8857, FRB449A@acs.tamu.edu
14. **Center for Space Power and Advanced Electronics**, Auburn University, Space Power Institute, 231 Leach Center, Auburn, AL 36849-5320, Director: Dr. Henry W. Brandhorst, Jr., Tel: 334-844-5894 , Fax: 334-844-5900brandhh@mail.auburn.edu, hyperoptic.spi.auburn.edu/ccdspage.html
15. **Satellite & Hybrid Communications Networks**, University of Maryland, Systems & Research Center, V. Williams Building, Room 3117, College Park, MD 20742, Established November 1, 199, Director: Dr. John S. Baras, Tel: 205-934-5329, Fax: 205-934-0480, baras@src.umd.edu
16. **Space Communications Technology Center**, Florida Atlantic University, 777 Glades Road, Boca Raton, FL 33431, Established November 1, 1991, Director: Dr. William Glenn, Tel: 561-297-2343, Fax: glenn@fau.edu

Appendix E. Acronym List

Acronyms used in the *Guide* are listed below. Further Information on NASA ISS-related acronyms is available through the Internet at:

✓ NASA ISS Acronyms

<http://spaceflight.nasa.gov/station/reference/index.html>

Acronym	Definition
AAA	Avionics Air Assembly
AAEF	Aquatic Animal Experiment Facility
AC	Assembly Complete
ACISS	Advisory Committee on the International Space Station
AFEX	Advanced Furnace for microgravity Experiment with X-ray radiography
AHSTF	Advanced Human Support Technology Facility
AIAA	American Institute of Aeronautics and Astronautics
AO	Announcement of Opportunity
APCF	Advanced Protein Crystallization Facility
APS	Automated Payload Switch
ARIS	Active Rack Isolation System
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
BR&C	Biomedical Research and Countermeasures
BRF	Biotechnology Research Facility
CAM	Centrifuge Accommodation Module
CB	Clean Bench
CBEF	Cell Biology Experiment Facility
ChCS	Crew Health Care System
CIR	Combustion Integrated Rack
CPD	Commercial Payload Development
CSA	Canadian Space Agency
CSC	Commercial Space Center
EFU	Exposed Facility Unit
ELF	Electrostatic Levitation Furnace
ELM-ES	Experiment Logistics Module – Exposed Section
ELM-PS	Experiment Logistics Module – Pressurized Section
EM	Experiment Module
EMCS	Experimental Modular Cultivation System
ERT	Engineering Research and Technology
ESA	European Space Agency
ESSP	Earth System Science Pathfinder
EVA	Extravehicular Activity
ExPA	EXPRESS Pallet Adapter
EXPRESS	EXPedite the PROcessing of Experiments to the Space Station
FB	Fundamental Biology
FCF	Fluids and Combustion Facility
FIR	Fluids Integrated Rack
FPEF	Fluid Physics Experiment Facility
GBF	Gravitational Biology Facility
GHF	Gradient Heating Furnace
HHR	Habitat Holding Rack
HOSC	Huntsville Operations Support Center
HQ	Headquarters (NASA Headquarters)

Acronym	Definition
HRDL	High-Rate Data Link
HRF	Human Research Facility
HRFM	High Rate Frame Multiplexer
ICS	Interorbit Communication System
IP	International Partner
IPU	Image Processing Unit
ISLSWG	International Space Life Sciences Working Group
ISPR	International Standard Payload Rack
ISS	International Space Station
ITF	Isothermal Furnace
JEM	Japanese Experiment Module
JEM-EF	Japanese Experiment Module - Exposed Facility
JEM-PM	Japanese Experiment Module – Pressurized Module
JEM-RMS	Japanese Experiment Module – Remote Manipulator System
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LSE	Laboratory Support Equipment
LTMPF	Low-Temperature Microgravity Physics Facility
LVLH	Local Vertical-Local Horizontal
MAMS	Microgravity Acceleration Measurement System
MDM	Multiplexer De-Multiplexer
MELFI	Minus Eighty-degree Laboratory Freezer for the ISS
MI	Module Insert
MIDEX	Medium-class Explorer
MIL-STD	Military Standard
MLE	Middeck Locker Equivalent
MoO	Mission of Opportunity
MPLM	Multi-Purpose Logistics Module
MRD	Microgravity Research Division
MRPO	Microgravity Research Program Office
MSFC	Marshall Space Flight Center
MSG	Microgravity Sciences Glovebox
MSRF	Materials Science Research Facility
MSRR	Materials Science Research Rack
NAC	NASA Advisory Council
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NRA	NASA Research Announcement
OES	Office of Earth Science
OLMSA	Office of Life and Microgravity Sciences and Applications
OSF	Office of Space Flight
OSS	Office of Space Science
PI	Principal Investigator
PIMS	Principal Investigator Microgravity Services
PIU	Payload Interface Unit
PM	Pressurized Module
POI	Payload Operation Integration
POIC	Payload Operations Integration Center
RMS	Root-mean-square
RPO	Research Program Office

Acronym	Definition
RSA	Russian Space Agency
RSP	Resupply Stowage Platform
RSR	Resupply Stowage Rack
SAMS II	Space Acceleration Measurement System
SAR	Shared Accommodations Rack
SIR	Standard Interface Rack
SMEX	Small Explorer
SPCF	Solution/Protein Crystal Growth Facility
SQUID	Superconducting Quantum Interference Device
SSE	Station Support Equipment
SSPO	Space Station Program Office
SSUAS	Space Station Utilization Advisory Subcommittee
STS	Space Transportation System (Space Shuttle)
TDRSS	Tracking and Data Relay Satellite System
TReK	Telescience Resource Kit
TSC	Telescience Support Center
UNESS	UNiversity Earth System Science
UNEX	University-class Explorer
UV	Ultraviolet
WORF	Window Observational Research Facility
XCF	X-ray Crystallography Facility
XPOP	X-axis Perpendicular to Orbital Plane
XVV	X-axis toward Velocity Vector
ZSR	Zero-G Stowage Rack