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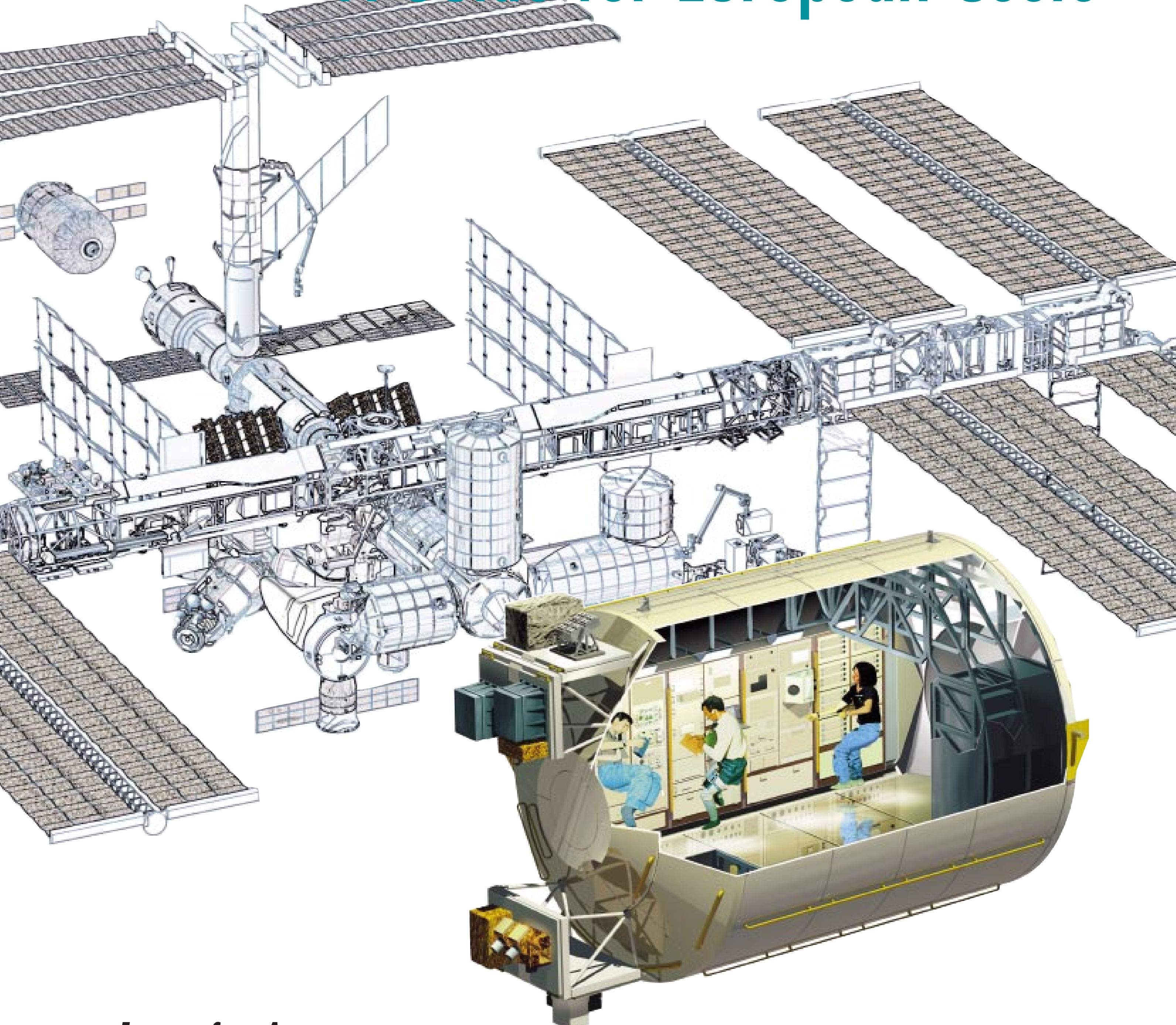
The International Space Station
A Guide for European Users



European Space Agency
Agence spatiale européenne

Directorate of Manned Spaceflight and Microgravity
Direction des Vols Habités et de la Microgravité

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Contents

Introduction

Purpose

The International Space Station: A Guide for European Users has been prepared to provide prospective users of the International Space Station (ISS) with basic information about the elements being assembled, the user facilities being developed and the programme processes involved in flight opportunities.

The information highlights the characteristics of the Station systems and the wide range of capabilities being provided for user utilisation. A road map is provided to help users gain access into the system.

Scope

This guide is oriented towards European users, emphasising European contributions to the Station and European-specific aspects of access and user support. Users may come from academic, applications or industrial communities as well as from national- or European-level communities.

More detailed information will be needed after this first introduction; further possibilities are provided at the end of the guide. A counterpart to this guide is the European document 'Exploiting the International Space Station: A Mission for Europe' which describes the wide range of research and applications that can be conducted aboard the ISS. It also summarises the currently identified major research directions of the benefiting main disciplines:

- Physical Sciences and Applications:
- Space Life Sciences and Medical Applications;
- Observing Sciences (Space Science and Earth Observation);
- Applications and Space Technology.

Status

The guide reflects the status of the ISS as of end-1998. Updates are planned to reflect the best-known information on the ISS programme and utilisation possibilities.

The ISS technical data given in the following chapters were compiled from a number of sources referenced in the final chapter 'Further Station Familiarisation'.

International Space Station Overview

This chapter provides an overview of the technical characteristics of the ISS elements as a prelude to the detailed utilisation accommodation and resource information given in the following chapters.

Background

A new Intergovernmental Agreement (IGA) was concluded on 29 January 1998 between the governments of the five International Partners – Europe (11 participating States), Canada, Japan, Russia and USA. This new IGA enlarges the earlier 1988-partnership agreement by including Russia in the largest international cooperative civil space programme ever undertaken.

It is the responsibility of the US National Aeronautics and Space Administration (NASA) to lead the ISS programme development and implementation, and in conjunction with the Russian Space Agency (RSA) provide the major foundation blocks for the Station (Table 1). The European Space Agency (ESA) and the National Space Development Agency of Japan (NASDA) provide additional elements that significantly enhance those blocks, and the Canadian Space Agency (CSA) provides an essential mobile robotics servicing capability.

The provision of these elements gives each ISS Partner certain rights for Station utilisation as well as participation in its management and operations. For example, each Partner has the right to provide suitably qualified flight crew. Each Partner may also access the Station using its own transportation system. Nevertheless, each Partner has to develop and maintain the elements that it provides, as well as participate in the equitable sharing of the Station's common operating costs.

<table>
<tr><th colspan="6">Table 1. Major ISS Elements to be Provided by the International Partners</th></tr>
<tr><th colspan="3">United States</th><th colspan="3">Russia</th></tr>
<tr><td colspan="3">¥ Space Station infrastructure elements
¥ Laboratory modules and equipment for attached payloads
¥ Flight elements to supply ISS
¥ Ground infrastructure elements</td><td colspan="3">¥ Space Station infrastructure elements
¥ Research modules and equipment for attached payloads
¥ Flight elements to supply and reboost ISS
¥ Ground infrastructure elements</td></tr>
<tr><th colspan="2">Canada</th><th colspan="2">Europe</th><th colspan="2">Japan</th></tr>
<tr><td colspan="2">¥ Mobile servicing system
¥ Special Purpose Dexterous Manipulator</td><td colspan="2">¥ Columbus Laboratory
¥ Automated Transfer Vehicle
¥ Outfitting Elements</td><td colspan="2">¥ Japanese Experiment Module
¥ Japanese Exposure Facility
¥ Flight elements to supply ISS
¥ Ground infrastructure elements</td></tr>
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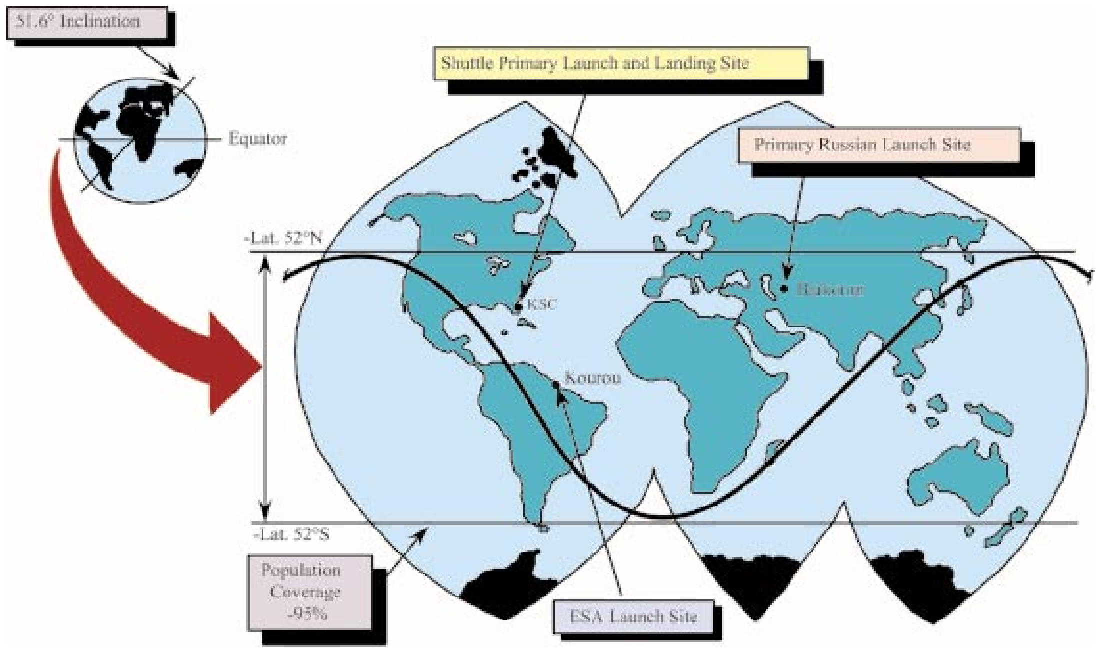


Fig. 1. The ISS orbit provides coverage of most of the world's inhabited regions.

ESA has acquired through its contributions the following utilisation shares:

- 51% usage of the user accommodation of the Columbus Laboratory, incl. attachment points
- 8.3% usage of the on-orbit utilisation resources (eg electrical power, crew time), as well as the right to purchase launch & return, and Tracking & Data Relay Satellite (TDRS) system communications services.

ESA has acquired further crew flight opportunities commensurate with its utilisation resources allocation.

Table 2. ISS Characteristics at Completion	
Truss length Total module length Mass	108 m 74 m about 420 t
Maximum power output	110 kW
Pressurised volume Atmospheric pressure	1200 m^3 1013 mbar
Orbital altitude Orbital inclination Orbital velocity Attitude	370-460 km 51.6.. 29 000 km/h local horizontal/vertical
Minimum crew	6
Data rate uplink Date rate downlink Ku-band coverage S-band coverage	72 kbit/s 150 Mbit/s 68% 50%
Expected lifetime	>10 years

ISS: General Description

The Space Station will be a permanently inhabited outpost in low Earth orbit and composed of flight elements, provided by all five Partners, and associated ground elements to support on-orbit operations and utilisation.

A summary of the ISS key characteristics at the end of the 5-year build-up period is provided in Table 2. ISS assembly began in November 1998 with the launch of the US-procured/Russian-built 'Zarya' Control Module.

On the second assembly flight, in December 1998, the US-built 'Unity' resource node was attached to Zarya. This will be followed by the third assembly flight with the Russian-built Service Module. A 3-person Permanent International Human Presence Capability will then begin in early 2000. At that time, the ISS will already be flying at an average altitude of 407 km in its 51.6° inclination orbit (Fig. 1).

European users will have some early payload utilisation opportunities before the launch of the Columbus Laboratory, once the US Laboratory module is on-orbit and operational for users, as well as on the Integrated Truss Assembly following the check-out of the Mobile Remote Servicer Base System (MBS) and the arrival of the first Express Pallets for external payloads in 2002.

The 6-person Permanent International Human Presence Capability will be established in late 2002. The Columbus Laboratory will be coupled to the ISS early in 2003 and Station assembly will be completed (Fig. 2) with the launch of the US Habitation module.

A summary of the major ISS elements, their first year on-orbit according to Assembly Sequence Revision D, and their potential availability for utilisation are presented in Tables 3 and 4.

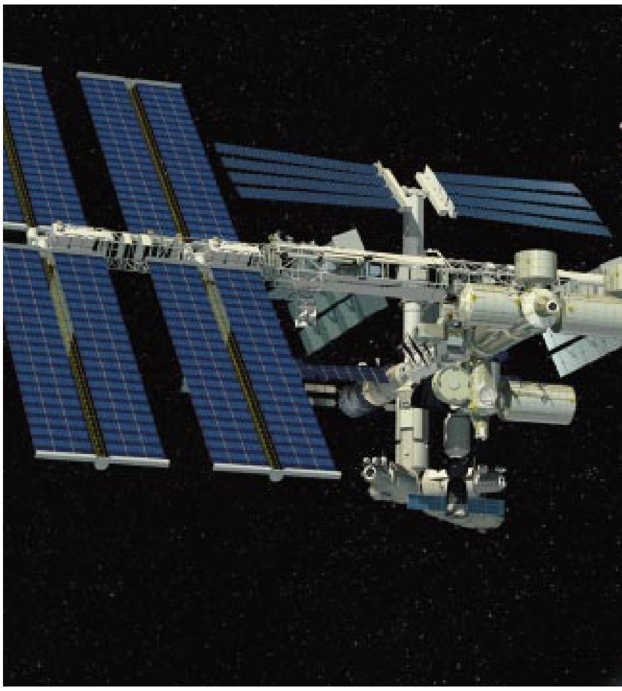


Fig. 2. ISS configuration when assembly is completed in 2004.

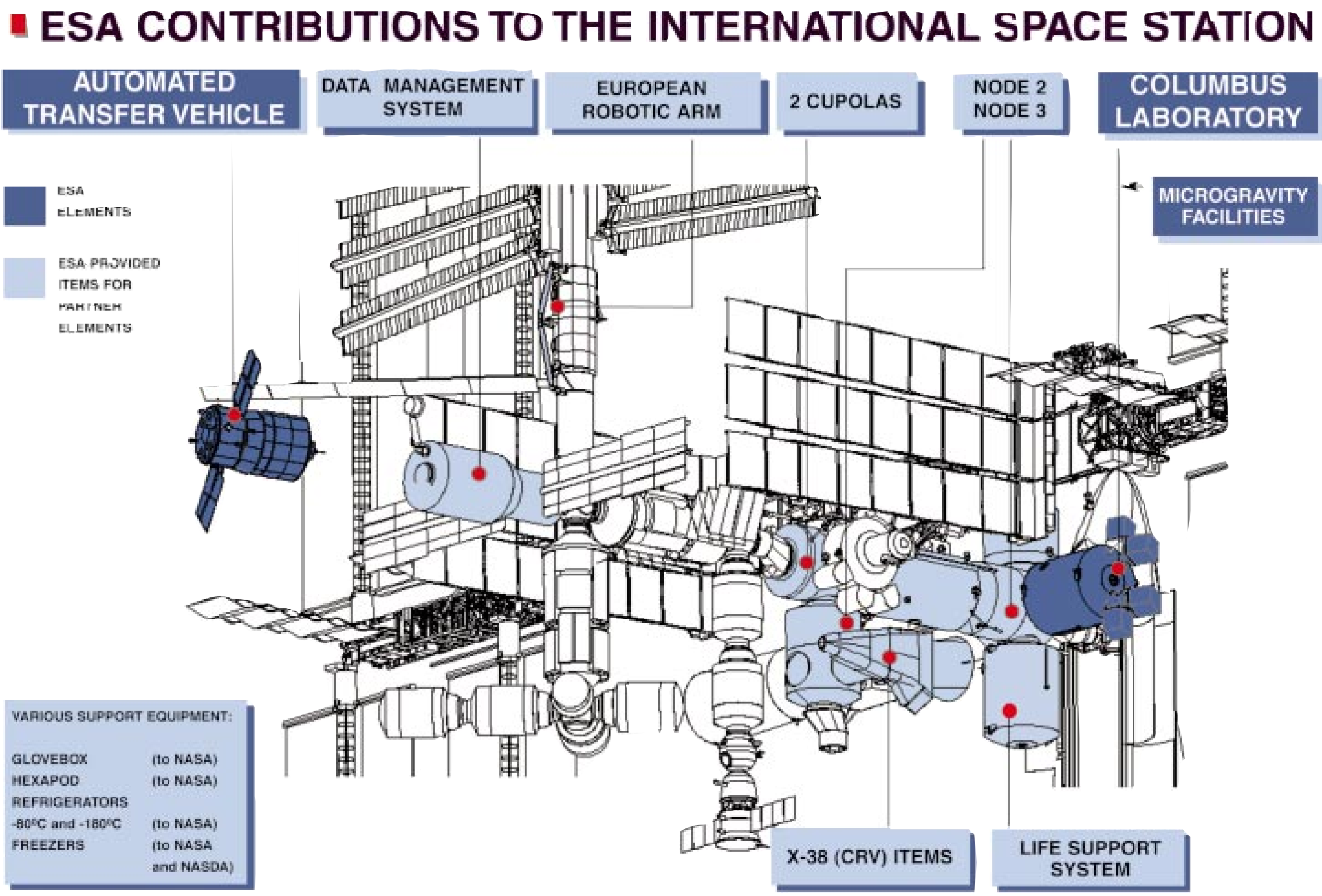


Table 3. Principal ISS Pressurised Elements

Pressurised Element	On-orbit (year)	Outer Dimensions (length x diameter)	Number of ISPRs	Comments
Zarya Control Module (FGB)	1998	12.6x4.1 m		Provides initial propulsion and power
Unity Node-1	1998	5.5x4.6 m		Connector node for pressurised modules
Service Module	1999	13.1x29.6 m (including solar panels)		Early crew living and working quarters. Limited possibilities for payloads
3-person Permanent International Human Presence Capability	2000			Soyuz crew return vehicle docked to ISS
US Laboratory module	2000	8.2x4.4 m	13	
Node-2	2001	6.4x4.6 m		
Japanese Experiment Module (JEM)	2002	11.2x4.4 m	10	Including Exposed Facility
Cupola	2002			360… viewing window
Russian Research Module-1	2002	Design details not available	Design details not available	
Node-3	2002	6.4x4.6 m		
Russian Research Module-2	2002	Design details not available	Design details not available	
6-person Permanent International Human Presence Capability	late 2002			
Columbus Laboratory	2003	6.1x4.4 m	10	Launched with 5 outfitted ISPRs
Centrifuge Accommodation Module (CAM)	2003		4	Contains a 2.5 m-dia centrifuge for g levels 0.01-2 g
US Habitation module	2004	8.2x4.4 m		

Table 4. Principal ISS Unpressurised Elements

Unpressurised Element	On-orbit (year)	Outer Size	Payload Adapters	Comments
Space Station Remote Manipulator System (SSRMS)	2000	17 m length		Initially a measuring worm capability (until MT available) to support ISS assembly & Orbiter cargo bay loading & unloading
Mobile Transporter (MT)	2000			Provides structural, power, data and video links between ISS and MBS
Mobile Remote Servicer Base System (MBS)	2000			Serves as stable base for SSRMS
Integrated Truss Assembly (ITA)	2002	108 m length	24	Utilisation start after MBS commissioning
JEM-Exposed Facility	2002	5x5.2 m widthxlength	10	
Special Purpose Dexterous Manipulator (SPDM)	2002	two 3.5 m-long arms		Extends SSRMS capability for intricate manipulations
Columbus-External Payload Facility (EPF)	2003		4	

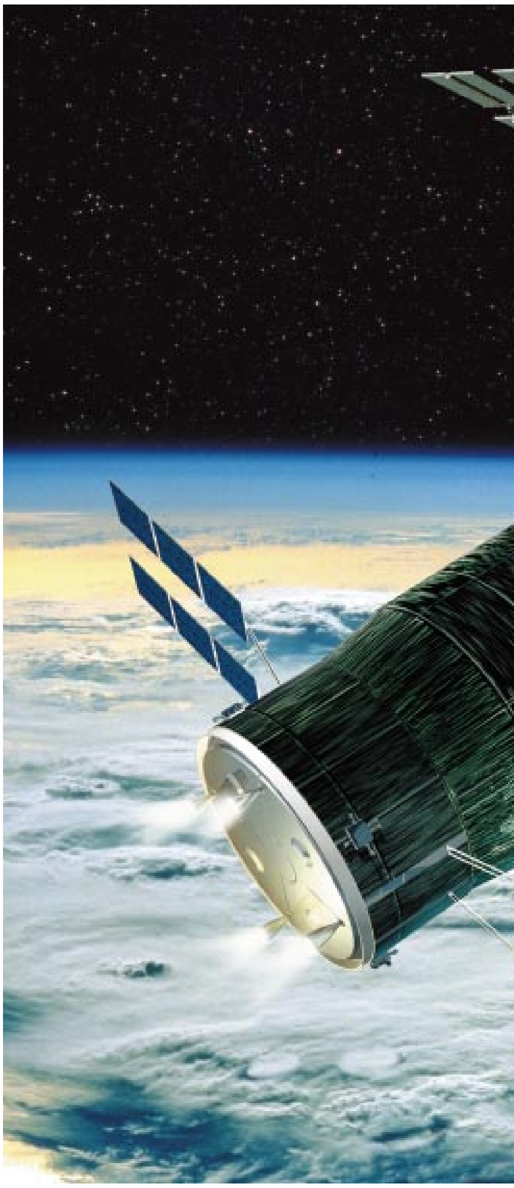


Fig. 3. ESA's Automated Transfer Vehicle (ATV) will transport mixed cargo items to/from the ISS. (ESA/D. Ducros)

The major elements of the Station include:

- modules and nodes housing essential systems, providing a habitable environment and serving as pressurised payload laboratories;
- the 108 m-long Truss is a major structural framework mounted on Unity (Node-1). It provides the ISS 'backbone' and interconnection between the pressurised modules, external payloads and systems equipment. It also hosts umbilicals, radiators, communications antennas, batteries, Mobile Transporter rails and mechanical systems such as joints and mechanisms. Truss segments are located on the starboard and port sides, and labelled accordingly. For example, the P6 section is on the outermost port side;
- the Mobile Servicing Center and Mobile Transporter make up the Mobile Remote Servicer Base System that will be used to remove payloads from the Shuttle cargo bay and transport them to designated locations on the outpost. The 17 m-long remote manipulator arm can carry payloads of up to 128 t, while the Special Purpose Dexterous Manipulator (SPDM), with two arms each 3.5 m long, can perform more delicate tasks such as connecting utilities or exchanging small hardware items.

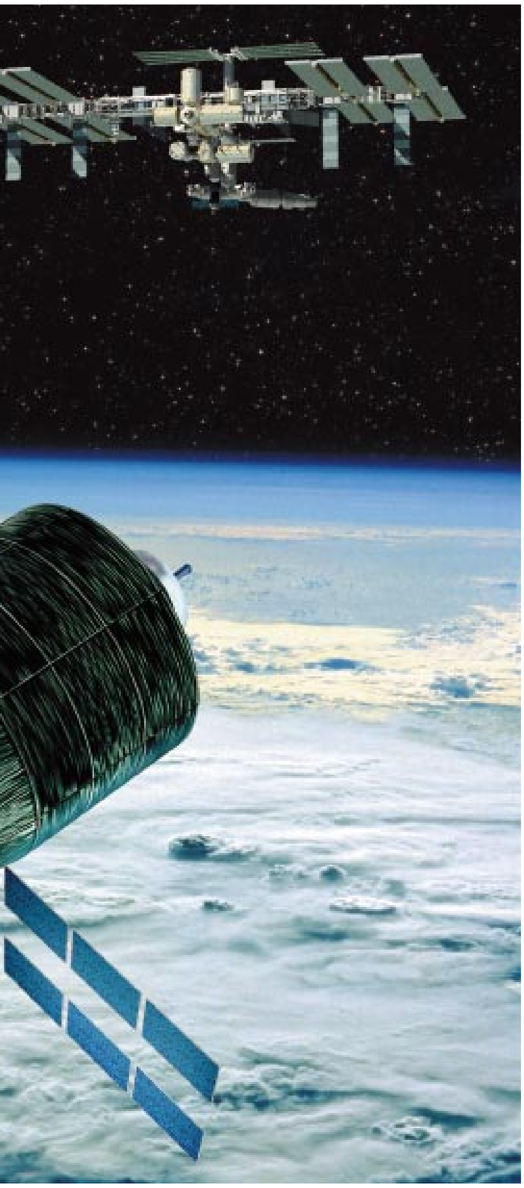
Payload Transportation and Logistics Carriers

A mixed fleet of launch vehicles is potentially available for the transportation of payloads. It includes:

- US Space Shuttle;
- Russian Proton;
- European Ariane-5;
- Japanese H-IIA.

The US Space Shuttle is the prime vehicle for transporting system elements, logistics, crew and payloads (including the Columbus Laboratory) to the Station. For the assembly of the Station from 1998 to 2004, some 34 Shuttle flights are projected, including several user-oriented flights. The Shuttle-to-Station cargo options also include:

- the Italian-built Mini Pressurised Logistics Module (MPLM) for transporting pressurised cargo to/from the Station, accommodating 16 racks comprising five powered for



refrigerators, freezers or active payloads and 11 racks for passive payloads;

- Unpressurized Logistics Carrier (ULC) for transporting external systems and payloads to/from the Station.

The Russian Proton is the prime vehicle for transporting the Russian pressurised and unpressurised elements to the Station. The Soyuz rocket will be used for delivering the Soyuz crew vehicle and the Progress cargo spacecraft.

The European Ariane-5 is the vehicle for launching the Automated Transfer Vehicle (ATV; Fig. 3) that will be used for transporting mixed cargo items to/from the Station.

The Japanese H-IIA is the prime vehicle for launching the H-II Transfer Vehicle (HTV) that will be used for transporting mixed cargo items to the Station.

Distributed Station Systems

Command & Data Handling (C&DH) System

As the 'brain' of the ISS, the C&DH system (Fig. 4) monitors all aspects of the Station's operations. Furthermore, it distributes payload and systems data to the crew, and to personnel on Earth via the Tracking and Data Relay Satellite (TDRS) system.

C&DH hardware includes data processors, control and monitoring processors, crew interface computers, data acquisition and distribution networks, and interfaces to systems and payloads. The C&DH data distribution architecture relies heavily on network technology, and is composed of three major components: local area networks (LANs) based upon IEEE 802.3; local data buses based upon MIL-STD-1553B; and high-rate data (HRD) links.

Even during the early stages of assembly, system and payload networks will be provided throughout the evolving Station to link all system and payload data units. The networks will be extended as the Station matures, with system and payload networks being routed through the Nodes, US Laboratory, JEM, Columbus Laboratory and the Russian Research Modules.

The MIL-STD 1553 data bus provides a low-rate data transfer capability; the IEEE 802.3 data bus provides a medium-rate data transfer capability. The HRD link provides payloads with return data rates higher than can be met by the LANs.

Laptops are available for the crew to: interface with the data system; monitor and control systems; display video, and

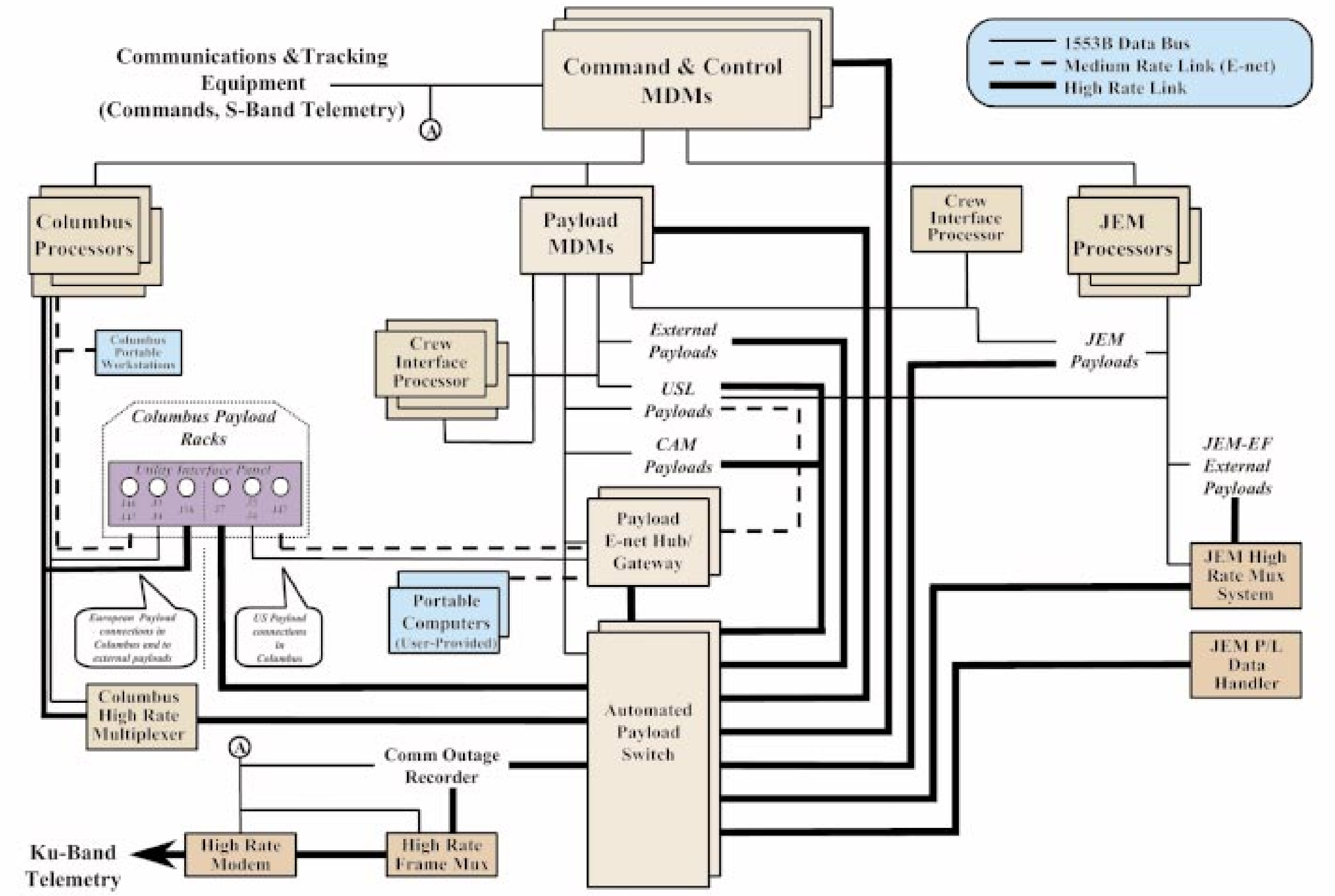


Fig. 4. Overview of the ISS Command & Data Handling System. MDM: Multiplexer/ Demultiplexer. C&T: Communications & Tracking. USL: US Laboratory.

payload and system data; and communicate with the ground. The crew Man Machine Interfaces for all the Station laptops are similar and the data displayed on them can also be displayed on monitors on Earth.

A stable frequency and time reference is provided by the C&DH time distribution system.

The interface between the Columbus processors and the Columbus payloads is achieved over the Utility Interface Panel; this is detailed in later chapters.

Payload users may develop and provide their own application software for integration into the element payload computers. However, the interfaces for the bulk of such applications consist primarily of standard services. These standard services provide payload and core systems with access to data communications, data acquisition and commanding and timing information. Payloads are required to use standard services for commands, and for all communications with the LANs and buses.

Communications and Tracking System (C&TS)

The C&TS provides audio, data and video communications with the ground and other spacecraft. Payload commands and audio may be transmitted from the ground to the Station. The downward ('return') usable data transmission capability is via the Ku-band system. The upward ('forward') transmission capability is via an S-band system from the ground for Station systems and payload operations.

The European end-to-end communications infrastructure is shown in Fig. 5.

NASA's TDRS system is the primary Station data and communications link with the ground. Data and commands are transmitted to/from the Station via TDRS to White Sands in New Mexico. The data are then distributed through a combination of satellite and terrestrial links.

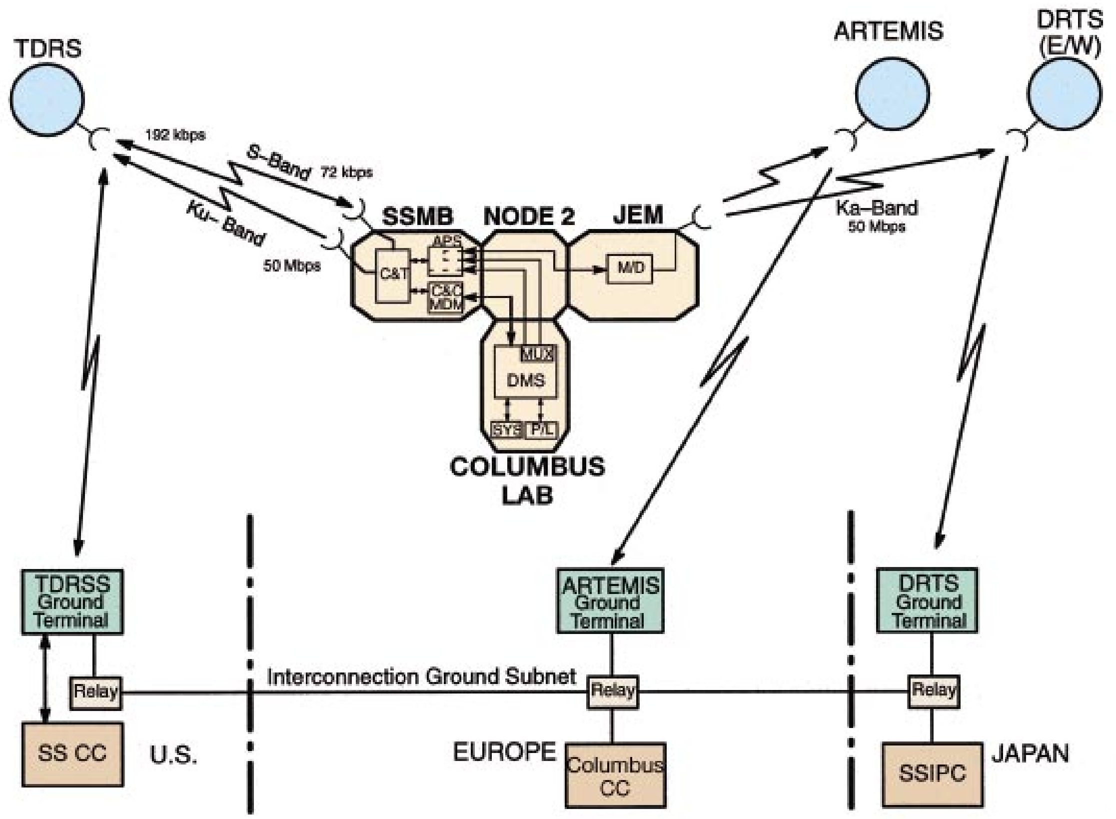


Fig. 5. The European communications infrastructure for ISS. APS: Automated Payload Switch. C&C MDM: Command & Control Multiplexer/ Demultiplexer. C&T: Communications & Tracking. DRTS: Data Relay & Test Satellite. SSCC: Space Station Control Center. SSIPC: Space Station Integration & Promotion Centre. SSMB: Space Station Manned Base.

The TDRS system and Station are in communication for most of each orbit except for a brief period known as the Zone of Exclusion (ZOE) when there is no TDRS-to-ground coverage, or during particular Station attitudes when there is no line-of-sight link between the Station and TDRS. The coverage period can range up to 60 min in any one 90 min orbit. During this time, users are able to transmit or receive data. There is also a very short period of disruption (of the order of 2 min each orbit) when communications are being handed over from one TDRS to the other.

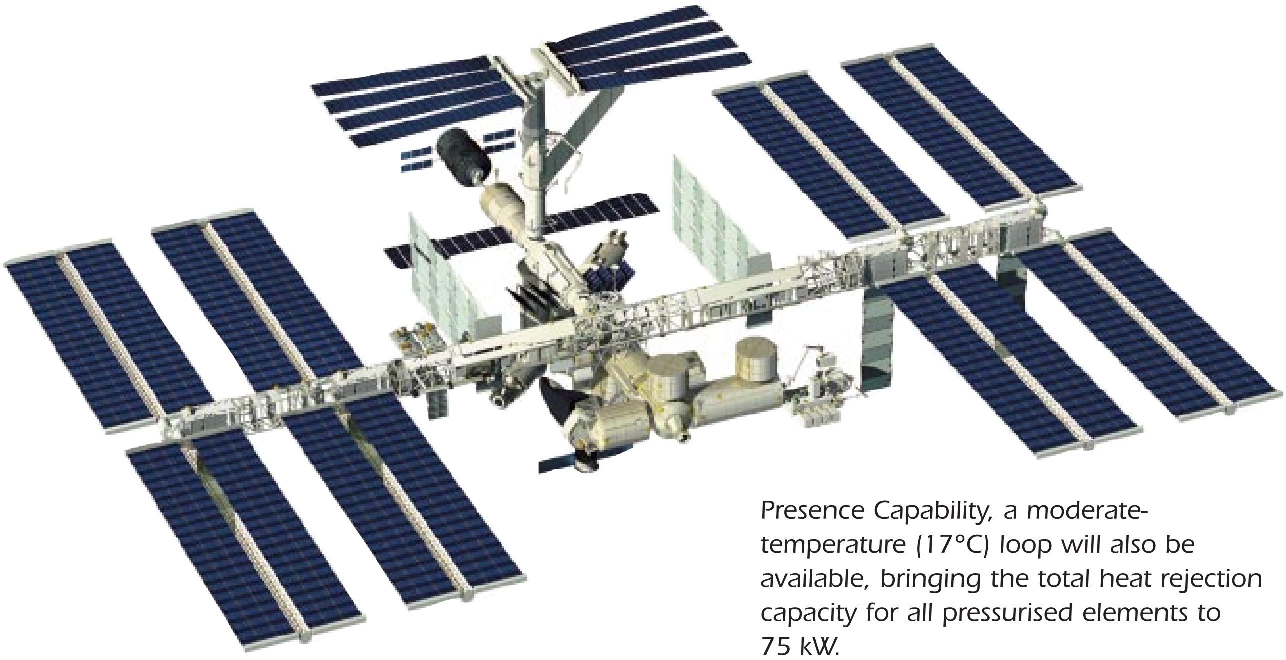
As an additional link, communications via the Japanese (DRTS) and European (Artemis) data relay systems are under consideration (Fig. 5).

Video cameras are located throughout the pressurised elements and on the Truss. The Video Switching Unit (VSU) allows images from any Station-supplied camera to be displayed on any monitor. The pulse frequency-modulated onboard video signals, distributed by fibre optic analog video lines, are compatible with the NTSC standard.

The JEM and Columbus Laboratory have video and audio systems that are compatible with the US network. Video and audio signals are digitised, assembled into data transfer frames (packets), and multiplexed with other data for Ku-band downlink transmission. Video, audio and data signals have time synchronisation for proper time stamping and voice/data correlation. However, the Russian elements use the SECAM video standard and there is no video connectivity with the other Partner video systems.

Electrical Power System (EPS)

Two parallel sets of solar array wings generate the primary Station power. Nickel-hydrogen batteries store the dc power generated by the solar arrays for use when the station is in the Earth's shadow. 18.75 kW of orbital average



power is generated initially, increasing to 110 kW with the full Station capability. The EPS provides 120 Vdc power to the user interface. The Russian segment also generates additional electrical power, for the Russian elements.

Thermal Control System (TCS)
The TCS maintains the Station's structure, systems, equipment and payloads within their allowable temperature ranges. Heat rejection is achieved through two large radiators attached to the Truss.

A passive thermal control system is provided through insulation coatings and heaters, and is responsible for maintaining Station structures and external equipment within allowable temperature ranges.

An active thermal control system is provided through mechanically-pumped fluid in closed loop circuits and is responsible for heat collection, heat transportation and heat rejection within the pressurised elements. Water is used in the active system within the pressurised elements; anhydrous-ammonia is used in the active system in the external areas. Both fluids remain in a liquid state.

Initially, two low-temperature (4°C) loops provide a total of 14 kW heat rejection. At 6-person Permanent International Human Presence Capability, a moderate-temperature (17°C) loop will also be available, bringing the total heat rejection capacity for all pressurised elements to 75 kW.

No active thermal control system is provided for attached payloads mounted on the Truss.

Guidance, Navigation and Control (GN&C)
The GN&C system maintains the Station attitude and orbit control that is optimised for the proper microgravity environment in support of payload requirements. In addition, GN&C controls include debris avoidance, reboost and rendezvous operations. The GN&C system can provide the Station's exact orbital speed, attitude and altitude as telemetry to payloads.

Flight Crew Systems
Flight crew systems include restraints and mobility aids, portable emergency provisions, housekeeping and trash management, Crew Health Care System (CHeCS), lighting, personal hygiene equipment, wardroom and crew privacy. They provide the crew with a safe environment and the basic necessities for life.

The most complex of these, CHeCS, comprises the Health Maintenance System (HMS), the Countermeasure System (CMS) and the Environmental Health System (EHS). The HMS monitors crew health, responds to crew illness or injury, provides preventative health care, and stabilisation and emergency transport between vehicles. The CMS evaluates *crew fitness, provides countermeasures for musculoskeletal and cardiovascular deconditioning, and monitors the crew during countermeasures. The EHS monitors the Station's internal environment and includes instruments for microbiological, toxicological, radiation and acoustics measurements. CHeCS interfaces with the C&DH system to provide onboard data display and data transmission to the ground.*

Environmental Control & Life Support System (ECLSS)

The ECLSS provides a comfortable shirtsleeve environment throughout the Station's pressurised elements. Temperature, humidity, air composition and atmospheric pressure are maintained, as well as nitrogen and potable water supplies, and fire detection/suppression equipment. The ECLSS maintains an atmospheric pressure of 978-1026 mbar (14.2-14.9 psia) with an oxygen concentration of not more than 24.1%.

Information Services

The Station programme coordinates and sustains diverse information services required for Station operations. These include command & control services, payload support services and automated information security services.

Command & control services provide for the interactive control and monitoring of payloads, elements and systems, as well as for the acquisition, transmission processing, storage and exchange of data among Partner system and payload operators and users. Within the European scenario, these services include information exchange between the ISS and the:

- *Mission Control Center-Houston (MCC-H), responsible for integrated Station operations;*
- *Payload Operations Integration Center (POIC), responsible for consolidating the planning and execution of all element payload operations;*

- Columbus Control Centre, responsible for integrating the planning and execution of all Columbus Laboratory payload and system flight operations;
- User Support and Operations Centre (USOC) or Facility Responsible Centre (FRC), responsible for monitoring and controlling one or more payload facilities.

Payload support services increase the productivity of payload user operations. Telescience, for example, allows payload users to access remote equipment and databases interactively in pursuit of their experimental objectives. One such aspect is the capability for users, at their home institutions or User Home Base (UHB), to control and monitor payloads in space. The Station delivers data to the payload user in the form in which it was acquired from the payload onboard. The handling and provision of ancillary data necessary for the meaningful processing of payload data is another support service. Examples of ancillary data include orbital position, attitude references and standard time references, as well as physical characteristics such as an element's temperature, oxygen partial pressure, or external environmental parameters.

Automated information security services control access to the information network and ensure the quality and integrity of the data traversing it on an end-to-end basis. The Station does not provide data encryption services for payload user data. However, payload users may encrypt their data if they wish.

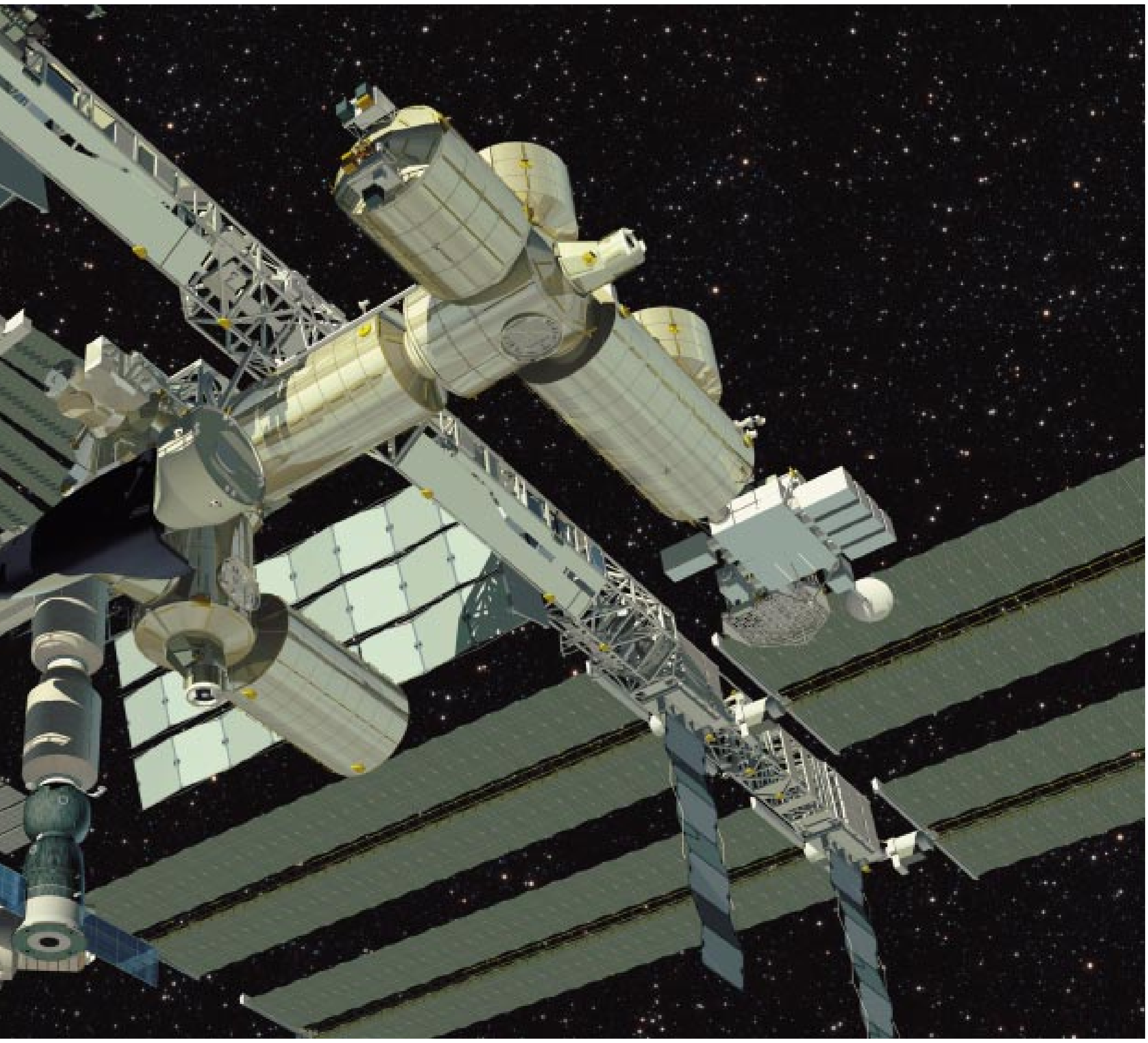
Environment Considerations

The natural environment exists unperturbed by the presence of the Space Station, while the induced environment exists as a result of the Station's presence. Payload users should be aware of the potential effects that these environments can have on payloads.

Natural Environment

The neutral atmosphere is significant for Station operations for two reasons. Firstly, it produces torques and drag that degrade the Station's altitude. Secondly, it affects the flux of trapped radiation encountered by the Station.

Plasma is important to Station operations because it controls the extent of spacecraft charging, affects the propagation of electromagnetic waves such as radio frequency signals, and probably contributes to surface erosion. Another important effect is the production of electric fields in the structure as the Station moves across the geomagnetic field.



Charged particle radiation can have sufficient energy to penetrate several centimetres of metal and, after penetration, still produce significant levels of ionised radiation. A high level of radiation can significantly affect materials, chemical processes and living organisms, and especially the crew. It can also affect electronics by causing soft upsets and degrading the performance or producing permanent damage. In addition, it can affect the propagation of light through optical materials by altering their optical properties.

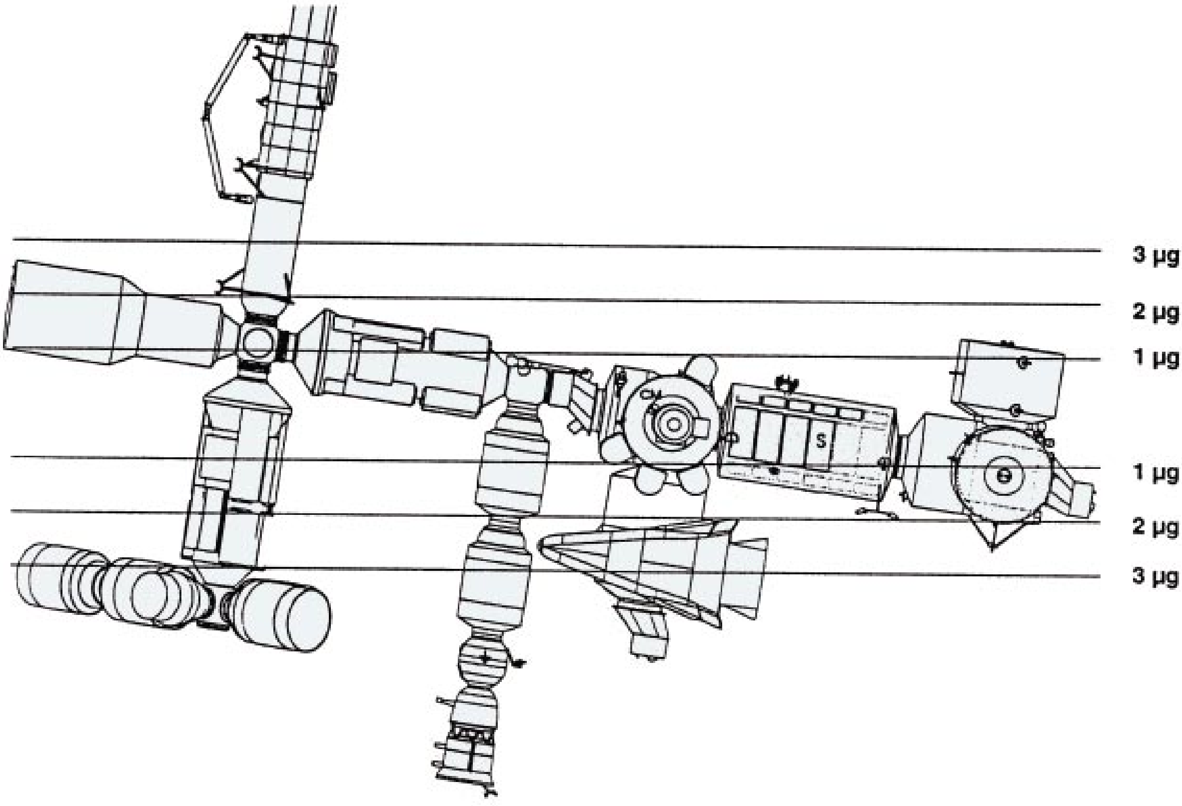
The Station's systems and payloads are immersed in electromagnetic radiation. Such radiation originates from the Earth, from plasmas surrounding the Earth, Sun and stars; and from the nearby ionosphere, and is disrupted by the passage of the Station itself. Intense radiation can affect the Station's systems or payloads.

Micrometeoroids and space debris can damage the Station and its attached payloads. Critical Station elements are protected by a combination of shielding and shadowing.

Induced Environment

*The Station provides an environment suitable for the performance of microgravity experiments (Fig. 6). Acceleration levels of $1.8 \times 10^{-6}g$ or less, at frequencies <0.1 Hz, are maintained for at least 50% of the pressurised user accommodation locations for continuous periods of up to 30 days beginning at 3-person Permanent International Human Presence Capability and continuing thereafter. These conditions are provided for at least 180 days per year. For frequencies of 0.1-100 Hz, the acceleration levels are less than the product of $18 \times 10^{-5}g$*frequency, while for frequencies exceeding 100 Hz, acceleration levels of $1.8 \times 10^{-3}g$ are predicted. The Station's use of control moment gyroscopes for attitude control*

Figure 6. The predicted quasi-steady acceleration environment side view. (NASA)



during normal operations minimises vibration disturbances. However, the greatest disturbances (~10^{-3}g) occur during Shuttle docking and Station reboost.

Microgravity quiescent and non-quiescent periods are scheduled in advance. Quiescent periods are maintained for up to 30 days, to provide optimal microgravity conditions. Non-quiescent periods, such as during Station reboost, may be unacceptable for the operation of some payloads. The predicted quasi-steady acceleration environment is shown in Fig. 6.

The Station's external environment will be affected by its presence, operation and motion with induced effects from:

- Plasma wake, the variation of plasma density from the ram to the wake side;
- Neutral wake, the variation of neutral density;
- Plasma waves induced by the Station's motion;
- Vehicle glow on the ram or forward side;
- Change of local plasma density and production of electrical noise caused by spacecraft charging;
- Enhancement of neutral density and the change of neutral composition by outgassing, offgassing and the plumes from thrusters;
- Emission of conducted and radiated electromagnetic power by systems on the Station;
- Deliberate perturbation of the environment by active experiments and devices such as:
  - Transmitters/wave injectors
  - Particle beam emitters
  - Plasma emitters
  - Chemical releases
  - Laser beams
- Visible light generated by the Station and reflections from it;
- Induced currents and voltage potential differences that are generated by the motion of the Station through Earth's magnetic field, which can draw current through the surrounding plasma.

Accommodation and Utilisation Resources Capabilities for Payloads

This chapter provides an overview of the resources that are potentially available for European utilisation and describes the accommodation possibilities of European-provided elements and facilities. The actual accommodation and resource requirements for a payload will be agreed and baselined between the payload user and the Agency at the beginning of the payload programme cycle.

Overall ISS Utilisation Capabilities

The overall utilisation capabilities of the International Space Station are shown in Table 5.

European Utilisation Capabilities

Europe has acquired, through its contributions to the ISS programme, the following access to user accommodation and utilisation resources:

- 5 ISPRs in the Columbus Laboratory;
- 2 Express Pallet Adapters on the Columbus external payload facility;
- 2.5 kW of electrical power (average);
- 13 h crew time per week.

In addition, a yearly average of 8.3% of TDRSS capability can be acquired by ESA from NASA.

During steady state operations, the average annual up and download requirements of the ESA payloads are:

- 1000 kg of pressurised payload mass upload;
- 780 kg of pressurised payload mass download;
- 600 kg of external payload mass upload;
- 600 kg of external payload mass download.

The utilisation and distribution of these accommodation and resource capabilities is achieved at International Partner level rather than at a specific laboratory or module level. This approach provides each International Partner with wider opportunities for planning to accomplish its specific payload mission objectives.

Table 5. ISS Utilisation Capabilities

Number of ISPRs	37
Additional payload accommodation volume in Russian Research Modules	Volume still unknown
Attached sites on the Truss corresponding to Express Pallet Adapters Payload sites on JEM-External Facility Express Pallet Adapters on Columbus-EPF	4 on S3 24 10 4
Russian Science Power Platform	Payload accommodation still unknown
Total average power for utilisation by US segment	30 k W
Crew time (based on crew of 7)	160 h/week
Date uplink Data downlink	72 kbit/s up to 43 Mbit/s (150 Mbit/s under consideration)

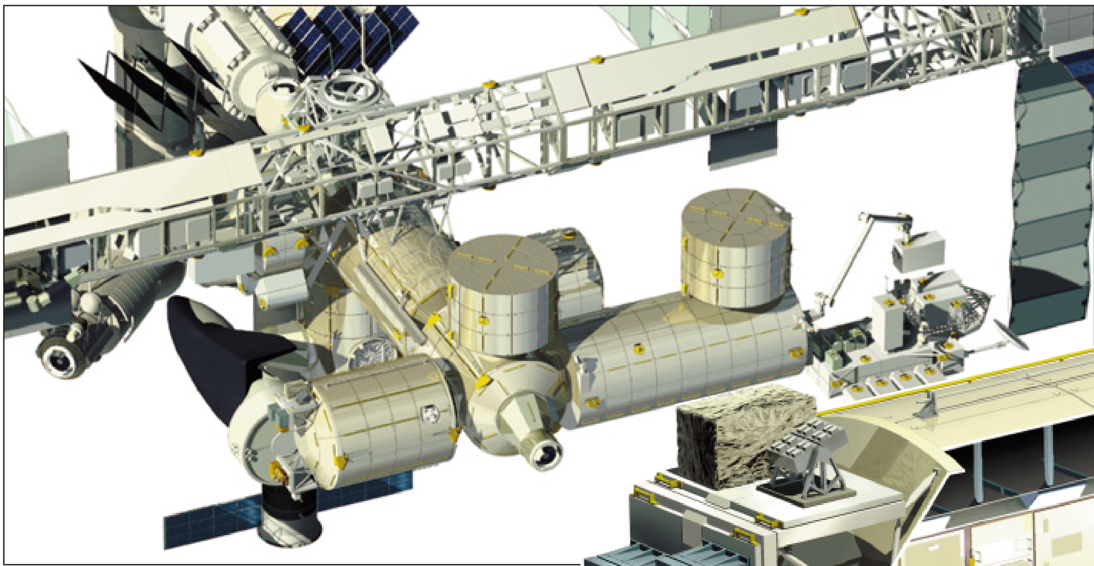


Fig. 7. The Columbus Laboratory will be attached to Node-2. (ESA/D. Ducros)

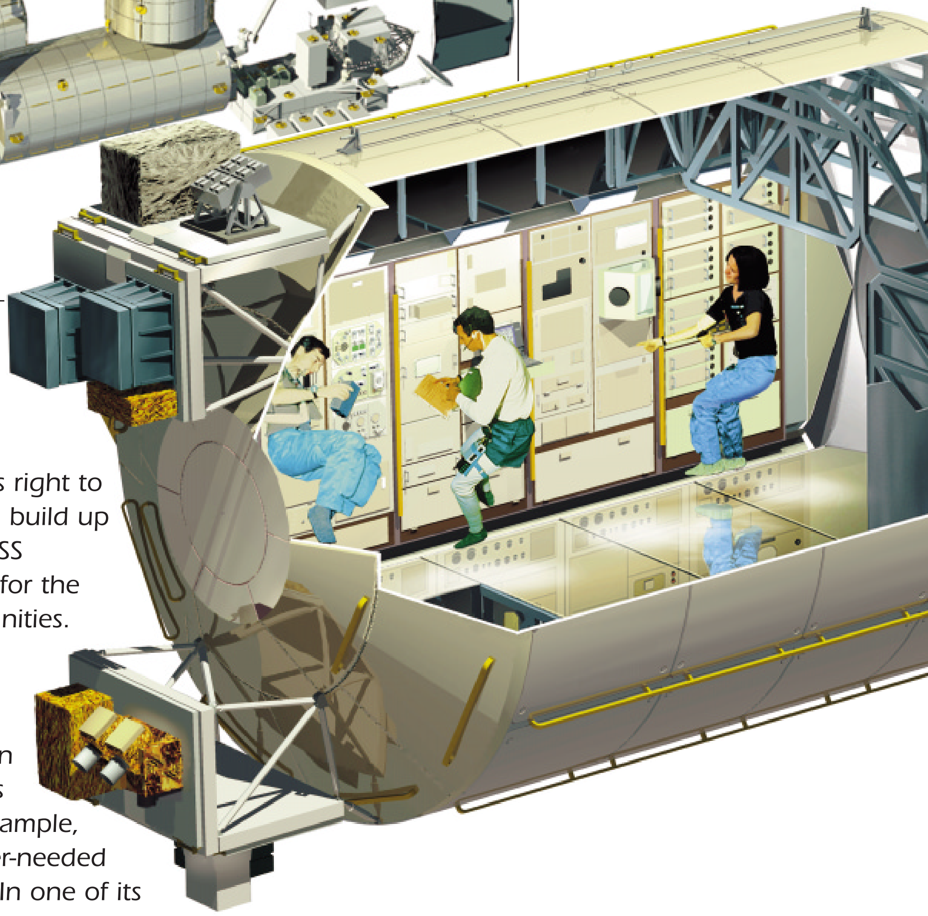


Fig. 8. The Columbus Laboratory is designed as a general-purpose laboratory. (ESA/D. Ducros)

Based upon this access right to the ISS, it is possible to build up a strong, long-lasting ISS utilisation programme for the European user communities.

In addition to its basic access, ESA can barter for additional European access with its Partners in exchange for, for example, the provision of Partner-needed European equipment. In one of its early barters, ESA secured access to early opportunities in the US Laboratory and on the attached sites before the Columbus Laboratory becomes available.

Columbus Laboratory Characteristics

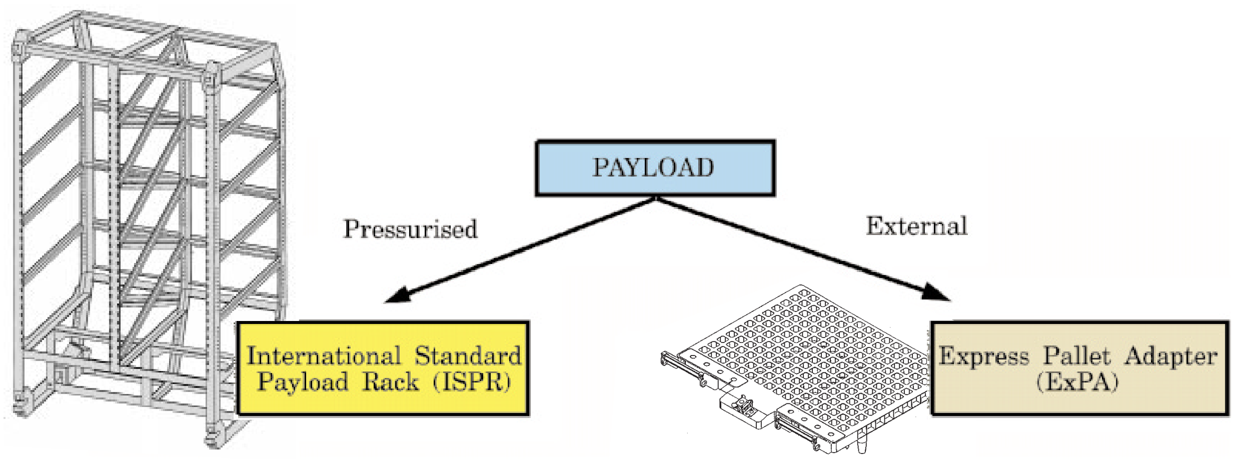
The Columbus Laboratory (Figs. 7/8) is designed as a general-purpose laboratory to accommodate payloads with experiments from life sciences, physical sciences and technology development. It will be launched by the Shuttle and attached to Node-2. External attachment sites are available on the end cone for payloads requiring celestial pointing, Earth pointing or other space environment.

The major characteristics of the Columbus Laboratory are shown in Table 6.

Basic Accommodation Units

Basic accommodation hardware is available for both pressurised and external payloads. These units can be provided directly to payload developers to allow them to develop, integrate and check out as much of their payloads as possible at their own sites and without the additional effort of developing their own direct-to-ISS element hardware.

The major accommodation characteristics of these units are illustrated in Fig. 9.



2.014 x 1.048 x 0.858 m	(height x width x depth)	1.244 x 0.863 x 1.168 m
1.35 m^3	Payload Volume/Footprint	1.00 m^2
500 kg for Columbus launch * 800 kg for post-Columbus launch payload *	Mass-Carrying Capability	227 kg (for payload only)
Payloads may be accommodated in standard 19-inch drawers	Special Features	Dimensions and mass must include both payload support equipment and payloads

* Includes mass of rack structure

Fig. 9. Principal accommodation characteristics of ISPRs and Express Pallet Adapters.

Table 6. Principal Characteristics of the Columbus Laboratory

Launched by Space Shuttle	early 2003
Launch mass Initial payload mass Maximum mass on-orbit	12.7 t 2.5 t (corresponds to 5 ISPRs + payloads) 18 t
Number of active payload racks Number of stowage racks	10 ISPRs 3 ISPRs
Total electrical power available Electrical power available for payloads	20 kW up to 13.5 kW
Thermal control and heat removal	up to 14 kW through medium-temperature water cooling loop Cabin air cooling
Earthlike atmosphere Cabin temperature (operating) Vacuum and venting lines to space	959-1013 mbar 16-30¡C
Control & Data Handling System Payload bus Payload LAN Video and high-rate data	 MIL-STD-1553B IEEE 802.3 Fibre optic
Communications	Via TDRS system for Ku-band and S-band

The ISPR basic accommodation units support the large pressurised facility-type payloads in complete racks. A range of European Standard Experiment Drawers (SEDs) and Mid-Deck Lockers (MDLs) within the European Drawer Rack (EDR) is available for smaller pressurised payloads to allow for easier integration and shorter flight access. The technical capabilities of the EDR are described in the 'Multi-User Facilities and Support Equipment' chapter.

Columbus Resources and Services to Payloads

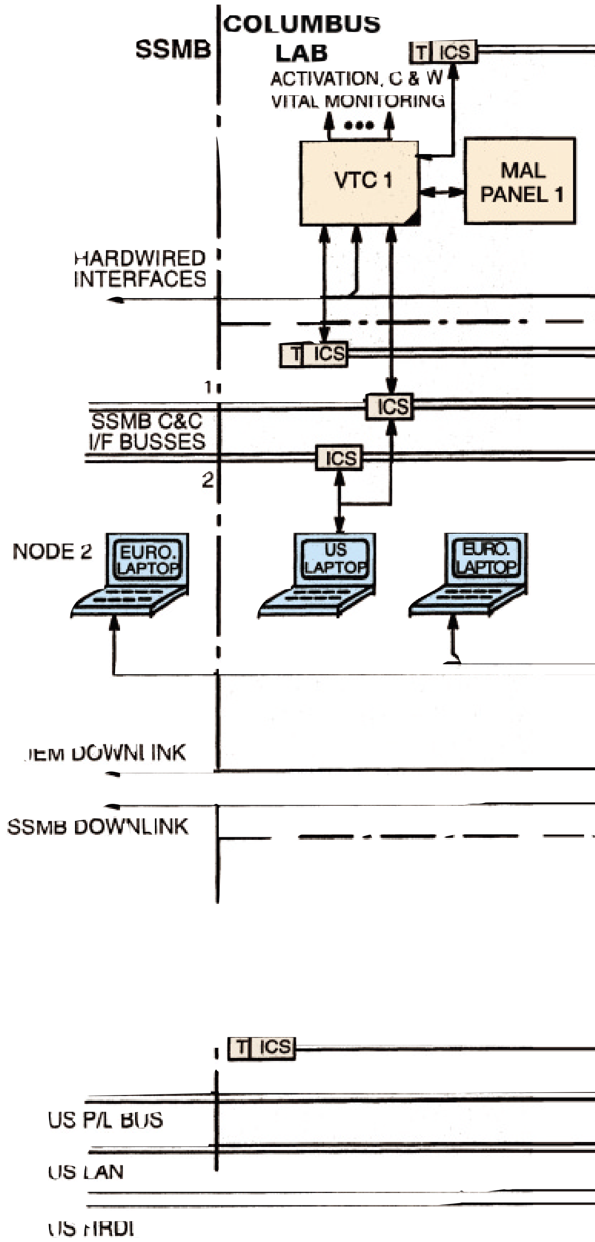
The Columbus Laboratory provides the following resources and services to payloads.

Data Management Services (DMS)

DMS (Fig. 10) standard services for payloads include:

- payload data acquisition, processing and routing, including protocol and packet support;
- payload user application software for execution in the Columbus DMS Payload Control Unit (PLCU) for payloads that do not have their own data processing;
- payload (flight) automatic procedure management and execution;
- payload failure management, including telemetry data exception monitoring;
- general services to payloads such as broadcasting, logging file transfer and data reduction.

A payload's DMS requirements for services will be collected during the preparation for flight and the appropriate Columbus



DMS software products will be developed to accomplish those requirements.

US payloads in Columbus (nominally five ISPRs) are controlled via the US Lab's DMS extending into Columbus.

Electrical Power

The Columbus Laboratory is designed to handle up to 20 kW of electrical power at 120 Vdc for systems and payloads. For the Columbus payloads, a maximum of 13.5 kW is available.

The electrical power is provided by the Columbus systems through two Power Distribution Units (PDUs) and distributed as either 6 kW medium- or 3 kW low-power to a payload rack location and 500 W to an aisle payload location.

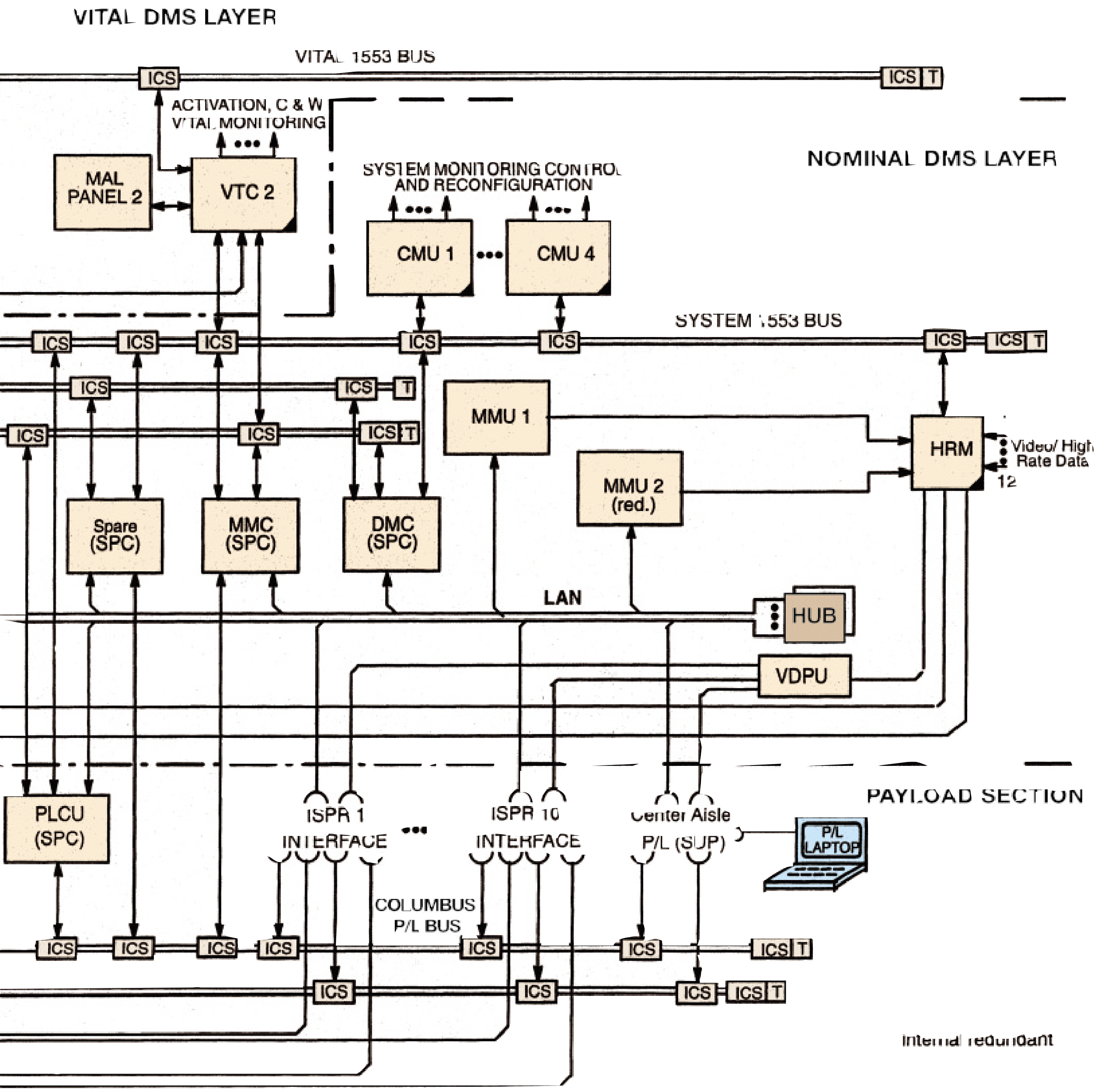


Fig. 10. Columbus Data Management System Configuration. C&C: Command & Control. C&W: Caution & Warning. CMU: Command & Monitoring Unit. HRDL: High-Rate Data Link. HRM: High-Rate Multiplexer. ICS: Inter Connection System. MAL: Master Alarm Light. MMC: Mission Management Computer. MMU: Mass Memory Unit. SPC: Standard Processor Controller. PLCU: Payload Control Unit. SSMB: Space Station Manned Base. VDPU: Video/Data Processing Unit. VTC: Vital Telemetry/ Telecommand Computer.

The electrical power provided for the Columbus External Payload Facility is provided through a dedicated Payload Power Switching Box and distributed at 2.5 kW to each adapter location.

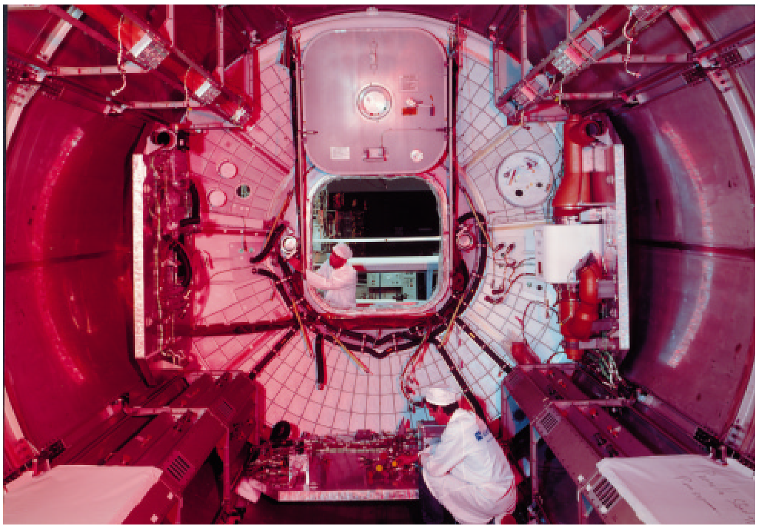
Auxiliary power of up to 1.2 kW is provided to the payload racks only, for safing operations when the primary PDU outlets fails.

Vacuum and Venting System (VVS)
A VVS system capability is available at each payload rack location for:
- venting of experiment process chambers;
- venting of cooling and purge gases;
- providing a sustained vacuum.

Separation between the vacuum system and the venting system is provided to avoid cross-contamination. Furthermore, venting is operationally timelined in order to minimise potential simultaneous contamination between payloads.

Cooling Water
Cooling water is provided at each payload rack location from the moderate-temperature cooling system. The payload rack can provide either its own heat exchanger for internal air-cooling or directly use the water-cooling capability. The thermal cooling capability of each rack corresponds to the electrical power available at that rack.

Nitrogen Gas
Nitrogen gas is available at each payload rack, and may be used for supporting payload-purging operations.



Video Communications

US National Television System Committee (NTSC)-format video capability is provided at each payload rack location and aisle outlet. The video may be downlinked or further processed onboard.

Telemetry and Telecommand Links

The telemetry and telecommand data links available at each payload rack location are:

- a fibre-optic video communications link that can be used for high-rate data up to 32 Mbit/s;
- a high-rate data link capability for the direct transmission of up to 100 Mbit/s through the US Lab's Automated Payload Switch (APS). This capability is available over the US DMS in Columbus;
- IEEE 802.3 primary and backup Ethernet LANs for payload telemetry access between the Columbus systems and the payload electronics. The 802.3 is used principally for medium-rate telemetry with individual payload rates up to 1.25 Mbit/s;
- MIL-STD-1553B primary and backup data buses for payload telemetry and telecommanding access between the Columbus systems and the payload electronics. The 1553B is principally used for telecommanding and low-rate telemetry, with individual payload rates up to 51.2 kbit/s;

The telemetry and telecommand data links available at each ExPA location are:

- a high-rate digital data link of up to 32 Mbit/s;
- IEEE 802.3 primary and backup Ethernet LANs for payload telemetry access between the Columbus systems and the payload electronics;
- MIL-STD-1553B primary and backup data buses for payload telemetry and telecommanding access between the Columbus systems and the payload electronics.

Fire Detection and Suppression (FDS)

Fire detection and suppression capabilities are provided for payload racks. This system allows for the automatic detection of internal payload rack smoke, and subsequent commanding of internal fire suppression measures, as well as automatically applying payload rack power-off. In addition, portable CO_2 fire extinguishers can provide manual fire suppression through a special fire suppression port on the front panel of each payload rack.

Emergency, Warning and Caution and Safing (EWACS)

Emergency, warning, caution and safing capabilities are provided at each payload rack and aisle payload. EWACS enables payloads to alert the Columbus Laboratory vital systems automatically when a malfunction occurs that requires safing.

Cabin Air

Cabin air heat rejection capability is provided within the Columbus Laboratory for up to 500 W from all payloads.

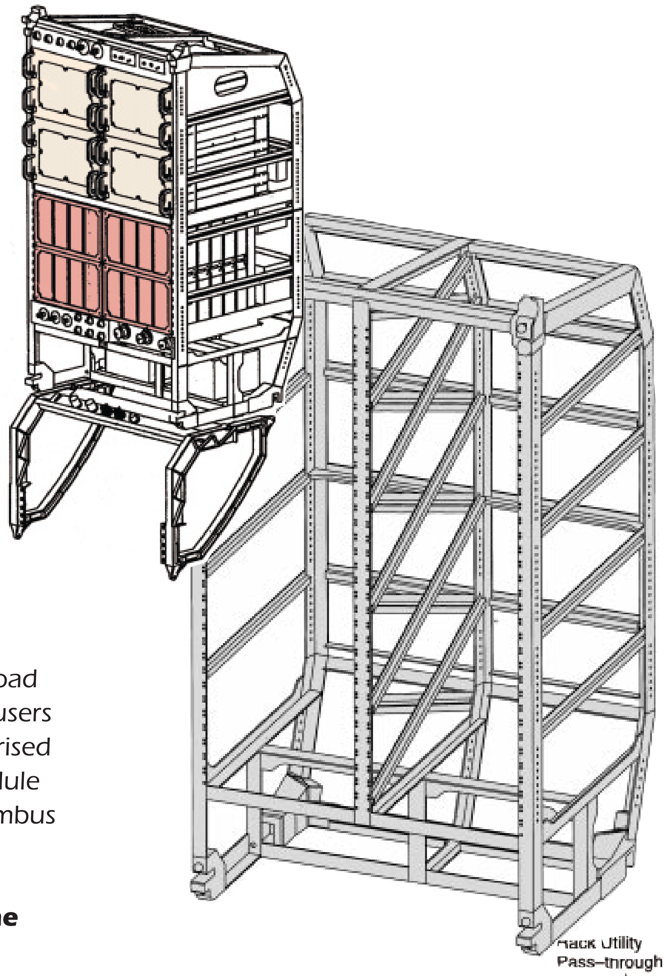


Fig. 11. The ISPR is the nominal payload accommodation element in the Columbus module.

Inset: ISPR configured as a European Drawer Rack

Columbus User Accommodation and Payload Interfaces

The user accommodation and payload interfaces for Columbus European users are described here, both for pressurised payloads within the Columbus module and external payloads on the Columbus External Payload Facility (EPF).

Pressurised Payloads within the Columbus Laboratory module

The International Standard Payload Rack (ISPR; Fig. 11) and the European Drawer Rack (EDR; Figs. 11/27) are the nominal payload accommodation units in the Columbus module.

The Columbus resources available to ISPR payloads are provided through a Utility Interface Panel. This is located under the ISPR and, together with the use of flexible utility lines, allows the ISPR to be tilted without disturbing the interfaces, thus supporting 'all-round' rack servicing and maintenance requirements. The Utility Interface Panel details are shown in Fig. 12.

The resources provided to an ISPR through the Utility Interface Panel are detailed in Table 7.

The European Drawer Rack resources are detailed in the chapter on 'Multi-User Facilities' and Support Equipment.

Columbus Lab Centre Aisle Payloads

Limited payload equipment may be accommodated on-orbit in the centre aisle. The allowed envelope is shown in Fig. 13.

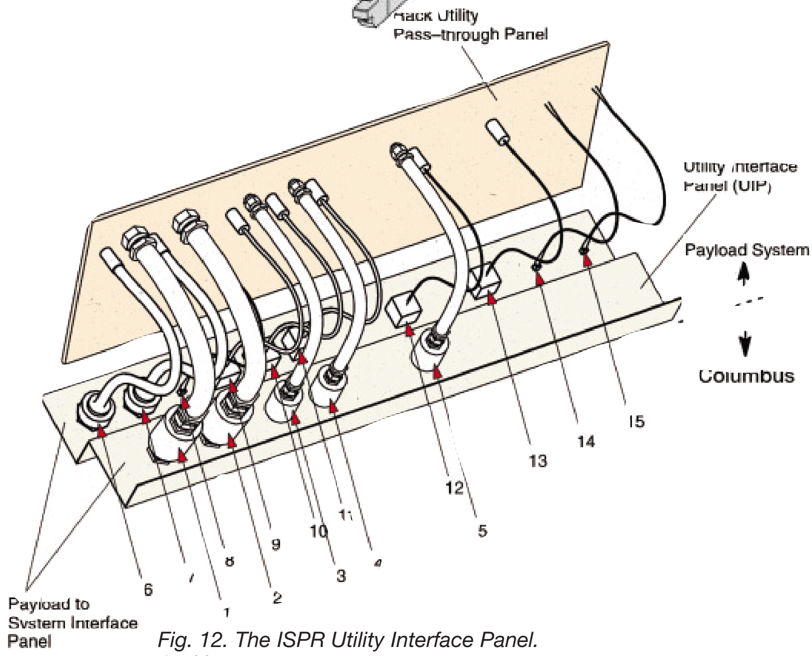


Fig. 12. The ISPR Utility Interface Panel.

1. *Vacuum*
2. *Waste gas*
3. *TCS MOD supply*
4. *TCS MOD return*
5. *GN_2*
6. *Essential/auxiliary power [J2]*
7. *Main power [J1]*
8. *Video/sync (fibre optic) [J16]*
9. *High Rate Data (fibre optic to Automated Payload Switch) [J7]*
10. *FDS/MAINT (Fire Detection/Power Maintenance Switch) [J43]*
11. *1553B-A (nominal MIL-STD-1553B bus) [J3]*
12. *1553B-B (redundant MIL-STD-1553B bus) [J4]*
13. *EWACS (Payload emergency, warning, safing) [J45]*
14. *LAN-2 (IEEE 802.3 redundant LAN) [J47]*
15. *LAN-1 (IEEE 802.3 nominal LAN) [J46]*

Table 7. Resources Provided to Columbus ISPRs by the Utility Interface Panel

Resource	Nominally Available	Comments
Main Power Auxiliary Power	6 kW or 3 kW @ 120 Vdc 1.2 kW @ 120 Vdc	6kW=medium power, 3kW=low power For back up in case of main power loss
Vacuum	0.13 Pa under a gas load of 0.1 Pa.litre/s	
Venting	1000 hPa to 0.13 Pa within 2 h for a payload chamber of 100 litre	Only 1 ISPR vented at any one time to prevent cross-contamination
Cooling Water	Inlet 16-20¡C Outlet <49¡C	Flow rate fixed/calibrated during payload integration between 30 kg/h and 190 kg/h
Nitrogen Gas	Max. flow rate 5.43 kg/h. Operating pressure 5170-8270 hPa. Max. pressure 1378 kPa. Temperature 15.6->45¡C	
Video	NTSC Standard	Can be configured for high-rate data up to 32 Mbit/s
High-Rate Data	Up to 32 Mbit/s	High-rate data to/from US Lab APS
Fire Detection System (FDS)		Payload signals required for credible fire risks (incl. smoke sensor & fans where necessary) and safing commands from Columbus Laboratory vital systems
EWACS		Emergency & Warning signal interfaces and commands with direct link to Columbus Laboratory vital systems
1553B Bus	51.2 kbit/s data rate	Primarily intended for payload low-rate data and payload commanding
802.3 LAN	<1.25 Mbit/s data rate for all payloads	Primarily intended for payload medium-rate (via HRM)

Table 8. Resources Provided to Centre Aisle Payloads by the Standard Utility Panel (SUP)

Resource	Nominally Available	Comments
Main Power	500 W @ 120 Vdc	
Video	NTSC Standard	Can be configured for high-rate data. Available at only two SUP locations
High-Rate Data	Up to 32 Mbit/s	High-rate data to/from US Lab APS but available at only two SUP locations
EWACS		Emergency & Warning signal interfaces and commands with direct link to Columbus Lab vital systems. Available at only two SUP locations
1553B Bus	51.2 kbit/s data rate	Primarily intended for payload low-rate data and payload commanding. Available at only two SUP locations
802.3 LAN	<1.25 Mbit/s data rate for all payloads	Primarily intended for payload medium-rate (via HRM) data. Nominal and redundant LANs

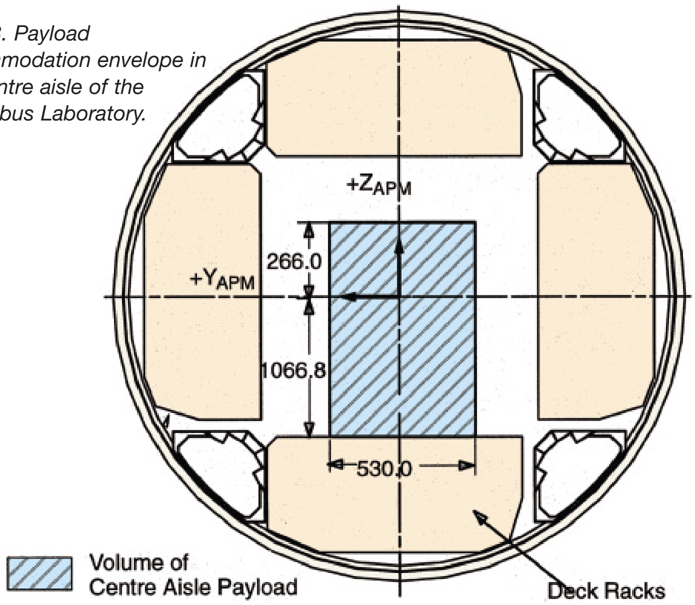


Fig. 13. Payload accommodation envelope in the centre aisle of the Columbus Laboratory.

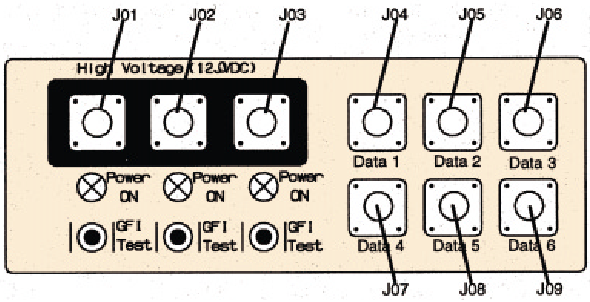


Fig. 14. Standard Utility Panels provide reduced Columbus resources to aisle payloads.

Reduced Columbus resources available to aisle payloads are provided at four locations. The Standard Utility Panel is shown in Fig. 14. The resources provided to centre aisle payloads through this Panel are given in Table 8.

External Payloads on the Columbus Laboratory Starboard End Cone

Columbus external payload accommodation is provided through four Express Pallet Adapters (ExPAs) mounted on the Columbus Laboratory's External Payload Facility (EPF); see Fig. 15.

The resources provided to Columbus external payload users are a reduced subset of those available to the Columbus pressurised payloads.

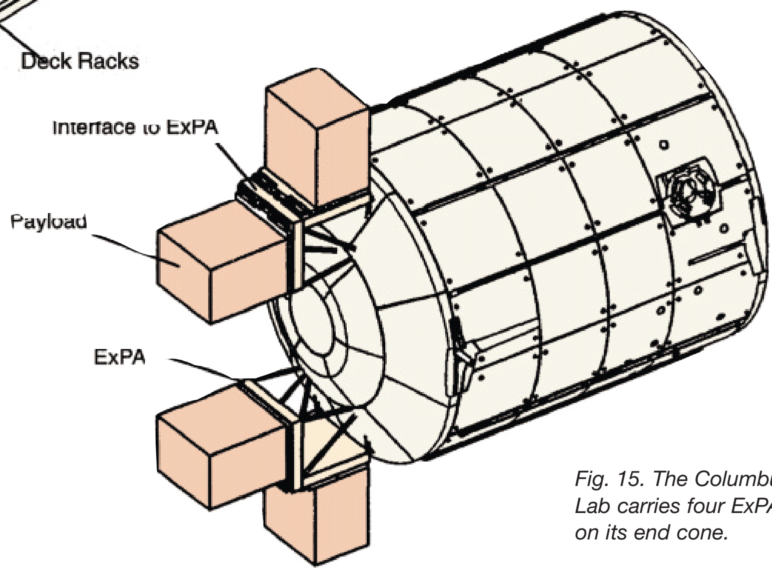


Fig. 15. The Columbus Lab carries four ExPAs on its end cone.

The resource planning, allocation and timelining of all European payloads (pressurised and external payloads) are bound together. The resources available for Columbus external payloads are given in Table 9.

Table 9. Resources Available to Columbus External Payloads

Resource	Nominally Available	Comments
Main Power	120 Vdc	2 feeders to each ExPA. Up to 2.5 kW available at all adapters, but only 2.5 kW may be consumed by all ExPAs
Data interfaces	Analog lines Command lines	Interfacing to Command and Monitoring Unit
High-Rate Data	Maximum 32 Mbit/s	Redundant pair to each ExPA. Extension of Columbus video/data link
1553B Bus	Selectable. Connected to Network Patch Panel*	Redundant pair to each ExPA
802.3 LAN	Selectable. Connected to Network Patch Panel*	Redundant pair to each ExPA

*Network Patch Panel provides for ExPA configuration between US Payload/Columbus payload bus and Ethernet LANs

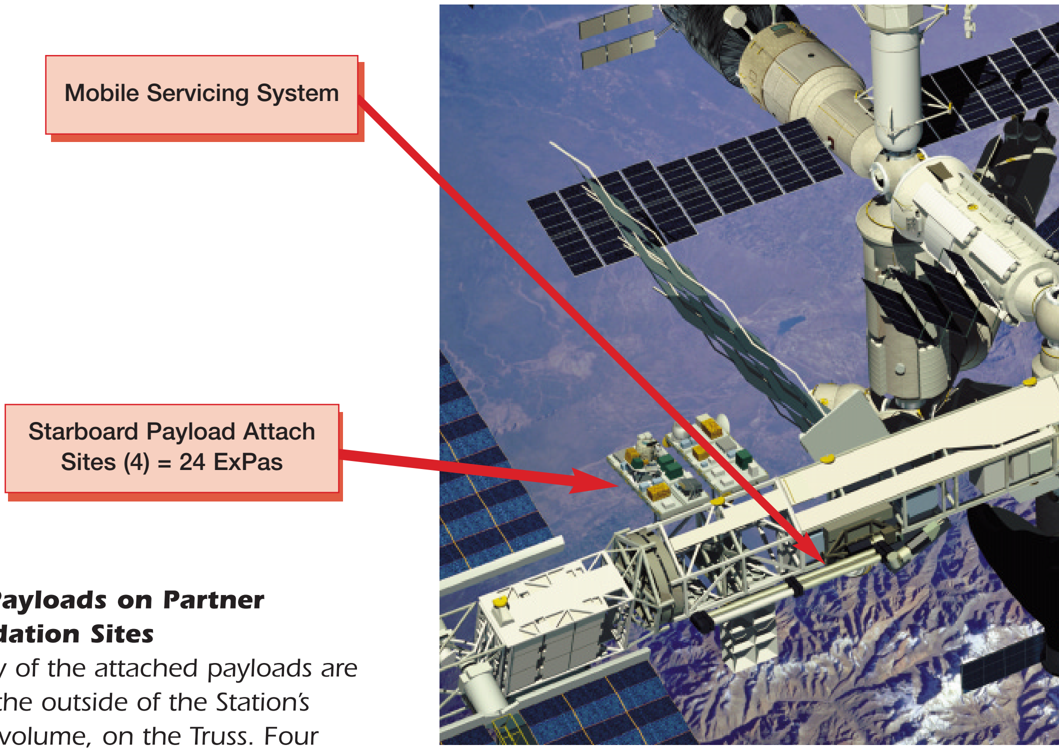


Fig. 16. Locations for attaching external payloads on the ISS.

External Payloads on Partner Accommodation Sites

The majority of the attached payloads are located on the outside of the Station's pressurised volume, on the Truss. Four locations on the S3 Truss segment offer attached payload accommodation for Express Pallets, and 10 locations on the JEM External Facility house attached payloads. These locations are shown in Fig. 16. An Express Pallet has six robotically replaceable adapters, Express Pallet Adapters (ExPAs), for payloads. An example of an Express Pallet with ExPA's is shown in Fig. 17a/b. The resources available to each ExPA are given in Table 10.

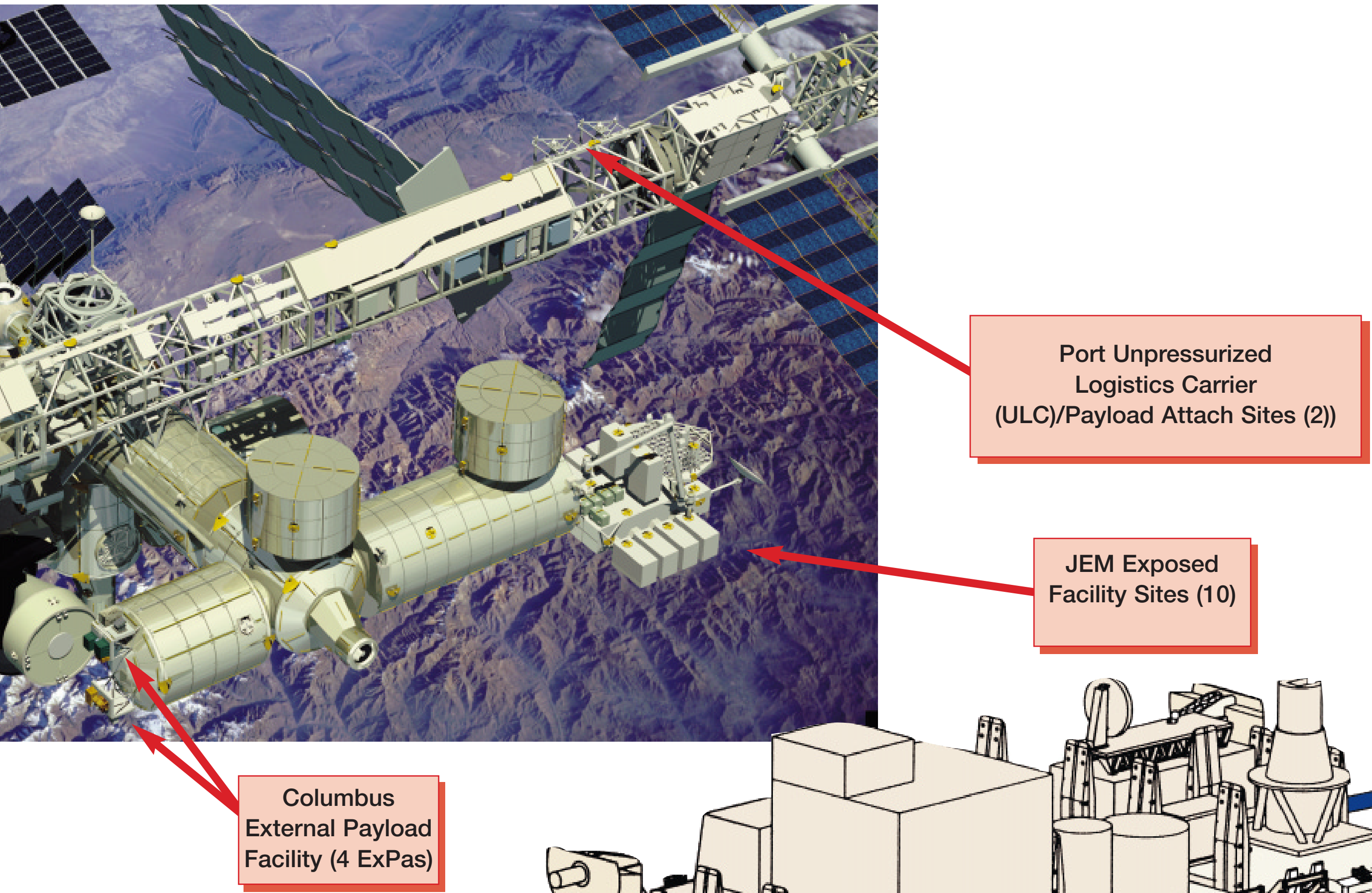
European payload components consisting of several individual payloads may be accommodated on a single ExPA. The ESA-developed Power Distribution Unit (PDU) and External Payload Computer (XPLC) provide the interfaces between these multiple payloads and the ExPA power/data connectors.

The Japanese attached payload sites additionally offer active cooling for payloads.

The Russian Science Power Platform offers further accommodation opportunities for external payloads. However, engineering details are still unknown.

Table 10. Resources Available to Each Express Pallet Adapter

Resource	Capability	Comments
Main Power	28 Vdc 120 Vdc	Two outlets per rating. Combined power for each ExPA limited to 2.5 kW max
Stay-alive power	120 W @ 120 Vdc	
1553B Bus	50 kbit/s	Used for low-rate telemetry and telecommanding. Total rate for all adapters
802.3 LAN	6 Mbit/s	Used for medium-rate telemetry. 6 Mbit/s maximum per Pallet
Analog inputs from payloads to ExPA	6	Used for monitoring analog payload parameters. For all payloads on an adapter
Discrete outputs & inputs between ExPA and payloads	6 (for input & output)	Used for monitoring discrete payload parameters
Field of View	Nadir, zenith, ram, wake & Earth limb	



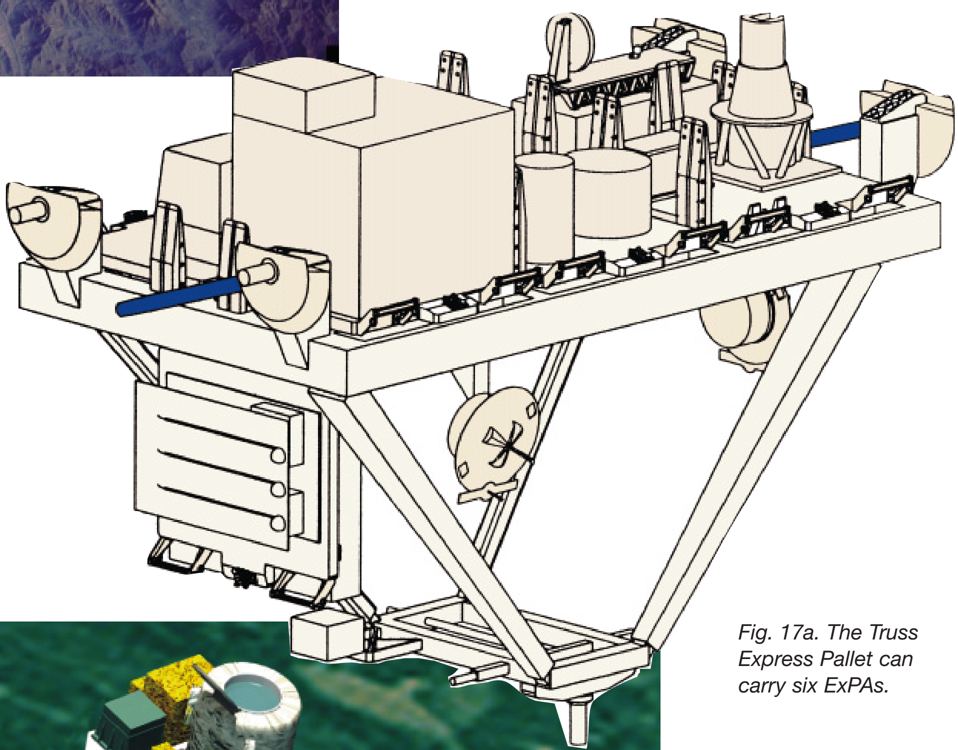


Fig. 17a. The Truss Express Pallet can carry six ExPAs.

Fig. 17b. The Express Pallet, carrying six ExPAs, mounted on the ISS Truss. (ESA/D. Ducros)

Multi-user Facilities and Support Equipment

Fig. 18. The Columbus Laboratory will provide a range of multi-user facilities.

This chapter describes ESA's significant contributions of multi-user facilities, Payload Support Equipment (PSE), Laboratory Support Equipment (LSE) and Standard Payload Outfitting Equipment (SPOE) to support the European Space Station users community. The known research facilities provided by the Partners are also summarised.

Table 11 provides an overview of those contributions and includes the currently planned Station laboratory location assignment for the pressurised payloads. The attachment site locations for the external payloads are under review. The contributions are then elaborated upon, with their utilisation characteristics.

The European pressurised multi-user facilities will allow laboratory multiple users or multiple experiments to employ specific capabilities in sequenced or simultaneous operations or in accessing the experiment/observation data transmitted to ground.

PSE and LSE for pressurised and external payloads comprises permanently on-orbit hardware that can be shared by payloads in support of their flight accommodation and operations.

SPOE for pressurised and external payloads covers qualified hardware items that may be payload-embedded to provide general operations and/or interface functions, and that pre-empt the need for users to undertake their own development.

Table 11. Range of European Facilities and Support Equipment Available to Users

		Facility	PSE/LSE	SPOE
Pressurised Payloads Accommodated In	Columbus Laboratory	Biolab[1]	ESA-developed: European Stowage Rack (ESR)	ESA-developed: Avionics Air Assembly (AAA)
		European Drawer Rack (EDR)[1]		Remote Power Distribution Assembly (RPDA)
		European Physiology Modules (EPM)[1]		Standard Payload Computer (SPLC)
		Fluid Science Laboratory (FSL)[1]		Turbo Molecular Pump (TMP)
		Material Science Laboratory (MSL)[1]		
		Protein Crystal Diagnostics Facility (PCDF, located in EDR)	US-developed: Mid-Deck Lockers (MDLs)	US-developed: Area Smoke Detector Assembly (ASDA)
			International Standard Payload Rack (ISPR)	Rack Main Switch Assembly (RMSA)
				Interface Connectors
			Japanese-developed: International Standard Payload Rack (ISPR)	
	US Laboratory	Advanced Protein Crystallisation Facility (APCF)[2]	ESA-developed: Cryosystem[2]	
		Handgrip Dynamometer[2]	Microgravity Science Glovebox (MSG)[2]	
		Material Science Laboratory (MSL)[1,2]	Minus Eighty degree Lab Freezer for ISS (MELFI)[2]	
		Modular Cultivation System (MCS)[2]	US-developed: Express Racks (ERs)	
		Muscle Atrophy Research & Exercise System (MARES)[2]	Active Rack Isolation System (ARIS)	
		Percutaneous Electrical Muscle Stimulator (PEMS)[2]	Mid-Deck Lockers (MDLs)	
External Payloads		Atomic Clock Ensemble in Space (ACES)[4]	ESA-developed: Coarse Pointing Device (CPD)	ESA-developed: External Payload Computer (XPLC)
		Expose[4]	Hexapod Pointing System[3]	Power Distribution Unit(PDU)
		Fire Detection Infrared Sensor System (FOCUS)[4]	US-developed: Environmental Monitoring Package (EMP)	US-developed: Express Pallet Adapters (ExPAs)
		Global Transmission System (GTS)[5]		
		Matroshka[5]		
		Solar Monitoring Observatory (SMO)[4]		
		Sky Polarisation Observatory (Sport)[4]		
		Technology Exposure Facility (TEF)[4]		

Notes: 1 The facilities FSL, Biolab, MSL and EPM are also collectively known as the Microgravity Facilities for Columbus (MFC). 2 Europe supplies this equipment to NASA under a barter agreement. The US Lab responsibility rests with NASA and ESA has utilisation rights. Further introductory details may be obtained from the appropriate document. 3 Hexapod is being developed by ESA in support of the Stratospheric Aerosol and Gas Experiment (SAGE III) instrument from NASA/Langley Research Center. 4 These European facilities are externally mounted on Express Pallet Adapters as part of the US Express Pallet under NASA cooperative agreements. 5 Matroshka is located on a Russian element.

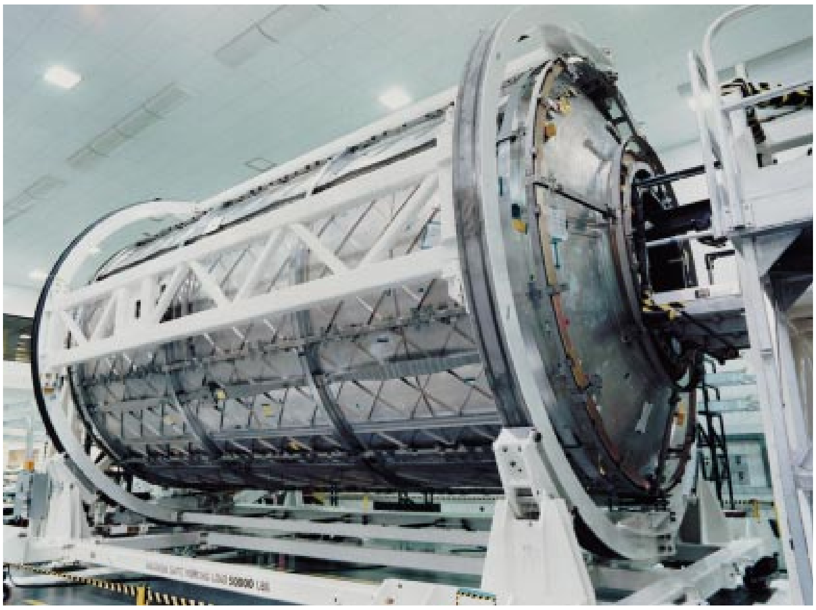


Fig. 19. The US Laboratory will provide a range of multi-user facilities. (NASA).

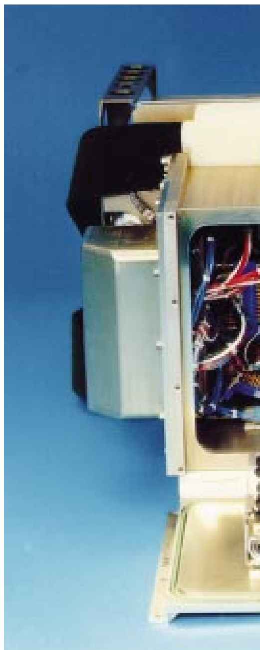


Fig. 20a. The Advanced Protein Crystallisation Facility will support protein screening experiments.

European Pressurised Multi-User Facilities in the US Laboratory

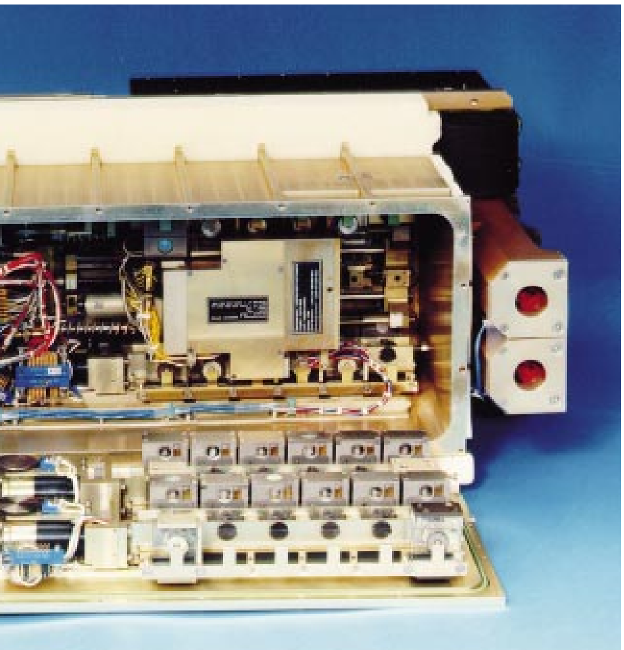
Advanced Protein Crystallisation Facility

The *Advanced Protein Crystallisation Facility* (APCF; Table 12; Fig. 20) offers a Mid-Deck Locker-size multi-experiment capability to perform protein screening experiments under reduced gravity and temperature-controlled conditions.

The APCF comprises a processing chamber and support systems. The processing chamber supports experiments contained in dedicated reactors that are activated and de-activated by software-driven electric motors. Multiple volume reactor sizes are available for users. The APCF support systems provide the interfaces with the MDL, as well as offering diagnostic capabilities.

Table 12. Advanced Protein Crystallisation Facility (APCF) Characteristics

Processing chamber	
Number of reactors	48
Reactor activation/deactivation	Selectable by groups of 12 reactors
Temperature	Selectable between 8¡C and 30¡C
Accuracy of temperature control	0.1¡C
Temperature ramping	Selectable through software
Reactor types	
Free Interface Diffusion	20-470 L Extended Length Protein Chamber up to 1.3 mL
Dialysis	15-188 L
Vapour Diffusion	Drop volume 4-8 L or 35-80 L
Observation possibilities	
Direct observation	LED illumination through drive-mounted optical system
Wide Field of View (WFOV)	5 reactors on one side
Narrow Field of View (NFOV)	5 reactors on opposite side
Interferometry	Mach Zehnder capability
Field of View	8.5x6.3 mm; 5.0x3.7 mm
Camera (resolution)	B & W CCD (582 lines @ 500 pixels/line)
Grey levels	256
Storage capability	Up to 15 000 images, plus houskeeping



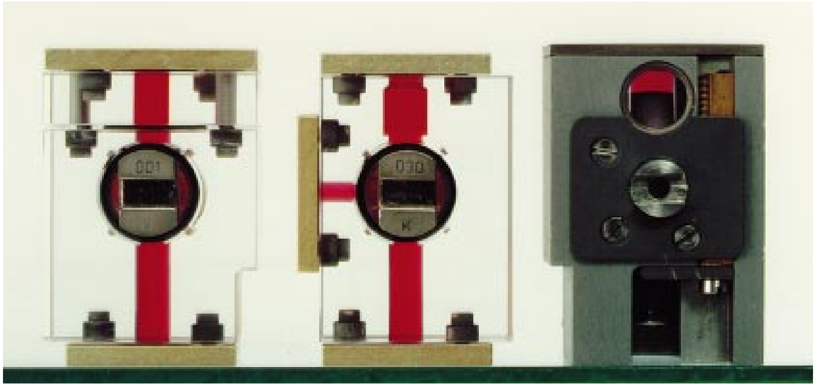


Fig. 20b. The three types of APCF reactors (from left): Dialysis; Free Interface Diffusion; Vapour Diffusion (Hanging drop).

Handgrip Dynamometer
The *Handgrip Dynamometer and Pitch Force Dynamometer* (Table 13; Fig. 21) is a hand-held capability used as a: measurement device for test-subject strength in connection with muscle-wasting under weightlessness; stressing device, particularly for stressing the autonomic nervous system; isometric exercise device for stressing the cardiovascular system.

The Handgrip Dynamometer is provided as part of the NASA Human Research Facility (HRF).

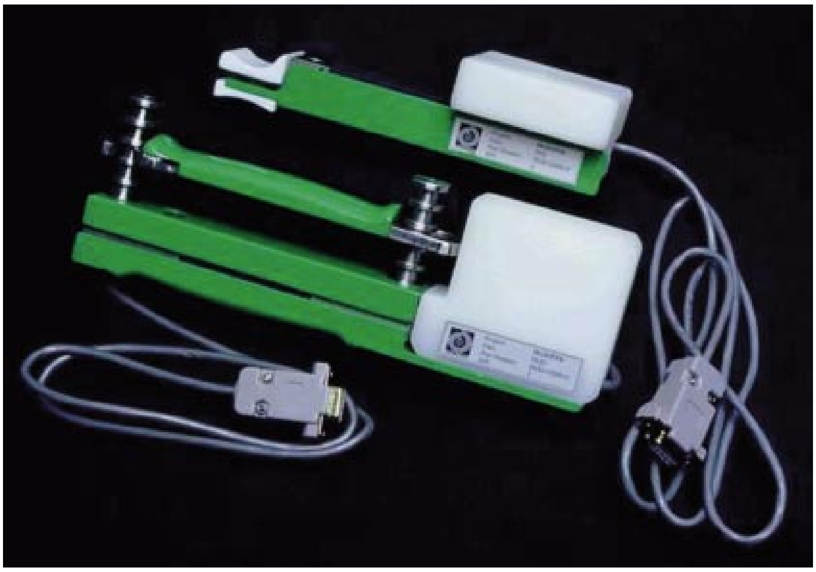


Fig. 21. The Handgrip Dynamometer and Pitch Force Dynamometer.

Table 13. Hand-Grip Dynamometer and Pitch Force Dynamometer Characteristics	
Hand-Grip Dynamometer	
Determines force applied by whole hand	
Force range	Up to 1000 N
Measurement accuracy	–7.5 N
Pitch Force Dynamometer	
Determines force applied between thumb and opposing fingers	
Force range	Up to 270 N
Measurement accuracy	–2 N

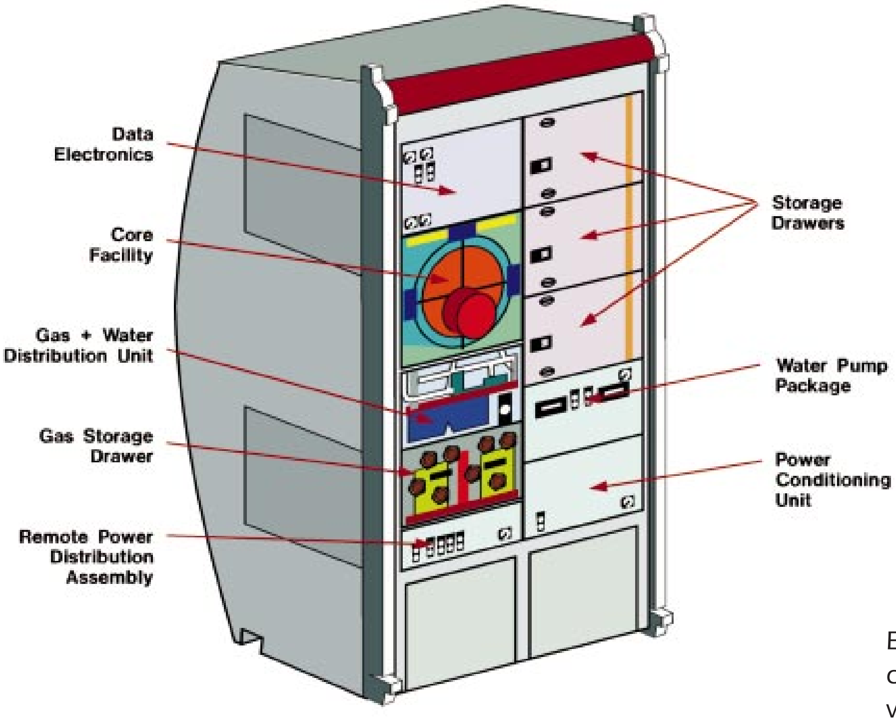


Fig. 22a. The Material Science Laboratory will investigate solidification physics, crystal growth with semi-conductors, thermophysical properties and the physics of liquid states.

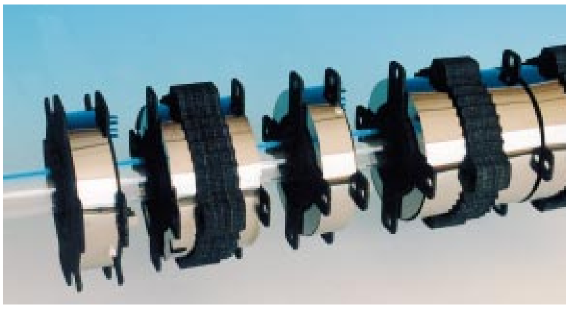


Fig. 22b. The Low Gradient Furnace (LGF) heater assembly for the Material Science Laboratory.

Material Science Laboratory

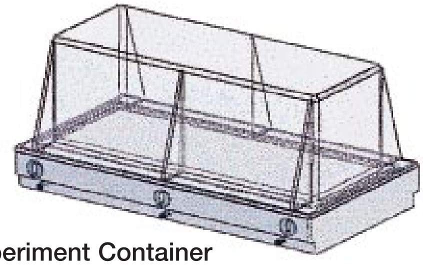
The *Material Science Laboratory* (MSL; Table 14; Fig. 22) offers a multi-user capability to support scientific research in solidification physics, crystal growth with semi-conductors, measurement of thermophysical properties and the physics of liquid states. MSL occupies about half of an ISPR in the US Lab, and one ISPR in the Columbus Laboratory. The two MSL versions are identical except for minor rack interface differences.

Each MSL comprises a core element consisting of a sealed process chamber in which interchangeable furnace inserts are hosted. These inserts process the samples. The sample cartridges are manually loaded into one of the furnaces. The furnace can be moved over the sample cartridge to displace the thermal gradients. Diagnostic systems provide scientific data on the facility and sample cartridge during operations. As the furnaces are modular, they can be upgraded or replaced according to utilisation needs. Additional MSL units complete the accommodation and operational interfaces to the laboratory.

Table 14. Material Science Laboratory (MSL) Characteristics

	QMI*	DMI*	FMF*	LGF*	SQF*
Maximum furnace temperature (K)	1673	TBD	1773	1873	2073
Temperature stability (K)	-0.3	-	-0.02	-0.02	-0.2
Isothermality of plateau heaters (K)	-	1	-	-0.5	-
Maximum thermal gradient (K/cm)	TBD	100	5-25	50	150
Diameter of furnace bore (mm)	TBD	50 (TBC)	42	30	30
Length of hot cavity (mm)	TBD	TBD	250	200	250
Cartridge diameter (mm)	27	48	<39	<29	10-28
Length of adiabatic zone (mm)	TBD	TBD	-	50	50-100 var.
Length of cold cavity/cooling zone (mm)	TBD	TBD	-	120	variable
Diagnosis & stimuli					
Processing speed (mm/s)	10^{-5}-2	-	10^{-5}-2	10^{-5}-2	10^{-5}-2
Thermocouples	Up to 12 individually selectable				
Pulse Marking	Peltier				
Sample resistive measurement	yes				
Seebeck voltage measurement	yes				
Cartridge shear cell activation	yes				
Fast quenching speeds	Up to 100 mm/s selectable or 100 mm displacement within 1 s				
Differential thermal analysis	By thermocouple zoom				
Acoustic Interface monitoring	Upon request				
Rotating magnetic field	-	-	yes	yes	-

*QMI: Quench Module Insert. DMI:Diffusion Module Insert. FMF: Floating Zone Furnace with Rotating Magnetic Field. LGF: Low Gradient Furnace. SQF: Solidification and Quenching Furnace. The QMI and DMI furnaces are provided by NASA but can be used by European scientists within the framework of the ESA/NASA MSL Utilization Agreement.



Experiment Container

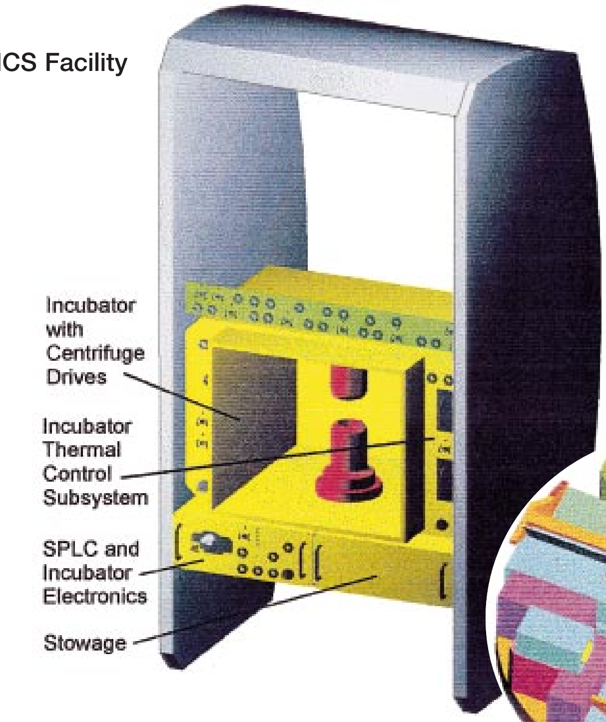


Fig. 23. The Modular Cultivation System will be accommodated in the US Laboratory.

Modular Cultivation System

The *Modular Cultivation System* (MCS; Table 15; Fig. 23) is a multi-user capability for research into the early development events in plants; long-term growth stability; gravity influence during early development and growth; perception and signal transduction in plant tropism, as well as providing the possibility for research on insects, amphibia and radiation effects on cells and tissues.

The scientific utilisation of MCS will be shared with NASA. MCS will be accommodated in a NASA Express Rack in the US Laboratory.

MCS comprises two major units: Experiment Containers and the multi-purpose cultivation unit. The Experiment Containers house the samples as well as all the experiment-specific hardware. Each Experiment Container is hosted on one of the multi-purpose cultivation unit rotors. A range of rotors with standard utility interfaces is available for users. The rotors provide the variable gravity environment. Additional MCS units complete the accommodation and operational interfaces to the laboratory.

Table 15. Modular Cultivation System (MCS) Characteristics

Experiment Containers	
Internal Volume	60x60x160 mm
O_2 content	15-22%
CO_2 content	0.03-0.5% but extendable from 1% to 5%
N_2 content	Remainder
Ethylene removal	Provided
Temperature control	18-40¡C
Humidity	50-95% relative humidity
Data interfaces	RS485. Command (digital I/O) and analog lines
Power lines	–12 Vdc, +5 Vdc
Plant Rotors	
Number of rotors	2
Experiment containers per rotor	4
Rotor speed	Selectable for 0 g and 0.001-2.0 g
Illumination:	
Day cycle	yes
Night cycle	Infrared
Video camera/signal	1 camera for 2 containers; 1 video signal per rotor Video frame-grabbing
Accommodation:	
Incubator, rotors and active containers	In 4 Mid-Deck Lockers
Electronics	1 Drawer

Fig. 24. The Muscle Atrophy Research and Exercise System (MARES) supports research into muscle atrophy under weightlessness. Shown is the knee flexion/extension motion.

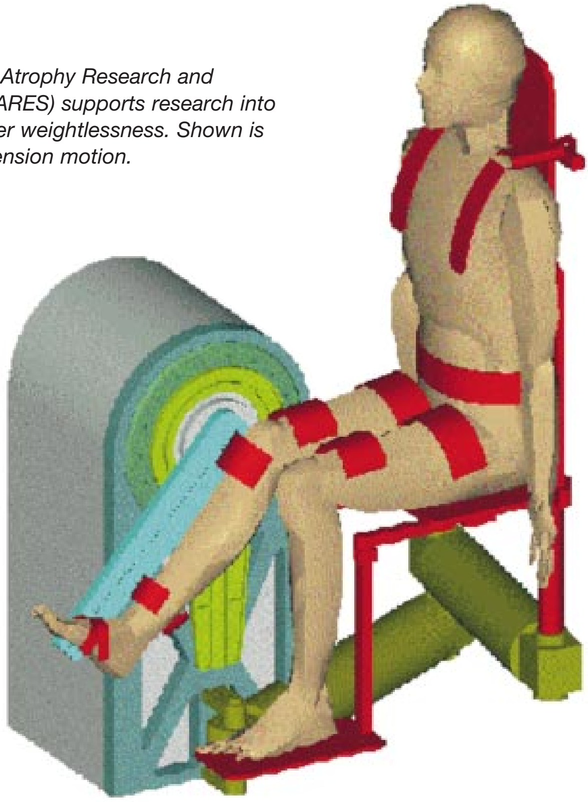


Table 16. Muscle Atrophy Research and Exercise System (MARES) Characteristics	
Movement possibilities	
Flexion/Extension	Ankle (dorsa/plantar), knee, hip, wrist, elbow, shoulder, trunk
Supination/Pronation & Radial/ulnar deviation	Wrist
Linear movement	Whole leg(s), whole arm(s)
Measurement modes	
Isometric	No movement/counteract subject forces
Isokinetic	Concentric/eccentric to maintain constant velocity during movement
Isotonic	Concentric/eccentric to maintain constant torque during movement
Position control	Based upon predefined complex position profiles
Velocity control	Based upon predefined complex velocity profiles
Torque/force control	Based upon predefined complex torque/force profiles
Power control	Constant power
Ideal elements	Simulate ideal spring, viscosity, inertia or some combination
Pseudo-gravitational	Simulate programmable mass and gravity vector
Quick-release	Sudden release of torque/force
Linear motions	
Force	†250 N
Velocity	†0.5 m/s
Length	†1 m
Angular motions	
Torque	<450 Nm continuous <900 Nm peak up to 200 ms
Velocity	<515¡/s
Angle	Unlimited number of turns
Power	Maximum 2700 W

Muscle Atrophy Research and Exercise System

The *Muscle Atrophy Research and Exercise System* (MARES; Table 16; Fig. 24) is a multi-user capability to support research in the area of muscle atrophy under weightlessness.

MARES comprises a custom-built motor system that includes torque and angular position/velocity sensors as well as a subject body restraint system consisting of a chair and limb adapters. These elements are controllable according to user-defined profile algorithms. The MARES Man-Machine Interface is accomplished on the Human Research Facility (HRF) laptop. This has two primary functions: to command the MARES-specific algorithms and to provide the operator/subject with feedback through displays.

MARES is provided by ESA as part of NASA's HRF.

Percutaneous Electrical Muscle Stimulator

The *Percutaneous Electrical Muscle Stimulator* (PEMS; Table 17; Fig. 25) is a research capability that provides stimulation of specific muscle groups in a test subject to study muscle atrophy occurring under weightlessness. It is provided by ESA as part of the NASA Human Research Facility.

PEMS will be used in conjunction with MARES for support in the measurement of the intensity of involuntary muscle contractions. Other features include:

- programmable trains of pulses (pulse width, amplitude, time between pulses);
- the possibility for adding a randomised delay before the first pulse.

Fig. 25. The Percutaneous Electrical Muscle Stimulator will study muscle atrophy in weightlessness.

Table 17. Percutaneous Electrical Muscle Stimulator (PEMS) Characteristics	
Stimulation form	Positive-going charge pulse followed by negative after-pulse as muscle is passively discharged
Pulse widths (width of positive-going pulse)	50 s and 250 s
Maximum charge per pulse	40 C
Muscle groups stimuli	1 Triceps surae (ankle) 2 Quadriceps (knee) 3 Triceps brachii/biceps brachii (2 groups for elbow) 4 Flexor/extensor carpi ulnaris/radialis (2 groups for wrist) 5 Adductor pollicis (thumb)

Fig. 26b. The Biolab mockup (right) in the Columbus simulator of the Space Station User Information Centre at ESTEC.

European Pressurised Multi-User Facilities in the Columbus Laboratory

Biolab

Biolab is a multi-user facility (Table 18; Fig. 26) designed to support biological experiments on microorganisms, animal cells, tissue cultures, small plants and small invertebrates. Biolab occupies one ISPR.

The facility features an incubator equipped with centrifuges offering controlled levels of accelerations. Experiment samples are contained in two versions of Experiment Containers placed on the centrifuges. The Experiment Containers can be handled automatically by the Biolab Handling Mechanism. Independent analysis instruments are available for supporting experiment sample test analyses. A capability for the visualisation of images is at hand. The atmospheric environment of the Experiment Container may be adjusted during centrifuge operations. Automatic temperature-controlled and ambient temperature stowage units are available for storing Experiment Container samples.

A Biolab glovebox provides a clean, controlled and enclosed environment for manual operations on Experiment Container samples. The glovebox, working under negative pressure, pre-empts any possible contamination to the laboratory atmosphere.

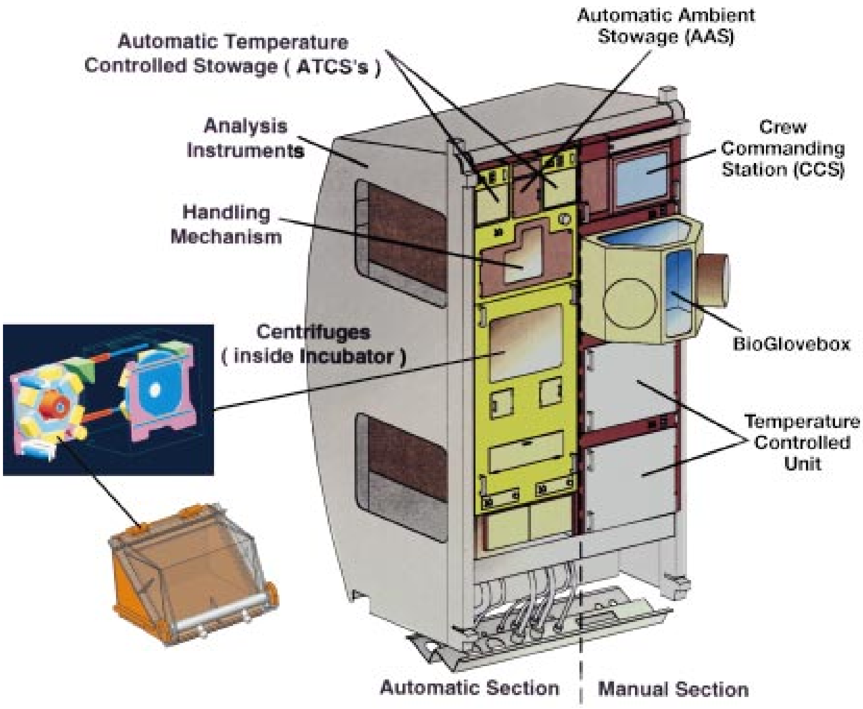


Fig. 26a. Biolab will support biological research. (ESA/D. Ducros)

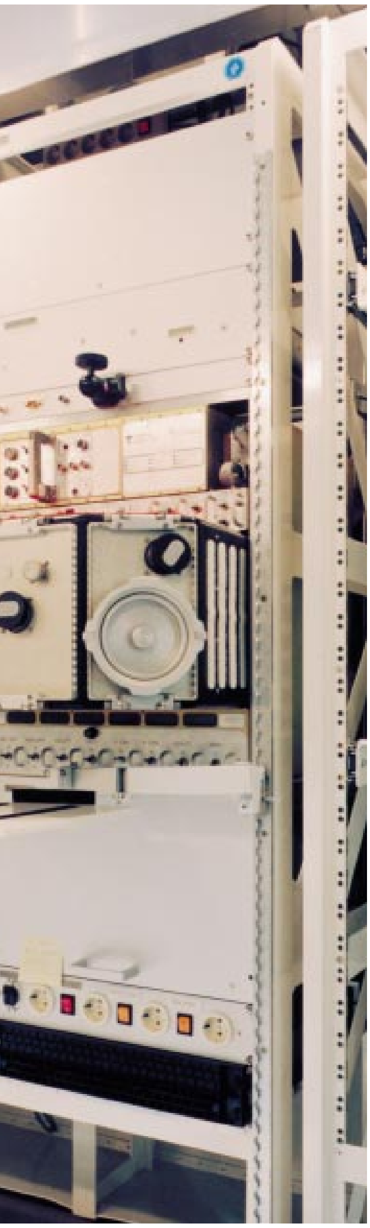


Table 18. Biolab Characteristics	
Experiment Container (EC)	
Available volume (Basic EC)	60x60x100 mm
Available volume (Advanced EC)	25 litre
Filter system	Particle filters with pore size <0.2 m
Power interfaces	–12 Vdc 5 W maximum
	+5 Vdc 10 W maximum
Data interfaces	RS-485 (serial)
	5 analog channels
	3 digital inputs/outputs
Video (Advanced EC only)	NTSC
Incubators	
Temperature range	Selectable 18¡C to 40¡C
Centrifuges	2
Centrifuge g-level control	Selectable 10^{-3}g to 2g
Number of containers	6 per centrifuge
Observation resolution	0.2 mm on a 40x40 mm FOV
Life Support System	
Relative humidity	Adjustable 60-90%
Atmospheric concentration	Adjustable CO_2, O_2 and N_2
Ethylene removal	yes
Automatic Temperature Controlled Stowage	
Temperature controlled stowage capability	89 vials; 2 ml/vial
Temperature range	Adjustable -20¡C to +10¡C
Ambient Stowage	
Ambient stowage capability	Up to 3 litre
Analysis Instruments	
Microscope	
Low resolution	5 m /1.5 mm diameter FOV
High resolution	0.5 m/0.15 mm diameter FOV
Mode	Single step or scan
Features	Phase contrast, Bright field, Dark field
Spectrophotometer	
Range	220-900 nm
Resolution	10 nm
Light sources	Deuterium lamp (UV); Tungsten lamp (VIS to NIR)
Handling Mechanism	
Piston speed	0.1-30 mm/s
Push/pull force	20 N
Rotation	4-120 rpm with 5 rpm steps
Torque	0.1 Nm
Piston movement	45 mm
Bioglovebox	
Workspace volume	355x300x280 mm (width x height x depth)
Operation mode	Closed loop
Disinfection mode	Ozone generator
Accessories	Light source; Video camera; Restraint tools
Temperature Controlled Unit	
Units available	2
Storage capacity	12 ECs or 10 ATCS inserts
Usable volume	about 20 litre
Temperature range	-20¡C to +10¡C
Temperature accuracy	–1¡C

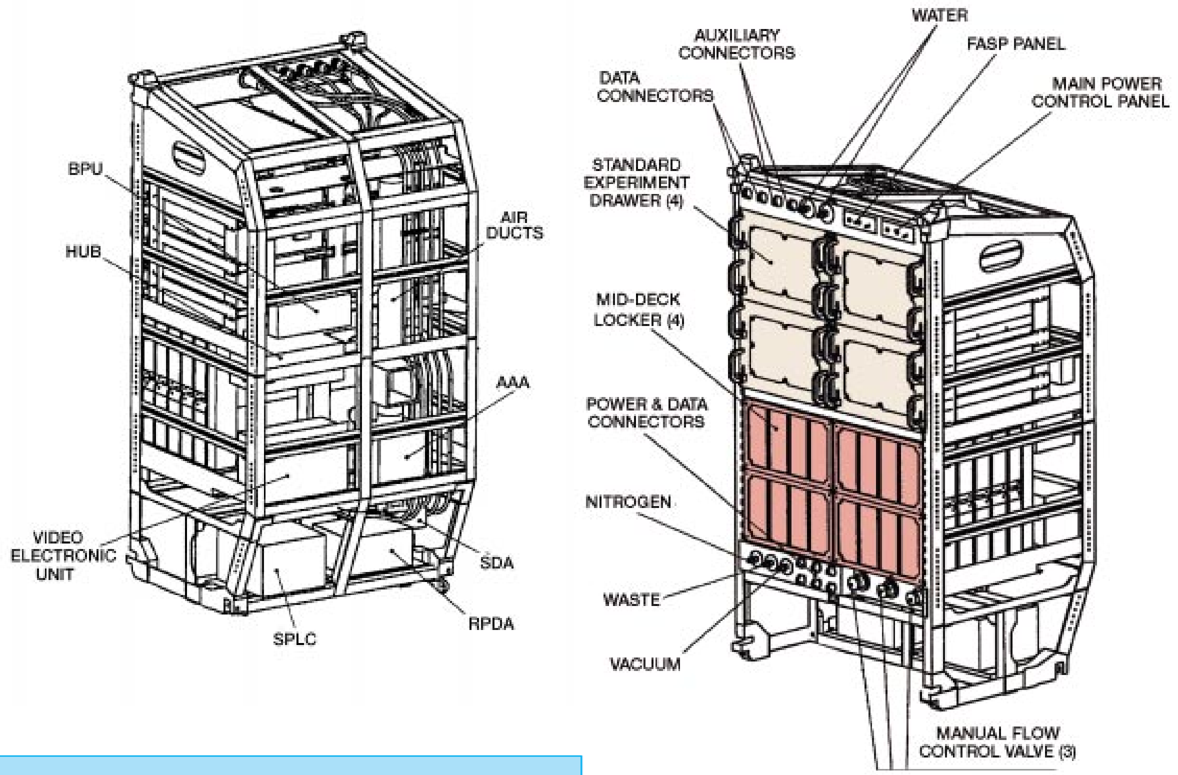


Fig. 27. The European Drawer Rack (EDR) provides a modular capability for sub-rack payloads. AAA: Avionics Air Assembly. BPU: Branching Protection Unit (power branching with fuses). FASP: Fire Annunciation Suppression Panel. MDL: Mid-Deck Locker. RPDA: Remote Power Distribution Assembly. SDA: Smoke Detector Assembly. SED: Standard Experiment Drawer. SPLC: Standard Payload Computer.

Table 19. European Drawer Rack (EDR) Characteristics

	SED	MDL
Number in baseline	4*	4*
Volume available to payload	72 litre	57 litre
Mass available to payload	38 kg	20 kg
Heat rejection capability (air cooling)[1]	300W	300W
Heat rejection capability (water cooling)[1]	500W	500W
Resources available to user	Via rear connector	Via UDP cable/s to MDL front
Main power 28 Vdc (5 A & 10 A)	1 per SED[2]	1 per MDL
Main power 120 Vdc (3 A)	1 per SED[2]	N/A
Auxiliary power 120 Vdc (3 A)	For selected SEDs only	For selected MDLs only
Analog video NTSC RS 170A	1 per SED	1 per MDL
Digital video or high-rate data[3]	1 per SED	1 per MDL
RS422	1 per SED	1 per MDL
Data IEEE 802.3 (Ethernet)	1 per SED	1 per MDL
Discrete Input	2 per SED	2 per MDL
Discrete Output	2 per SED	2 per MDL
Analog Input	2 per SED	2 per MDL
Common resources		
Water cooling[4]	Via UDP	Via UDP
Gaseous Nitrogen[4]	Via UDP	Via UDP
Vacuum (venting)[4]	Via UDP	Via UDP

*the initial launch configuration for the EDR includes 4 SEDs and 4 MDLs.
1 The maximum rack cooling capability for air cooling is up to 1200 W and for water cooling up to 2000 W. A combination of both types of cooling is possible provided that the individual cooling capacity is not exceeded and the overall capacity of 2000 W is not exceeded. 2 SEDs will be configurable either for 28 Vdc or for 120 Vdc. 3 This connection is a high-rate data connection to be used by payloads that perform their own video processing. ESA s Protein Crystallisation Diagnostics Facility is an example. 4 The fluid utilities are routed through the Utility Distribution Panels (UDPs). The interfaces may be shared among the different payloads.
These characteristics represent the baseline version. However, the modular configuration permits adaptations to be accommodated.

European Drawer Rack

The *European Drawer Rack* (EDR; Table 19; Fig. 27) provides a modular capability for sub-rack payloads contained in standard experiment drawers (SEDs) and Mid-Deck Lockers (MDLs) accommodated in an ISPR.

The EDR supports the independent operation of the multiple sub-rack payload hardware as well as the provision of a standardised interface to laboratory resources. It supports payload exchange at SED or MDL level.

A fundamental goal of the EDR is to support the development of smaller sub-rack payloads through the provision of accommodation and flight opportunities where quick turnaround mission objectives are required.

Fig. 28. The European Physiology Modules (EPM) will support physiological research. (ESA/D. Ducros)

European Physiology Modules

The *European Physiology Modules* (EPM; Table 20; Fig. 28) constitute a multi-user facility supporting physiological experiments in respiratory/cardiovascular conditions, hormonal/body fluid shift, bone demineralisation and neuroscience. EPM incorporates physiological instruments (Science Modules) provided by the ESA microgravity programme and the national programmes of ESA member states. The EPM will be accommodated in one ISPR.

EPM comprises a number of diverse Science Modules to support typical physiological experiments having duration times ranging from hours to a few months.

Table 20. European Physiology Modules (EPM) Characteristics

Bone Analysis Module (BAM)	
Determines changes in bone properties via measurement of changes in the ultrasound transmission properties of a subject s heel bone (Calcaneous)	
Respiratory Monitoring Module (RMM)	
Gas components analysed	Freon-22, O_2, CO_2, CO, SF_6, CH_4
Gas analysis response time	~150 ms
Flow meter type	Fleisch, turbine, ultrasonic
Mouthpiece pressure	Relative pressure –100 mbar & accuracy –0.2 mbar
Additional instrumentation:	
ECG	3-lead
Blood pressure	Portapres (continuous BP registration from the finger)
Respiratory Inductance Plethysmograph	Lung volume changes
Ambient conditions	Temperature, pressure, relative humidity
Multi-Electrode Electroencephalogram Mapping Module (MEEMM)	
Supports EEG and EMG, or a combination of both	
Number of channels	128
Physiological Pressure Measurement Instrument (PPMI)	Danish module
Provides a pressure-sensitive catheter that can be used, for example, for central venous pressure or esophageal pressure determination	
Xenon Skin Blood Flow Measurement Instrument (XSMI)	Danish module
Measures skin blood flow by determining wash-out of injected bolus of radioactive Xe-133	
Cardiolab	CNES/DLR module
To measure arterial blood pressure and heart rate & fluid volume regulation. Comprises a set of sensor modules, a set of stressor modules and a data management central unit	
Elite-S2	ASI module
Tracks postural movements in 3D. Uses IR video techniques using four cameras. Body markers located on subject reflect IR flashes from flash-guns mounted close to cameras. Cameras record reflections from the markers. System calculates 3D coordinates of markers in real time	
Samples Collection and Waste Management Drawer	
Provides accommodation for clinical and medical laboratory equipment necessary for in-flight samples of blood, saliva and urine, and the processing of solid and/or liquid waste produced during EPM usage.	

Fig. 29. The Fluid Science Laboratory will study fluid behaviour in the absence of gravitational effects. (ESA/D. Ducros)

Fluid Science Laboratory

The *Fluid Science Laboratory* (FSL; Table 21; Figs. 29/30) is a multi-user research capability to study dynamic phenomena of fluid media in the absence of gravitational forces. FSL occupies one ISPR.

For facility users, the most significant FSL element is the Facility Core Element that houses the central experiment module, the optical diagnostics module and the standardised Experiment Containers (ECs). The central experiment module is divided into two parts:

1. contains the suspension structure for the ECs, including all the functional interfaces and optical equipment, and is designed to be pulled out from the rack to allow insertion and removal of the EC;
2. contains all the diagnostic and illumination equipment and its control electronics to command and monitor the electro- and opto-mechanical components.

Fig. 30. Principal features of the Fluid Science Laboratory.

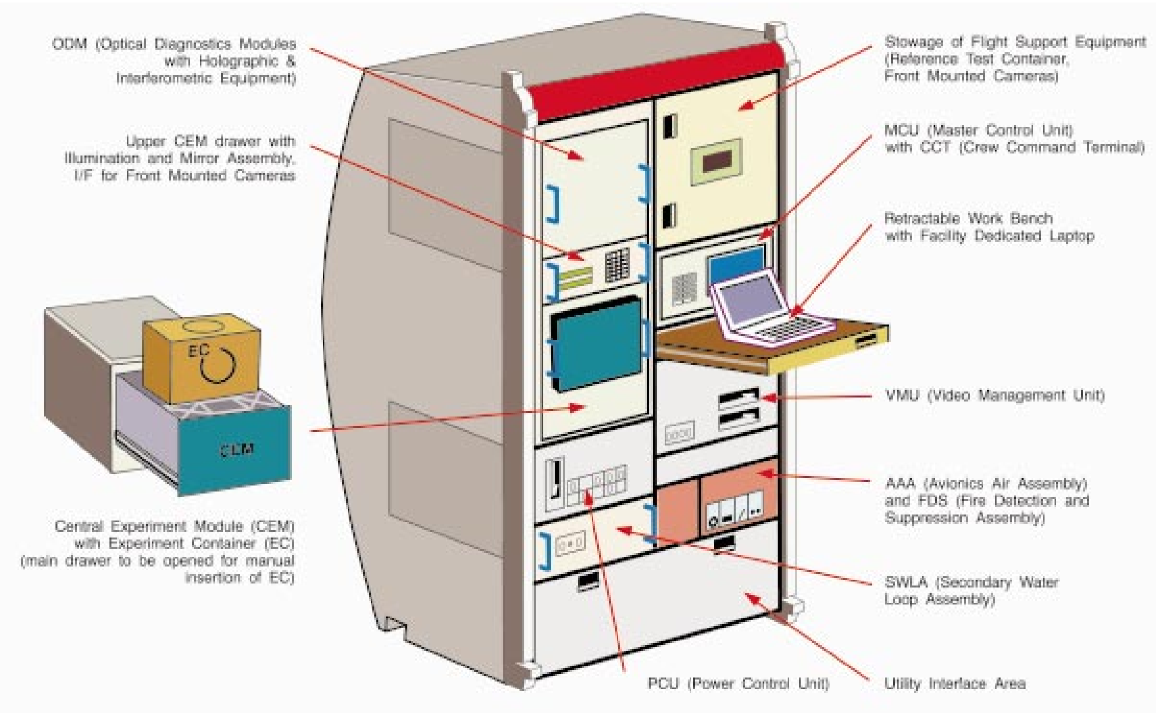


Table 21. Fluid Science Laboratory (FSL) Characteristics	
Experiment Container	
Power available	+28, +15, -15, +12, +5, -5 Vdc
High-voltage supply	Future upgrade
Mass	<40 kg
Dimensions	400x270x280 mm
Fluid volume	1-1000 cm^3
Measurement channels	e.g. 16 analog/ 8 digital
Experiment Container housing	
Containment	Double/triple type
Sealed	yes
Pressurised	yes
Toxic Fluids	yes
Diagnostic/Analysis tools	
Integrated cameras	Integrated CCD or CMOS imagers
Front-mounted cameras	Still, high-speed, high-resolution, IR as required
Parameter setting & diagnostic calibration	Optical reference targets
Standard facility diagnostic capabilities	
White light background	yes
White light and monochromatic light sheet	Variable 0.1-30 mm
Infrared	yes
Visual spectral range	yes
Electronic Speckle Pattern Interferometer	In reflection/transmission modes
Wollaston interferometer	yes
Schlieren interferometer	yes
Holographic interferometer	yes
Complementary Experiment Container diagnosis possibilities	
Special interferometers	yes
Light scattering diagnosis	yes
Laser Doppler anemometer	yes
3-D photogrammetry	yes
Microscopes, endoscopes	yes
Special laser sources	Selectable wavelengths
High-rate non-optical diagnosis	Pressure/temperature sensors
Microgravity reduction capability	
Use of Canadian Space Agency Microgravity Vibration Isolation Mount (MIM) under investigation	

The optical diagnostics module houses the equipment for visual and interferometric observation, their related control electronics and the attachment points and interfaces for front-mounted cameras. The ECs provide the exchangeable receptacle to host the experiment fluid cells as well as any process stimuli and specific user diagnostics, and their supporting container electronics.

The FSL can be operated in fully automatic or semi-automatic modes by the flight crew, or in a remote-control mode from the ground (telescience).

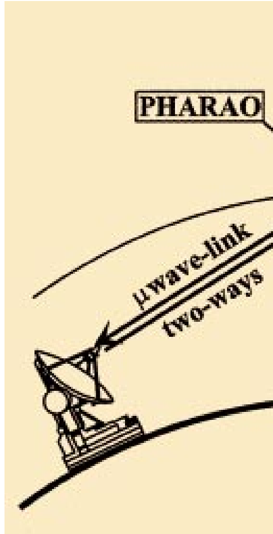


Table 22. Protein Crystallisation Diagnostic Facility (PCDF) Characteristics	
Process Unit	
Process chamber temperature Process chamber capacity	Selectable 14-30¡C 4 Experiments Boxes including reactor temperature control system
Experiment Boxes	
Reactor temperature Solution injection Stirrer capability Individual process control for temperature and concentration	Selectable 4-40¡C yes yes yes
Reactor types	
Dialysis Extended length dialysis Batch Manufacturing material Temperature sensors	Volumes 300, 130, 100 and 50 L 1.1 mL 3 mL to 6 mL final Quartz glass yes
Diagnostic capabilities	
Specific diagnostic capabilities on central carrousel in process chamber location:	
B & W digital video camera	yes
Dynamic light scattering system	Back Scattering (170..)
Specific diagnostic capabilities in experiment box location:	
90¡ dynamic light scattering system	yes
Mach-Zehnder interferometer	yes
General diagnostic capabilities	
High-resolution video camera Housing: Ascent/descent power	Wide-field/Microscope modes Mid-Deck Locker yes
Electronic Unit	
Process controller Telemetry/telecommanding Housing	Pre-programmed sequences Interface to host EDR European drawer

Protein Crystallisation Diagnostic Facility

The *Protein Crystallisation Diagnostic Facility* (PCDF; Table 22) offers a multi-user research facility to enable an in-depth knowledge and understanding of protein crystal growth processes under microgravity conditions without convection and sedimentation effects. The PCDF will be accommodated in the European Drawer Rack.

The PCDF comprises a process unit and an electronics unit. The process unit includes a process chamber housing experiment boxes containing the reactors in which experiment solutions are hosted as well as the reactor control electronics. The experiment boxes include drive systems for the individual injection of solutions into the reactors, complemented by a stirrer for experiment solution distribution. Diagnostics are provided within the process chamber or can be installed directly in the experiment boxes. The electronics unit accommodates all the controls for performing experiments as well as the interfaces to the European Drawer Rack.

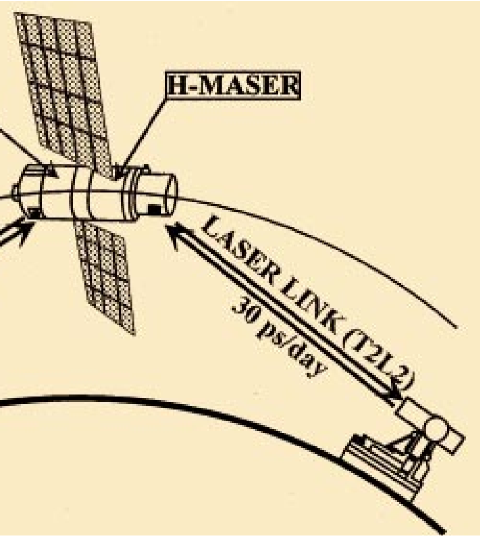


Fig. 31. The ACES concept. Pharao is the laser-cooled atomic clock.

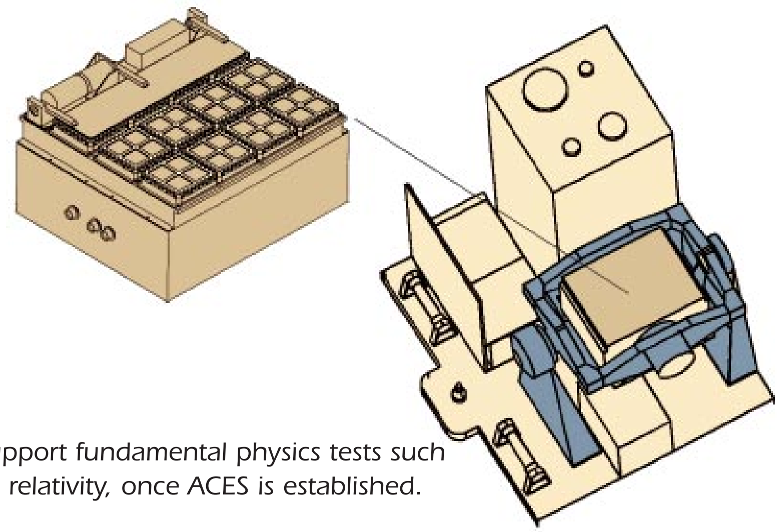


Fig. 32. The Expose unit (mounted on the Coarse Pointing Device) will expose biological specimens to the space environment.

European External Facilities on US Express Pallets

Under a barter agreement, ESA has access to five Express Pallet Adapters on US Express Pallets. For these opportunities, ESA made an Announcement of Opportunity in 1997 and selected the following external facilities.

Atomic Clock Ensemble in Space

The *Atomic Clock Ensemble in Space* (ACES) is a programme to test the performance of a new type of clock that exploits and depends upon microgravity conditions. It consists of four key elements: a laser-cooled atomic clock; a hydrogen maser; a laser link for optical transfer of time and frequency; a microwave link for transfer of time and frequency.

The aims of ACES are to:

- validate the performance of this new generation of clocks in space;
- provide an ultra-high performance global time scale;
- support fundamental physics tests such as relativity, once ACES is established.

ACES occupies one Express Pallet Adapter.

Expose

Expose (Table 23; Fig. 32) is a multi-user external facility to support long-term in-situ studies of microbes in artificial meteorites as well as microbial communities from special ecological niches such as endolithic and endoevaporitic ecosystems. Investigations include the study of photobiological processes in simulated planetary radiation climates (e.g. early Earth, early and present Mars, and the role of the ozone layer in protecting the biosphere from harmful UV radiation).

Expose is mounted on the Coarse Pointing Device. Together, they occupy about half of an Express Pallet Adapter. Expose is equipped with experiment containers that are individually covered by entrance optics. A subset of the containers is covered by lids that allow controlled Sun exposure times.

Table 23. Expose Characteristics

Pointing requirements	Expose requires zenith orientation and solar pointing
Pointing	Coarse Pointing Device
Sample exposure variable control	Motorised lids/shutters
Expose features:	
Sample containers	12
Selectable open/close lids	8
Permanently open	4
Atmosphere	Vacuum or inert gas
Temperature control	Heating (only)
Sensors	U V, radiation, temperature and pressure
Active signals	Real time telemetry

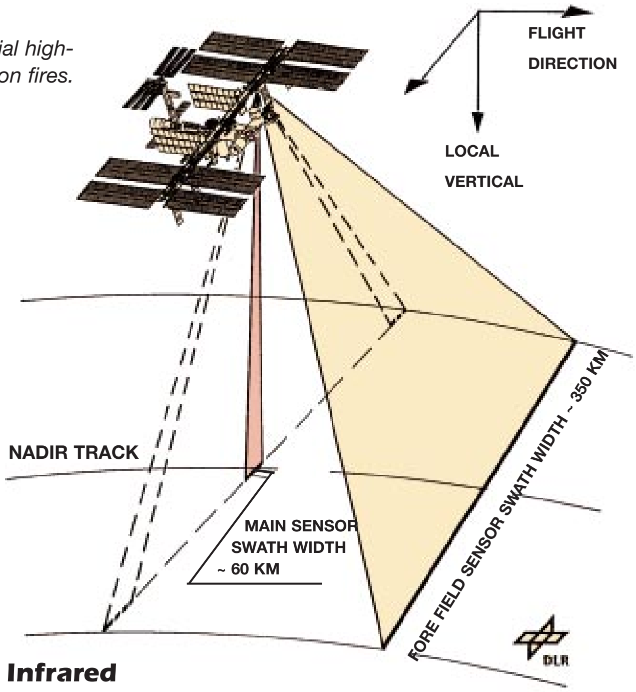


Fig. 33. Focus will detect terrestrial high-temperature events such as vegetation fires.

Intelligent Fire Detection Infrared Sensor System (Focus)

The *Intelligent Fire Detection Infrared Sensor System* (Focus; Table 24; Fig. 33) aims towards the autonomous detection and analysis from space of high-temperature events such as vegetation fires and volcanic eruptions. It is a forerunner for a spaceborne high-temperature environment disaster recognition system. Focus occupies one Express Pallet Adapter.

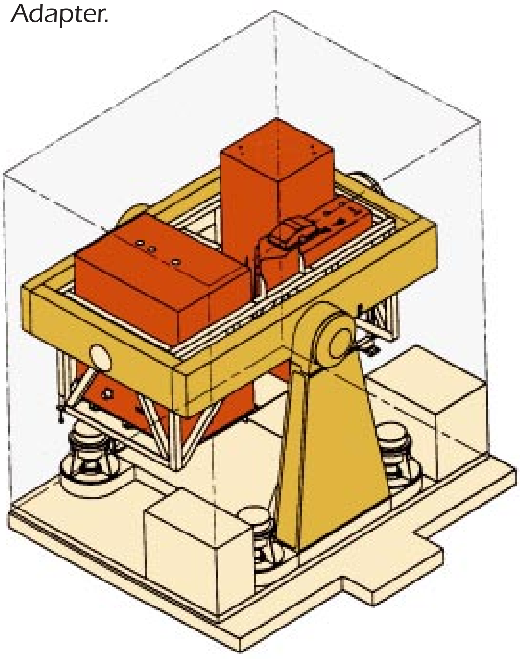


Fig. 34. The Solar Monitoring Observatory will measure the Sun's total and spectral irradiance.

Table 24. Intelligent Fire Detection Infrared Sensor System (Focus) Characteristics	
Viewing direction	Local vertical
Fore field sensor swath width	~350 km
Main sensor swath width	~60 km
Pixel size resolution	30-150 m
Spectrometer footprint (diameter)	10 km
Mass	227 kg

Solar Monitoring Observatory

The *Solar Monitoring Observatory* (SMO; Fig. 34) carries three instruments to measure the solar total and spectral irradiance. It is mounted on a Coarse Pointing Device (CPD) in order to orient the instruments towards the Sun. SMO occupies one Express Pallet Adapter.

SMO measures the solar flux across almost the whole spectrum: 17-3000 nm, which carries 99% of the Sun's energy emission. The three instruments are:

- SOVIM: solar variable and irradiance monitor;
- SOLSPEC: solar spectral and irradiance measurements;
- SOL-ACES: auto-calibrating extreme ultraviolet and ultraviolet spectrophotometers

Sky Polarisation Observatory

The *Sky Polarisation Observatory* (Sport; Fig. 35) surveys the polarisation of diffuse cosmic background radiation in the range 20-70 GHz. The Galaxy's synchrotron radiation is the strongest source of polarisation emission in this range.

Sport occupies half of an Express Pallet Adapter.

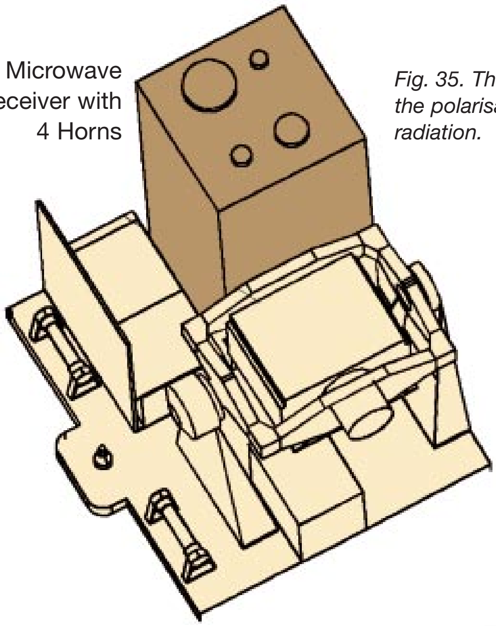


Fig. 35. The Sky Polarisation Observatory will survey the polarisation of the diffuse cosmic background radiation.

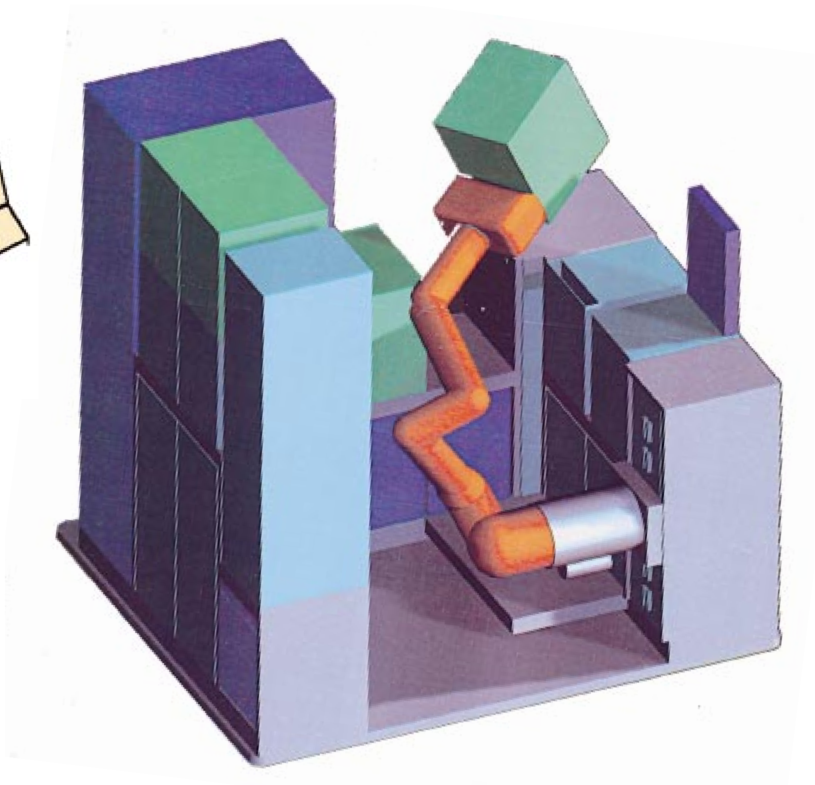


Fig. 36. The Technology Exposure Facility (TEF) supports space technology research and development.

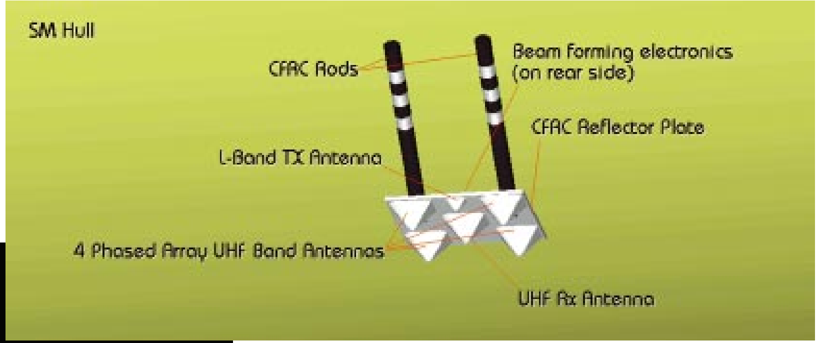
Technology Exposure Facility

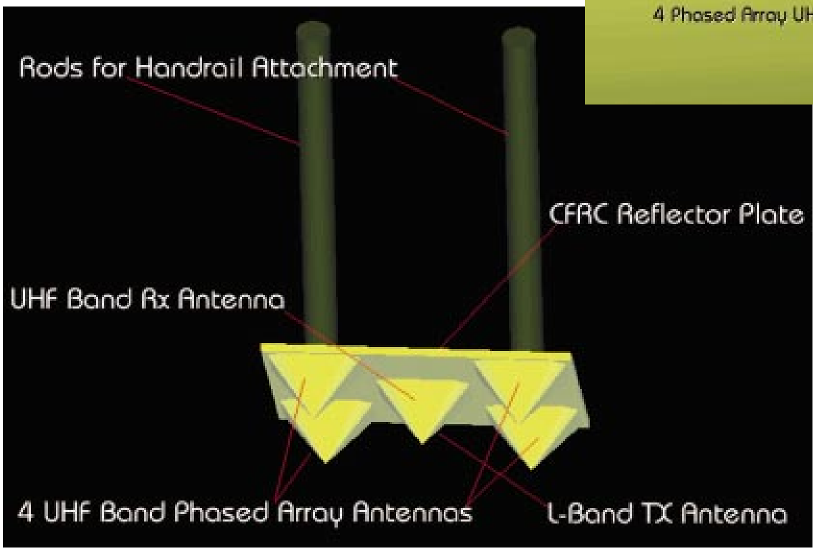
The *Technology Exposure Facility* (TEF; Table 25; Fig. 36) is an externally-mounted multi-user capability that provides a physical and operational infrastructure for a wide range of on-orbit investigations and experiments in technology research and development. Experiments can be mounted in modules that provide standard services. TEF occupies one Express Pallet Adapter.

Table 25. Technology Exposure Facility (TEF) Characteristics

Number of Payload Modules (PMs)	Maximum 15
PM Dimensions	200x250x600 mm or double sized
Retrieval opportunities	After 1.5 years or within 3 years
Robotic manipulation opportunities	Pointing, re-locating, inspection and measurement
Power availability	For the full platform: 600 W peak, 400 W average
Mass capability	225 kg
Data transfer capability	yes
General accommodation possibilities	
Ram-facing surface area	yes
Surface area not receiving ram effects	yes
Maximal inherent isolation from microgravity disturbances	yes
Zenith-facing area with wide field of view	yes
Out-of-plane-facing area	yes
Nadir -facing area	yes
Volumetric exposure of known geometry	yes
Solar flux exposure (cyclical & sustained)	yes
Inertial stabilisation	yes
Local pointing	yes
General facility capabilities	
Centralised environment radiation measurement data unit	yes
Test article translation	Inside and outside the facility
Support pointing & controlled acceleration	yes
Material properties laboratory	yes

Fig. 37. The Global Transmission System provides high-accuracy time and data signals to ground users.





European External Facilities on Russian Elements

Global Transmission System
The Global Transmission System (GTS; Table 26; Fig. 37) provides a capability for transmitting highly accurate time and data signals via a Space Station external antenna to ground-based users. The data signals can be coded according to the specific user requirements and can include such information as the Station orbital position.

GTS' main objectives are to:

– verify the performance and accuracy of a time signal transmitted to Earth from Low Earth Orbit;
– assess the ground-received signal quality and data rates;
– measure disturbing effects, including Doppler shifts, multipath reflections, shadowing and elevation impacts.

The GTS uses a transmitter operating at two dedicated frequencies and mounted externally on the Russian Service Module. The GTS signals are available to ground receivers for periods of 5-12 min several times a day.

Although GTS primarily provides a service to ground users, identical services are available to Russian-element users onboard the Station.

Table 26. Global Transmission System (GTS) Characteristics

	400 MHz Transmitter	1.4 GHz Transmitter
Operating frequency	400.10 MHz	1428 MHz or 1430 MHz, depending on final allocation
Bandwidth	50 kHz	1.5 MHz
Transmitter power	1.0 W	0.5 W
Antenna type and number	4-element phased array	crossed dipole
Antenna transmission cone	140 degrees	140 degrees
Antenna polarisation	Left-Hand Circular	Right-Hand Circular
Expected max. communications range	1200 km	1200 km
Scientific data rates	1000 bit/s	1000 bit/s
Data format	NRZ-L	NRZ-L
Modulation type	QPSK	BPSK

Matroshka

Matroshka (Table 27; Figs. 38/39) is a multi-user external human 'phantom' facility representing the upper part of the human body. The goal is to support studies into the depth dose distribution of different orbital radiation field components during Extra Vehicular Activities on different sides of human organs.

Matroshka is equipped with user-provided passive and/or active detectors for ionising radiation placed at different locations within the facility. Matroshka will be mounted on the outside of the Russian Service Module.

Fig. 38. Matroshka will be mounted on the outside of the Russian Service Module.

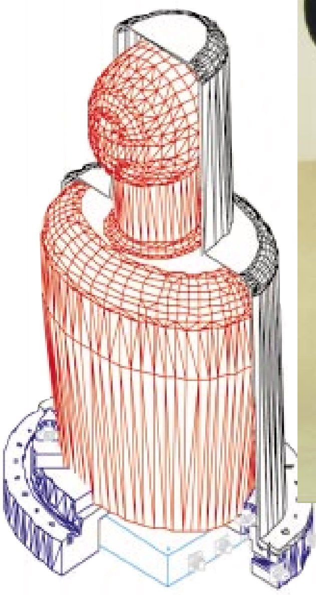


Fig. 39. Cutaway of the Matroshka human 'phantom'.

Table 27. Matroshka Characteristics	
Composition	Multi individual slices of tissue/bone/organ equivalent materials
User diagnostic capabilities	Active & passive radiation experiment packages embedded into individual slices
Active signals	Real time radiation telemetry

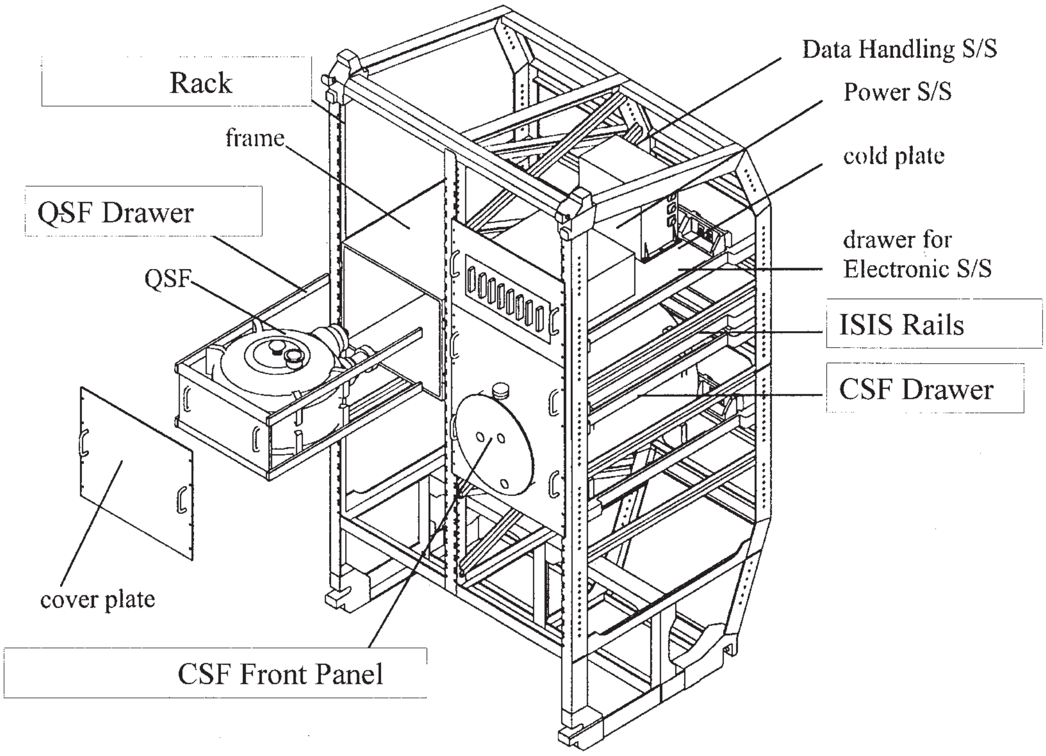


Fig. 40. The Cryosystem stores biological specimens down to -180°C.

Support Systems for Pressurised Facilities

Cryosystem

Cryosystem is a combined set of facilities built by ESA under an ESA/NASA cooperative agreement for the Life Sciences user community in support of optimal preparation, preservation and storage of biological samples and protein crystals down to -180°C.

The major elements of Cryosystem consist of the Cryogenic Storage Freezer (CSF), the Quick/Snap Freezer (QSF), the On-Orbit Preservation Assembly Rack (OPAR) and the Transportation Rack (Track). In addition, Orbital Support Equipment (OSE) consisting of tools and accessoiries as needed during on-orbit operations.

The CSF provides for the storage and preservation of already-frozen biological samples and supplies. The QSF provides the means for the ultra-rapid cooling of samples as well as the temporary holding of cryogenic samples during CSF maintenance. The OPAR, housed in one ISPR rack, is outfitted with a liner and the subsystems to accommodate and support the CSF and QSF operations, and is intended to be integrated into the Centrifuge Accommodation Module (CAM). The Track is functionally similar to the OPAR but is used for the transportation and operations of the CSF and passive payloads in the Mini Pressurised Logistics Module.

Table 28. Cryosystem Characteristics

Cryogenic Storage Freezer (CSF)	
Type of samples stowed	Animal (organisms, cells, enzymes); Vegetable (cells); Harvested protein crystals
Storage temperature	Mode 1: Tissues, blood and other fluids: <-160.C Mode 2: Harvested protein crystals: -180–5.C
Modular stowage volume	Single cold volume (dewar) with multiple cavities, each containing a storage tube for ten 2 m L or five 5 m L containers
Stowage capacity	1 2000 2 m L containers, or 2. 1000 5 m L containers, or 3 a combination not exceeding the volume of either 1 or 2
Power-off survival	Temperatures maintained for 8 h without electrical power
Power supply	Main and auxiliary bus automatic switching provided on ISS (not in MPLM during transportation)
Frequency of up/down load	CSF may be up/downloaded on every MPLM flight (every 3 months)
Monitoring	1 Continuous during nominal operations. 2 Temperature Data Recorder provided for power-off conditions
Location in ISS	1 Transportation to/from ground in MPLM. 2 Installed in Cryosystem Orbital Rack (OPAR) in CAM
Quick/Snap Freezer (QSF)	
Type of samples: Quick freezing Snap freezing	Animal (organisms, cells, enzymes); Vegetable (cells) Animal internal organs, muscles, tendons, ligaments, tissues; Vegetal tissues
Sample dimensions: Quick freezing Snap freezing	2 m L and/or 5 mL containers Specimen surface area equivalent to a circle of 6-mm radius. Sweet zone (no cellular damage) extends over at least 10% of the surface area described above
Temporary stowage volume	Cavities for ten 5 m L container and twenty 2 m L containers
Operation capability: Quick freezing Snap freezing	6 samples in 2 h 4 samples in 2 h
Frequency of operations	3 cycles of 2 h each, with interval of 1 h between successive cycles followed by a minimum recovery time of 16 h
Frequency of samples transfer to CSF	Every 8 h or three operation cycles of 2 h
Monitoring	1 Continuous during nominal operations. 2 Temperature Data Recorder provided for power-off conditions and transfer conditions
Power-off survival	Temperature maintained for 1 h (min) without electrical power
Interfaces	ISIS sub-rack payload interfaces
Location in ISS	1. quick/snap freezing operations performed while attached at the Life Science Glovebox (LSG) rack 2. transfer of samples to/from CSF and stand-by operations performed while attached at the Cryosystem Orbital Rack (OPAR) located in CAM 3. reception of harvested and frozen protein crystals containers at the X-Ray Crystallography Facility (TBD)
Monitoring	1 Continuous during nominal operations. 2 Temperature Data Recorder provided for power-off conditions
Orbital Rack (OPAR)	
Volume taken by Cryosystem elements	1 CSF Drawer (24 PU); 1 QSF drawer (12 PU); 1 Utilities drawer (8 PU); 1 Cryosystem Stowage drawer (4 PU)
Volume available to other payloads	6 Drawers (4 PU each)
Mass available to other payloads	180 kg (30 kg per drawer)
Heat rejection capability for Cryosystem elements	600 W
Heat rejection capability for other payloads	None
Resources for other payloads	None
Location in ISS	CAM
Transportation Rack (Track)	
Volume taken by Cryosystem elements	1 CSF Drawer (24 PU); 1 Utilities drawer (8 PU)
Volume available to other payloads	10 Drawers (4 PU each)
Mass available to other payloads	300 kg (30 kg per drawer)
Heat rejection capability for Cryosystem elements	300 W
Heat rejection capability for other payloads	None
Resources for other payloads	None
Location in ISS	MPLM

Fig. 41. The European Stowage Rack (left) provides storage for samples and equipment.

Fig. 42. The Microgravity Science Glovebox (right) provides a confined environment to handle primarily material science payloads.

European Stowage Rack

The *European Stowage Rack* (ESR; Table 29; Fig. 41) provides a modular capability for the stowage of payload equipment and samples contained in Standard Experiment Drawers (SEDs) and Mid-Deck Lockers (MDLs), which require no power, data and thermal control resources.

Once the ESR is on-orbit, standard equipment drawers and Mid-Deck Lockers will be regularly exchanged using the (upmass/downmass) logistics flights.

Microgravity Science Glovebox

The *Microgravity Science Glovebox* (MSG; Table 30; Fig. 42) is built by ESA under an ESA/NASA cooperative agreement and provides a large-volume glovebox for small- to medium-size payloads, primarily in material science.

Table 29. European Stowage Rack (ESR) Characteristics

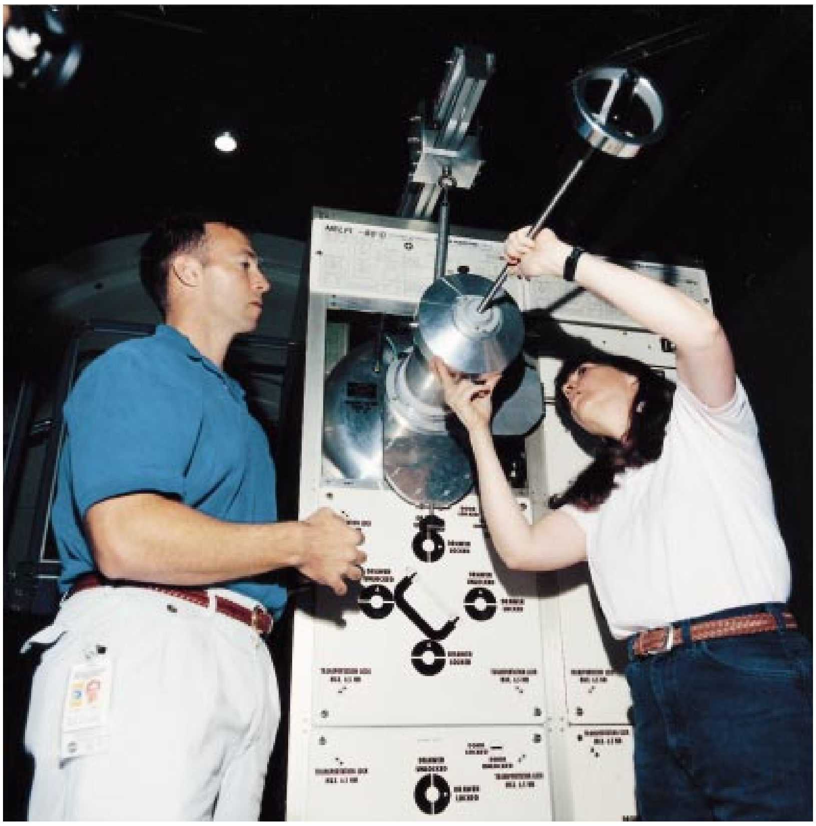
	SED	MDL
Number in baseline	8	*
Volume available to payload	72 litre	57 litre
Mass available to payload	38 kg	26 kg

*the launch configuration for the ESR includes 8 SEDs, although on-orbit it is also possible to accommodate MDLs in place of drawers.

Table 30. Microgravity Science Glovebox (MSG) Characteristics

Work volume for experiments	255 litre
Largest access dimension	40 cm diameter
Pressure environment with respect to cabin	Negative pressure with air circulation and filtration
Airlock module capability for transfer of payloads and equipment	Maximum 40 litre
Resources available to glovebox users:	
Power	+120, +28, –12, +5 Vdc
Video link (analog)	yes
Video cameras	4
Video recorder	3 + 1 hard disc
Gaseous Nitrogen	yes
Vacuum and venting	yes
Cooling	Up to 200 W by air, up to 800 W by cold plate

Fig. 43. The Minus Eighty Degree Laboratory Freezer for the ISS (MELFI) stores and preserves biological specimens.



Minus Eighty Degree Laboratory Freezer for the ISS

The *Minus Eighty Degree Laboratory Freezer for the ISS* (MELFI; Table 31; Fig. 43) is built by ESA under an ESA/NASA cooperative agreement and provides for stowage and retrieval of cold biological specimens.

Table 31. Minus Eighty Degree Laboratory Freezer for the ISS (MELFI) Characteristics	
Modular stowage volume	4 independent compartments (dewars) of 75 litre each. Total refrigerated stowage volume of 300 litre
Minimum active configuration	At least 1 dewar at -80¡C
Multiple mission configuration	One to three -80¡C dewars active plus a +4¡C or a -26¡C dewar active Two -80¡C dewars active plus a +4¡C and a -26¡C dewar active Two -80¡C dewars active plus two -26¡C dewars active
Controlled temperatures	-80¡C mode: samples maintained below -68¡C -26¡C mode: samples maintained at -37¡C to -23¡C +4¡C mode: samples maintained at +0.5¡C to +6¡C
Standard dewar outfitting	4 sliding trays of 575 mm length 2 type A box modules of half-tray length 12 type B box modules of quarter-tray length 18 vial bags 12 vial cards
Types of samples stowed	Cell culture of 1-10 mL size Fluid samples (blood, media, etc) of 1-500 mL size Specimens/dissection tissues of 2-10 mL size Specimens (whole) of 10-500 mL size
Power off survival	Temperature conditions maintained for 8 h without electrical power
Contingency survival	Cooler replaceable in-orbit in less than 8 h Cooler and support equipment needed for replacement available in the rack Electronic box containing computer replaceable in-orbit in less than 8 h Replacement for the electronic box available in the rack
Power supply	Main and auxiliary bus automatic switching provided
Power consumption	Ranging from 600 W to 900 W, depending on the active configuration

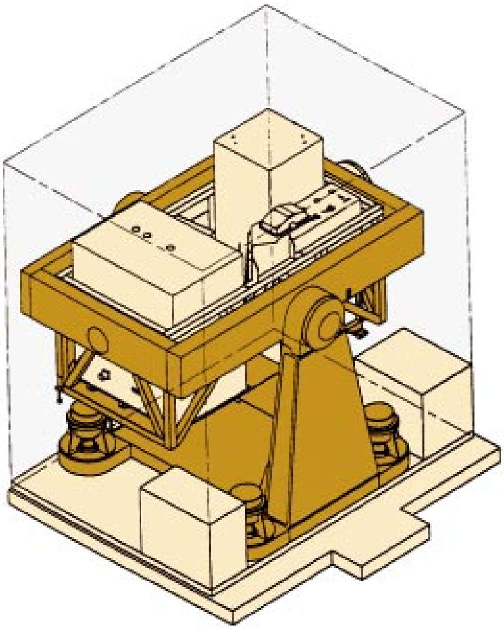


Fig. 44. The Coarse Pointing Device provides pointing for external payloads.

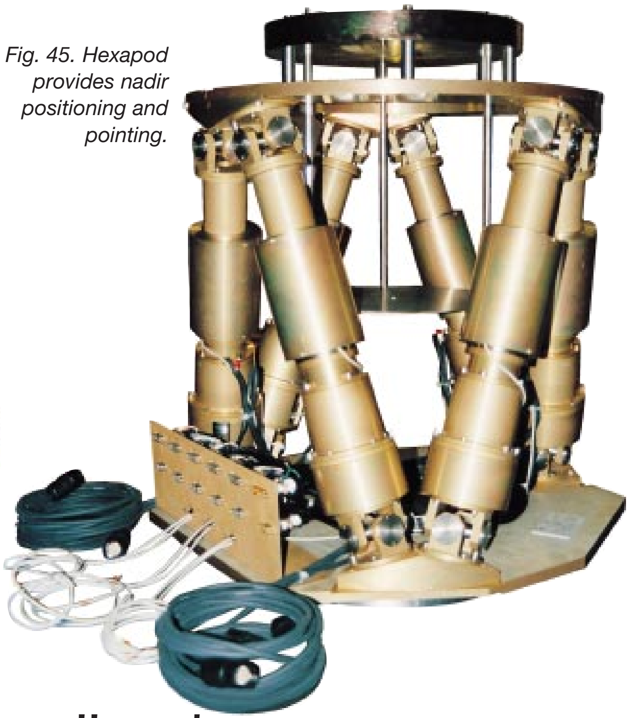


Fig. 45. Hexapod provides nadir positioning and pointing.

Support Equipment for External Payloads

Coarse Pointing Device

The *Coarse Pointing Device* (CPD; Table 32; Fig. 44) provides a 2-axis pointing capability for external payloads to achieve a pointing accuracy in the order of 1° to compensate for Station orbital motions and seasonal Sun apparent motion. Two versions of the CPD are under development for supporting the SMO and Expose facilities.

Hexapod

Hexapod (Table 33; Fig. 45) is built by ESA under an ESA/NASA cooperative agreement and provides nadir positioning and pointing for the NASA Stratospheric Aerosol and Gas Experiment (SAGE III) external payload. It could provide, however, pointing in any direction for other payloads with appropriate adaptations and modifications.

Table 32. Coarse Pointing Device (CPD) Characteristics

Pointing accuracy	–1¡
Pointing stability	0.1¡ over 10 s
Number of rotational axes	2
User load capability	Max 75 kg
CPD envelope stowed (including Payloads)	Within EXPA envelope
Payload mounting plate footprint	Adaptable to payload requirements. Two versions under development, for: half and full pallet adapters
CPD Power	150 W_{max}
Data interface for payloads	RS422
Power supplies to payloads	28 Vdc
CPD controller	Based on ESA SPLC
CPD operations modes	Off, standby, tracking

Table 33. Hexapod Characteristics

Degrees of freedom	6
Pointing range	–8..
Pointing accuracy	–90 arcsec
Pointing stability	9 arcsec/s
SAGE III sensor assembly mass	35 kg
SAGE III approximate envelope size	340x340x740 mm

Standard Payload Outfitting Equipment

Standard Payload Outfitting Equipment (SPOE; Fig. 46) covers pressurised and external standardised space-qualified hardware items that can be procured and embedded into payloads to support more general payload functions and/or Station interface functions and so pre-empt the need for users to undertake any specific development.

The use of SPOE within the framework of Columbus Laboratory payload facilities and the ground test equipment is shown in Fig. 46.

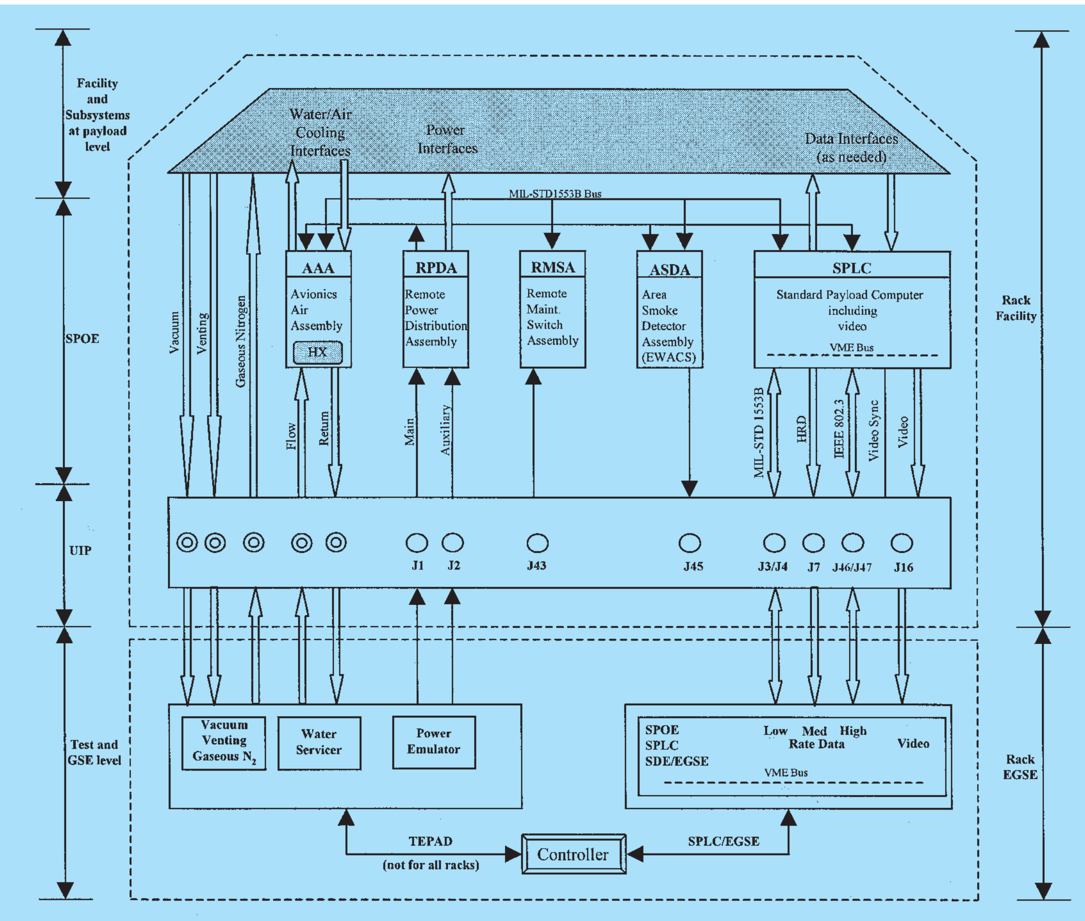
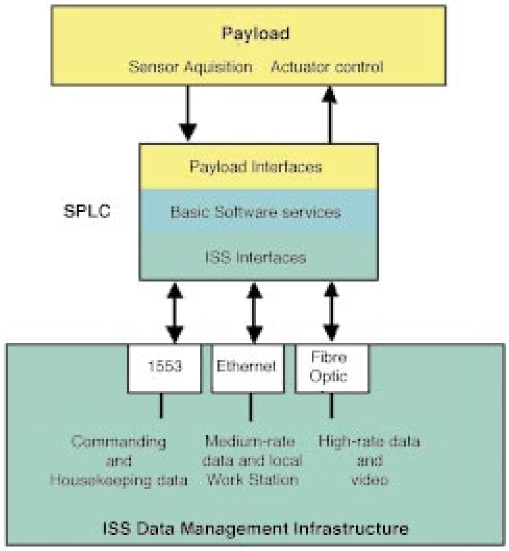


Fig. 46. Standard Payload Outfitting Equipment within Rack Facility/EGSE.

Fig. 47. The Standard Payload Computer with ISS interfaces.



Avionics Air Assembly

The *Avionics Air Assembly* (AAA) provides ISPR payloads with an air cooling capability for up to 1200 W and employs a water-to-air exchanger with selectable speed fan. The AAA uses the moderate temperature cooling loop available at the rack interface.

External Payload Computer

The *External Payload Computer* (XPLC) provides data management interfaces between the payloads on an Express Pallet Adapter and the Express Pallet or the Columbus EPF. The XPLC is based upon the Standard Payload Computer (see SPLC) as modified for the external Station environment and specific adaptations for the Express Pallet Adapter payloads.

Table 34. Power Distribution Unit (PDU) Characteristics	
Input voltage	120 Vdc
Output voltage	28 Vdc
Nominal mode:	
Output current capability	5 A
Output stage protection trip line	5 ms < t < 10 ms with 1.5 x $current_{max}$
Output control per output stage	Programmable at activation
Stay Alive mode:	
Output voltage	28 Vdc
Stay-alive current capability	1 A
Output control per output stage	None

Table 35. Remote Power Distribution Assembly (RPDA) Characteristics	
Input voltage	120 Vdc
Output voltage	120 Vdc, 28 Vdc
Output current protection ratings:	
120 Vdc	1, 3, 5 & 10 A
28 Vdc	5 & 10 A

Power Distribution Unit

The *Power Distribution Unit* (PDU; Table 34) provides power conversion, switching and protection functions for payloads on an ExPA.

Remote Power Distribution Assembly

The *Remote Power Distribution Assembly* (RPDA; Table 35) provides power distribution, power control, power status monitoring, overcurrent protection and power conversion from 120 Vdc to 28 Vdc with rack exchangeable modules to facilitate on-orbit reconfiguration and/or replacement.

Standard Payload Computer

The *Standard Payload Computer* (SPLC; Table 36; Fig. 47) provides a modular and configurable data-handling system based on an industrial-standard VME Bus and a self-standing processor with interfaces connected via a standardised local bus.

The processor board is equipped with a minimum set of interfaces and includes a local bus to allow the addition of mezzanine interface boards. For complex payloads, a VME extension board can provide the same local bus as that of the processor board and is able to support additional mezzanine interface boards. Specialised VME boards for performing complex functions can be added because of the open VME bus architecture.

Table 36. Standard Payload Computer (SPLC) Characteristics	
CPU Module	
Power interface	5 V/10 W without mezzanine boards
Data interfaces	Master VME bus, A32/D32 mode, 6 serial interfaces, 2 x local mezzanine interfaces
CPU	ERC32
Memory	8 MB SRAM, 4 MB EEPROM
Software	Basic software package and V x Works kernel in ROM
Temperature range	-55¡C to +125¡C
Mass	700 g
Mass Memory Module	
Power interface	5 V/<5 W
Host CPU data interfaces	Slave VME Bus
Memory	Disk or DRAM
Storage capacity	50 MB
Mass	600 g
Extension Module	
Power interface	5 V/200 m A (without mezzanine boards)
Host CPU data interfaces	Slave VME Bus and mezzanine I/O local Bus (x 4)
Mass	500 g
MIL 1553B Mezzanine Board	
Power interface	5 V/250 mA, 12 V/300 mA
Host CPU data interfaces	Mezzanine I/O local Bus
MIL Bus	MIL STD-1553B
Mass	120 g
Ethernet I/F Mezzanine Board	
Power interface	5 V/1 W
Host CPU data interfaces	Mezzanine I/O local Bus
LAN Data interface	AUI
Mass	80 g
Serial I/F Mezzanine Board	
Power interface	5 V/200 mA
Host CPU data interfaces	Mezzanine I/O local Bus
Data interface	2 Asynchronous RS 422/RS 485
Mass	100 g
Analog Input I/F Mezzanine Board	
Power interface	5 V/<1 W , -12 V/<1.2 W
Host CPU data interfaces	Mezzanine I/O local Bus
Performance	12 bit resolution, max. 100 samples/s, 8 differential input channels
Mass	100 g
Digital I/F Mezzanine Board	
Power interface	5 V/<1 W
Host CPU data interfaces	Mezzanine I/O local Bus
Performance	12 Opto-isolated input/output lines, max. 100 samples/s
Mass	100 g
SPLC Housing	
Mass	3.4 kg including power supply, backplane and harness
Housing size	160x295x260 mm
Number of VME slots	5
Construction	Coated aluminium
Power supply	120 Vdc or 28 Vdc input
SPLC EGSE	
Development environment	Unix and V x Works
Test system	PACTS
Hardware platform	V M E

Turbo Molecular Pumps
The *Turbo Molecular Pumps* (TMPs; Table 37) provide a higher vacuum capability than is available with the Columbus Laboratory central vacuum system. Two sizes of TMP are available.

Partner Research Facilities
The research facilities provided by ESA's Partners are summarised in Table 38.

Partner Payload/Laboratory Support Equipment
The *Environmental Monitoring Package* (EMP) measures a number of contamination environment parameters (radiation, plasma, mass deposition of contaminants) external to the Station as a service to the attached payloads community, which requires characterisation of operational conditions.

The *Express Rack* (ER) provides accommodation for payloads that do not require the entire volume of an ISPR and provides physical interfaces for payloads contained in International Subrack Interface Standard (ISIS) drawers, Mid-Deck Lockers (MDLs) or their equivalents.

The *International Standard Payload Rack* (ISPR) provides standardised payload accommodation that is interchangeable on-orbit between the pressurised modules of NASA, NASDA and ESA (See the chapter 'Accommodation and Utilisation Resources Capabilities for Payloads').

The *Mid-Deck Locker* (MDL) provides standard Space Shuttle locker accommodation with limited capabilities (power, air-cooling) for mid-size payloads.

A number of further Partner payload and laboratory support equipment is under

Table 37. Turbo Molecular Pump (TMP) Characteristics

	TPH 180 HM	TMH 065
Volume flow rate N_2	170 litre/s	56 litre/s
Volume flow rate He	170 litre/s	48 litre/s
Compression ratio N_2	$>10^{12}$	$>10^{10}$
Compression ratio He	$>10^{8}$	10^{7}
Ultimate pressure N_2	2×10^{-9} mbar	$<4\times10^{-9}$ mbar
Nominal rotation speed	50 000/min	90 000/min
Maximum backing pressure N_2	20 mbar	20 mbar
Maximum gas throughput N_2	6 mbar.litre/s	0.6 mbar.litre/s
Cooling type	Natural convection or cold plate	Natural convection or cold plate
Input power: Back pressure 1 mbar run-up	59 W	57 W
Input power: Back pressure 1 mbar nominal	40 W	13 W
Run-down time until stop: Back pressure 1 mbar	~12 min	~12 min
Mass with ISO-K flange	9.38 kg	2.51 kg

Table 3B. The Research Facilities to be Provided by ESA s Partners

Initial outfitting in US Laboratory	Initial outfitting in JEM
PRESSURISED:	PRESSURISED:
Avian Development Facility	Cell Biology Experiment Facility & Clean Bench
Biomass Production Facility	Fluid Physics Experiment Facility
Gravitational Biology Facility	Zone Melting Furnace with X-ray radiography
Human Research Facility 1 & 2	Gradient Heating Furnace
Crew Health Care System*	Solution/Protein Crystal Growth Facility
Biotechnology Facility	Isothermal Furnace
Material Science Research Facility	Electrostatic Levitation Furnace
Fluids & Combustion Research Facility	Aquatic Animal Experiment Facility
X-ray Crystallography Facility	Advanced Furnace for Microgravity Experiment with X-ray Radiography
W indow Operational Research Facility	Image Processing Unit
Facilities for engineering and commercial research	
EXTERNAL:	EXTERNAL:
Stratospheric Aerosol & Gas Experiment (SAGE III)	Laser Communication
Alpha Magnetic Spectrometer (AMS)	Submillimetre-Wave Limb Emission Sounder
Environmental Monitoring Package (EMP)	X-ray monitoring
Low Temperature Microgravity Physics Facility	Space Environmental Data Acquisition
In preparation:	
Advanced Cosmic Ray Experiment for ISS (ACCESS)	
Extremely Heavy Cosmic Ray Composition Observer (ECCO)	

Canada
Aquatic Research Facility
Insect Habitat
Levitation Furnace
Microgravity Isolation Mount (MIM)

*The Crew Health Care System is not a research facility although elements of it will be used by the Human Research Facility (HRF) to support HRF research.

development, and descriptions are given in Partner documentation.

Partner Standard Payload Outfitting Equipment

The *Active Rack Isolation System* (ARIS) can be installed in the US-developed ISPR. It attenuates vibration disturbances to support specific requirements for a microgravity environment.

The *Area Smoke Detector Assembly* (ASDA) provides the capability for detecting smoke within a fire protection zone and initiates an alarm to the Columbus Laboratory Vital Monitoring System.

The *Express Pallet Adapter* (ExPA) provides an external payload accommodation and interface capability that can be exchanged on-orbit using the Space Station Remote Manipulator System (see the chapter 'Accommodation and Utilisation Resources Capabilities for Payloads').

Interface Connectors provide for quick connect/quick disconnect between payload racks and the utility interfaces provided in the pressurised modules.

The *Rack Main Switch Assembly* (RMSA) provides the capability for the crew to shut down power to a payload rack for maintenance and exchange activities.

Payload Programme Cycle

This chapter provides an overview of the many preparatory activities that have to be completed by both the user and the Agency before the flight takes place.

Fig. 48 helps users to appreciate:

- outer circle A: the major programme phases that payloads generically undertake;
- circle B: a perspective of the corresponding hardware development phases;
- circle C: the generic evolution of the science objectives and aims;
- circle D: the Agency point-of-contact for users to address their programme technical and programmatic issues and concerns.

The inner circles are synchronised with the outer circle.

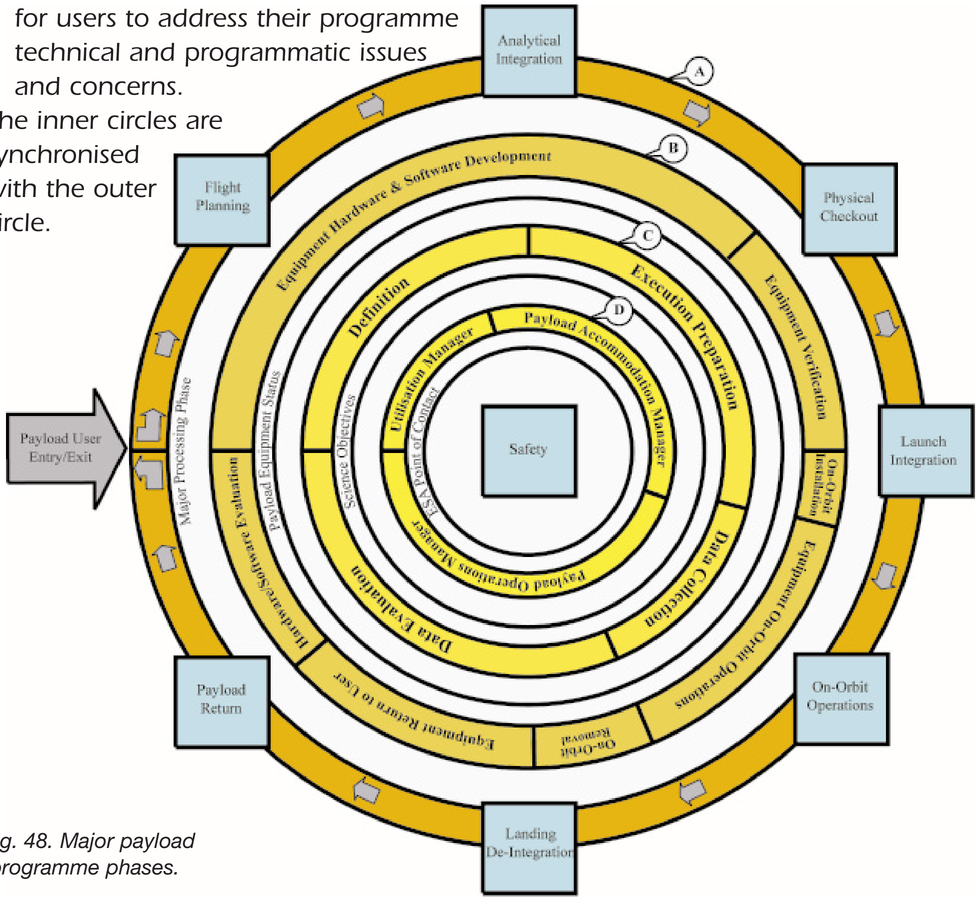


Fig. 48. Major payload programme phases.

Payload Reviews and Planning Template

As part of the programme cycle, a number of reviews are planned in order for the Agency to determine payload progress and compliance with Columbus laboratory requirements. These reviews are:

- Preliminary Design Review (PDR), to demonstrate the payload functional requirements and compatibility of preliminary design with the Columbus carrier, ground physical and operations environments, payload integration schedule and initial payload data sets;

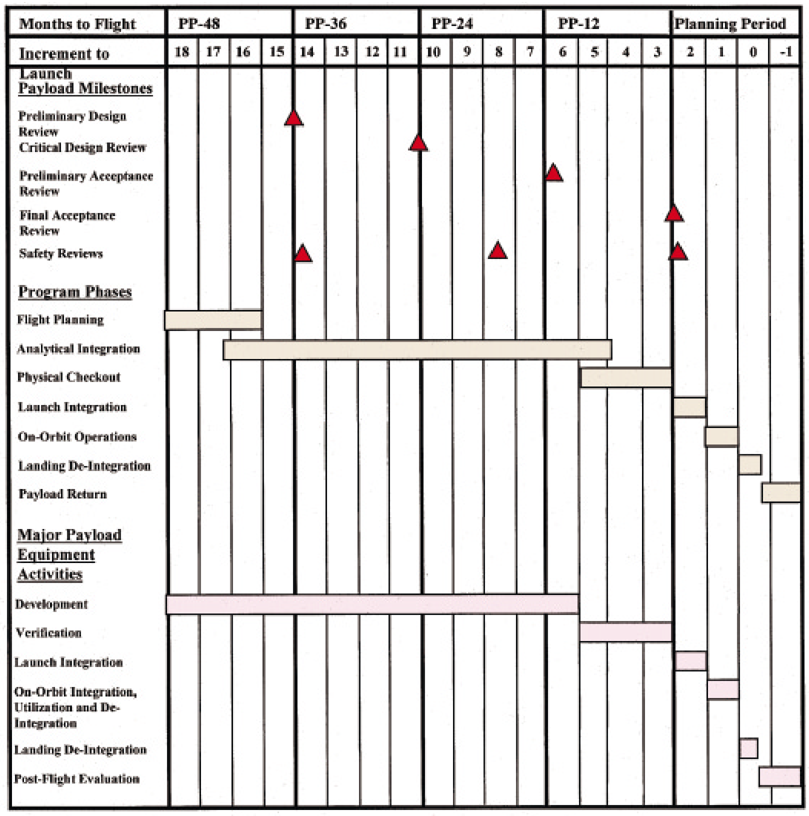


Fig. 49. Generic payload planning template.

- Critical Design Review (CDR), to demonstrate the payload detailed design and compatibility with the Columbus Laboratory, and payload compatibility with the ground physical and operations

- Preliminary Acceptance Review (PAR) to demonstrate the payload qualification/ acceptance programme of the Flight Model (FM) and associated equipment prior to shipment to Columbus Laboratory compatibility testing;

- Final Acceptance Review (FAR) to demonstrate the completion of the qualification testing, the post-shipment checkout and the laboratory/payload interface compatibility verification;

- Safety Reviews (SRs) to demonstrate the progressive reporting of all payload hazard items, that their assessment and appropriate hazard controls have been implemented and hazard reports have been completed.

The Agency will provide support to payload users in the preparation of material for these reviews. The planning of these reviews and the major payload activities are shown in Fig. 49. The indicated schedule is typical for major complex payloads (Class 1 facility types). The major phases shown are detailed below.

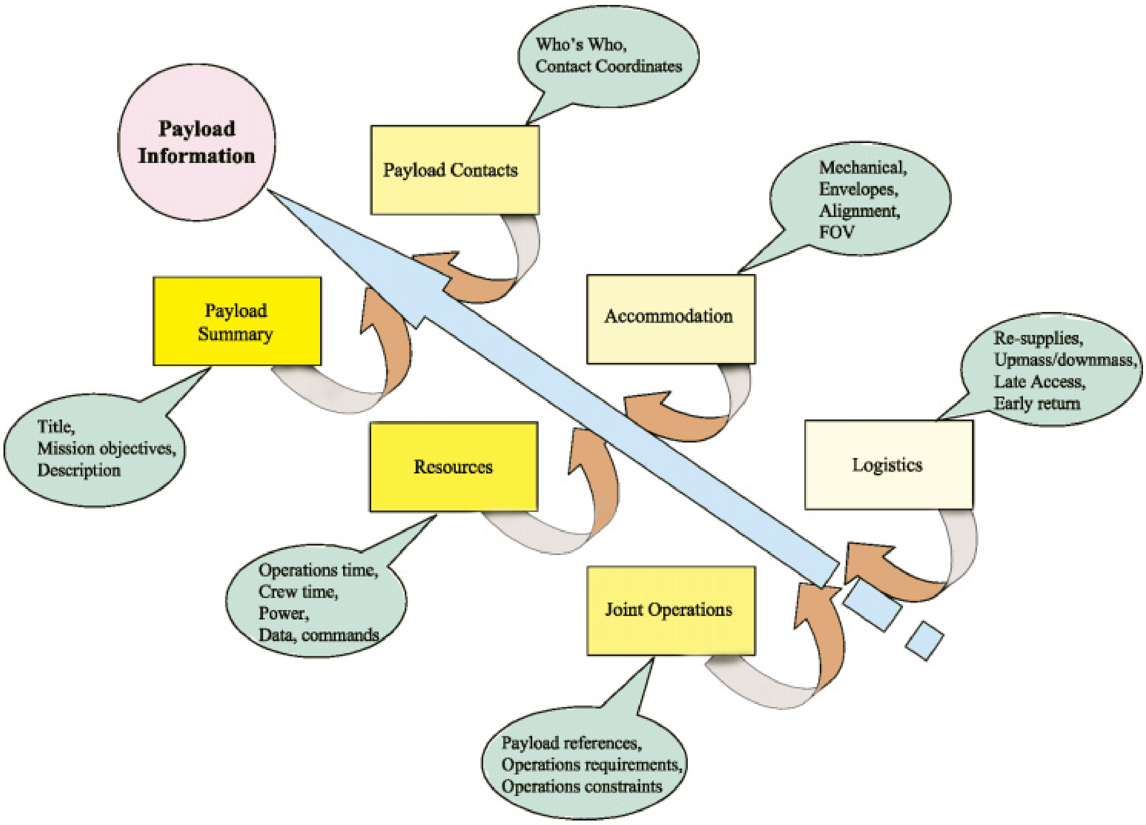
Flight Planning

The first step in the programme cycle begins with entering payload information for evaluation and possible inclusion into the ESA-specific Partners Utilisation Plan (PUP). The information required is highlighted in Fig. 50.

All the ISS Partners regularly develop and maintain their PUPs for combination into the Consolidated Operations and Utilisation Plan (COUP). This COUP provides the ISS Operations and Utilisation Plan for the upcoming 5 years and includes the assignment of new payloads for flight in a specific year.

The payloads addressed in this chapter are complete rack facilities or complex instruments on an Express Pallet Adapter size; these are sometimes known as Class 1 or Facility Class payloads. Payloads 'embedded' in a facility (sometimes known as Class 2 payloads) have specific programme requirements and capabilities that are available directly from the facility-responsible developer. Their schedules are considerably shorter than for the Class 1 payloads, as are the drawer-type payloads to be accommodated in the EDR.

Fig. 50. Overview of payload information requirements.



Once ESA has accepted a payload into its PUP, the Agency then prepares the Payload Interface Agreement (PIA) for agreement with the payload developer. The PIA and its Addendum detail the programmatic requirements, including roles and responsibilities as well as schedules and commitments for specific flights and on-orbit needs. Following signature of that agreement, the Agency initiates payload interface control documentation development. The major items of this documentation include:

- Interface Control Document (ICD), which provides the controlled description of all the interfaces between the Station element and the payload.
- Payload Verification Plan (PVP), which provides the controlled description of the ICD verification requirements and their traceability. For every ICD developed, there will be a corresponding PVP to be developed;
- Payload Data Set (PDS) records, which provide the controlled description of those data needed to integrate a payload into the physical and operational environment of the Station.

The Agency will undertake the development of this documentation together with the payload developer as part of its utilisation integration responsibility.

This documentation is regularly updated as the payload development proceeds and the payload assignment to a specific Increment approaches. The updating is generally synchronised with the various payload development reviews, where payload developers can expect to provide the majority of the review inputs.

The ESA Utilisation Manager provides the Agency point-of-contact during this starting phase.

Around 30 months before the year for flight, further detailed payload inputs enable ESA planners to evaluate the payload for a specific Increment within that year. An Increment is of about 3 months duration and basically reflects the period between two consecutive Shuttle visits.

Once the payload has been assigned to a specific Increment, then the ESA Payload Accommodation Manager (PAM) becomes the Agency point-of-contact and analytical integration can start. The PAM is responsible for the total Increment payload complement from this point on until the successful on-orbit activation of the payload has been accomplished.

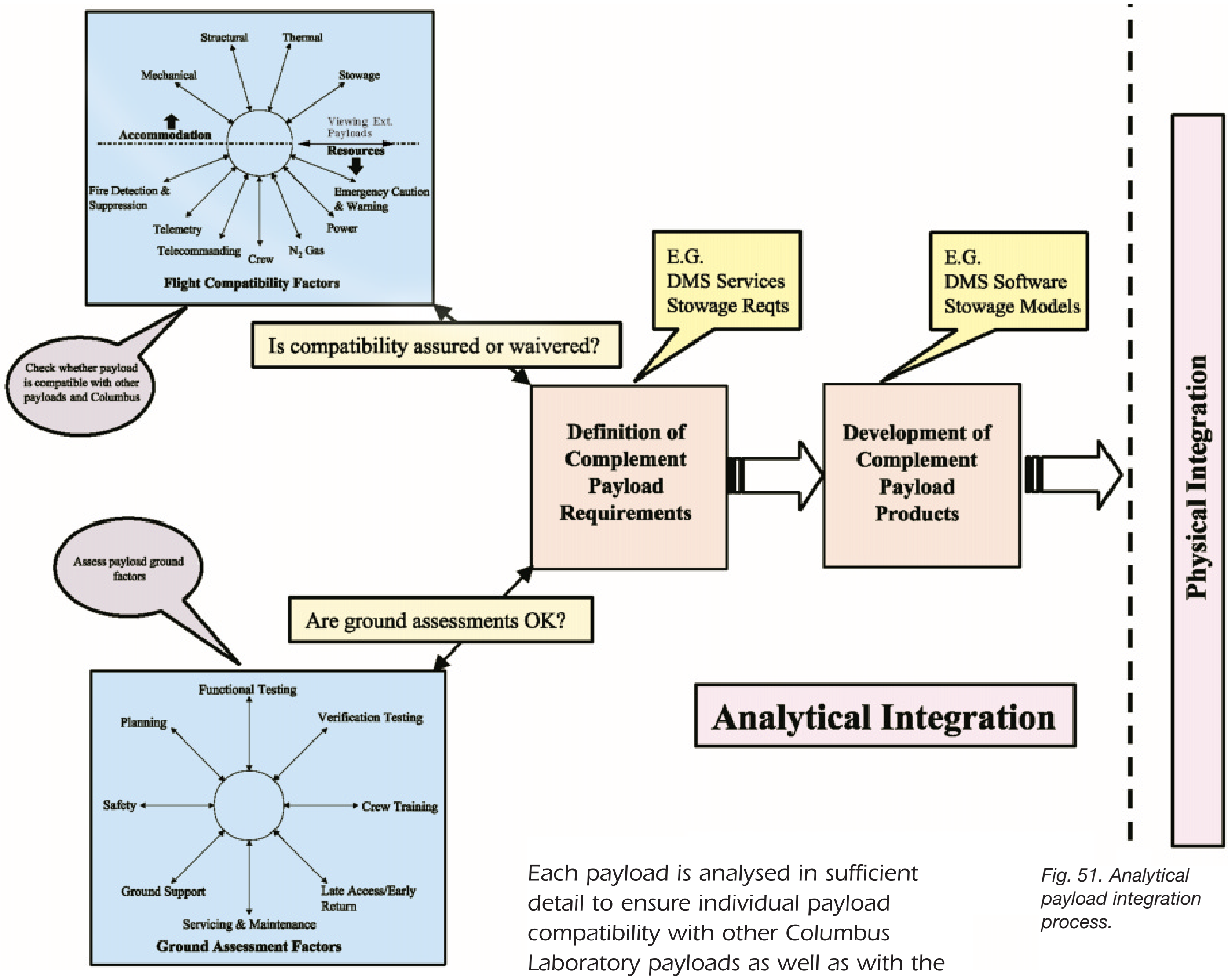


Fig. 51. Analytical payload integration process.

Each payload is analysed in sufficient detail to ensure individual payload compatibility with other Columbus Laboratory payloads as well as with the Columbus Laboratory systems.

During this step, the payload development model philosophy is established to ensure that adequate payload models are developed to support flight qualification, crew training and in-flight ground control operations.

The necessary tools required to support training will be consolidated at Laboratory level for a specific planning period. These tools, including training hardware and software as well as hi-fidelity simulators, will support the training activities, for both flight and ground crews, that begin during this step and continue through the programme cycle.

Analytical Integration

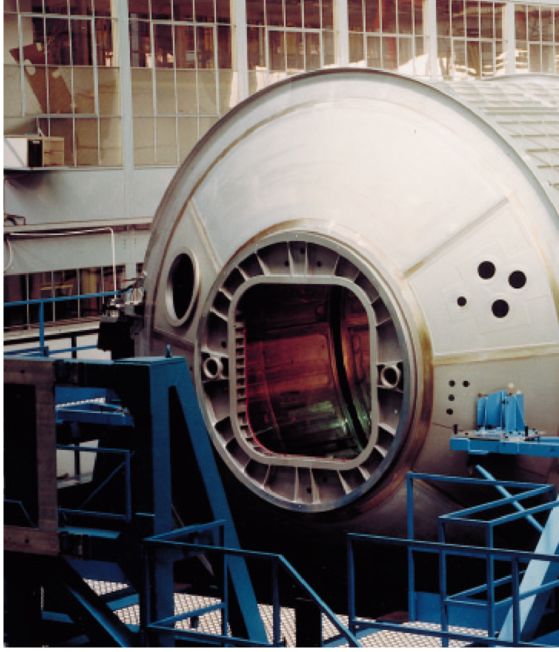
The second step in the programme cycle begins with a provisional manifesting of a payload for inclusion in an Increment's payload complement in the Columbus Laboratory or on its external accommodation site.

The analytical integration is shown in Fig. 51. The Agency undertakes the analytical integration function as part of its utilisation integration responsibility. Should incompatibilities be established during this process, then the Agency will require the payload user to develop and establish a solution that ensures compatibility.

Physical Checkout

The third step in the programme cycle starts off with the user completing payload development. That means, for example, that the payload checkout has been completed in readiness for Columbus Laboratory compatibility verification.

The compatibility verification is accomplished through the Rack Level Test Facility (RLTF) for rack payloads or, for external payloads, through the Suitcase Test Equipment (STEP) capability.



The RLTF is an integration and test environment that provides a high-fidelity emulation of the resource interfaces between an ISPR and the Columbus Laboratory. This capability provides the opportunity for payload developers to complete payload verification and acceptance. The STEP provides an equivalent capability for external payloads.

The Agency leads the physical checkout function as part of its utilisation integration responsibility. The payload user is expected to support this activity and ensure that the payload is working according to the agreed baseline.

Following the successful completion of verification and acceptance activities, the Payload Accommodation Manager (PAM) accepts and certifies the payload for flight readiness, and subsequently delivers the qualified payload to the launch integration process.

Launch Integration

The fourth step in the programme cycle begins with the delivery of the qualified payload to the launch integrator by the PAM.

For the Columbus Laboratory launch complement, the Columbus Prime contractor represents the launch integrator and performs the actual integration of the payload racks into the laboratory. The launch complement payloads will be tested in their on-orbit locations to verify power-up and checkout. This is followed by a short mission sequence test to verify simultaneous payload operations. After completion of all tests, the Columbus laboratory is then delivered to the Space Shuttle launch site for Orbiter integration and launch.

For post-Columbus Laboratory launch payload racks, as well as for all Columbus Laboratory launch complement mid-deck stowage items and external payloads, the launch integrator is represented by the NASA Payload Mission Integrator (PMI) team. The PMI team will receive the payload items from the PAM at the Shuttle launch site. The PMI will integrate the Mid-Deck Lockers and payload supply items into the Mini Pressurised Logistics Module (MPLM) or on to the unpressurised payload cargo carrier.

On-Orbit Operations

The fifth step in the programme cycle begins with the arrival of the payload at the ISS, where it is transferred into its Columbus Laboratory on-orbit location. After physical integration, a short activation checkout is then performed to verify payload readiness for on-orbit user operations.

Up until the successful accomplishment of payload activation, the PAM is the user's primary point of contact with the ISS programme. After successful payload activation, the Payload Operations Manager becomes the European point of contact.

On-orbit operations cover a wide variety of aspects and include nominal operations to accomplish the payload's mission objectives as well as any nominal servicing and maintenance that may be

needed to ensure the continued well-being of the payload's equipment. The payload users, located at their local USOC or UHB, will be able to monitor and interactively control their experiment operations based upon the data received through the ground communications.

At the completion of the payload's on-orbit operations, it is shut down and transferred from the ISS to the returning Shuttle. All mission samples and specimens are transferred to Shuttle mid-deck or MPLM stowage for return to Earth, or to the ATV for controlled destructive reentry.

Landing De-Integration

The sixth step in the programme cycle begins with the delivery of the payload to the point-of-contact by the NASA PMI after de-integration from the Shuttle and/or MPLM.

The point-of-contact performs a local checkout of the payload and follows this up with the transportation preparation and shipment of all payload items to the payload developer site.

In parallel with these transportation activities, the User Support and Operations Center (USOC) provides a complete history of all the payload's telemetry/telecommanding history to the payload user in an electronic form.

Payload Return

The last step in the programme cycle begins with the delivery of the payload equipment, including the complete history of electronic data products, to the payload user. The payload users are expected to make a detailed examination of their equipment and data, and subsequently prepare both their 'lessons learned' and scientific results. The 'lessons learned' will be consolidated at Columbus Laboratory level with the goal of identifying whether system issues need to be addressed in pursuit of improving payload control and support functions.

This last activity of payload return marks the end of the payload's utilisation for that campaign.

Safety

The role of safety and product assurance is continuously active from the beginning through to the completion of a payload's engagement in the ISS programme. All ground and flight segment equipment and operations are regularly assessed for hazardous situations that could endanger the crew, other payloads, ground team, etc. Regular safety reviews are organised within the programme cycle, when all the hazards and hazard controls are addressed. The successful completion of these reviews plays a very significant role in the eventual certification of flight readiness for a payload.

Smaller Payloads

Essentially the same kind of steps will have to be followed by smaller Class 2 payloads but in a simplified and shortened schedule. It is the objective of the Programme to offer rapid access for less small and complex payloads.

How to Get Access to the Space Station

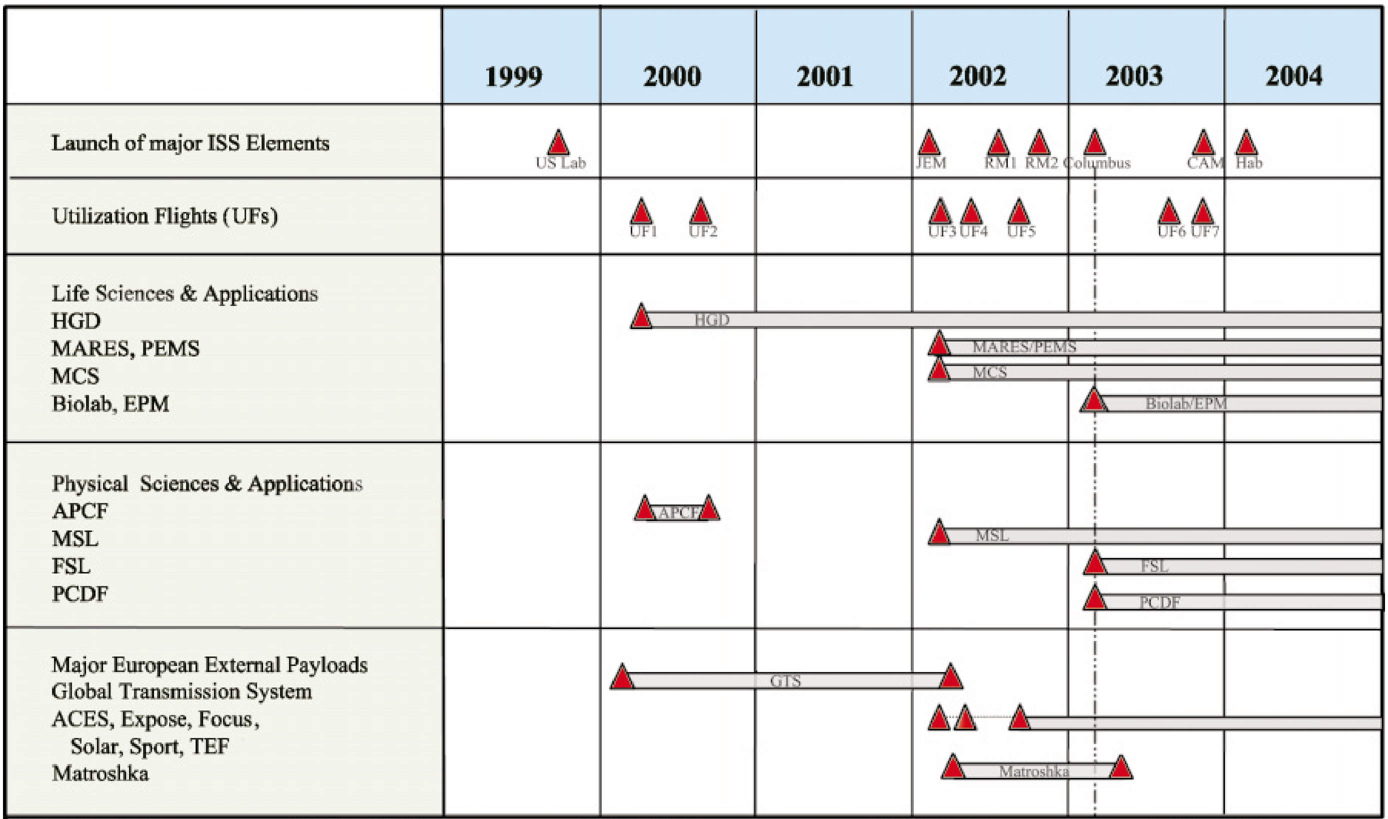
The International Space Station will provide broad opportunities for researchers from the life and physical sciences, remote sensing, technology and commercial fields for accessing the unique attributes of space. These include prolonged exposure to microgravity, near-vacuum and the space radiation environment, as well as exploiting the Station as an observation platform for celestial and Earth viewing.

A number of experiments can be performed during the assembly phase when the Space Shuttle and Russian launchers visit the Station, and between flights when the onboard crew is available as experiment operators or research subjects.

Sets of research hardware will be transported to the Station primarily in dedicated Shuttle Utilization Flights (UFs). These flights start with UF1 in 2000 and end with UF7 in 2003. At that time, all the laboratories and external payload sites will be outfitted with the first generation of research equipment. From then on, five Shuttle flights and additional logistics flights from the Partners mixed fleet are planned each year for exchanging the astronauts and resupplying the ISS logistics and payload items. The milestones for major utilisation-related launches are shown in Fig. 53. This schedule is based upon Assembly Sequence Revision D, and is under review to accommodate a delay in the Service Module launch. Consequently, the milestones indicated are subject to change

Research teams can use the onboard equipment or bring their own equipment to the Station. For access to the ESA-managed ISS utilisation share, there are two routes that can be followed: responding to the periodically issued ESA Announcement of Opportunities (AOs), or applying directly through the payment of an access fee. In the first route, users have to submit their cases to scientific or technological merit evaluation and, if successful, obtain a Station right-of-entry without an access fee. In the second route, users will not undergo merit evaluations. This route is intended primarily for commercial applications, granting full protection of intellectual property rights.

Fig. 52. Columbus is a general-purpose laboratory. (ESA)



ACES = Atomic Clock Ensemble in Space	Expose = Exposure Unit for Exobiology Samples	JEM = Japanese Experiment Module	PCDF = Protein Crystallisation Diagnostics Facility	UF = Utilization Flight
APCF = Advanced Protein Crystallisation Facility	Focus = Fire Detection Infrared Sensor Payload	MARES = Muscle Atrophy Research & Exercise System	PEMS = Percutaneous Electrical Muscle Stimulator	
CAM = Centrifuge Accommodation Module	HAB = US Habitation Module	MCS = Modular Cultivation System	RM = Russian Research Module	
EPM = European Physiology Modules	HGD = Hand Grip Dynamometer	MSL = Material Science Laboratory	TEF = Technology Exposure Facility	

Fig. 53. The milestones for major utilisation-related launches. (ISS Assembly Sequence Revision D).

The first AOs have already been issued by ESA:

- *Externally-mounted payloads for the early Station utilisation period*; issued in December 1996 as ESA SP-1201;
- *International Life Science Research Announcement (LSRA)*, also issued initially in December 1996 as ESA SP-1210, followed by a second issue in June 1998. (ESA-AO-98-LSRA).

For the externally-mounted payloads, six major instruments and facilities have been selected for flight opportunities between 2002 and 2005. These payloads involve some 30 research teams from all over Europe, including non-European Partner researchers in many cases.

For the initial LSRA, an international peer evaluation resulted in the selection of 15 European experimenter groups. For the second LSRA, the selection will be announced in 1999.

A further ESA AO for Microgravity Research and Applications in Physical Sciences and Biotechnology, issued in November 1998, is accessible at the WWW address http://www.estec.esa.nl/spaceflight/map Proposals from European lead teams are solicited that show promise in contributing substantially to progress in science and technology of the above disciplines. Proposals may concern basic or applications-oriented research programmes. Experiments may be conceived for sounding rockets, Spacehab or ISS, specifically the early utilisation opportunies available to ESA as an International Partner. Proposals are due not later than 28 February 1999.

Further periodic AOs will be issued by ESA on a yearly basis and adapted to the overall ISS yearly planning cycle as referred to in the previous chapter. These will be announced on ESA's website.

As already implemented for Life Sciences, internationally coordinated AOs for Physical Sciences and Biotechnology are in preparation and will be issued in due course.

This internationally coordinated AO approach enables the wide range of onboard research facilities to be offered to all Partner users and thus allows optimisation of the total Station resources.

The AO selection process follows three stages:

- evaluation of the proposal's scientific or technological merit;
- assessment of the technical feasibility of the proposed experiment;
- appraisal of the proposal relevance to the programme priorities of the sponsoring Partner Agency.

The merit evaluation will be accomplished by independent internationally recognised scientific or technological experts. The feasibility assessments will be undertaken to determine whether the proposed experiment can be safely flown, taking into account the available flight opportunities and resource utilisation. Finally, the appraisal will examine the proposal's programmatic coherence and the funding possibilities of the sponsoring Agencies. For European users, a sponsor can be an ESA user programme, one of the European National Agencies or other European Institutions.

Utilisation rules concerning access to ESA's ISS utilisation share are being prepared by the Agency and will be approved by the participating ESA Member States.

The utilisation will be divided into consecutive phases to take into account gained experience and promotional aspects. The early utilisation phase, which comprises ESA's utilisation rights on the ISS Truss and in the US Lab, is intended to promote the use of the Space Station. It is based on an open access policy. However, allocation is primarily intended for users from ESA Member States.

Detailed rules, addressing in particular industrial/commercial applications, will be drawn up for the phases following the early utilisation phase.

Table 39. ESA Points of Contact	
ISS Utilisation	K. Knott Office Code MSM-GU
Space Sciences	H. Olthof Office Code SCI-R
Earth Observation	C. Readings Office Code SCI-VR
Space Technology	R. Aceti Office Code IMT-TTD
Life Sciences	D. Schmitt Office Code MSM-GS
Microgravity Research and Applications in Physical Sciences and Biotechnology	H.U. W alter Office Code MSM-GA
ESTEC mailing address: ESTEC, Postbus 299, NL-2200 A G Noordwijk, The Netherlands	

Table 41. International Par tners Points of Contact

Country	Point of Contact
Canada	B. W etter CSA Space Science Programme PO Box 7275 CAN-Ottawa K1L 8E3
Japan	S. Yoshitomi NASDA Tsukuba Space Center 2-1-1 Sengen Tsukuba-SH1 JAP-Ibaraki 305
Russia	A. Botvinko Russian Space Agency Schepkina Street 42 RUS-129857 Moscow
USA	M. Uhran NASA Headquarters USA-Washington DC 20546

Potential users who wish to obtain more information on the utilisation opportunities offered by the ISS may address either the ESA points of contact (Table 39) or ESA Member States points of contact (Table 40). The International Partners points of contact are given in Table 41.

Table 40. ESA Member State Points of Contact

Country	Point of Contact
Austria	K. Pseiner Austrian Space Agency Garnisongasse 7 A-1000 Vienna
Belgium	M.C. Limbourg P/O SPPS 8 rue de la Science B-1040 Brussels
Denmark	J.U. Dalgaard Ministry of Research and Information Technology Bredgade 43 DK-1260 Copenhagen K
Finland	H. Sandell TEKES PO Box 69 FIN-00101 Helsinki
France	A. Ammar CNES 2 place Maurice Quentin F-75039 Paris Cedex 01
Germany	H. Ripken DLR K nigswinterstrasse 522-524 Postfach 30 03 64 D-53227 Bonn
Ireland	B. O Donnell Forbait Glasnevin IRL-Dublin 9
Italy	J. Sabbagh Agenzia Spaziale Italiana Via Civitavecchia 7 I-00168 Rome
Netherlands	M. Heppener SRON Sorbonnelaan 2 NL-3584 CA Utrecht
Norway	B. Andersen Norwegian Space Center Drammensveien 165 PO Box 113 Skoyen N-0212 Oslo
Spain	P. Gonzalez CDTI Directorate of Strategic Programmes Edificio Cuzco IV PO Castellana 141, 12a E-28046 Madrid
Sweden	L. Nordh Swedish National Space Board Albygaten 107 PO Box 4207 S-17104 Solna
Switzerland	J.F. Conscience Office F d ral de l Education et de la Science PO Box 2732 CH-3001 Bern
UK	P. Murdin British National Space Centre 151 Buckingham Palace Road GB-London SW1W 9SS

Further Station Familiarisation

The previous chapters have provided a potential user and payload developer with background information on the capabilities of the ISS, with particular reference to the European utilisation elements. Further detailed information is available for potential users and payload developers to find out the current status of the capabilities and Station assembly.

Space Station User Information Centre

Potential users, payload developers and the European National User Support Organisations need access to official and centrally-controlled data on the ISS to prepare their experiments and facility operations. ESA is establishing a Space Station User Information Centre at its ESTEC Noordwijk site, and this centre will be the focal point in Europe for new and updated Station information and data. The major services provided by this centre include:

- provision of information to potential users on Station utilisation capabilities;
- provision of advice to selected users on how to prepare their research activities aboard the Station.

In respect of the provision of information to users, the centre's data bank encompasses the entire library of user-related documentation jointly established among the Station Partners. The information is under configuration control and accessible electronically. Further information will be available at the users' national User Support and Operations Centres or their Facility Responsible Centres.

As far as the provision of advice to users, the centre's objective is to familiarise potential and newly selected users with research opportunities on the Station, the standard user interfaces and the availability of existing standard accommodation hardware. Replicas of the Columbus Laboratory for the pressurised payloads and the external payload accommodation provisions are available to demonstrate the opportunities. These will be supplemented with ISPRs and Express Pallet Adapters as well as the range of Standard Payload Outfitting Equipment, Laboratory Support

Equipment and Payload Support Equipment available to European users. Virtual replicas of the Partner laboratories and external accommodation provisions are also available to demonstrate the complete Partner flight configurations. Expert personnel are on hand to discuss the opportunities with potential users, and provide further guidance.

Further general centre facilities include:

- video and voice communications during on-going Station operations;
- support for Media representatives to cover both planned and unforeseen events;
- conference capabilities to support both educational and multi-user discussions;
- studio capabilities for video/audio editing and broadcasting.

Reference Documents

Reference documents provide an elaborated definition of the technical capabilities and constraints that need to be observed by a facility-class payload in an ISS module or laboratory.

The following documents are for reference by Columbus Laboratory payload developers:

– Columbus Payload Accommodation Handbook Main Volume COL-RIBRE-MA-0007-00;
– MSM Operations Processes Volume I Concept Overview OPS-ESA-PL-001/1;
– MSM Operations Processes Volume II Tasks to be performed by the ESA Operations Management Team OPS-ESA-PL-001/2;
– MSM Operations Processes Volume III Tasks to be performed by the Flight Control Team OPS-ESA-PL-001/3;
– MSM Operations Processes Volume IV Tasks to be performed by the Engineering Support Team OPS-ESA-PL-001/4;
– MSM Operations Processes Volume V Tasks to be performed by the Payload Development and Operations Team OPS-ESA-PL-001/5;
– MSM Operations Processes Volume VI Tasks to be performed by the IGS Control Team OPS-ESA-PL-001/6;

- MSM Operations Processes Volume VII Tasks to be performed by the Crew Operations Team OPS-ESA-PL-001/7;
- MSM Operations Processes Volume VIII Tasks to be performed by the Payload Integration Team OPS-ESA-PL-001/8;
- MSM Operations Processes Volume IX Tasks to be performed by the Logistics Support and Ground Processing Team OPS-ESA-PL-001/9;
- MSM Operations Processes Volume X Tasks to be performed by the ATV Cargo Integration Team OPS-ESA-PL-001/10.

The MSM Operations Processes Volumes are available on the World Wide Web under the URL: http://ioigsd.esoc.esa.de

The following documents are references for non-Columbus payload developers:

- Pressurized Payloads Interface Requirements Document SSP 57000;
- Attached Payloads Interface Requirements Document SSP 57003;
- Japanese Payload Accommodation Handbook (JPAH) JCX-95006;
- Express Pallet Preliminary Payload Accommodation Document NASA version 30 June 1998.
- Attached Payloads Payload Accommodation Handbook SSP 57021;
- Pressurized Payloads Accommodations Handbook SSP 57020;
- Laboratory Support Equipment Accommodations Handbook SSP TBD.

Reference documents are subject to configuration control.

Information Documents

Information documents provide general information on the capabilities of an ISS module or laboratory. They are not subject to configuration control. The following documents provide fuller information:

- Exploiting the International Space Station: A Mission for Europe (ESA, BR-141);
- International Space Station Familiarization TD9702;
- NASA Facts sheets,
- The International Space Station: Improving Life on Earth and Space. The NASA Research Plan, An Overview;
- The International Space Station: Research & Technology Utilization Guide;

and are accessible on NASA World Wide Web public pages at the URL:
http://station.nasa.gov/reference

- JEM: Japanese Experiment Module

accessible at the URL:
http://www.nasda.go.jp/

Abbreviations & Acronyms

AAA	Avionics Air Assembly
Access	Advanced Cosmic Ray Experiment for ISS
ACES	Atomic Clock Ensemble in Space
AMS	Alpha Magnetic Spectrometer
AO	Announcement of Opportunity
APCF	Advance Protein Crystallization Facility
APS	Automated Payload Switch
ARIS	Active Rack Isolation System
ASDA	Area Smoke Detector Assembly
ASI	Agenzia Spaziale Italiana
ATCS	Automatic Temperature Controlled Stowage
ATV	Automated Transfer Vehicle
B&W	Black and White
BAM	Bone Analysis Module
Biolab	Biological Laboratory
BIVOG	Binocular Videooculgraph
BMAS	Bio-Medical Analysis System
BP	Blood Pressure
BPSK	Bipolar Phase Shift Keying
C&DH	Command & Data Handling System
C&TS	Communications & Tracking System
CAM	Centrifuge Accommodation Module
CCD	Charged Couple Device
CDR	Critical Design Review
CHeCS	Crew Health Care System
CMS	Countermeasure System
CNES	Centre National d'Etudes Spatiales
COUP	Consolidated Operations and Utilisation Plan
CPAH	Columbus Payload Accommodation Handbook
CPD	Coarse Pointing Device
CSA	Canadian Space Agency
CSF	Cryogenic Storage Freezer
DLR	Deutsche Forschungsanstalt für Luft- und Raumfahrt
DMS	Data Management Services
D/MSM	ESA Directorate for Manned Spaceflight & Microgravity
EC	Experiment Container
ECCO	Extremely Heavy Cosmic Ray Composition Observer
ECG	Electrocardiogram
ECLSS	Environmental Control & Life Support System
EDR	European Drawer Rack
EEG	Electroencephalogram
EGSE	Electrical Ground Support Equipment
EHS	Environmental Health System
EMG	Electromyogram
EMP	Environmental Monitoring Package
EPF	External Payload Facility
EPM	European Physiology Modules
EPS	Electrical Power System
ER	Express Rack
ESA	European Space Agency
ESR	European Stowage Rack
ESTEC	European Space Research & Technology Centre
EWACS	Emergency, Warning and Caution and Safing
ExPA	Express Pallet Adapter
FAR	Flight Acceptance Review
FDS	Fire Detection and Suppression
FM	Flight Model
Focus	Intelligent Fire Detection Infrared Sensor System
FOV	Field of View
FRC	Facility Responsible Centre
FSL	Fluid Science Laboratory
GAS	Get Away Special
GN&C	Guidance, Navigation & Control
GTS	Global Transmission System
Hexapod	Hexapod pointing system
HMS	Health Maintenance System
HRD	High Rate Data
HRF	Human Research Facility
HTV	H-II Transfer Vehicle

ICD	Interface Control Document
IEEE	Institute for Electrical and Electronics Engineering
IGA	Intergovernmental Agreement
ISIS	International Subrack Interface Standard
ISPR	International Standard Payload Rack
ISS	International Space Station
ITA	Integrated Truss Assembly
JEM	Japanese Experiment Module
JEM-EF	JEM-Exposed Facility
JPAH	Japanese Payload Accommodation Handbook
LAN	Local Area Network
LGF	Low Gradient Furnace
LSE	Laboratory Support Equipment
LSRA	Life Sciences Research Announcement
MAP	Microgravity Application Promotion
MARES	Muscle Atrophy Research System
MBS	Mobile Remote Servicer Base System
MBS	Magnetic Brain Stimulator
MCC-H	Mission Control Center-Houston
MCS	Modular Cultivation System
MDL	Mid-Deck Locker
MEEMM	Multi-Electrode Electroencephalogram Mapping Module
MELFI	Minus Eighty Degree Laboratory Freezer for the ISS
MIM	Microgravity Isolation Mount
MPLM	Mini Pressurised Logistics Module
MSG	Microgravity Science Glovebox
MSL	Material Science Laboratory
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NIR	Near-Infrared
NRZ-L	Non-Return to Zero
NTSC	National Television System Committee
OPAR	Orbital Rack
PAM	Payload Accommodation Manager
PAR	Preliminary Acceptance Review
PCDF	Protein Crystallisation Diagnostics Facility
PDR	Preliminary Design Review
PDS	Payload Data Set
PDU	Power Distribution Unit
PEMS	Percutaneous Electrical Muscle Stimulation
PIA	Payload Interface Agreement
PLCU	Payload Control Unit
PMI	Payload Mission Integrator
POIC	Payload Operations Integration Centre
PPMI	Physiological Pressure Measurement Instrument
PSE	Payload Support Equipment
PUP	Partners Utilisation Plan
PVP	Payload Verification Plan
QPSK	Quadrature Phase Shift Keying
QSF	Quick Snap Freezer
RLTF	Rack Level Test Facility
RMM	Respiratory Monitoring Module
RMSA	Rack Main Switch Assembly
RPDA	Remote Power Distribution Assembly
RSA	Russian Space Agency
SAGE	Stratospheric Aerosol and Gas Experiment
SED	Standard Experiment Drawer
SMO	Solar Monitoring Observatory
SOAR	Station Off-Axis Rotator
SPDM	Special Purpose Dexterous Manipulator
SPLC	Standard Payload Computer
SPOE	Standard Payload Outfitting Equipment
Sport	Sky Polarisation Observatory
SQF	Solidification and Quenching Furnace
SR	Safety Review

SSRMS	Space Station Remote Manipulator System
SSUIC	Space Station User Information Centre
STEP	Suitcase Test Equipment
SUP	Standard Utility Panel
TBD	To Be Defined
TCS	Thermal Control System
TDRSS	Tracking and Data Relay Satellite System
TEF	Technology Exposure Facility
TEPAD	Test Equipment for Payload Development
TMP	Turbo Molecular Pump
Track	Transportation Rack
UF	Utilization Flight
UHB	User Home Base
URL	Universal Reference Locator
US	United States
USOC	User Support and Operations Centre
UV	Ultraviolet
VEG	Virtual Environment Generator
VIS	Visible
VME	Versa Module Europe
VSU	Video Switching Unit
VVS	Vacuum and Venting System
XCF	X-ray Crystallography Facility
XPLC	External Payload Computer
XSMI	Xenon Skin Blood Flow Measurement Instrument
ZOE	Zone of Exclusion

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