→ 7 INTERNATIONAL SPACE STATION – ISS

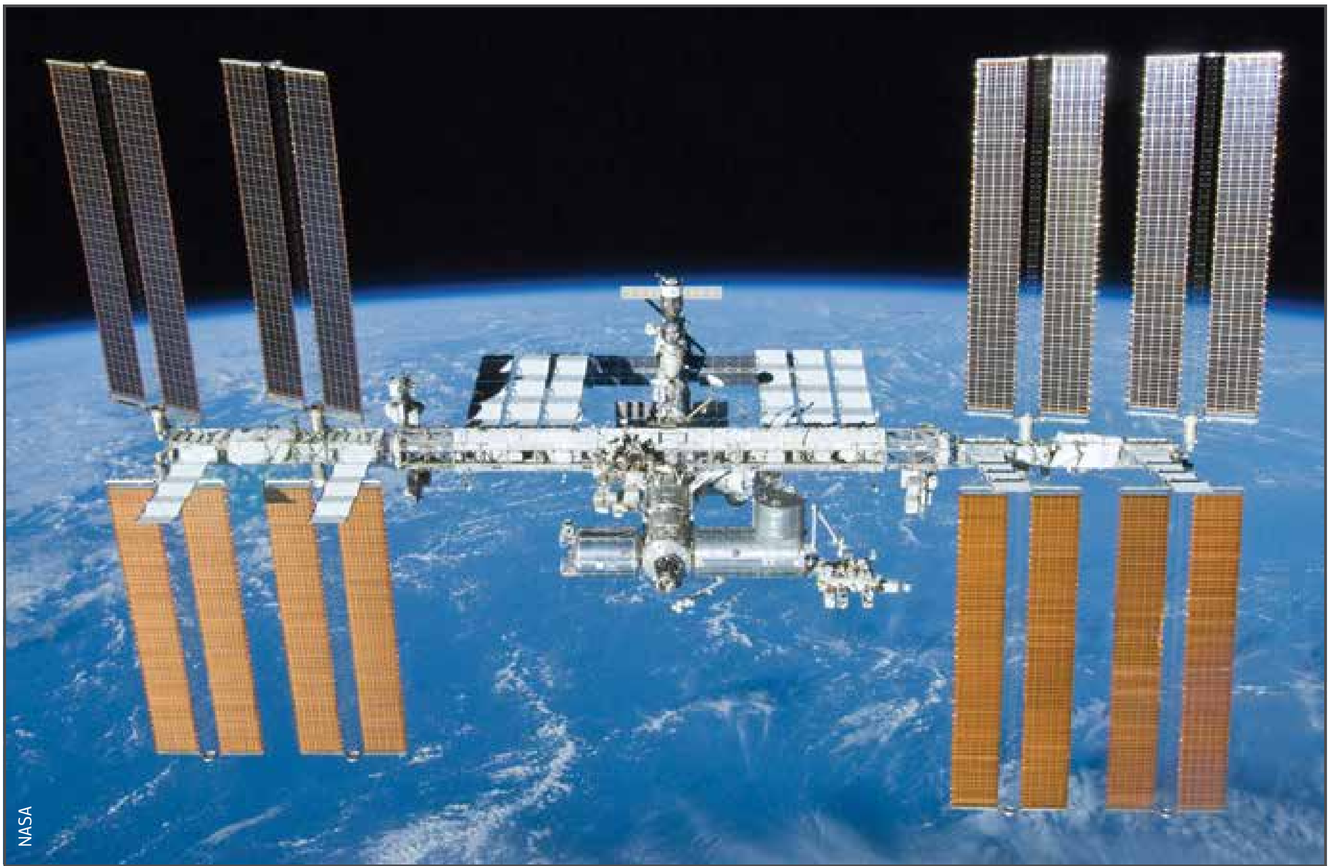


Image 7-1: International Space Station

This chapter is aimed at providing users with basic utilisation information regarding the International Space Station (ISS).

7.1 Introduction to the ISS

7.1.1 What is the ISS?

After the Space Shuttle entered service in 1981, NASA regarded a permanently manned space station as the next logical step in human spaceflight. The objectives of the space station were:

International Space Station

Continuous microgravity time
Width: 108 m
Length: 73 m (~87 m incl. ATV or Progress)
Height: 20 m
Total mass at completion: ~450 000 kg

- to serve as a permanently manned Earth-orbiting laboratory for carrying out long-term scientific research in the unique environment of space;
- to accelerate innovations in technology and engineering with resulting applications on Earth;
- to study the effects on humans of working and living in space for long periods of time, thus acting as a stepping-stone to future human exploration of the Moon, Mars and beyond;
- to promote partnerships between industries and research institutes;
- to promote the image of science and engineering, influencing the educational paths chosen by future generations;
- to sustain and reinforce the highly technological aerospace industry;
- to support the human nature of exploration by preparation of missions beyond Low Earth Orbit (LEO).

As a consequence, NASA established the 'Space Station Task Force' in May 1982 to study user requirements and to propose a conceptual design of a Space Station. NASA decided to turn this project into an international cooperative programme, and invited Canada, Europe (represented by the European Space Agency, ESA) and Japan to take part.

The Soviet Union meanwhile had undertaken the Salyut programme - the world's first crewed space station - which consisted of a series of four crewed scientific research space stations and two crewed military reconnaissance space stations over a period of 15 years from 1971 to 1986. Salyut was designed to carry out long-term research into the problems of living in space and a variety of astronomical, biological and Earth-resources experiments.

Figure 7-1: Space Station "Freedom" concept – 1988

The US Space Station project was finally approved by President Ronald Reagan in January 1984 and in 1985, Canada, ESA and Japan all signed a Memorandum of Understanding (MOU) with NASA covering the preliminary design of a Space Station. In June 1988, the new Space Station configuration (named "Freedom" by President Reagan), made up of the various international elements and modules, was presented (Figure 7-1). In September of that year, a Space Station Inter Governmental Agreement (IGA) was signed by NASA, Canada and ESA, and successively by Japan in March 1989.

Between 1988 and 1993 the Space Station underwent several redesigns, mainly due to budget cuts, and on more than one occasion, the entire programme came close to being cancelled by US Congress.

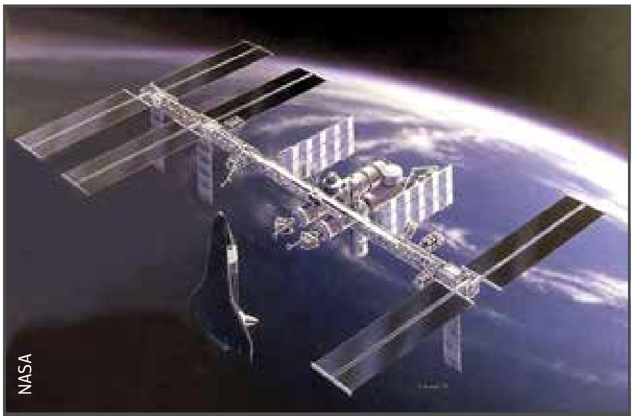


Figure 7-2: International Space Station Configuration at 1998 IGA signing

Experience gained from the Salyut stations went on to pave the way for next multimodular Russian space station project - Mir and in 1993, with the Cold War at an end, the Russian Federation was invited to join the international endeavour. An interim agreement was signed with the Russians, giving birth to the International Space Station (ISS).

In late 1997, the Italian Space Agency (ASI) and NASA signed a bilateral Memorandum of Understanding (based on the original one signed in 1991) for additional Multi-Purpose Logistics Module (MPLM) flight units with enhanced operational capabilities. Also in 1997, NASA and the Brazilian Space Agency (AEB) signed an Implementing Arrangement for Brazil's contribution of Space Station hardware and payload facilities in exchange for utilisation rights from NASA's allocation.

As a result of significant Russian participation and programme design changes that were undertaken after 1988, new agreements between the various partners and NASA were necessary. In January 1998, senior government officials from the U.S., Russia, Japan, Canada and participating countries of the European Space Agency (Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom), met in Washington to sign an Intergovernmental Agreement on Space Station Cooperation. This agreement established the framework for cooperation among the partners on the design, development, operation and utilisation of the International Space Station. Also on that date, three separate bilateral memoranda of understanding were signed by the NASA Administrator and his counterparts: the Russian Space Agency General Director, the ESA Director General and the Canadian Space Agency President. The memorandum of understanding between NASA and the government of Japan was signed almost a month later on 24 February 1998.

On 20 November in the same year, the first element of the ISS, the Russian Control Module "Zarya", was launched. Zarya, relied heavily on technologies developed in the Soviet Salyut programme and its launch initiated the assembly of the largest international project ever undertaken.

7.1.2 What does the ISS offer?

The International Space Station offers:

- the capability to perform an experiment or science programme over an extended period of time in weightless conditions or/and exposed to the space environment. Typically, experiments can be performed over a period of hours up to years;
- the possibility of frequent and regular access to and return from the Station of payloads, experimental hardware, and samples;
- access to a significant level of on-board resources (e.g. crew time, power, cooling, telemetry, etc.);
- the permanent presence of crew during experiment execution, to carry out established procedures or for troubleshooting;
- an extensive range of facilities (including external sites) that allow for research in a wide spectrum of utilisation fields;
- providing the capability for human spaceflight researchers and the medical community to conduct multi-year investigations with various astronauts as test subjects in a consistent environment;
- from its specific orbit inclination, the ISS provides a coverage of 90 per cent of the world's populated area, making it a valuable outpost for Earth monitoring from space;

7.1.3 Why use the ISS?

The ISS offers a range of research facilities in a unique laboratory environment. Almost as soon as the International Space Station was habitable, researchers began using it to study the impact of microgravity and other space effects on many aspects of our daily lives. This unique platform continues to enable scientists from all over the world to put their talents to work on innovative experiments that could not be done anywhere else.

ISS research advances the state of scientific knowledge in life and physical sciences - areas such as human health and telemedicine, biotechnology, advanced materials, chemo-physical processes, Earth observation, vaccine development, disaster relief and climate change monitoring. Education programmes driven by research inspire future scientists, engineers and space explorers. The benefits drive the legacy of the Space Station - its research strengthens economies.

ISS research can be as complex as an experiment that occupies a complete rack (the largest item available to users to accommodate experiments within the pressurised volume of the Station) or utilises one or more of the external experiment accommodation sites. It could be as simple as access to data that has been collected on the Station by others who earlier performed on-board experiments.

Although each space station partner has distinct agency goals for station research, each partner shares a unified goal to extend the resulting knowledge for the betterment of humanity.

7.1.4 Principal parameters and characteristics of the ISS

The ISS has a nearly circular orbit inclined at 51.63° to the equator with an average altitude that has, since assembly began, ranged between 330 and 400 km. The ISS moves along its orbit at a velocity of almost 28 000 km/hr, orbiting Earth every 90-93 minutes (depending on the exact altitude).

The operational environment of the ISS - including altitude, attitude and inclination will be further described in section 7.2 below.

Table 7-1: Principal ISS parameters at Assembly Complete

PARAMETER	ASSEMBLY COMPLETE (2014)
Length	73 m (~87 m with either ATV or Progress docked)
Module Length	51 m
Width	108,5 m (along truss)
Solar Array Length	73 m
Height	20 m
Mass	450 000 kg
Habitable Volume	388 m^3
Pressurized Volume	916 m^3
Power Generation	84 kW (8 solar arrays)
Pressurised Laboratory Modules	5 (1 US, 2 Russian, 1 European, 1 Japanese)
ISPR Racks	33 (13 in US Lab, 10 in Columbus, 10 in Kibo)
Multi-user External Payload Sites	18 (4 on S3 Truss, 4 on Columbus module, 10 on Kibo External Facility)
Crew	6 (crew complement is nominally 3 or 6 depending on increment phase but sometimes as high as 9 [in the post-Shuttle era] during an additional ESA short duration mission)
Orbit inclination	51.64°
Mean Altitude	350 – 450 km
Orbital period	~91 minutes
Orbital velocity	~7.66 km/s
Eccentricity of orbit	~0
Nominal Attitude	XVV (LVLH)
Average Research Crew Time/Week (Hours)	35-40 hrs/wk (for both US and Russian segment)
S-Band Command Uplink Rate	High Data Rate (HDR): 72 kbps, Low Data Rate (LDR): 6 kbps
S-Band Telemetry Downlink Rate	High Data Rate (HDR): 192 kbps, Low Data Rate (LDR): 12 kbps
S/G Voice loops	4
Ku-Band Video Downlink channels	6
Data/Video Downlink Rate (Ku-Band)	300 Mbps total (US Segment only) of which 259 Mbps usable after overheads. ~100 Mbps available for utilisation.
Ku-Band Contingency Command Uplink	1 kbps
Ku-Band Internet Protocol Uplink	25 Mbps
S-Band & Ku-Band coverage	30 – 70 %

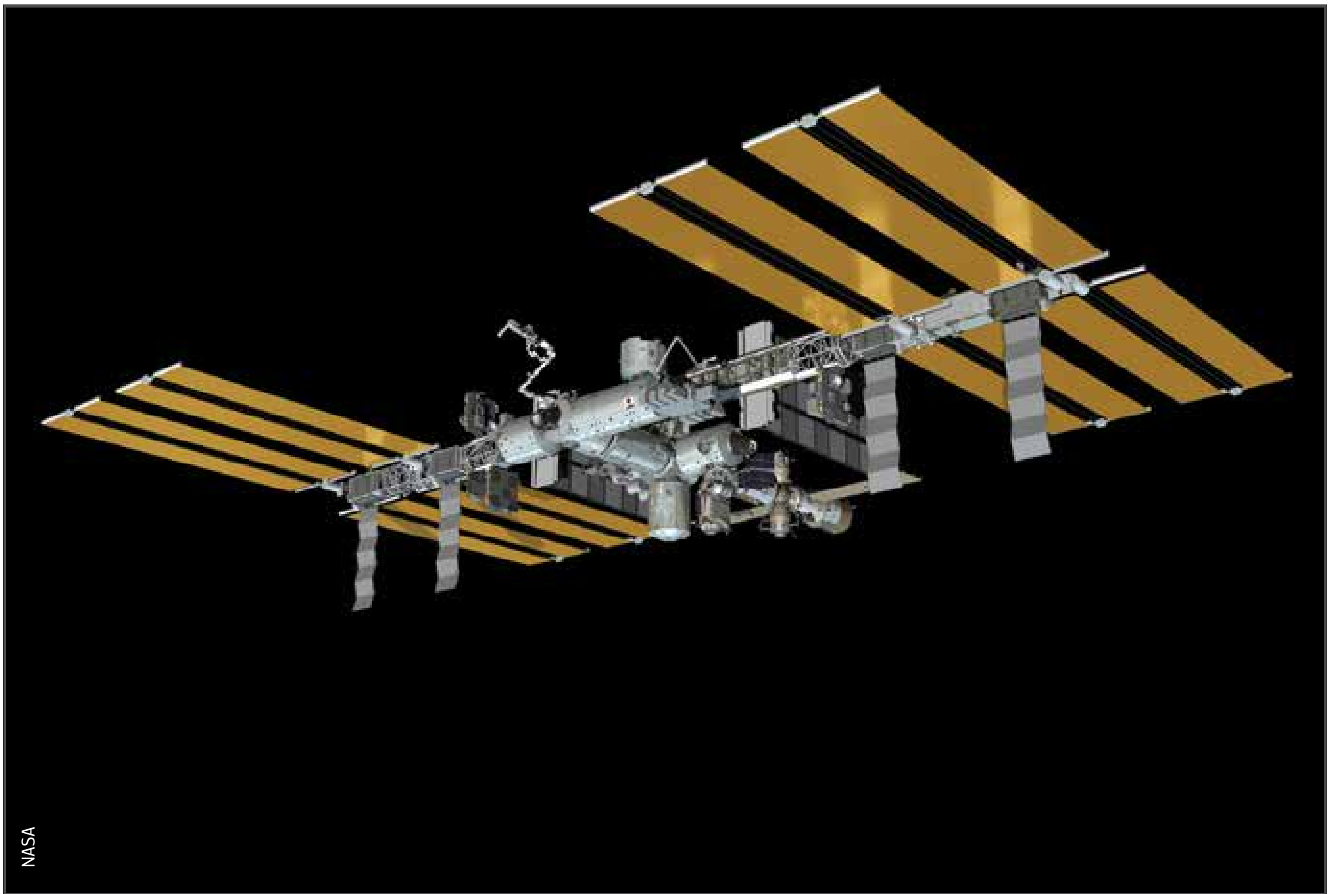


Figure 7-3: ISS at Assembly Complete

At assembly complete, the ISS has a total mass of approximately 450 tonnes, made up of elements that together result in a structure with dimensions of 108x79x43 m, providing an overall pressurised volume of 1300 m^3. The maximum power output available is 108 kW, with an average of 30 kW (minimum 25 kW, maximum 35 kW) available to payload operations and support to payload operations.

7.1.5 Major elements and launch dates

In January 2005, the Heads of Space Agencies from the USA, Russia, Japan, Europe and Canada met in Montreal, Canada to review and further advance ISS cooperation. During this meeting the Heads, endorsed by the Multilateral Coordination Board, approved the ISS configuration (Figure 7-4), which had already been presented at a previous Heads of Agencies meeting held in July 2004 at the ESTEC facility of ESA in the Netherlands.

The following tables and figures provide a summary of the principal elements of the ISS, and are grouped into the following:

- pressurised laboratory modules;
- elements dedicated to exposed payloads;
- structural and logistics elements/modules.

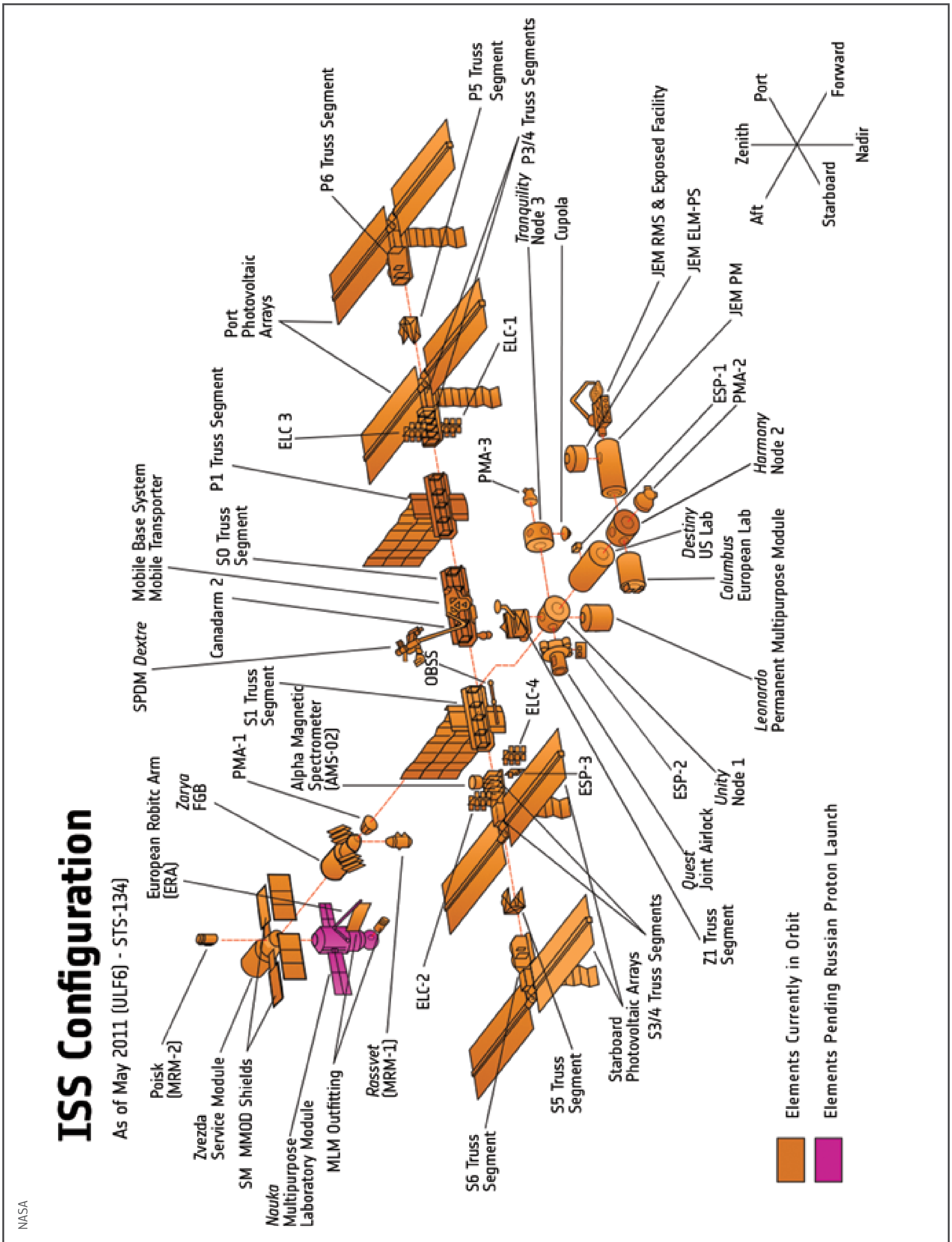


Figure 7-4: Exploded view of ISS Assembly Complete configuration

Table 7-2: ISS Pressurised Laboratory Modules

LAUNCH DATE	MODULE NAME	DESCRIPTION	OWNERSHIP
02/2001	US Lab "Destiny"	American pressurised laboratory module for multidisciplinary research. 13 Utilisation International Standard Payload Rack (ISPR) locations available.	NASA
02/2008	Columbus	European pressurised laboratory module for multidisciplinary research. 10 Utilisation ISPR locations available.	ESA/NASA
06/2008	JEM PM "Kibo"	Japanese pressurised laboratory module for multidisciplinary research. 10 Utilisation ISPR locations available.	JAXA/NASA
NET 2017	MLM – Multipurpose Laboratory Module	Russian pressurised laboratory module for multidisciplinary research (until MLM is on orbit Russia is undertaking research in the Russian segment of the ISS).	Roscosmos

Table 7-3: Elements dedicated to exposed payloads

LAUNCH DATE	ELEMENT NAME	DESCRIPTION	OWNERSHIP
02/2008	Columbus External Payload Facility – CEPF	European exposed platforms located on the starboard end cone of the Columbus module. Accommodates up to 4 exposed payloads (on CEPA).	ESA
06/2008	JEM-RMS Japanese Remote Manipulator System	Japanese robotic arm used for handling the payloads and logistics of the JEM-EF.	JAXA
07/2009	JEM-EF Japanese Exposed Facility	Japanese external platform capable of accommodating up to 10 exposed payloads.	JAXA
ELC1 & ELC2: 11/2009 ELC4: 02/2011 ELC3: 05/2011	ExPRESS Logistics Carrier (Truss Express Pallets)	External accommodation platforms for exposed payloads. Each pallet is capable of accommodating up to 6 smaller payloads.	NASA

Table 7-4: Structural and Logistic elements/modules			
LAUNCH DATE	**ELEMENT NAME**	**DESCRIPTION**	**OWNERSHIP**
11/1998	Functional Cargo Block “Zarya”	Russian control module and first element of ISS in orbit. Provided initial propulsion and power to ISS.	Roscosmos
PMA 1: 12/1998 PMA 2: 12/1998 PMA 3: 10/2000	Pressurised Mating Adaptors (PMA) 1, 2 and 3	PMA 1 attaches Unity to Zarya; PMA 2 & PMA 3 acted as Shuttle docking ports to the US segment of the ISS.	NASA
12/1998	Node 1 “Unity”	Connecting node providing docking ports for other modules. Also provides temporary stowage capabilities.	NASA
07/2000	Service Module “Zvezda”	Structural and functional core of Russian segment, providing early ISS living quarters, life support, electrical power distribution, data processing, flight control, communication and propulsion systems.	Roscosmos
First element (Z1 ITA): 10/2000 Last element (S6): 03/2009	Integrated Truss Structure - ITS	Lattice framework structural elements that make up the “backbone” of the ISS. The solar arrays, radiators, and the MSS are all located on the ITS.	NASA
First panel (P6): 12/2000 Last panel (S6): 03/2009	Thermal Control Panels	Act as radiators in the overall ISS thermal control system.	NASA
ESP-1: 03/2001 ESP-2: 07/2005 ESP-3: 08/2007	ESP – External Stowage Platform	Externally attached platforms providing temporary accommodation for orbital replacement units and spares.	NASA
First flight: 03/2001 Last flight: 07/2011	Multi-Purpose Logistics Module – MPLM	Italian built pressurised modules that served as “moving vans”, carrying laboratory racks filled with equipment, experiments and supplies to and from the ISS on board the Space Shuttle.	NASA
Canadarm2: 04/2001 MBS: 06/2002 SPDM: 03/2008	Mobile Servicing System – MSS	Mobile robotic system located on central truss used for assembly and maintenance tasks including moving equipment and supplies, supporting astronauts, servicing instruments and payloads. Made up of three parts: Canadarm2 (SSRMS), Mobile Base System (MBS) and Special Purpose Dextrous Manipulator (SPDM).	CSA
07/2001	Airlock “Quest”	Airlock for spacewalks using either US EMUs (Extravehicular Mobility Units) or Russian Orlan spacesuits.	NASA

09/2001	Docking Compartment 1 “PIRS”	Docked to Zvezda, serves as docking port for transport and cargo vehicles to ISS and as an airlock for spacewalks by 2 crewmembers using Russian Orlan spacesuits.	Roscosmos
10/2007	Node-2 “Harmony”	ESA-developed element that controls and distributes resources from truss and Destiny to other connected elements (Columbus, Kibo, HII Transfer Vehicle, Dragon and Cygnus).	NASA
First arrays (P6): 12/2000 Final arrays (S6): 03/2009	Photovoltaic Arrays	Solar array structures for provision of power to the ISS.	NASA
ELM-PS: 03/2008 ELM-ES: 07/2009	JEM Experiment Logistics Modules (ELM)	Japanese logistics modules serving as on-orbit storage areas that house materials for experiments, maintenance tools and supplies. Made up of two parts: the Pressurised Section (PS) attached to Kibo, and the Exposed Section (ES) accommodated on the JEM-EF.	JAXA
11/2009	Poisk (MRM-2)	The Mini-Research Module 2 (MRM-2) is docked to the zenith port of the Zvezda module and serves as a docking port for Soyuz and Progress spacecraft and as an airlock for spacewalks. Poisk also provides extra space for scientific experiments and provides power-supply outlets and data-transmission interfaces for external scientific payloads.	Roscosmos
First flight: 01/2010	ULC – Unpressurised Logistics Carrier	General purpose unpressurised carrier for transporting cargo to and from ISS in Shuttle payload bay. Temporarily attached to ISS truss during change-out of orbital replacement units.	NASA
02/2010	Node-3 “Tranquility”	ESA-developed element that controls and distributes resources from Node 1 to connected elements (Cupola, PMA 3). Also houses environmental control and life support systems.	NASA
02/2010	Cupola	ESA-developed pressurised observation and work area for ISS crew giving visibility to support the control of the SSRMS and EVA activities, and general external viewing of the Earth, celestial objects and visiting vehicles.	NASA

05/2010	Rassvet (MRM-1)	The Mini-Research Module 1 (MRM-1), formerly known as the Docking Cargo Module (DCM), is primarily used for cargo storage and as a docking port for visiting spacecraft. Rassvet is docked to the nadir port of Zarya.	Roscosmos
02/2011	Permanent Multipurpose Module (PMM)	The Leonardo Permanent Multipurpose Module (PMM) is primarily used for storage of spares, supplies and waste on the ISS. Leonardo PMM was a Multi-Purpose Logistics Module (MPLM) before 2011, but was modified into its current configuration.	NASA
NET 2017	Nauka (MLM)	The Multipurpose Laboratory Module (MLM) will be Russia's primary ISS research module. It will also serve as a crew rest area and will be used for docking and cargo storage. Nauka will be docked to the nadir port of Zvezda.	Roscosmos
NET 2017	European Robotic Arm (ERA)	Large re-locatable symmetrical robotic arm with 7 degrees of freedom attached on various points of the Russian Multipurpose Laboratory Module.	ESA

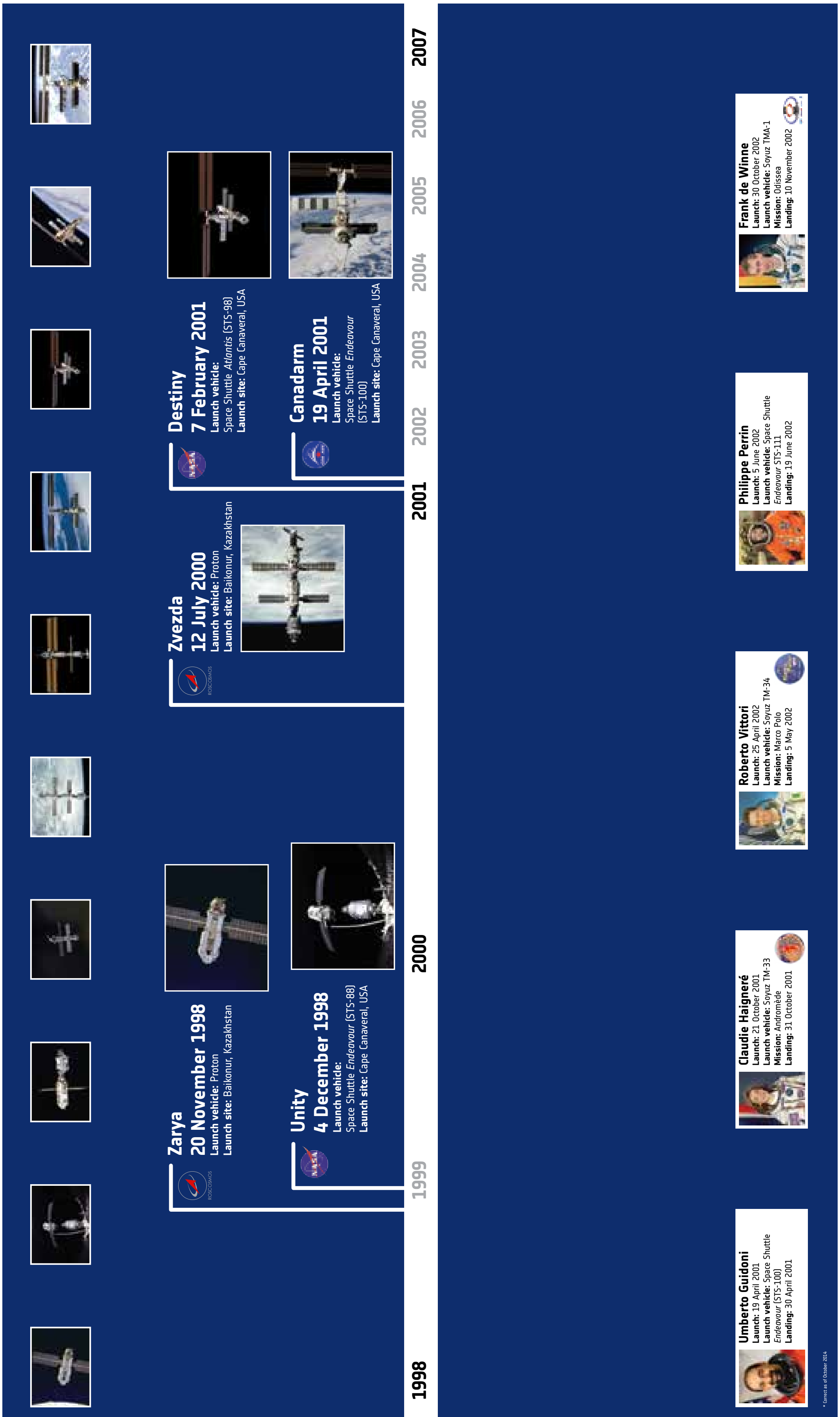


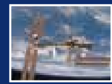
Figure 7-5: ISS Timeline











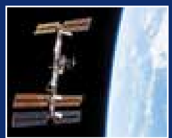
Kibo
11 March/ 31 May 2008/ 15 July 2009
Launch vehicle:
Space Shuttles *Endeavour* (STS-123), *Discovery* (STS-124), *Endeavour* (STS-127)
Launch site: Cape Canaveral, USA

HTV-1
10 September 2009
Launch vehicle: H-IIB
Launch site: Tanegashima, Japan

2008

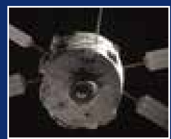
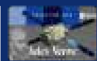
2009

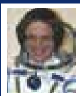
Node-2
23 October 2007
Launch vehicle:
Space Shuttle *Discovery* (STS-120)
Launch site: Cape Canaveral, USA



Columbus
7 February 2008
Launch vehicle:
Space Shuttle *Atlantis* (STS-122)
Launch site: Cape Canaveral, USA

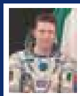
ATV-1
9 March 2008
Launch vehicle: Ariane 5ES
Launch site: Kourou, French Guiana

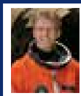


Pedro Duque
Launch: 18 October 2003
Launch vehicle: Soyuz TMA-3
Mission: Cervantes
Landing: 28 October 2003

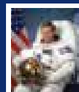
André Kuipers
Launch: 19 April 2004
Launch vehicle: Soyuz TMA-4
Mission: Delta
Landing: 30 April 2004



Roberto Vittori
Launch: 15 April 2005
Launch vehicle: Soyuz TMA-6
Mission: Eneide
Landing: 25 April 2005



Thomas Reiter
Launch: 4 July 2006
Launch vehicle: Space Shuttle *Discovery* (STS-121)
Mission: Astrolab
Landing: 22 December 2006

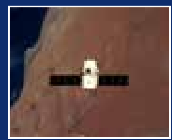


Christer Fuglesang
Launch: 10 December 2006
Launch vehicle: Space Shuttle *Discovery* (STS-116)
Mission: Celsius
Landing: 22 December 2006

HTV-2
22 January 2011
Launch vehicle: H-IIB
Launch site: Tanegashima, Japan

PMM
24 February 2011
Launch vehicle:
Space Shuttle *Discovery* (STS-133)
Launch site: Cape Canaveral, USA

HTV-3
21 July 2012
Launch vehicle: H-IIB
Launch site:
Tanegashima, Japan

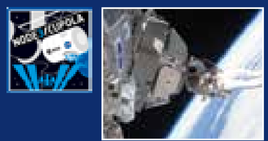


DRAGON C2+
22 May 2012
Launch vehicle: Falcon 9
Launch site: Cape Canaveral, USA

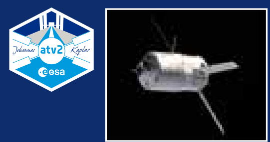
DRAGON CRS-1
8 October 2012
Launch vehicle: Falcon 9
Launch site: Cape Canaveral, USA

2010 **2011** **2012** **2013**

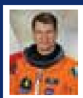
Node-3 + Cupola
8 February 2010
Launch vehicle:
Space Shuttle *Endeavour* (STS-130)
Launch site: Cape Canaveral, USA



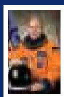
ATV-2
16 February 2011
Launch vehicle: Ariane 5ES
Launch site: Kourou, French Guiana



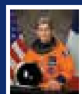
ATV-3
23 March 2012
Launch vehicle: Ariane 5ES
Launch site: Kourou, French Guiana



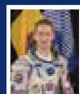
Paolo Nespoli
Launch: 23 October 2007
Launch vehicle: Space Shuttle *Discovery* (STS-120)
Mission: Esperia
Landing: 7 November 2007



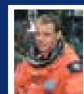
Hans Schlegel
Launch: 7 February 2008
Launch vehicle: Space Shuttle *Atlantis* (STS-122)
Mission: Columbus
Landing: 20 February 2008



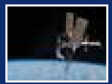
Leopold Eyharts
Launch: 7 February 2008
Launch vehicle: Space Shuttle *Atlantis* (STS-122)
Mission: Columbus
Landing: 27 March 2008

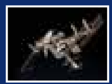


Frank de Winne
Launch: 27 May 2009
Launch vehicle: Soyuz TMA-15
Mission: OasISS
Landing: 1 December 2009



Christer Fuglesang
Launch: 29 August 2009
Launch vehicle: Space Shuttle *Discovery* (STS-128)
Mission: AlISSé
Landing: 12 September 2009



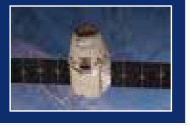


DRAGON CRS-2
1 March 2013
Launch vehicle: Falcon 9
Launch site: Cape Canaveral, USA

HTV-4
3 August 2013
Launch vehicle: H-IIB
Launch site: Tanegashima, Japan

Cygnus Orb-D1
18 September 2013
Launch vehicle: Antares 110
Launch site: Wallops Flight Facility, USA

Cygnus Orb CRS-1
9 January 2014
Launch vehicle: Antares 120
Launch site: Wallops Flight Facility, USA



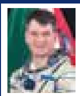
DRAGON CRS-3
18 April 2014
Launch vehicle: Falcon 9
Launch site: Cape Canaveral, USA

Cygnus Orb CRS-2
13 July 2014
Launch vehicle: Antares 120
Launch site: Wallops Flight Facility, USA

2014

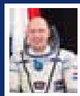
ATV-4
5 June 2013
Launch vehicle: Ariane 5ES
Launch site: Kourou, French Guiana

ATV-5
29 July 2014
Launch vehicle: Ariane 5ES
Launch site: Kourou, French Guiana

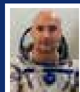


Paolo Nespoli
Launch: 15 December 2010
Launch vehicle: Soyuz TMA-20
Mission: MagISStra
Landing: 24 May 2011

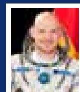
Roberto Vittori
Launch: 16 May 2011
Launch vehicle: Space Shuttle *Endeavour* (STS-134)
Mission: DAMA
Landing: 1 June 2011



André Kuipers
Launch: 21 December 2011
Launch vehicle: Soyuz TMA-03M
Mission: PromISSe
Landing: 1 July 2012



Luca Parmitano
Launch: 28 May 2013 (GMT)
Launch vehicle: Soyuz TMA-09M
Mission: Volare
Landing: 10 November 2013

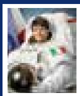


Alexander Gerst
Launch: 28 May 2014 (GMT)
Launch vehicle: Soyuz TMA-12
Mission: Blue Dot
Landing: 11 November 2014

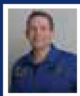
DRAGON CRS-4
21 September 2014
Launch vehicle: Falcon 9
Launch site: Cape Canaveral, USA

2015 **2016** **2017**

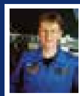
ERA
NET 2017*
Launch vehicle: Proton
Launch site: Baikonur, Kazakhstan



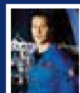
Samantha Cristoforetti
Launch: 23 November 2014
Launch vehicle: Soyuz TMA-15M
Mission: Futura
Landing: 12 May 2014



Andreas Mogensen
Launch: September 2015 (TBC)
Launch vehicle: Soyuz TMA-18M
Mission: Iriss
Landing: October 2015 (TBC)



Timothy Peake
Launch: November 2015 (TBC)
Launch vehicle: Soyuz TMA-19M
Mission: Principia
Landing: May 2016 (TBC)



Thomas Pesquet
Launch: November 2016 (TBC)
Launch vehicle: TBC
Mission: TBC
Landing: May 2017 (TBC)

European Space Agency

7.1.6 Launch and transfer vehicles

During the assembly and utilisation phases of the International Space Station programme, various types of launch and transfer vehicles have been used to deliver crew, assembly elements, experimental equipment, water, food, propellant, etc. to orbit. The following tables provide a brief description of these vehicles.

Table 7-5: ISS programme launch vehicles

VEHICLE NAME	DESCRIPTION	OWNERSHIP	LAUNCH DATE
Ariane 5 ES	Ariane 5 is Europe's main expendable launcher used for placing communications, Earth observation and scientific research satellites into geostationary transfer orbits, medium and low Earth orbits and sun-synchronous orbits. The ES ATV version was designed to place ESA's Automated Transfer Vehicle (ATV) into low Earth orbit, from where the ATV uses its own propulsion to reach and dock with the ISS (see Table 7-6). Launches take place from Kourou, French Guiana.	ESA	First ISS flight: 03/2008
Space Shuttle	The re-usable American Space Shuttle was the main launch and transportation vehicle for carrying crew, assembly elements and cargo to and from the ISS. It retired in 2011.	NASA	First ISS flight: 12/1998 Last ISS flight: 07/2011
Proton	Russian expendable launcher used to launch larger Russian elements and modules during the assembly phase of the ISS. (see Table 7-6).	Roscosmos	First ISS flight: 11/1998
Soyuz	Russian expendable launcher used to launch the manned Soyuz and unmanned Progress transfer vehicles to the ISS. (see Table 7-6).	Roscosmos	First ISS flight: 08/2000
H-II B	Japanese expendable launcher used to launch the H-II Transfer Vehicle (HTV) to the ISS (see Table 7-6).	JAXA	First ISS flight: 09/2009
Falcon 9	American launcher used to launch the commercial spacecraft Dragon to the ISS (see Table 7-6).	SpaceX	First ISS flight: 05/12
Antares	American launcher used to launch the unmanned resupply spacecraft Cygnus to the ISS. (see Table 7-6).	Orbital Sciences Corporation	First ISS flight: 09/13

Figure 7-6: ISS programme launch vehicles

Table 7-6: ISS programme transfer vehicles

VEHICLE NAME	DESCRIPTION	OWNERSHIP	LAUNCH DATE
Automated Transfer Vehicle (ATV)	European unmanned transfer vehicle that is placed in orbit by the European Ariane 5 launcher. It provides the ISS with pressurised cargo, water, air, nitrogen, oxygen and attitude control propellant. It is loaded with unwanted equipment and waste before undocking, and burns up upon re-entry into Earth's atmosphere. ATV is also used to re-boost the ISS to a higher altitude to compensate for atmospheric drag.	ESA	First ISS flight: 03/2008 Last ISS flight: 06/2014
H-II Transfer Vehicle (HTV)	Japanese unmanned transfer vehicle launched to the ISS with the H-II B launcher. Designed to deliver up to 6 tonnes of pressurised and unpressurised cargo to the ISS. Like ESA's ATV, it is loaded with unwanted equipment and waste before undocking, and burns up upon re-entry into Earth's atmosphere.	JAXA	First ISS flight: 09/2009
Progress M	Russian unmanned re-supply vehicle based on Soyuz design used to bring supplies and fuel to the ISS. Also has the ability to raise the Station's altitude and control its orientation. Before undocking it is filled up with trash, unneeded equipment, and waste water. It burns up during re-entry into Earth's atmosphere after undocking from ISS.	Roscosmos	First ISS flight: 08/2000
Soyuz TMA	Russian manned vehicle that serves as the International Space Station's crew transportation vehicle, acting as a lifeboat in the unlikely event of an emergency that would require the crew to abandon the ISS. A new Soyuz capsule is delivered to the station four times per year. A Soyuz stays at the ISS for approximately six months.	Roscosmos	First ISS flight: 10/2002
Dragon	US commercial servicing and logistic vehicle put in orbit by the Falcon 9 launcher. Dragon is designed to deliver cargo and is scheduled to be certified to transport crew members by 2017.	SpaceX	First demo flight: 12/2010 First ISS commercial flight: 05/2012

Cygnus	US commercial servicing and logistic vehicle launched by the Antares rocket. It provides the International Space Station with pressurized passive cargo and is capable of transporting active cargo with a dedicated configuration of the Pressurized Cargo Module (PCM). At the conclusion of the mission it removes waste from the station performing a destructive re-entry into Earth's atmosphere.	Orbital Sciences Corporation	First demo flight: 09/2013 First ISS commercial flight: 01/2014

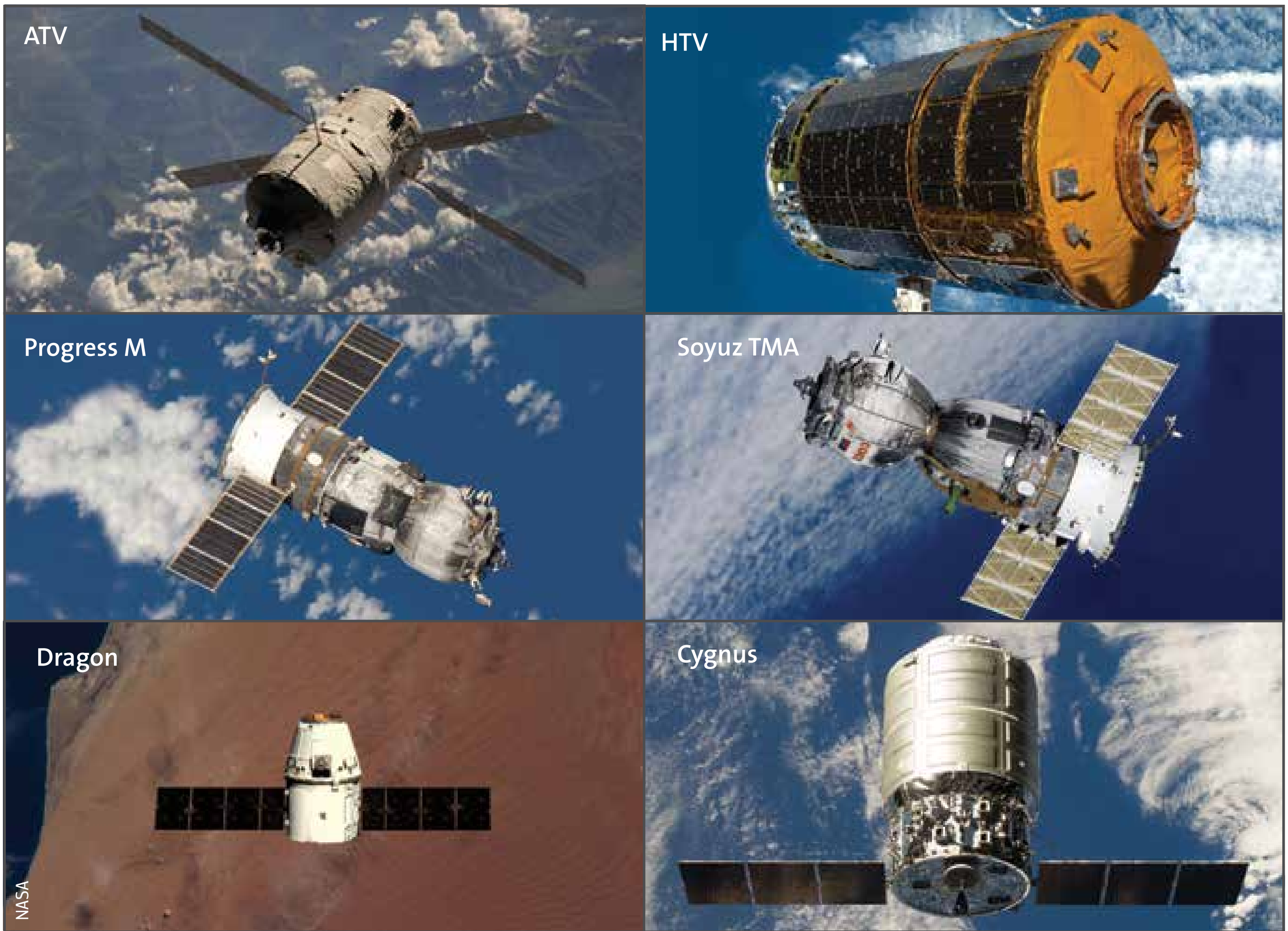


Image 7-2: ISS Logistics Vehicles

7.1.6.1 Automated Transfer Vehicle (ATV)

The Automated Transfer Vehicle (ATV) was ESA's unmanned pressurised module, which provided a contribution to the logistic servicing of the ISS. It flew five missions between 2008 and 2015.

- it re-boosted and provided support to attitude control for the ISS;
- it delivered items (dry pressurised cargo, water, gases and propellant);
- it disposed of ISS wastes, solid and liquid.

Every 12 months or so, ATV lifted about 7 tonnes of cargo from its launch site in Kourou, French Guiana (into orbit). High-precision navigation systems guided ATV on a rendezvous trajectory to the ISS where it automatically docked with the Station's Russian service module. ATV remained there as a pressurised and integral part of the Station for up to six months until its final mission: a fiery one-way trip into Earth's atmosphere to dispose of up to 6.4 tonnes of ISS waste.

Detailed cargo accommodation information can be found in ATV-HB-AI-0001 Issue 05 "ATV Cargo Accommodation Handbook", March 2004.

7.2 Operational parameters of the ISS

The International Space Station orbits at a set altitude (its height relative to Earth's sea level), at a particular inclination to Earth's equator (the path of its orbit) and at a certain attitude (the orientation of the ISS itself - its modules, solar arrays etc. - relative to the orbital path). This section discusses these three parameters along with a description of the standard and re-boost modes of operation.

7.2.1 Altitude

The altitude of the ISS is determined primarily by safety and logistics considerations. It needs to be low enough to optimise transportation flights but also needs to be kept above 278 km (the so-called Minimum Recoverable Altitude) to avoid the danger of re-entry. The ISS altitude profile is also managed to conserve propellant and minimise crew radiation exposure, and provide optimal orbital characteristics for ISS vehicle traffic (dockings/undockings). At its altitude, atmospheric drag causes it to lower by about 100 and 200 metres per day. The descent rate variation is caused by changes in the density of the outer atmosphere, a consequence of solar activity. Visiting spacecraft are used to re-boost the altitude to counteract this degradation, or sometimes to avoid space debris. The re-boosts take place at intervals between 10 and 80 days. The Russian segment of the ISS itself also has thrusters allowing it to make small changes to the altitude of the ISS.

The variation in altitude of the ISS between April 2013 and April 2014 is shown in Figure 7-7. The altitude range of the ISS over this period was higher than normal due to the enhanced re-boost capability of the ATV.

Since 'Assembly Complete', the ISS can be operated in two 'operational modes': Standard Mode and Re-boost Mode. The latter mode occurs when the altitude is being re-boosted.

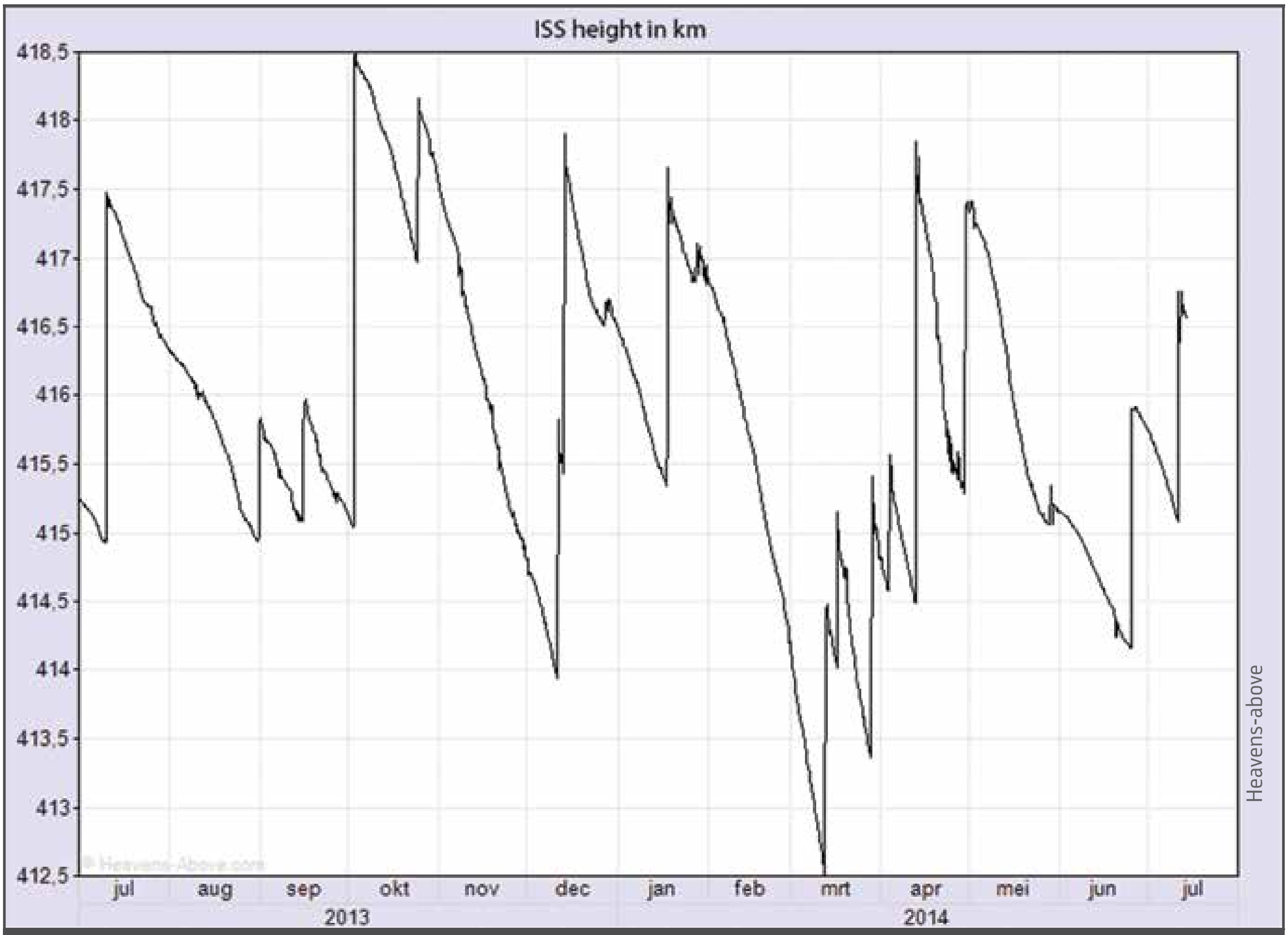


Figure 7-7: Orbital height of ISS

A third mode - Microgravity Mode - was used before ISS assembly complete, but has not been used since. Two further modes are used in emergency situations. All five are listed in Table 7.7 below but the two current operating modes are described here.

7.2.1.1 Standard Mode

Standard Mode is the primary mode of ISS operation. It provides full support for research payloads. Although Standard Mode is designed to offer a consistent scientific microgravity environment, at certain times - such as the control of the ISS attitude by propulsive means - the microgravity environment specifications are exceeded.

7.2.1.2 Re-boost Mode

Re-boost mode is necessary when the altitude of the ISS needs to be raised. The re-boost period requires one or two orbits (up to three hours) and represents an assured, but temporary, interruption in the maintenance of the Station's microgravity specification. Table 7-7 provides a brief description of the various ISS operational modes.

7.2.1.3 Example operational modes timeline

An example timeline with respect to altitude of the ISS operational modes (defined in Table 7-7), showing the modes interspersed with each other, is given in Figure 7-8 (both the timeline and altitude are not to scale).

The timeline begins with the start of an increment, i.e. the arrival of a new increment crew, which in this case was on board the Space Shuttle. The timeline shows the duration of each mode as well as the cumulative increment duration in days. As can be seen in the figure, a visiting vehicle will usually rendezvous with the ISS when its orbit is relatively low. The increment terminates with the arrival of the new increment crew. Since the six-person crew operations, two increment crews are on board the ISS, each having duration of approximately six months according to the planning time frame. Excluding increment start and end, a further two vehicles will rendezvous in the example given, at 51 days and at 160 days. Two extravehicular activity periods (EVAs) are shown in the example at 56 days and 114 days. In this example, three microgravity periods of 30 days each are foreseen.

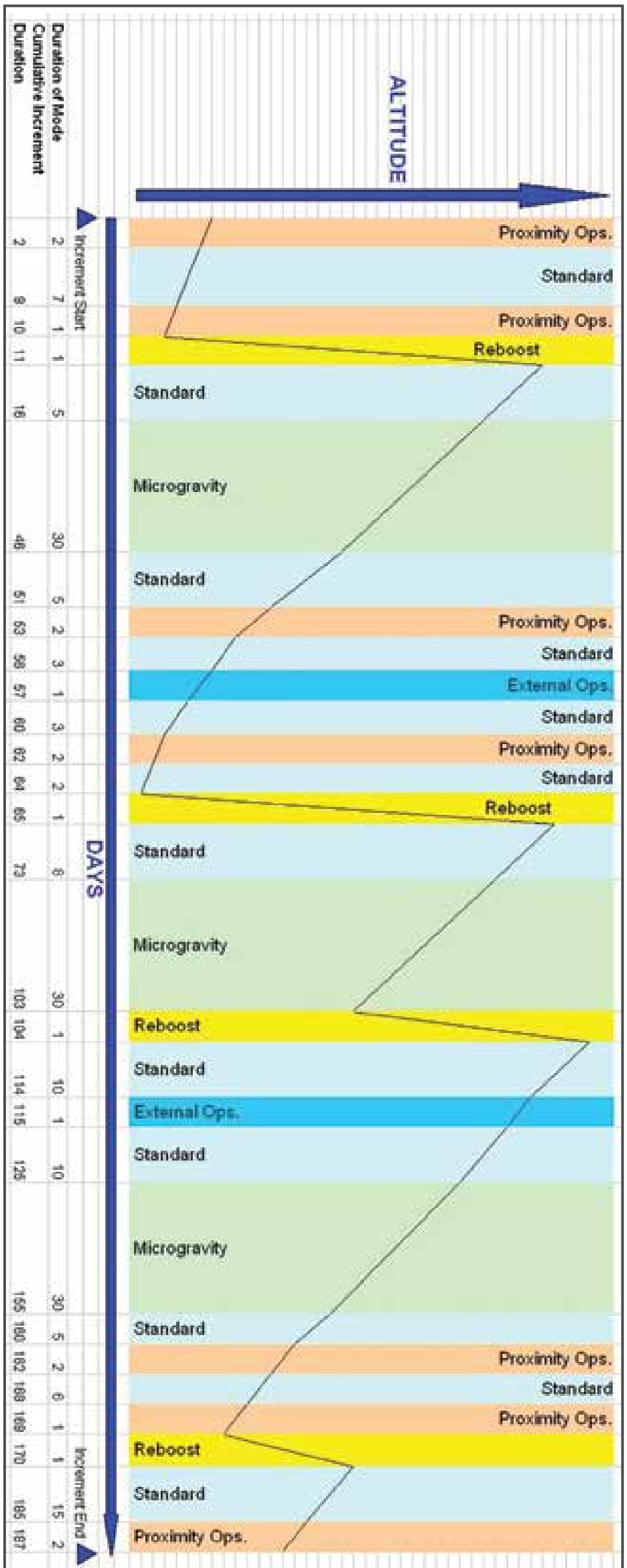


Figure 7-8: Example Operational Modes Timeline

Table 7-7: ISS Operational Modes

MODE	DESCRIPTION	COMMENTS
Standard	Represents core operations when tended or preparing to support human presence. Provides “shirt sleeve” environment. Internal and external operations supported, monitored and controlled.	Similar to the Microgravity mode, but allows a number of operational activities that could result in the microgravity specifications being violated, e.g., propulsive control of attitude. Use of control moment gyroscopes for attitude control during normal operations, minimises vibration disturbances. Nominal payload operations may be performed.
Re-boost	Used to obtain additional altitude while maintaining a habitable environment and supporting internal and external user payload operations. Altitude controlled propulsively.	Required to raise the orbit, occurring once every 10 to 80 days and having a duration of 1.5 to 3 hours (i.e., one to two orbits). Microgravity specifications will be exceeded during these periods. Payload operations not requiring stringent microgravity conditions may be performed.
Microgravity	Consists of conditions required for microgravity research by user payloads in a habitable environment or externally. Does not include effects of crew activity, but does include effects of crew equipment (e.g., exercise devices).	The ISS is operated to meet stringent Microgravity requirements (see 7.3). Schedulable Extra Vehicular Activity and Intra Vehicular Activity servicing events, re-boosts and visiting vehicles operations should occur outside of these quiescent periods. Nominal payload operations may be performed.
Survival	Initiated upon command or when a warning of imminent threat (e.g., loss of attitude control, loss of thermal conditioning, available power out-of-range) is not acknowledged by the on-orbit crew, or the ground. Autonomously attempts to correct the threatening condition and provides keep-alive utilities to Station’s crew/core systems. Precludes support or commanding of external or internal operations.	By its nature, this is an unplanned activity, and as the safety of the crew is paramount in this scenario, payload operations may be compromised. Nominal automated payload operations may be performed. Crew may not be available for interactive payload operations.
Proximity Operations	Provides capabilities related to supporting safe operations with other vehicles while maintaining a habitable environment and supporting internal and external user payload operations. Vehicle is actively determining and controlling attitude non-propulsively.	Payload operations may be compromised. Along with the re-boost mode, docking of visiting vehicles, will cause the greatest disturbance to the microgravity level. Payload operations not requiring stringent microgravity conditions may be performed.

Assured Safe Crew Return	Provides mitigation capability for life threatening illness, unrecoverable loss of Station habitability, or extended problem requiring re-supply/ servicing, which is prevented from occurring due to launch problems. Consists of actions, operations and functions necessary to safely populate a crew rescue vehicle, separate, return to earth, and egress the crew rescue vehicle upon recovery on the ground.	This is likely to be a planned mode, although the planning timescale could be quite short (i.e., days or even hours). Nominal automated payload operations may be performed, but they may be compromised.
External Operations	Utilises functionality related to supporting ISS-based external operations while maintaining a habitable environment and supporting internal and external payload operations. Vehicle actively determining and controlling its attitude non-propulsively.	Nominal payload operations may be performed, but they may be compromised.

7.2.2 Inclination

The inclination of the ISS is set at 51.63 degrees, relative to the equator. This is the lowest inclination orbit into which the Russian programme can directly launch its Soyuz and Progress spacecraft. Earth rotates west to east. Ideally spacecraft would launch due east from a launch site to maximise the cargo-to-orbit capability. Launching due east from Baikonur, would place spacecraft in a 45.6 degrees inclination orbit – the launch site's latitude. However, doing so would also drop the lower stages of the boosters on China. To avoid this, the Russian programme set the minimum inclination to 51.63 degrees. This inclination also has the added benefit to Earth science as it means that the ISS flies over 75% of the Earth's surface – about 95% of the inhabited area.

Figure 7-9: Example of ISS ground tracks (shaded area refers to night time areas)

7.2.3 Attitude

The attitude describes how the ISS is oriented in three-dimensional space. Attitude control keeps the ISS pointing in the proper direction and maintains the microgravity environment needed for scientific research.

To control the attitude, the ISS has two navigation systems working in tandem, one in the Zvezda Service module and one in the Destiny Laboratory. These systems operate simultaneously with one designated as the master system at any given time, but with both systems exchanging data continuously for fault detection and redundancy.

Maintaining the ISS attitude is mostly provided by four Control Moment Gyroscopes (CMGs). The CMGs are used more often than the rocket engines to control the ISS attitude because the gyroscopes do not require propellant, which is expensive to launch to the ISS. Instead, the CMGs use power generated by the solar panels. Similar to a toy gyroscope, each CMG contains a wheel which spins very fast. By pointing the wheels in different directions, the CMGs can either rotate the ISS, or prevent it from rotating.

When describing the position of objects on Earth, they can be defined using our fixed systems relative to our 'flat' view of Earth's sphere – latitude, longitude, and height. In space, visualising the orientation of objects is a little more complicated – this guide will first look at the coordinate systems to describe the orbital environment.

7.2.3.1 ISS coordinate systems

Coordinate systems define an 'origin' and then three axes relative to the origin – x, y and z.

One coordinate system is the ISS Body Coordinate System. This describes the position of objects within the Station – akin to a latitude and longitude system.

- the origin is the ISS centre of mass;
- the x-axis is parallel to the longitudinal axis of the US Lab "Destiny" and is positive in the direction moving away from the Russian segment;
- the y-axis is parallel to the Integrated Truss Segment (ITS) and is positive in the starboard direction;
- completing the right-handed coordinate system is the z-axis - positive in the nadir direction.

The other used coordinate system is the Local-Vertical/Local-Horizontal (LVLH) coordinate system. This is defined in terms of the ISS orbit.

- the origin is the ISS centre of mass;
- the x-axis is along the orbital path, positive in the direction of motion;
- the z-axis points radially toward the Earth's centre;
- completing the right-handed coordinate system, the y-axis is perpendicular to the orbital plane.

7.2.3.2 ISS attitude

Attitude for the ISS is described as a set of three angles between the axes of the LVLH and the Body Coordinate systems:

- angle between X-LVLH and X-body axes;
- angle between Y-LVLH and Y-body axes;
- angle between Z-LVLH and Z-body axes.

A given attitude can be achieved by rotations around one or more axes of the Body Coordinate systems. These rotations are called roll (around X), pitch (around Y) and yaw (around Z), as can be seen in Figure 7-10.

Until the primary solar arrays were in position, there were three attitude systems used on the ISS:

- X-axis in the Velocity Vector (XVV);
- Y-axis in the Velocity Vector (YVV);
- X-axis Perpendicular Out of Plane (XPOP).

Now that the primary solar arrays are in place on the ISS, the XVV attitude is nearly always used. YVV is used rarely. XPOP is no longer used and will not be described in this section.

7.2.3.3 X-axis in the Velocity Vector (XVV) attitude

X-axis in the Velocity Vector (XVV) is an 'airplane like' attitude. The ISS orbits facing forward, with Kibo and

Columbus to the front, the Russian segment facing the back and the Truss pointing out to each side. XVV is the nominal flight attitude of the station.

XVV points the X-axis of the Body Coordinate System along the direction of the X-axis of the LVLH system. The overall ISS design is optimised to fly in the XVV attitude for the following reasons:

- it provides the best microgravity conditions;
- it supports altitude re-boosts;
- it supports service vehicle docking;
- it minimises aerodynamic drag.

7.2.3.4 Y-axis in the Velocity Vector (YVV) Attitude

Y-axis in the Velocity Vector (YVV) is a rarely used flight attitude required to meet the requirements of Earth-viewing payloads. This attitude also serves to keep ISS components from violating high temperature limits while maintaining a lower drag profile.

The YVV attitude is perpendicular to the XVV attitude. YVV points the Y-axis of the Body Coordinate System along the direction of motion – i.e. the X-axis of the LVLH system.

7.2.3.5 Optimal attitude of the ISS

To optimise the thermal control, power generation and communication links, etc. the normal XVV attitude is ±15° roll (around x), ±15° yaw (around z) and +10 to -20° pitch (around y) with respect to LVLH.

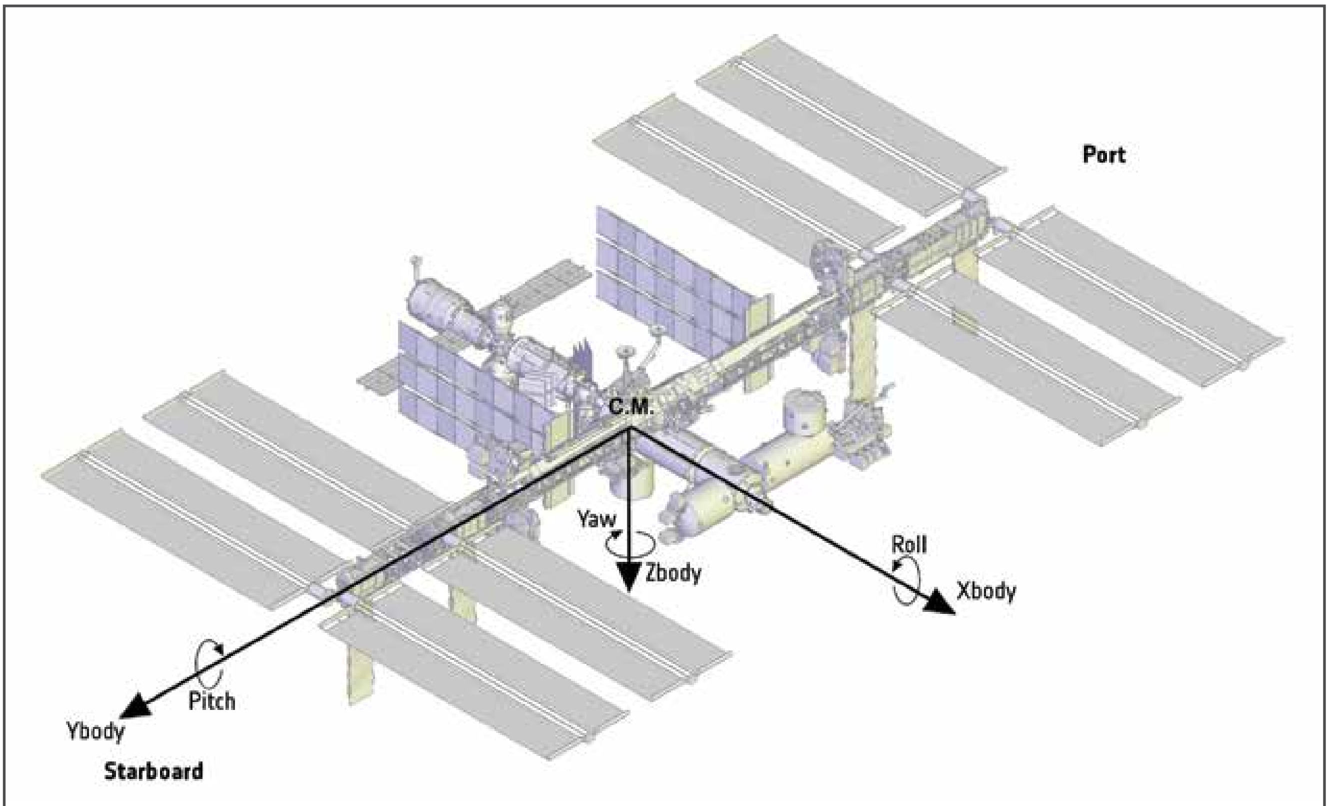


Figure 7-10: ISS Body coordinate system

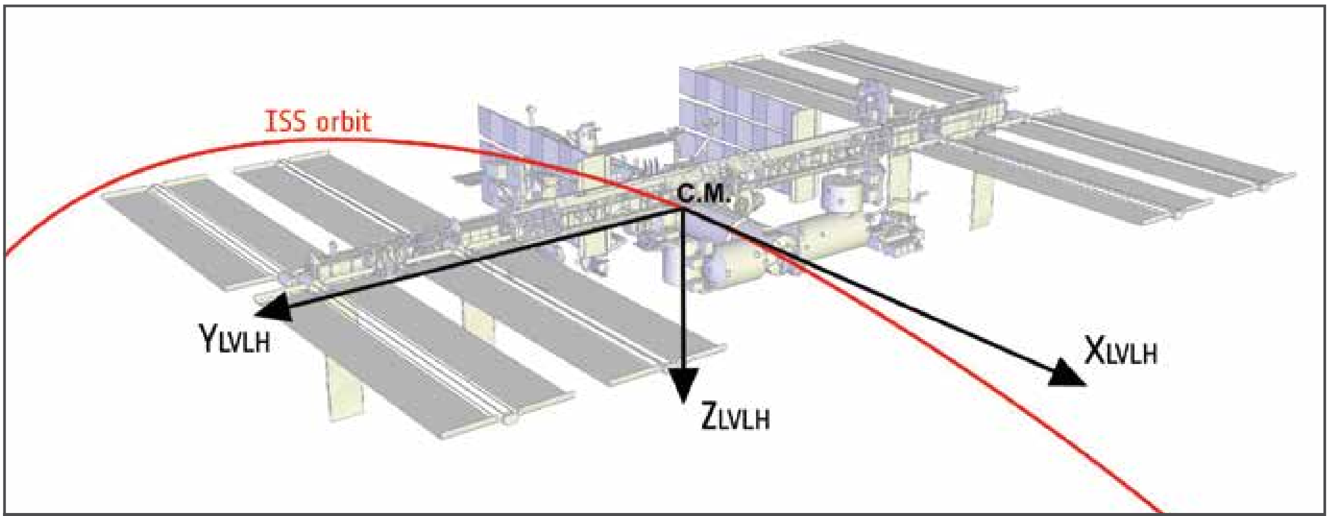


Figure 7-11: LVLH reference system

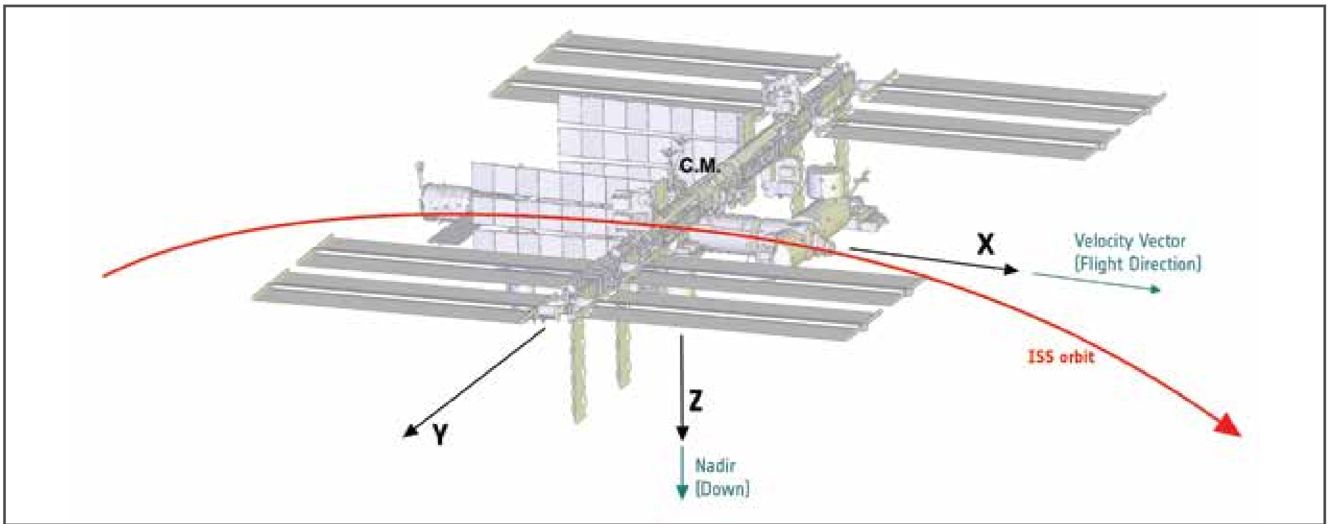


Figure 7-12: XVV attitude

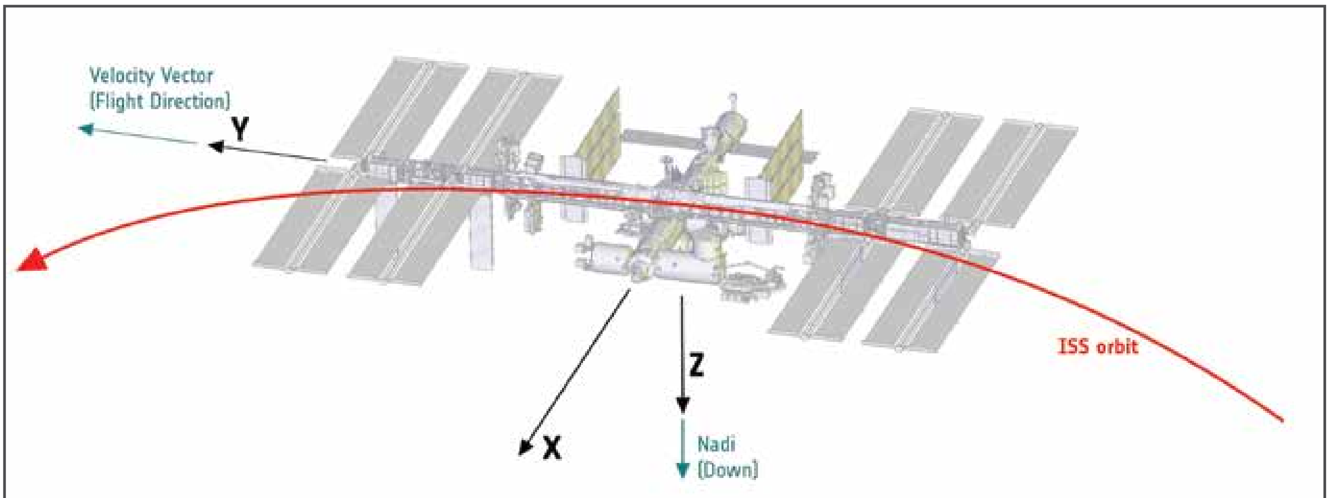


Figure 7-13: YVV attitude of the ISS

7.3 Gravity

Earth's gravitational field at the altitude of the ISS has 88.8% of its strength at the surface.

If an object is dropped on earth, it falls at 1 g towards the centre of the Earth. If an astronaut on the Space Station drops it, it also falls (at 0.88 g). It appears to float because the spacecraft falls with the same acceleration of 0.88 g. Since they are falling together, the crew and the objects appear to float when compared to the spacecraft. This is sometimes referred to as microgravity. To maintain the condition of free fall for an indefinite amount of time the spacecraft needs to be in orbit. For the ISS to stay in orbit at about 400 km of altitude the orbital speed needs to be around 28.000 km per hour.

On the ISS, microgravity measures about 1×10^{-4} g - the acceleration of objects and persons relative to their surroundings is reduced to ten thousand of the value measured on the Earth's surface (9.81 m/s^2 or 1 g). The microgravity environment experienced on the ISS and other orbiting spacecraft is actually due to three principal classes of residual accelerations:

- quasi-steady acceleration;
- vibratory acceleration;
- transient acceleration.

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

7.3.1 Quasi-steady accelerations

Quasi-steady accelerations are accelerations whose magnitude and direction vary relatively slowly, on a timescale greater than 100 seconds (i.e. with a frequency < 0.01 Hz). Accelerations are considered quasi-steady if at least 95% of their power lies below 0.01 Hz as measured over a 5400-second period (the approximate time of one orbit). Generally these accelerations have a magnitude of approximately 1 µg, when the Station is in Standard Mode (see section 7.2.1.1).

Quasi-steady accelerations are caused mainly by two factors:

- the aerodynamic drag that the ISS experiences due to the residual atmosphere at low Earth orbit. This drag causes the Station to lose altitude, and consequently to accelerate along its orbital velocity vector;
- gravity gradient effects: any point not exactly at the ISS centre of mass will tend to want to follow its own orbit. Such points, however, because they are physically part of the ISS are subject to accelerations from the structural forces that keep them attached to the Station as it orbits.

7.3.2 Vibratory accelerations

The requirements for the vibratory microgravity environment on ISS are defined in terms of a 'spectrum' of allowed root-mean-square (RMS) acceleration as a function of vibrational frequency from 0.01 Hz to 300 Hz. The total vibrational level experienced by the Station arises from the combined effects of the payload and vehicle systems. The vibratory microgravity requirements are therefore defined using an RMS acceleration vs. frequency curve for the allowed contribution to the total system vibration by the vehicle alone, with a separate curve for the allowed contribution by the entire complement of payload systems.

The vibratory acceleration environment (vehicle + payloads) applies at the structural interface between the laboratory module and the International Standard Payload Racks (ISPRs), and are defined as follows:

- for frequencies (f) $0.01 \leq f \leq 0.1$ Hz: the Root Mean Square microgravity disturbance should be less than 1.8×10^{-6} g;
- for $0.1 < f \leq 100$ Hz: the disturbance must be less than the product of [1.8 x 10-5 (g) * frequency (Hz)];
- for $100 < f \leq 300$ Hz: the disturbance should not exceed 1.8×10^{-3} g.

The above environment is represented in the graph in Figure 7-14.

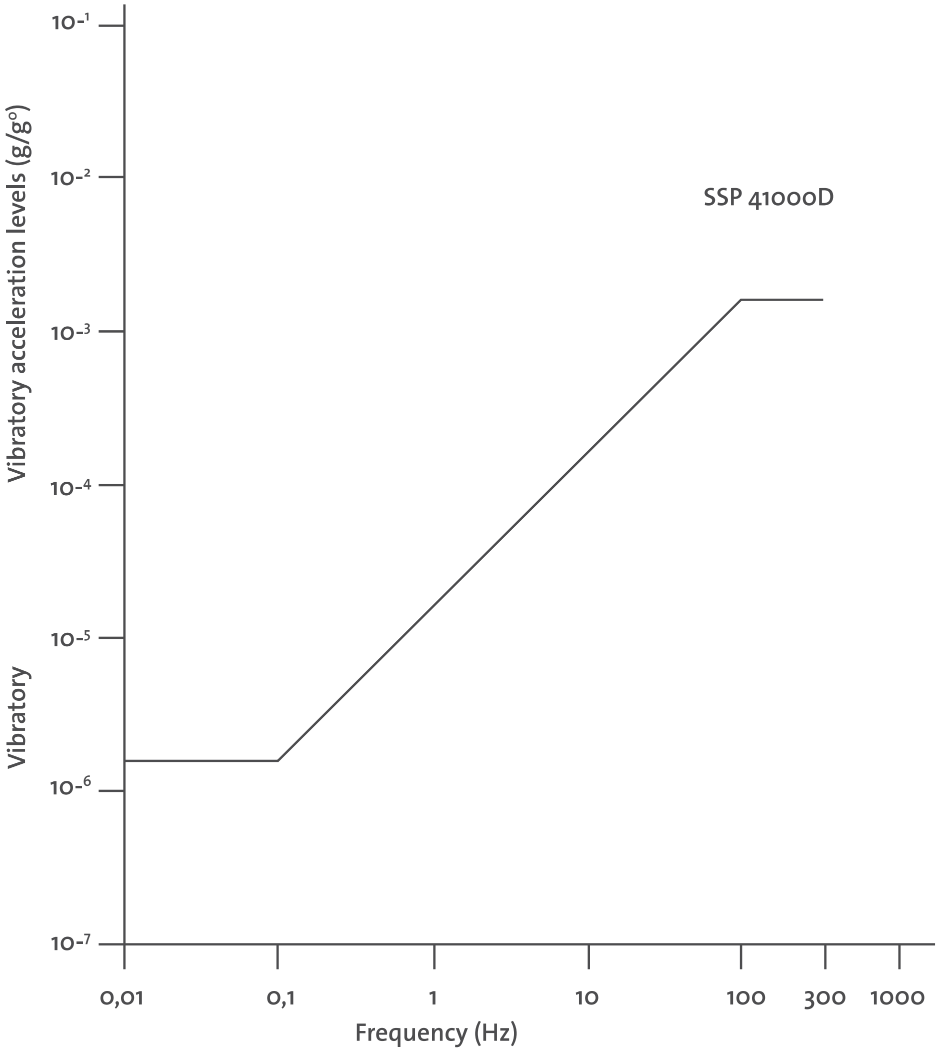


Figure 7-14: Payloads and Vehicle vibratory acceleration environment

The fact that a payload complement vibratory requirement exists should be noted by any user considering development of a payload for the ISS, because the requirement has implications for placing constraints on how much vibration an individual payload can produce.

7.3.2.1 Rack level isolation systems

7.3.2.1.1 Active Rack Isolation System

In parallel to efforts to further reduce the perturbations by timelining and reduction at the source, NASA also developed the Active Rack Isolation System (ARIS). The ARIS has been designed to attenuate vibratory disturbances at selected user payload locations in support of United States On–orbit Segment (USOS) requirements for the microgravity environment, such that the on-rack environment will meet the system vibratory specifications. The ARIS is an active electromechanical damping system attached to an International Standard Payload Rack (ISPR – see section 7.8.1) that imparts a reactive force between the payload rack and module in response to sensed vibratory accelerations, thereby reducing disturbances to user payloads within the rack.

The ARIS reports ISPR acceleration measurements to a payload controller for evaluation of ISS microgravity performance, analysis of microgravity effects on payloads, and analysis of disturbance–related anomalies. The ARIS is designed for compatibility with the EXPRESS (EXpedite the PRocessing of Experiments to Space Station) and non–EXPRESS payload racks.

More information regarding the ARIS can be found in the document SSP 57006 Rev. B, "Active Rack Isolation System (ARIS) User's Handbook", 2009.

7.3.2.1.2 Passive Rack Isolation System (PaRIS)

The PaRIS is a passive rack vibration isolation system intended for use in the United States Destiny laboratory, with some capability within the JAXA 'Kibo' module and in the Columbus Lab. By suspending the integrated payload rack from the ISS module structure using passive dampers, it will attenuate vibratory accelerations above 1 Hz to the user payloads.

The combination of integrated rack and PaRIS provides vibration isolation in both dynamic load path directions (i.e., attenuating vibrations imposed on the rack by the ISS vehicle as well as attenuating vibrations induced on the ISS vehicle by the rack) without consuming any ISS power, thermal, or data/command system resources.

For more information users can consult the following document: SSP 57058 "Passive Rack Isolation System (PaRIS) to International Standard Payload Rack (ISPR) Interface Control Document (ICD)", 2009.

7.3.2.2 Sub-rack level isolation systems

7.3.2.2.1 Microgravity Isolation Mount (MIM)

This facility was developed by the CSA to help isolate experiments from the g-jitter present on all spacecraft. The MIM provides a significant improvement in the acceleration environment for critical experiments that are extremely sensitive to vibrations. The MIM is also capable of imparting vibrations of known frequency and amplitude to an attached experiment.

The MIM consists of a magnetically levitating plate called the Flotor upon which small experiments can be mounted. Sensors inside the MIM detect incoming vibrations and then cancel them out with equal and opposite vibrations to the Flotor. Vibration levels on the Flotor are attenuated by a factor of 10 or more. The MIM can also create known vibrations of up to 100 Hz for experiments mounted to the Flotor. This is most useful for studying the free-surface response of fluids to a known input. Fluids are extremely sensitive to vibrations at or near their natural frequency and typically respond by visible agitation.

An isolation system derived from the MIM technology, known as the Microgravity Vibration Isolation Subsystem (MVIS) has been developed by the CSA for ESA's Fluid Science Laboratory (FSL), in exchange for 5 % of the utilisation rights of the FSL. Its purpose is to isolate an Experiment Container together with the optical bench in which it is accommodated from the support systems of the laboratory. This approach has the advantage of necessitating minimum mass, volume and power for the isolation system. MVIS is the third generation of the MIM technology.

7.3.3 Transient accelerations

The Standard Mode (see 7.2.1.1) of operation, the generally operated mode on ISS since 'Assembly Complete', does not include the effects of crew activity, but does include the effects of transient accelerations caused by crew equipment, such as the operation of exercise devices and latched or hinged enclosures.

Crew are instructed to mitigate their effects on experiments by limiting sudden movements. At the structural mounting interfaces to the internal payload locations the transient accelerations limits are:

- a transient acceleration limit for individual transient disturbance sources less than or equal to 1000 micro–g per axis;
- an integrated transient acceleration limit for individual transient disturbance sources less than or equal to 10 micro–g seconds per axis over any 10 second interval.

Table 7-8: Principal Investigator Microgravity Services (PIMS) acceleration data analysis techniques

DISPLAY FORMAT	REGIME (S)	NOTES
Acceleration vs. Time	Quasi-steady, Vibratory	Precise accounting of measured data w.r.t. time. Best temporal resolution.
Interval Min/Max Acceleration vs. Time	Quasi-steady, Vibratory	Displays upper and lower bounds of peak-to-peak excursions of measured data. Good display approximation for time histories on output devices with resolution insufficient to display all data in time frame of interest.
Interval Average Acceleration vs. Time	Quasi-steady, Vibratory	Provides a measure of net acceleration of duration greater than or equal to interval parameter.
Interval Root Mean Square (RMS) Acceleration vs. Time	Vibratory	Provides a measure of peak amplitude.
Trimmed Mean Filtered Acceleration vs. Time	Quasi-steady	Removes infrequent, large amplitude outlier data.
Quasi-Steady Mapped Acceleration vs. Time	Quasi-steady	Uses rigid body assumption & vehicle rates and angles to compute acceleration at any point in the vehicle.
Acceleration vs. Time	Quasi-steady, Vibratory	Precise accounting of measured data w.r.t. time. Best temporal resolution.
Interval Min/Max Acceleration vs. Time	Quasi-steady, Vibratory	Displays upper and lower bounds of peak-to-peak excursions of measured data. Good display approximation for time histories on output devices with resolution insufficient to display all data in time frame of interest.
Interval Average Acceleration vs. Time	Quasi-steady, Vibratory	Provides a measure of net acceleration of duration greater than or equal to interval parameter.
Interval Root Mean Square (RMS) Acceleration vs. Time	Vibratory	Provides a measure of peak amplitude.
Trimmed Mean Filtered Acceleration vs. Time	Quasi-steady	Removes infrequent, large amplitude outlier data.
Quasi-Steady Mapped Acceleration vs. Time	Quasi-steady	Uses rigid body assumption & vehicle rates and angles to compute acceleration at any point in the vehicle.
Quasi-Steady 3D Histogram (QTH)	Quasi-steady	Summarises acceleration magnitude and direction for a long period of time. Indication of acceleration "centre-of-time" via projections onto three orthogonal planes.
Power Spectral Density (PSD) vs. Frequency	Vibratory	Displays distribution of power w.r.t. frequency.
Spectrogram (PSD vs. Frequency vs. Time)	Vibratory	Displays power spectral density variations with time Identifies structure & boundaries in time and frequency.
Cumulative RMS Acceleration vs. Frequency	Vibratory	Quantifies RMS contribution at and below a given frequency. Quantitatively highlights key spectral contributors.

Frequency Band(s) RMS Acceleration vs. Time	Vibratory	Quantifies RMS contribution over selected frequency band(s) as a function of time.
RMS Acceleration vs. One-Third Frequency Bands	Vibratory	Quantifies RMS contribution over proportional frequency bands. Compares measured data to ISS vibratory
Principal Component Spectral Analysis (PCSA)	Vibratory	Summarises magnitude and frequency excursions for key spectral contributors over a long period of time. Results typically have finer frequency resolution and high PSD magnitude resolution relative to a spectrogram at the expense of poor temporal resolution.

7.3.4 Measuring the ISS microgravity environment

As discussed previously, the ISS microgravity acceleration environment consists of two regimes: the quasi-steady environment and the vibratory environment. Currently, the measurement of the microgravity acceleration environment is accomplished by two NASA accelerometer systems, through its Principal Investigator Microgravity Services (PIMS) project at the Glenn Research Center. These two systems on board the ISS are:

- the Space Acceleration Measurement System-II (SAMS-II): The vibratory environment covering the frequency range 0.01 – 400 Hz, is measured by the SAMS-II. Due to the localised nature of these vibrations, this frequency range requires measurement of the environment near the experiment hardware of interest. SAMS-II provides this distributed measurement system through the use of Remote Triaxial Sensor systems;
- the Microgravity Acceleration Measurement System (MAMS): The MAMS will record the quasi-steady microgravity environment ($f < 0.01$ Hz), including the influences of aerodynamic drag, vehicle rotation, and venting effects.

The data obtained from the above systems is managed, processed and archived by the PIMS, allowing researchers and payload developers information about:

1. the current locations of accelerometers – Figure 7-15 shows an example;
2. real time plots – users can receive information about real-time plots of data coming from the accelerometers. The various display formats and data analysis techniques are summarised in Table 7-8;
3. request archived data – users can request archived data.

From the above data, a general characterisation of the ISS microgravity environment can be obtained that affords scientists and hardware developers the pre-flight ability to anticipate the acceleration environment available for experimentation.

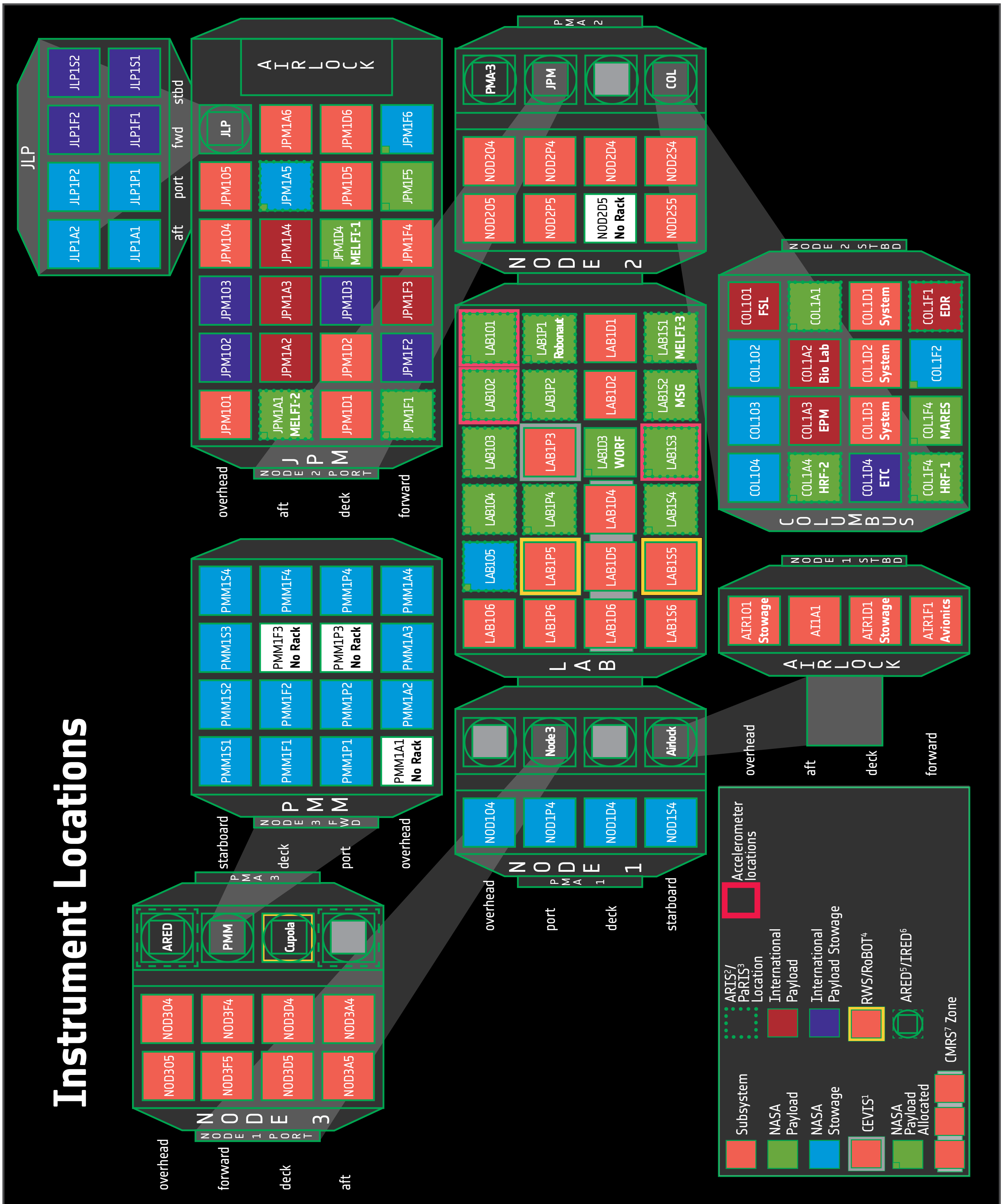


Figure 7-15: Instrument and accelerometer locations (configuration as of May 2014)

1. Cycle Ergometer with Vibration Isolation and Stabilization System (CEVIS)
2. Active Rack Isolation System (ARIS)
3. Passive Rack Isolation System (PaRIS)
4. Robotic Work Station (RWS)/RoBOT
5. Advanced Resistive Exercise Device (ARED)
6. Interim Resistive Exercise Device (IRED)
7. Crew Medical Restraint System (CMRS) Zone

7.4 Internal environment

7.4.1 Cabin atmosphere

The characteristics of the ISS cabin atmosphere are summarised in Table 7-9.

Table 7-9: Characteristics of internal cabin atmosphere

PARAMETER	OPERATIONAL VALUE
Normal Total Cabin Pressure Range	97.9 – 102.7 kPa
Contingency Total Cabin Pressure Range	95.8 – 104.8 kPa
Normal Composition of Atmosphere	21 % Oxygen; 78 % Nitrogen
Maximum Allowable % Oxygen in Atmosphere	24.1 %
Maximum N_2 Partial Pressure	80 kPa
O_2 Partial Pressure Range	19.5 – 23.1 kPa
CO_2 Levels	The medical operations requirement, and the ISS specification, for CO_2 level is a 24-hour average of 0.7 % or less, although a 24-hour average exposure as high as 1 % is allowable during crew exchanges. The ISS programme has agreed to maintain the cabin CO_2 level to 0.37 % (with the goal of reaching 0.3 %) for two 90-day periods each year. Modelling has shown that with two U.S.- and one Russian-segment CO_2 scrubbers a level closer to 0.2 % can be expected.
Average CO_2 Partial Pressure during normal operations	0.71 kPa
Air Temperature	17 – 28 °C
Dew Point	4.4 – 15.6 °C
Relative humidity	25 – 75 %
Ventilation velocity	0.076 – 0.203 m/s
Airborne microbial growth	≤ 1000 Colony Forming Units (CFU)/m^3
Atmosphere Particulate level	Class 100 000 (i.e. less than 100 000 particles/ft^3, for particles less than 0.5 microns in size).

Values are US Fed standard clean room data values.

Table 7-10: Payload required illumination levels

TYPE OF TASK	REQUIRED LUX (FOOT-CANDLES)*
Medium payload operations (not performed in the aisle) (e.g., payload change-out and maintenance)	325 (30)
Fine payload operations (e.g., instrument repair)	1075 (100)
Medium glovebox operations (e.g., general operations, experiment set-up)	975 (90)
Fine glovebox operations (e.g., detailed operations, protein crystal growth, surgery/dissection, spot illumination)	1450 (135)

* As measured at the task site

7.4.2 Illumination

The internal lighting of the ISS consists of:

- general illumination: produced by a number of Module Lighting Units distributed throughout the station, which may be controlled either remotely or locally (i.e., a manually-operated switch on each unit). The general illumination of the Space Station in the aisle will be a minimum of 108 lux (10–foot candles) of white light. This illumination will be sufficient for ordinary payload operations performed in the aisle (e.g., examining dials or panels, reading procedures, transcription, tabulation, etc.);
- portable lighting: a number of portable lighting units are available for temporary crew use (e.g., to increase the local illumination in particularly inaccessible areas);
- emergency lighting: an emergency lighting system is common throughout all pressurised modules of the ISS.

Additional illumination for payload tasks must be taken into account following the set of requirements listed in Table 7-10.

7.4.3 Interior colour

A common interior colour scheme is used throughout all pressurised modules (excluding those in the Russian segment) to ensure a consistent environment for the crew. Depending on the type of hardware, the principal surface colours and finishes adopted are:

Table 7-11: Interior hardware colours and finishes

COLOURS	FINISHES
White	Lustreless
Black	Semi gloss
Off-white	Gloss
Nickel plate	
Medium grey	
Tan	

Label colours include red (emergency use items only), yellow (Caution & Warning items only), green, blue and orange. No more than nine colours, including black and white, should be used in a coding system.

7.4.4 Internal contamination

The control of contamination within the pressurised modules is crucial to maintain an efficient working environment for the crew, equipment and user payloads. Contamination can affect the health of the crew, reduce the operational lifetime of equipment, and increase required maintenance activities. Typical sources of contamination are the crew, equipment, materials, experiment processes – all of which combine to produce trace gases, carbon dioxide, particulates and microbial contaminants. The microbial growth and particulate level within the living and working environment of the ISS will be monitored and controlled according to the limits specified in Table 7-9.

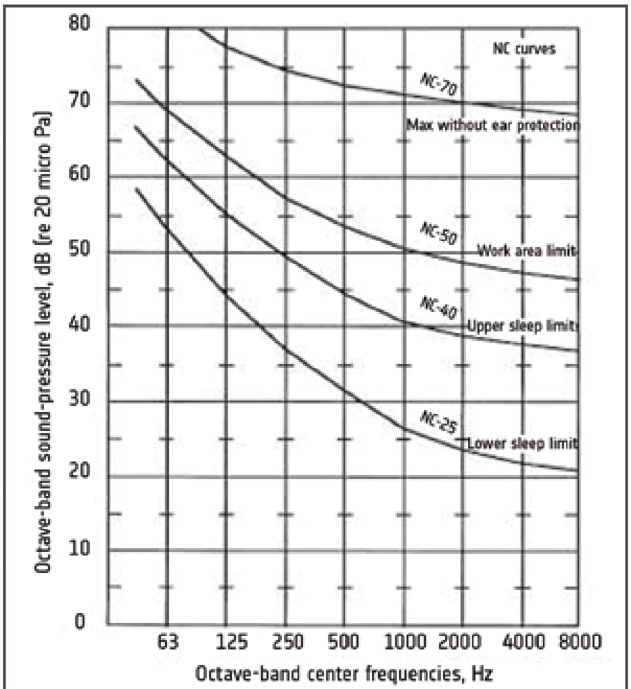


Figure 7-16: ISS Interior Noise criteria curves

7.4.5 Noise

The ISS interior is subject to various noise levels caused by pumps, fans and other operating systems and subsystems. Stringent limits have been set regarding noise in the interior of the ISS. The maximum allowable continuous broadband sound pressure levels (SPLs) produced by the summation of all the individual SPLs from all operating systems and subsystems considered at a given time shall not exceed the values shown in Figure 7-16 for work periods and sleep compartments, respectively. Noise of constant sound levels of 85.0 dB and greater are considered hazardous regardless of the duration of exposure. Hearing protection devices are provided for crew to use during exposure to noise levels of 85.0 dBa or greater. Hearing protection devices are provided for crew to use during exposure to noise levels below 85.0 dBA in case of prolonged exposure.

7.4.6 Touch temperatures

In order to avoid endangering the crew or damaging sensitive equipment, exposed surfaces within the habitable areas of the ISS are subject to requirements regarding minimum and maximum temperatures:

- surfaces that are subject to continuous contact with a crewmember's bare skin and whose temperature exceeds 45 °C, are required to be provided with guards or insulation to prevent crewmember contact;
- surfaces which are subject to incidental or momentary contact (30 seconds or less), with a crewmember's bare skin and whose temperatures are between 45 and 50 °C, are required to have warning labels that will alert crewmembers of the temperature levels;
- surfaces that are subject to incidental or momentary contact (30 seconds or less), with a crewmember's bare skin and whose temperatures exceed 50 °C, are required to have guards or insulation;
- surfaces which are subject to continuous or incidental contact with a crewmember's bare skin and whose temperatures are below 4 °C, must provide crew with protective equipment and warning labels must be provided at the surface site.

7.5 External environment

Users should be aware of the ISS external environment for two reasons:

- it may affect the design and operations of external payloads; and
- it may be the object of investigation for external experiments.

The ISS external environment consists of:

- The Induced External Environment – this is the space environment that exists as a consequence of the presence of the ISS and its related operations;
- The Natural External Environment – this is the space environment that exists even if the ISS were not in orbit. This includes neutral atmosphere, plasma, charged particle radiation, electromagnetic radiation, meteoroids, space debris, magnetic field, and gravitational field.

7.5.1 Induced external environment

7.5.1.1 Quiescent periods

The ISS programme specifications impose three restraints regarding the induced external environment during quiescent periods, i.e. Standard or Microgravity modes.

- molecular column density;
- particulate background;
- molecular deposition.

7.5.1.1.1 Molecular column density during quiescent periods

The contribution to the molecular column density created by the presence of the ISS contamination sources along any unobstructed line of sight will not exceed $1x10^{14}$ molecules/cm^2 for individual released species. This includes contributions from outgassing, venting, leakage and other ISS contamination sources. It does not include ram–wake effects.

7.5.1.1.2 Particulate background during quiescent periods

The release of particulates from the ISS is limited to one particle, 100 microns or larger, per orbit per $1x10^{-5}$ steradian field of view as seen by a 1 metre diameter aperture telescope. This includes contributions of particulates originating from external ISS surfaces, compartments vented to space, movable joints, vents (of solids, liquids and gases) and other ISS particulate sources but excludes particulates in the natural environment and their effect on ISS hardware (e.g., their impact on ISS surfaces).

Attached payloads must limit any active venting release of particulates to less than 100 microns in size.

7.5.1.1.3 Molecular deposition during quiescent periods

The flux of molecules emanating from the ISS is limited such that the 300 K mass deposition rate on sampling surfaces is limited to $1x10^{-14}$ g/cm^2/s (daily average). The sampling surfaces are typically located at the solar arrays, thermal radiators, observation windows, truss attached payloads, and the JEM Exposed Facility. Contamination requirements directed specifically at effects on attached payloads and the ISS vehicle by other attached payloads specify that an attached payload shall not deposit material at a rate greater than $1x10^{-14}$ g/cm^2/s on other attached payloads and $1x10^{-15}$ g/cm^2/s on ISS vehicle elements.

7.5.1.2 Non-quiescent periods

The ISS programme specifications imposes one restraint - on molecular deposition - regarding the induced external environment during non-quiescent periods, i.e. other than Standard or Microgravity modes.

7.5.1.2.1 Molecular deposition during non-quiescent periods

Total deposition at 300K on the sampling surfaces will not exceed $3.16x10^{-14}$ g/cm^2/s

7.5.2 Natural external environment

7.5.2.1 Pressure

A natural high-quality vacuum exists outside of the ISS, providing numerous experimental possibilities for a number of research fields. The ISS external on-orbit average pressure environment is about $1.3x10^{-8}$ mbar (as indicated by standard models such as the MSISE-90/00).

ESA experiment MEDET monitored the pressure environment from February 2008 to September 2009,

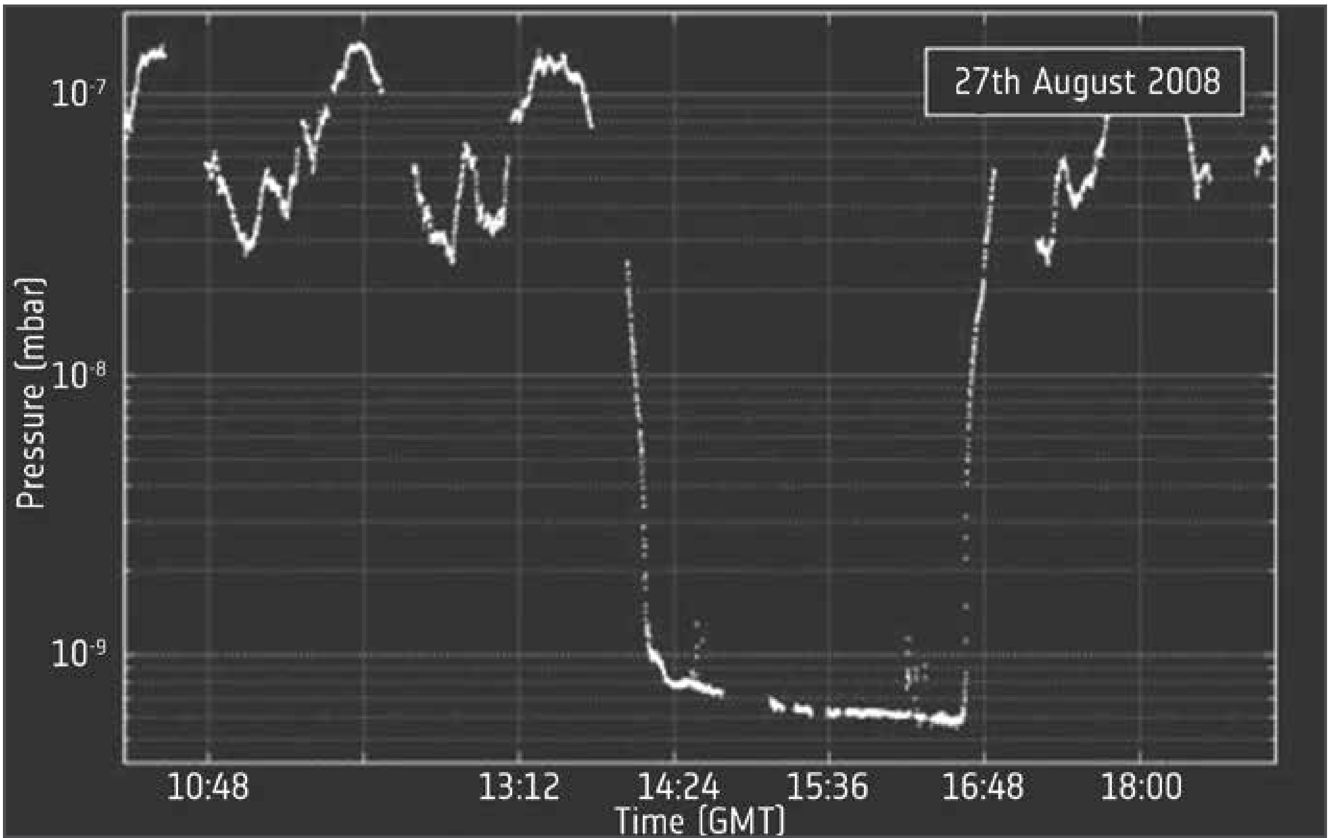


Figure 7-17: Ram-wake effect due to reorientation of the Station

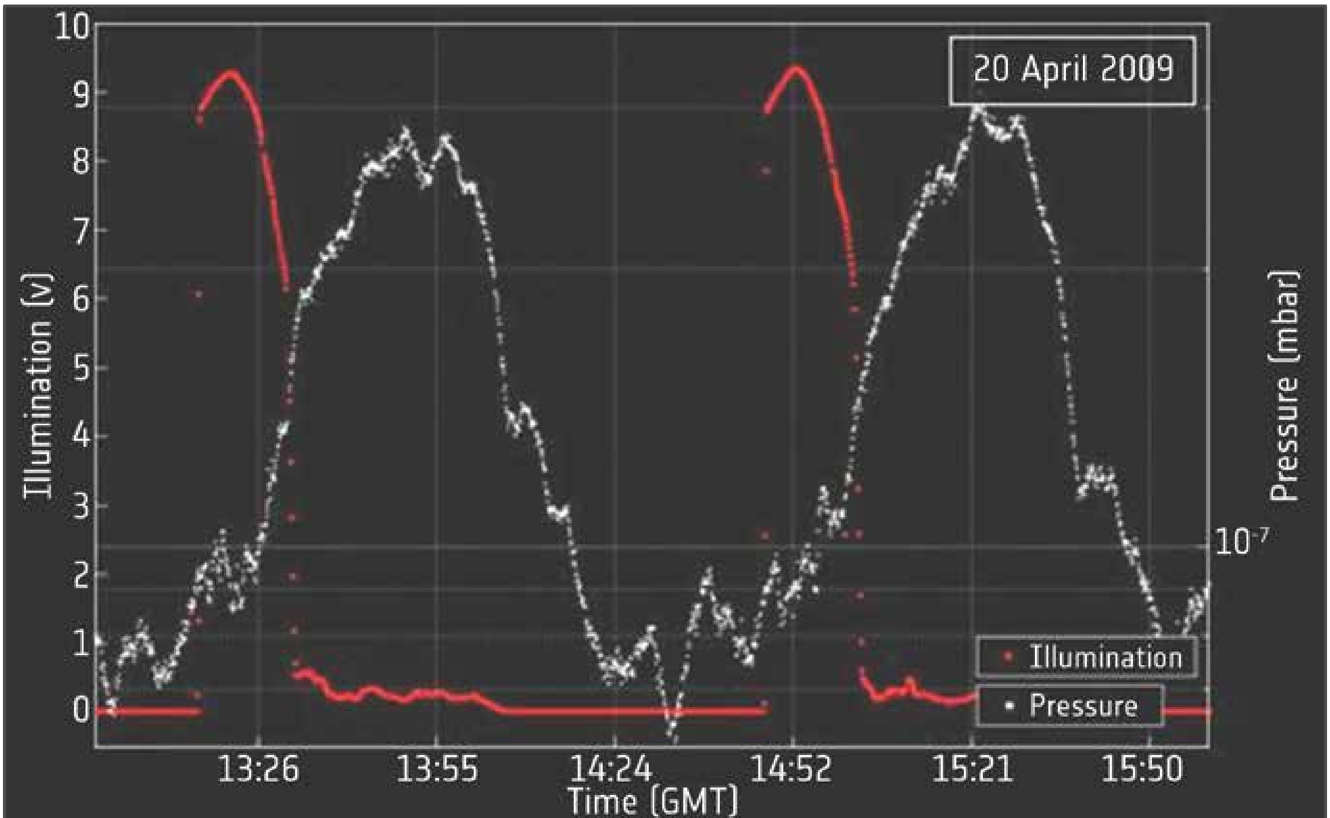


Figure 7-18: Illumination-pressure variations correlation

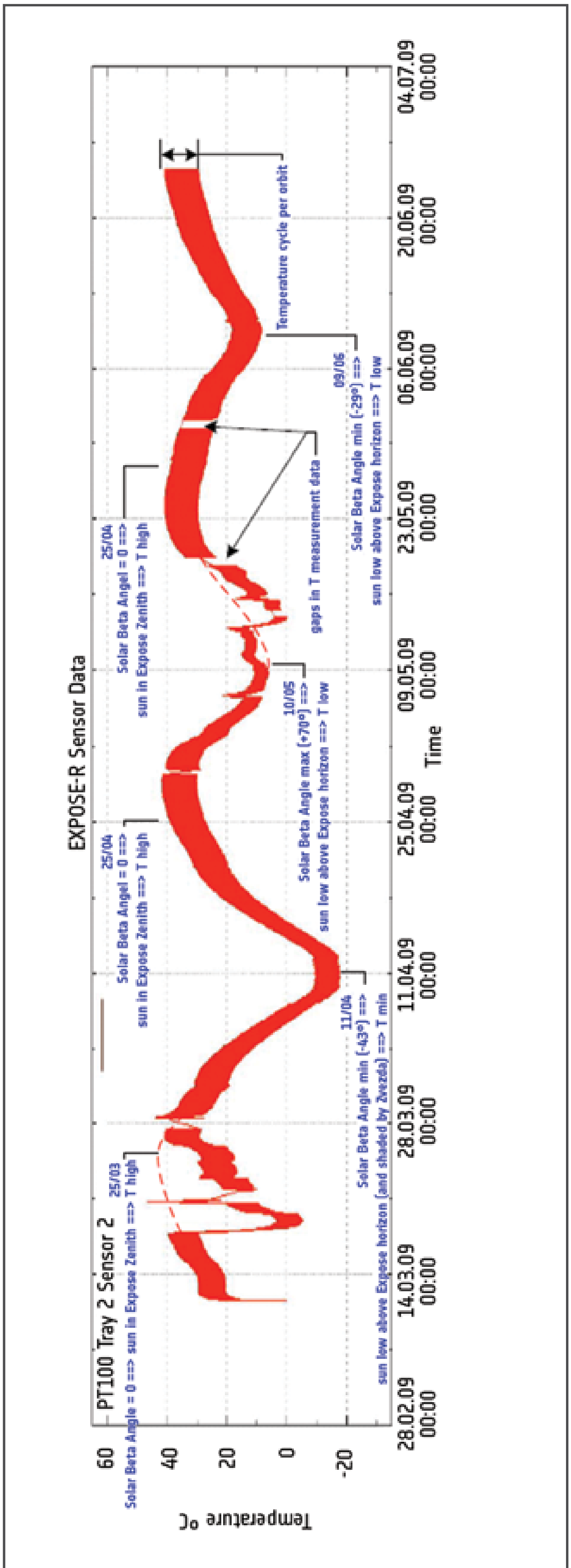


Figure 7-19: EXPOSE-R temperature profile

using an external pressure gauge mounted on an exposed platform of Columbus.

For the majority of the time, the pressure gauge was in the nominal ram direction, and it can be seen that the average pressure was around 5x10^{-6} to 1x10^{-7} mbar. This is at least an order of magnitude greater than the predicted standard models, explained by the ram pressure effect, as confirmed by Figure 7-17: the ram-wake effect is clear to see due to reorientation of the ISS by 180 degrees, during an ATV debris avoidance manoeuvre on 27 August 2008.

The wake pressure is some two to three orders of magnitude less than the ram. The flat portion at the bottom of the graphs is due to the detection limit of the gauge.

Other significant features include a diurnal variation in the pressure, thought to be related to solar heating effects, as seen in Figure 7-18. In particular, by superimposing data from one of the MEDET Illumination Sensors on the pressure data, the diurnal pressure variation can be correlated with the solar illumination.

7.5.2.2 Thermal environment

ISS external elements and payloads will be exposed to:

- thermal solar constants, albedo, and Earth Outgoing Long-wave Radiation (OLR) environments as defined in Table 7-12;
- a space sink temperature of 3 K;
- the induced thruster plume environment and induced thermal environments from vehicle(s) docking and docked with the ISS, vehicle(s) undocking from the ISS, and from the ISS itself;
- thermal interactions with other on-orbit segments.

Table 7-12: Hot and Cold natural thermal environments

CASE	SOLAR CONSTANT (W/M^2)	EARTH ALBEDO	EARTH OLR (W/M^2)
Cold	1321	0.2	206
Hot	1423	0.4	286

The thermal environment results in maximum and minimum external surface temperatures of ~+120 °C and –120 °C, respectively.

As an example, an extract of the temperature profile of the ESA exposed facility EXPOSE-R (mounted on the Russian segment for 22 months until January 2011) is shown in Figure 7-19. The red band is formed by the quick orbit temperature cycles, therefore showing the max and min temperatures for each orbit. It is clear how the Solar Beta Angle plays a focal role in determining the payload temperature. It must be stressed that the sample case presented here is to be taken purely as a reference, since data collected on different payloads with different exposure, operating modes, and thermal capacity may have completely different results.

7.5.2.3 Humidity

ISS external elements and payloads will be exposed to an external environment of 0% relative humidity during on–orbit operations.

7.5.2.4 Atomic oxygen

At Low Earth Orbit altitude, the ISS encounters the Earth's low-density residual atmosphere, which at this altitude is primarily composed of oxygen in an atomic state (molecular bonds being broken by the solar ultraviolet rays). Although the particle density is low, the flux (i.e., combined product of density, relative velocity and surface area) is high. The incidence of this neutral oxygen flux can result in significant erosion of certain surfaces depending on their nature. External surfaces may be exposed to fluxes of up to 4.4×10^{19} atoms/cm^2/day.

7.5.2.5 Electromagnetic radiation

Important sources of electromagnetic noise exist over the entire frequency spectrum from direct current (dc) to X–ray at the ISS orbit altitudes. These noise sources broadly separate into four categories:

- galactic;
- solar;
- near–Earth natural plasma;
- man–made radio noise.

The highest power densities expected to be irradiating the ISS are from the solar radiation in the ultraviolet and visible portions of the electromagnetic spectrum. The ultraviolet radiation can damage materials exposed to it. Other effects of electromagnetic radiation to be considered include radio noise and the effects of field strengths from the natural sources at the ISS. Field strengths produced from quasi–static field structures in the plasma have typical values around 25 mV/m, but can be larger. These values generally occur at latitudes greater than 50°.

7.5.2.6 Plasma

Plasma is a quasi–neutral gas consisting of neutral and charged particles that exhibit collective behaviour. From approximately 80 km altitude to about 1000 km altitude, a plasma environment surrounding Earth is designated as the ionosphere. A plasma environment extends further from Earth into a region designated as the magnetosphere and still further into the solar wind. A primary interaction of plasma with a spacecraft is the accumulation of an electrical charge by the spacecraft until electrical equilibrium is reached between the spacecraft and the local plasma environment. Because electrons have greater thermal velocities than do ions at similar temperatures, a spacecraft tends to reach equilibrium potential at a few volts negative with respect to the plasma at ISS altitudes. However, active components and their associated structure (such as solar arrays) may accumulate sufficient negative potential to produce arcing to other elements of the spacecraft.

7.5.2.7 Ionising radiation

The ionising radiation environment results from the natural radiation in LEO due to trapped electrons, trapped protons, and solar, anomalous, and galactic cosmic rays. The contribution of other LEO environmental constituents such as neutrons and x–rays are negligible and are not considered by the ISS Programme. The ionising radiation environment interacts with devices and materials to produce radiation dose effects and single event effects (SEE).

From February 2008 to September 2009, relevant data were collected by ESA using a spectrometer-dosimeter in experiment R3DE (Radiation Risks Radiometer-Dosimeter R3D) for EXPOSE-E facility on European Technological Exposure Facility (EuTEF) outside of European Columbus module. Typically these data

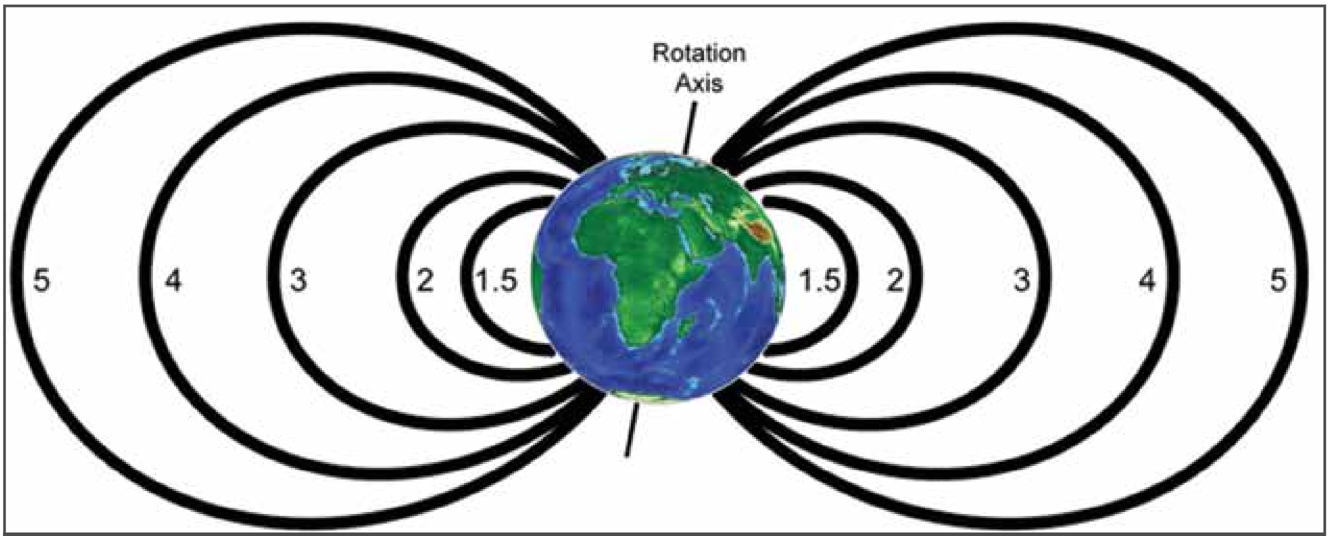


Figure 7-20: Plot showing field lines for L-values 1.5, 2, 3, 4 and 5

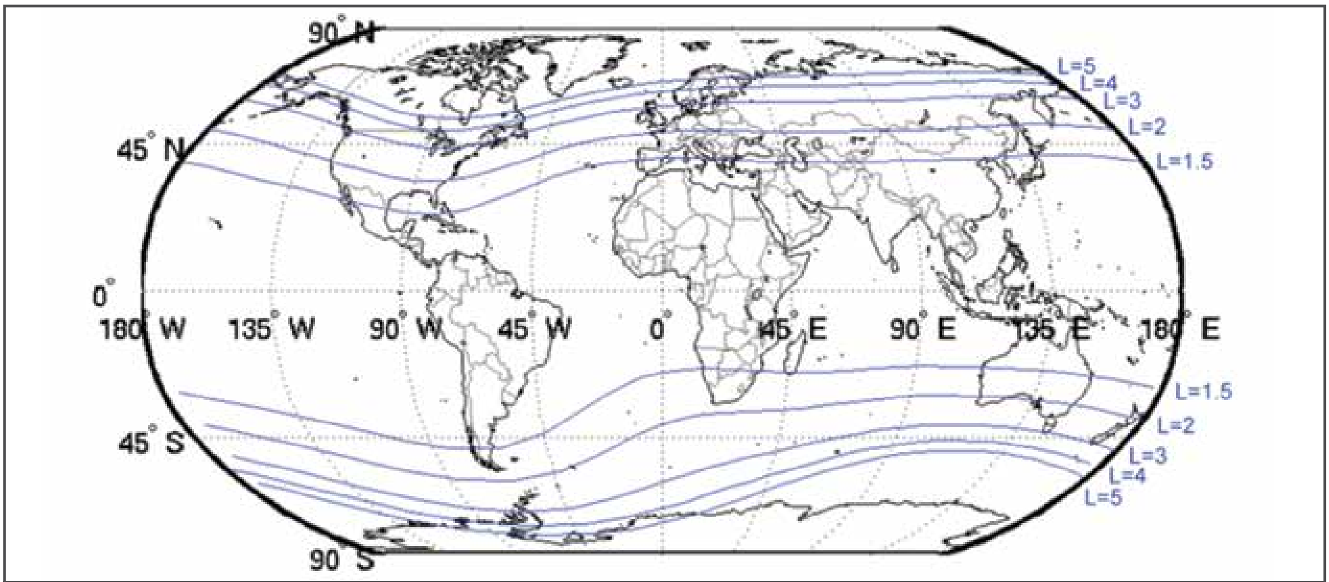


Figure 7-21: Map of L-value field line locations on the surface of the Earth

are presented showing the latitudinal distribution against L-values (see Figure 7-20). L-values describe the set of magnetic field lines which cross the Earth's magnetic equator at a number of Earth-radii equal to the L-value. For example, "L=2" describes the set of the Earth's magnetic field lines which cross the Earth's magnetic equator two earth radii from the center of the Earth.

Three different radiation sources are easy to distinguish from an extract of the data collected by R3DE from 11-21 July 2008 (see Figure 7-22). The majority of measurements are concentrated in the GCR (Galactic Cosmic Rays) points, in red, which are seen as the area with many points in the lower part of the panel in L-values range between 0.9 and 6.2. The covered dosed rate range is between 0.03 and 20-25 microGray per hour (µGy/h). The lowest rates are close to the magnetic equator, while the highest are at high latitudes.

The second source are the protons (green) in the inner radiation belt (RB), which are situated as large maximum in the upper-left part of the panels. They cover the range in L-values between 1.2 and 2.6. This area is usually denoted as the South Atlantic anomaly (SAA) region. The dose rates in the SAA region vary between 10^{-15} and 1130 µGy/h.

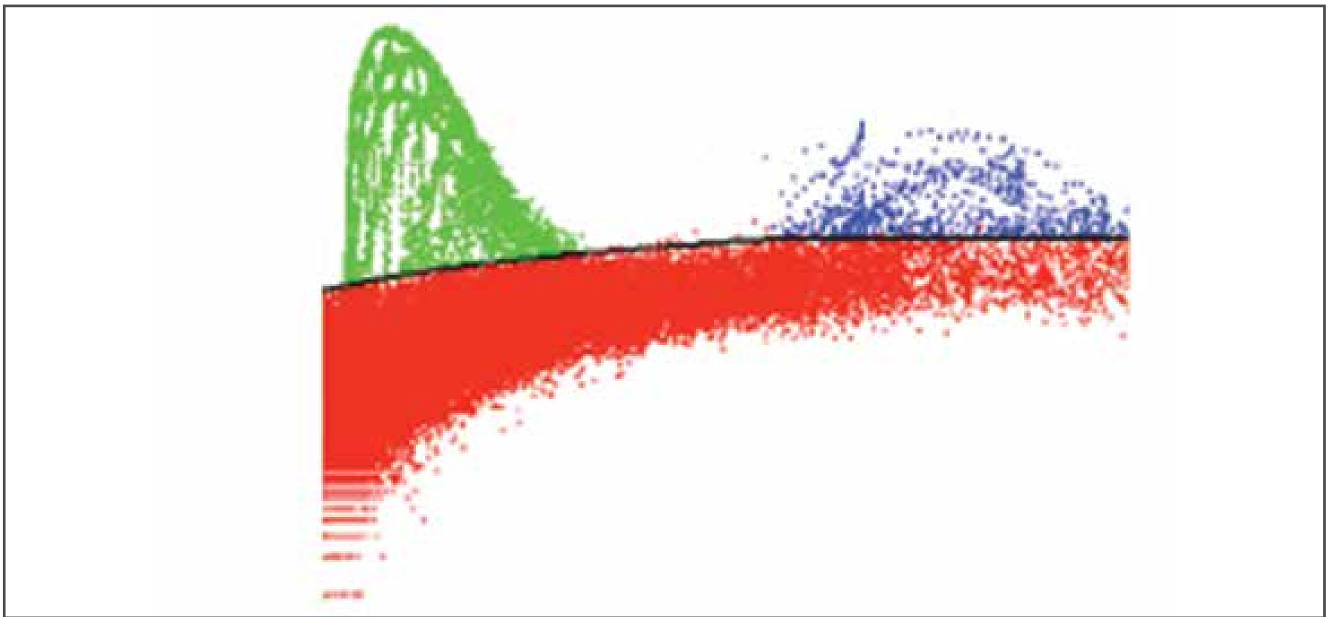


Figure 7-22: Profile of the ISS ionising radiation environment

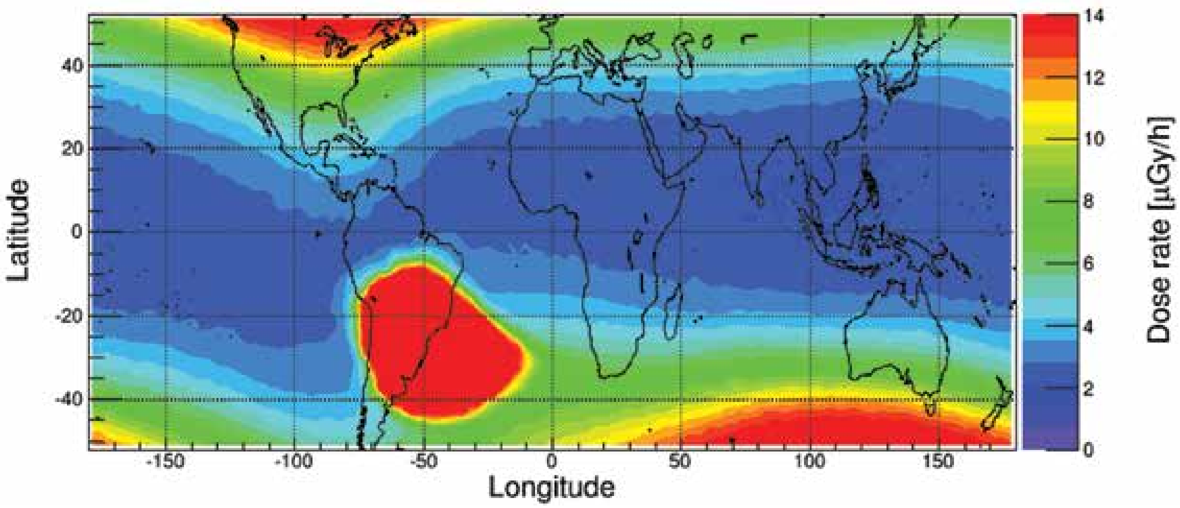
The wide maximum in L-values between 3.5 and 6.2 is connected with the observations of rare sporadic Relativistic Electrons (blue) Precipitations (REP) generated in the outer RB.

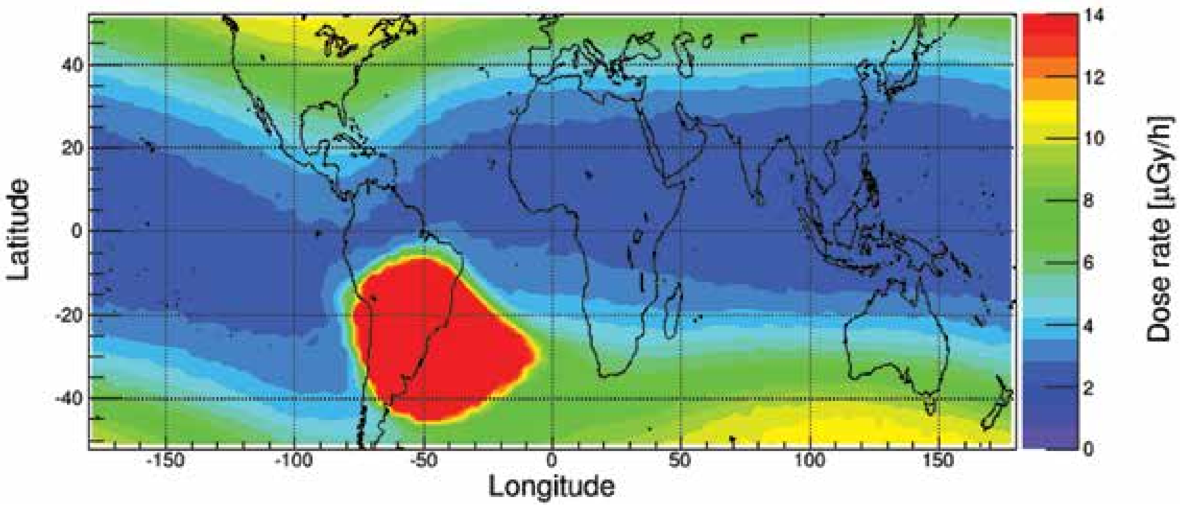
The radiation field inside the International Space Station is highly complex due to the interaction of the primary radiation environment with the hull and the interior of the ISS. This radiation field depends on the location inside the ISS but also changes within the solar cycle and varies with both the ISS altitude as well as its attitude. The radiation environment inside the ISS is not only harmful to electronics, but also to biological systems and humans. Therefore radiation monitoring inside the ISS is performed within various international projects and is essential to secure the health of astronauts and to limit long-term risks of adverse effects.

From May 2009 till June 2011 and from July 2012 onwards relevant data on the temporal variation of the radiation field inside the Columbus Laboratory of the ISS was, and is currently, collected with two active silicon semiconductor radiation detector telescopes (DOSTEL) in the frame of the ESA DOSIS (Dose Distribution inside the ISS 2009 – 2011) and the ESA DOSIS 3D (Dose Distribution inside the ISS 3D 2012 - present) projects. The active instruments are mounted at a fixed location beneath the European Physiology Module (EPM) and allow the determination of all relevant radiation field parameters necessary for further radiation risk assessment for astronauts working on-board the ISS. In addition the spatial variation of the radiation environment is measured at eleven positions inside Columbus by passive radiation detectors.

The absorbed dose rate recorded by the active instruments can be separated in contributions from Galactic Cosmic Rays (GCR) and from charged particles trapped in the Earth's radiation belts. Trapped particles impact the ISS while crossing the South Atlantic Anomaly (SAA) above South America.

The contributions from GCR vary with the activity of the sun and the relevant connected interplanetary magnetic field. Therefore, during solar minimum conditions (as in 2009) the contributions from GCR are highest, while during solar maximum conditions (as of 2013) the contribution from GCR is lower due to the stronger interplanetary magnetic field. The upper panel of Figure 7-23 shows absorbed dose rate in dependence on the geographical position for the year 2009. The scale (0 µGy/h – 14 µGy/h) was chosen to visualize the variation of absorbed dose rate from GCR with geomagnetic latitude and longitude due to Earth's magnetic field. The magnetic field allows fewer particles to penetrate at lower latitudes and as a consequence the lowest dose rates occur in the equatorial region.





DLR

Figure 7-23: Variation of the absorbed dose rate for solar minimum (DOSIS year 2009, upper panel) and solar maximum (DOSIS 3D year 2013, lower panel) conditions. The scale (0 µGy/h – 14 µGy/h) was chosen to illustrate the variations in the dose rate from Galactic Cosmic Rays while the dose rate in most parts of the South Atlantic Anomaly (roughly between 10°W and 80°W; 5°S and 45°S) are above the scale.

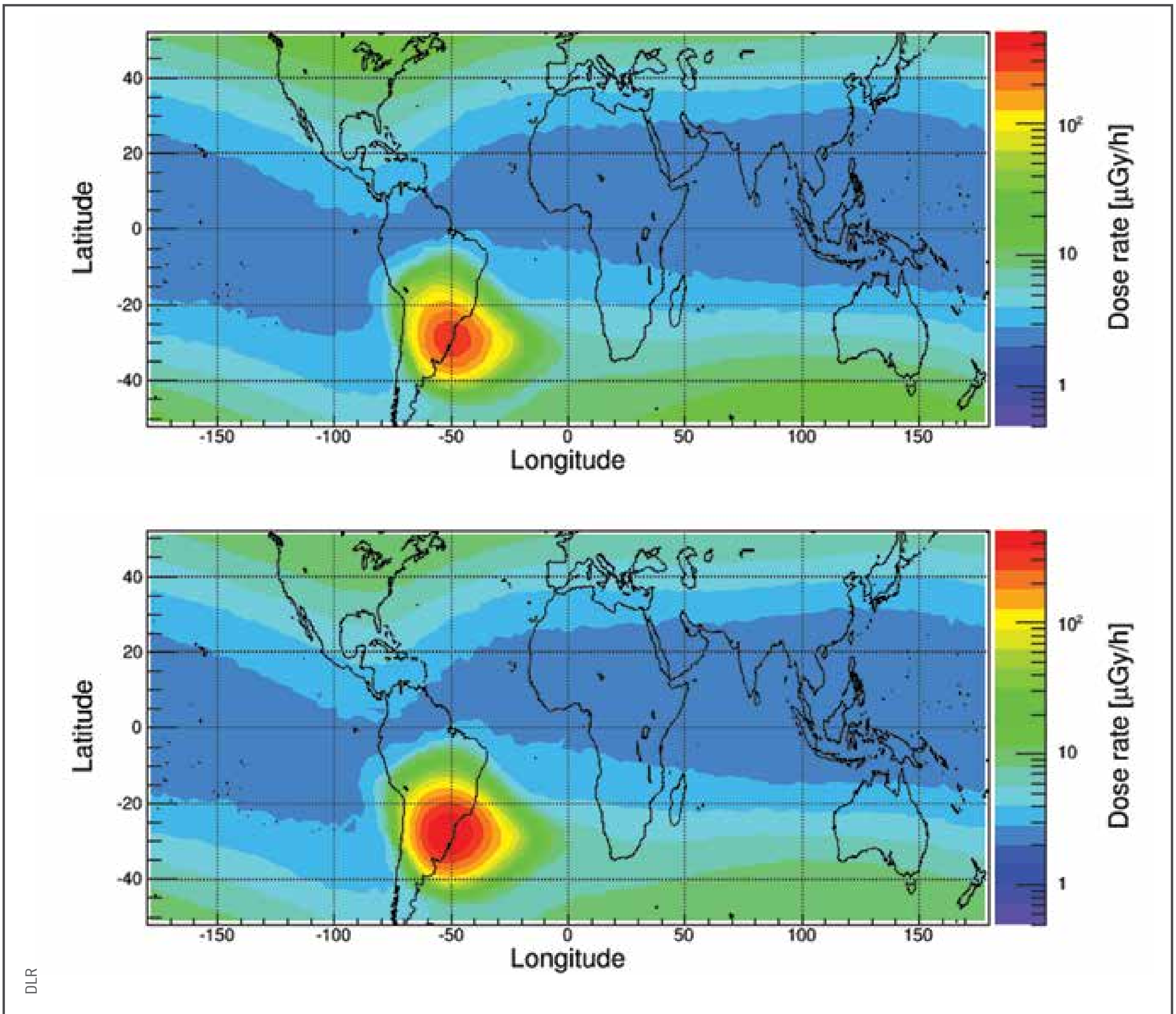


Figure 7-24: Variation of the absorbed dose rate in logarithmic scale (0 µGy/h – 500 µGy/h) for the illustration of the South Atlantic Anomaly (roughly between 10°W and 80°W; 5°S and 45°S) for low ISS altitude (DOSIS year 2009: ~350 km, upper panel) and high ISS altitude (DOSIS 3D year 2013: ~420 km, lower panel).

The lower part of Figure 7-23 presents the dose rates in the year 2013 at solar maximum conditions. During this period the dose rate caused by GCR had decreased due to the stronger interplanetary magnetic field. This effect is especially pronounced at higher geomagnetic latitudes. The solar cycle variations lead to a decrease in the daily average absorbed dose rate due to GCR from 160 µGy/d (2009) to 140 µGy/d (2013).

In the logarithmic scale of Figure 7-24 the dose rates during the crossings of the South Atlantic Anomaly (roughly between 10°W and 80°W; 5°S and 45°S) is resolved. The SAA is a region where particles from the radiation belt come closer to the Earth surface due to the shift and tilt of the geomagnetic axis against the geographical axis. The upper part of Figure 7-24 shows the dose rate in the SAA while the ISS was at altitudes of around 350 km (2009) and the lower part of Figure 7-24 shows the dose rate for SAA crossings at altitudes of around 420 km (2013). The extended time spent in the SAA caused by the widening of the SAA at higher altitudes in combination with higher peak dose rates lead to an increase of the daily average absorbed dose rate from SAA crossings from 80 µGy/d (2009 at 350 km) to 150 µGy/d (2013 at 420 km).

These results show that the radiation environment inside the Columbus Laboratory is highly complex and variable, depending on the ISS altitude and the solar cycle. Smaller deviations caused by ISS attitude changes occurring for example during spacecraft dockings can further influence the radiation dose.

7.5.2.8 Radiation dose environment

Dose effects are ionising radiation–induced changes in devices and materials resulting from exposure to the trapped proton and electron environment during the orbital lifetime. Dose effects are usually manifested as degradation of electronic device and material performance and are cumulative with exposure to the ionising radiation environment.

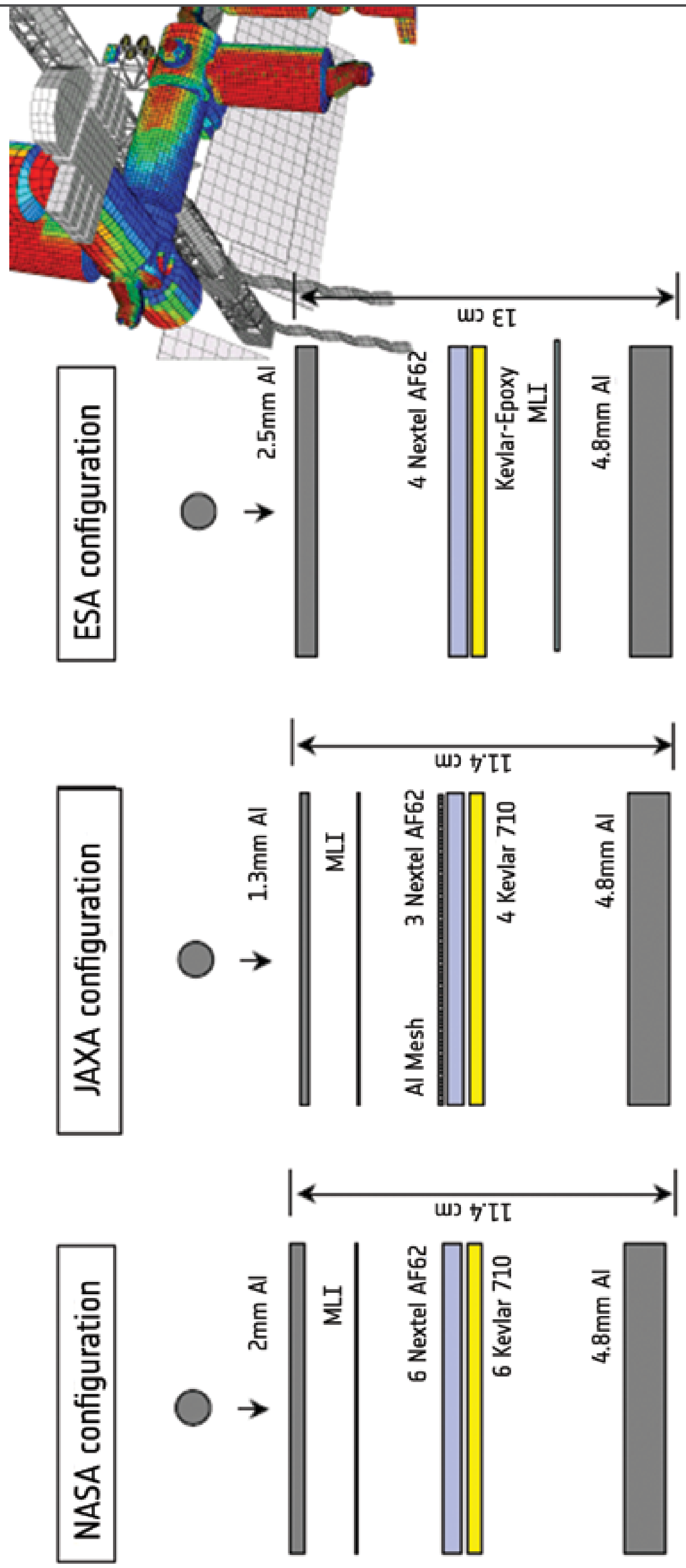
7.5.2.8.1 Single Event Radiation Dose Environment

SEE are ionising radiation–induced effects produced when single, ionised particles interact with electronic devices to change the electrical states or characteristics of the devices. These effects include single event upset, transients, latchup, burnout, and gate rupture. The ionising radiation environment for SEE is divided into a nominal environment and an extreme environment.

- nominal SEE – The nominal SEE design environment is the environment, which the Space Station will typically experience, and consists of trapped protons and cosmic rays. The SEE trapped proton environment represents daily average proton fluxes. The trapped proton flux is a maximum during passes through the South Atlantic Anomaly (SAA), where fluxes are more severe than the daily average environment. The ISS will pass through the SAA on 50 % of its orbits and will spend 5–10 minutes of these orbits in the SAA. Cosmic ray particles originate from outside the solar system and although the fluxes are low, they include heavy energetic ions for which it is difficult to shield against. Cosmic rays are known to result in Single Event Upset and “latchup” in electronic components and an uncertain radiobiological effect on biological organisms;
- extreme SEE – The extreme SEE environment consists of protons and heavy ions emitted during the most intense solar flares in a solar cycle. The extreme environment occurs once over an 11 year solar cycle period, and lasts for approximately 24 hours. Three different aspects of this environment are defined:
    - peak proton flux;
    - peak heavy ion flux;
    - orbit–averaged heavy ion fluency for the worst-case flare event.

7.5.2.9 Plume impingement

With the retirement of the Space Shuttle, commercial spacecraft supplement the Russian Progress, the European Autonomous Transfer Vehicle (ATV, until 2015), and the Japanese H-II Transfer Vehicle (HTV) to supply the International Space Station (ISS) with cargo. Furthermore, to carry crew to the ISS and supplement the capability currently provided exclusively by the Russian Soyuz, new designs and a refinement to a cargo vehicle design are in work. Many of these designs include features such as nozzle scarfing or simultaneous firing of multiple thrusters resulting in complex plumes. This results in a wide variety of complex plumes impinging upon the ISS. Therefore,



NASA

Figure 7-25: Typical MMOD shielding configurations for U.S., European, and Japanese modules to ensure safe "proximity operations" near the ISS, the need for accurate and efficient high fidelity simulation of plume impingement to the ISS is as high as ever.

External payloads and exposed secondary structures (e.g. Multi-Layer Insulation – MLI – blankets) will be exposed to the maximum effective normal pressure of 0.16 kPa and shear plume impingement pressure of 0.038 kPa.

7.5.2.10 Meteoroids and orbital debris

In orbit, the ISS will encounter meteoroids and orbital debris. Either type of object can pose a serious threat of damage or decompression to the ISS upon impact. Meteoroids are natural in origin, and debris is the result of man–made material remaining in Earth orbit.

The Micrometeoroids and Orbital Debris (MMOD) shields on ISS are the most capable shields ever developed and flown on a spacecraft. These shields consist of multiple layers of aluminium, ceramic cloth, and ballistic protection fabrics. U.S., Japanese, and European modules employ 'Stuffed Whipple' (see Figure 7-24) shielding on the areas of their modules exposed to the most impacts from orbital debris and meteoroids (ram facing areas and side/zenith areas, as shown with a colour code in Figure 7-24). This kind of shielding is capable of defeating a sphere of aluminium of at least 1.3 cm in diameter, impacting (normally) at 7 km/s.

The Columbus laboratory had a launch mass of 12 800 kg, of which 2500 kg was payload and 2000 kg was its Meteoroid and Debris Protection System. For its position in the ISS assembly, Columbus is particularly exposed to impacts from micrometeoroids. Its shield consists of 81 panels of two different designs:

- simple panels, with a 1.6 mm thick aluminium sheet, at the aft side of the module and inner cone;
- dual panels, with a 2.5 mm thick aluminium sheet, and another sheet composed of 18 layers of Kevlar reinforced with epoxy resin and covered with four layers of Nextel, on the ram side and outer cone.

Both simple and dual panels are mounted several cm away from the module pressure shell. Their mission is to dissipate the energy from the impacts before they reach the structure of the pressurized module itself.

7.6 Scientific utilisation of the ISS

Scientific research on the ISS involves a variety of experiments that make use of one or more of the space conditions present in low Earth orbit. The primary fields of research include human research, biology, physics and chemistry, astronomy, atmospheric sciences, and technology.

While the various ISS Partners may emphasize different aspects of research in their use of the ISS, the unique blend of unified and diversified goals among the world's space agencies leads to improvements in life on Earth and preparation for Human Space Exploration.

The following sections provide users with an overview of the various utilisation fields that apply to the ISS.

7.6.1 Life and Physical Sciences

In 2000, ESA prepared a preliminary ISS Research Plan defining the scientific priorities in the life and physical sciences for a five year period, with a horizon of 10 years. The compilation of this Research Plan was initiated by a bottom-up analysis of all the research proposals received at that time by ESA. As a next step that same year, ESA asked the European Science Foundation (ESF) to assess the research priorities in a dedicated user consultation meeting. At this meeting in conjunction with user consultations and in the subsequent ESF recommendations, the concept of Research Cornerstones was defined.

The Research Cornerstones describe areas of research where concerted efforts at the European level have already produced, or are promising to lead to, eminence if not a leading position on a global level. They provided therefore, an excellent basis for ensuring that new proposals will address issues that have been recognised as constituting a particular strength in Europe.

The ISS Research Plan is by definition a living document. Research priorities may shift, new promising research fields may emerge, or new results are taken into account. For that reason, it was envisaged that the process of user consultation should be repeated at regular intervals.

Following this, a second user consultation on Life and Physical Sciences in Space was organised again by ESF in 2004. On this occasion a larger number of scientists participated and more time was available to discuss the individual disciplines during two workshops. After this consultation, the ESF recommended updated Research Cornerstones.

In 2006, ESA announced the SURE Announcement of Opportunity (AO) for scientists and Small Medium Enterprises (SMEs) to perform fundamental and applied research projects on board the ISS. SURE was funded by the European Commission under the Sixth Framework Programme.

Two more AOs in 2009 solicited life science and physical science research on the ISS. The first of these, ILSRA (International Life Science Research Announcement) had a second AO released in 2014 and was again coordinated by the International Space Life Sciences Working Group (ISLSWG). The ISLSWG includes NASA, ESA, JAXA, CSA and European national space agencies (CNES of France, ASI of Italy and DLR of Germany).

Furthermore, the ESF produced a review report about the ELIPS programme during 2011, see document at: **http://www.esf.org/fileadmin/Public_documents/Publications/elips_01.pdf**

7.6.2 The ELIPS programme

The European Programme for Life and Physical Sciences in Space (ELIPS) started in 2001. Currently 15 ESA member states participate.

ELIPS is the continuation of the earlier European Microgravity Research (EMIR) 1&2 programmes, and the Microgravity Facilities for Columbus (MFC). The main research fields are fluid physics, material sciences, fundamental physics, human research, biology and exobiology.

The ELIPS programme coordinates the science and provides the payloads for research on the ISS, and on other platforms that can provide weightlessness during shorter periods such as drop towers, parabolic flights and sounding rockets. To prepare for future human exploration of space, various ground-based investigations are also performed as part of the programme - in particular bedrest studies, isolation studies and investigations into biological effects of radiation at ion beam facilities.

On average, about 30 ELIPS supported experiments are performed on the ISS and, including all platforms, it totals about 100 investigations. Currently about 1500 scientists are involved in the ELIPS programme. Short descriptions and results of all experiments are archived and available at the Erasmus Experiment Archive (EEA). ELIPS is an optional programme within ESA which receives subscription by participating member states at the ESA councils at ministerial level, taking place every three to four years. ELIPS Period 4 runs until the end of 2015.

7.6.2.1 Objectives of the ELIPS programme

The ELIPS programme is essential to ensure that the European investments in the development and exploitation of the ISS would lead to a broad range of scientific results. The ELIPS programme promotes global cooperation. It also maintains and strengthens international research solicitation and peer reviews.

7.6.2.2 Criteria for defining the ELIPS research plan

ESA's research capabilities were defined as a combined implementation of ground-based reference experiments and activities to those implemented on board the ISS and complementary autonomous mission platforms.

7.6.2.3 Research strategy

Until the definition of ELIPS, no European research strategy had been set out for implementation by ESA's human spaceflight programme. The research strategy was worked out on the basis of a number of criteria, one being an overall set of principle topics. Thus, starting with the ELIPS programme, a proposal should in principle fall under one of the following strategically defined main categories:

- exploring nature;
- improving health;
- innovating technologies and processes;
- caring for the environment.

Under these strategic headings, seven main research domains naturally appear in relation to ESA's research focus on ISS:

- fundamental physics;
- fluid and combustion physics;
- material science;
- human research;
- biology and astrobiology;
- radiation/ monitoring space environment;
- technology demonstrations.

And under these disciplines fourteen so-called cornerstones are identified and are listed in the following sections.

7.6.2.4 Research domains and cornerstones of the ELIPS programme

7.6.2.4.1 Fundamental physics

Complex plasmas and dust particles physics, with particular emphasis on understanding the three dimensional behaviour of particles in a plasma reproducing fundamental molecular phenomena, and aggregation processes in a vacuum or atmospheric environment, requiring weightlessness.

Cold atoms and quantum fluids, with special significance given to the development and utilisation of a cold atom clock in space, which can attain accuracy levels unreachable on Earth.

7.6.2.4.2 Fluid and combustion physics

Structure and dynamics of fluids and multiphase systems, such as critical fluids, binary and ternary systems and granular materials, which are non-uniform on a macroscopic scale in the Earth's gravitational field. Of singular interest are also fluid flows in a central geometry and the evolution of multiconstituent systems like foams and emulsions.

Combustion experiments with gas, liquid or solid fuels, to quantitatively investigate phenomena superimposed on Earth by buoyancy convection.

7.6.2.4.3 Material sciences

Thermophysical properties of liquid metals will utilise the possibilities of containerless sample processing under conditions only attainable under weightlessness.

New materials and processes can be gained from experiments in space by eliminating gravity-induced effects. This encompasses understanding the mechanisms of crystal growth and solidification of metals, inorganic and organic materials, and biological macromolecules.

7.6.2.4.4 Human Research

Integrated physiology studying the effects of low gravity, and other extreme conditions, on whole-body regulations, e.g. in the cardiovascular respiratory and sensorimotor systems.

Muscle and bone physiology , e.g. muscle atrophy and bone mass turnover using conditions of reduced gravity to learn about effects of load on functional elements.

Neuroscience understanding the effects of gravity on control of posture, locomotion, and cognition.

7.6.2.4.5 Astro/exobiology and planetary exploration

Origin, evolution and distribution of life, studying the survivability of organisms under extreme conditions on Earth, in space, and in (simulated) planetary environments.

Preparation for human planetary exploration, quantifying the effects of radiation doses and investigating the impact of isolation in high-stress environments on humans. In addition, develop the scientific knowledge base for identification and utilisation of in-situ resources. Also study life support for long-duration planetary missions.

7.6.2.4.6 Biology

Cell and developmental biology, examining the effects of an altered gravitational environment on the development of the cell and the whole organism, including reproduction, with special emphasis on signal transduction, gene expression and neural development.

Plant physiology, mechanosensory elements, e.g. genes and proteins, involved in gravitropism.

Biotechnology studies under conditions of weightlessness of transmembrane and intracellular flux of mediators controlling cell potency and differentiation as well as cell-matrix interaction.

7.6.3 Announcements of Opportunity for ISS experiments

The ESA Directorate of Human Spaceflight and Operations (HSO) maintains a research web page where the latest Announcements of Opportunities (AOs) are listed.

The page can be found at:
www.esa.int/Our_Activities/Human_Spaceflight/Human_Spaceflight_Research/Currently_open_research_announcements

7.6.4 Education and Outreach

Education is a fundamental part of the mandate of ESA. The ISS Education Programme makes use of human spaceflight, in particular the ISS, as a means to capture the attention and the interest of students, to attract them to study scientific and technical disciplines, and to appreciate and understand the benefits, challenges, and importance of Space for Europe. The ISS Education activities focuses on providing a range of educational activities and material for primary, secondary, and university students, and their teachers. This includes the development and dissemination of teaching material, as well as supporting student experiments to be executed on board the ISS and other spacecraft.

The development of products is carried out after consulting with teachers from all ESA Member States, involving them through workshops and conferences.

Development events are usually organised at ESTEC in the Netherlands, and participating teachers are introduced to the ISS through a managed programme of information briefings, videos, and guided tours of relevant facilities and models. These events are used to investigate what the needs of the teachers are, to identify common elements in the European curricula, and to help develop a concept that meets both the aims of Human Spaceflight education, and those of the teachers in the classroom.

7.7 ISS resources and partner utilisation rights

NASA provides the overall leadership of the ISS programme development and implementation, and together with Russia provides the major building blocks of the ISS infrastructure. ESA, together with JAXA and the Canadian Space Agency (CSA) are providing additional elements, which significantly enhance the Space Station. The overall ISS obligations and utilisation rights are divided among the Partners, according to the elements and infrastructure they provide (e.g. Columbus Laboratory for ESA). Outside the Russian segment, which itself comprises 50% of the ISS resources, the current share of resources between the remaining US Orbital Segment (USOS) Partners is as follows: NASA: 76.6 %, JAXA: 12.8 %, ESA: 8.3 % and CSA: 2.3 %.

Those rights are defined in the Intergovernmental Agreement (Article 9) and the different Memoranda of Understanding signed by all of the Partners.

European users perform experiments in accordance with the European Space Agency's utilisation rights. Those rights comprise three different types of allocations:

- the "user accommodations", which are the Space Station elements available for utilisation and potential commercialisation (laboratories, external platforms);
- the "utilisation resources", which are derived from the ISS global infrastructure (e.g. power/cooling and communications), once resources for ISS system operations are covered (i.e."housekeeping resources");
- the utilisation of crew time and cargo transportation

The baseline utilisation allocations at ISS assembly complete in terms of percentages of the on-orbit facilities, resources and services for the five International Partners are summarised in Table 7-13. Each Partner has the right to barter or sell any portion of its respective allocations and resources. An example of this is the Memorandum of Understanding between NASA and ESA concerning ESA's provision of a Cupola in exchange for NASA's provision of Shuttle launch and returns services for five external European payloads.

7.7.1 ESA utilisation rights and resources

In return for its contribution, ESA has a resource allocation of 51 % of the internal and external user accommodation of the Columbus Laboratory. Other allocation rights to ESA comprise 8.3 % of the US Orbital Segment resources and 8.3 % of the total crew time. Note that this excludes all of the Russian accommodations and resources, as this is retained by Russia for its own use. This results in the utilisation rights shown in Table 7-14 for European use.

Table 7-15 summarises the Russian ISS flight opportunities that have thus far included an ESA astronaut on-board, following the signature of the Framework Agreement in May 2001.

7.7.2 ESA barter agreements

ESA has engaged in a series of barter arrangements with other space agencies within the framework of the ISS programme. These arrangements formalise exchanges of goods and/or services with the other agencies without a corresponding financial transaction, i.e. without an exchange of funds.

The legal framework for and list of ESA's ISS barter agreements can be found on the following page: **www.esa.int/Our_Activities/Human_Spaceflight/International_Space_Station/ESA_s_International_Space_Station_barter_agreements**

Table 7-13: Baseline International Partner utilisation allocations (excluding Russia)

UTILISATION RESOURCES, ACCOMMODATIONS & SUPPORTING SERVICES	ESA (%)	NASA (%)	CSA (%)	JAXA (%)
Columbus Laboratory (rack locations; external attachment points)	51	46.7	2.3	-
Destiny Laboratory (rack locations)	-	97.7	2.3	-
Truss Payload Accommodations	-	97.7	2.3	-
Japanese Experiment Module (rack locations; external attachment points)	-	46.7	2.3	51
Utilisation allocated resources (power/crew time)	8.3	76.6	2.3	12.8

Table 7-14: Global ISS utilisation capabilities

ACCOMMODATIONS/RESOURCES/ SUPPORTING SERVICES	TOTAL ISS
Pressurised accommodation in the research modules: Columbus Laboratory Destiny Laboratory Kibo Laboratory	33 International Standard Payload Racks: 10 13 10
External (unpressurised) accommodation: Columbus External Payload Facility ISS S3 Truss segment sites Kibo Experiment Module-Exposed Facility	 4, each taking 1 Columbus External Payload Adapter – CEPA. 4, currently 1 site is occupied by a single payload (AMS), and 3 by Express Pallets, each of which can have up to 6 Express Pallet Adapters, i.e. 18 Express Pallet Adapters in total. 10 (5 allocated to JAXA payloads, and 5 to NASA payloads).
Power:	84 kW (8 solar arrays)
Crew:	35-40 hrs/wk (for both US and Russian segment)
Data:	S-Band command uplink: High Data Rate (HDR) 72 kbps, Low Data Rate (LDR) 6 kbps Ku-Band data/video downlink: 300 Mbps total (US Segment only) of which 259 Mbps usable after overheads. ~100 Mbps available for utilisation.

Table 7-15: ESA Russian flight opportunities deriving from ESA/Roscosmos Framework Agreement (May 2001)

ISS MISSION	ESA MISSION NAME	VEHICLE ID	LAUNCH DATE	LANDING DATE	ESA ASTRONAUT	ASTRONAUT NATIONALITY
ISS 3S	Andromede	Soyuz TM-33	21/10/2001	31/10/2001	Claudie Haigneré	French
ISS 4S	Marco Polo	Soyuz TM-34	25/04/2002	05/05/2002	Roberto Vittori	Italian
ISS 5S	Odissea	Soyuz TMA-1	30/10/2002	10/11/2002	Frank De Winne	Belgian
ISS 7S	Cervantes	Soyuz TMA-3	18/10/2003	28/10/2003	Pedro Duque	Spanish
ISS 8S	DELTA	Soyuz TMA-4	19/04/2004	30/04/2004	Andre Kuipers	Dutch
ISS 10S	Eneide	Soyuz TMA-6	15/04/2005	25/04/2005	Roberto Vittori	Italian

7.8 ISS laboratories, facilities and payloads

The ISS is constructed from a number of pressurised modules which are listed here in order of installation.

The Russian Zarya module was the first module of the ISS to be launched. It provided electrical power, storage, propulsion and guidance to the ISS during the initial stage of assembly. Zarya is now primarily used for storage.

Unity, or Node 1, is one of three nodes, or connecting modules, in the US Orbital Segment of the station. It was the first US-built component of the Station to be launched. Essential space station resources such as fluids, environmental control and life support systems, electrical and data systems are routed through Unity (to and from different ISS modules) to supply work and living areas of the station.

The Russian Zvezda module provides many of the station's critical systems and its addition rendered the station permanently habitable for the first time, adding life support for up to six crew and living quarters for two. Zvezda handles guidance, navigation and control for the ISS.

Destiny is the primary research facility for United States payloads aboard the ISS. The laboratory houses a total of 24 racks, six on each side, some of which are used for environmental systems and crew daily living equipment. 13 racks are International Standard Payload Racks. Destiny also serves as the mounting point for the station's Truss Structure.

Quest is the only US segment human airlock, and is able to host spacewalks with both United States EMU and Russian Orlan spacesuits. It consists of two segments: the equipment lock, which stores spacesuits and equipment, and the crew lock, from which astronauts can exit into space. This module has a separately controlled atmosphere.

Pirs and Poisk are Russian airlock and docking modules. Pirs is additionally used to store, service, and refurbish Russian Orlan suits and provides contingency entry for crew using the slightly bulkier American suits.

The European-built Harmony, or Node 2 is the second of the station's node modules and a utility hub of the US segment. The module contains four racks that provide electrical power, and data handling plus additional resources, electronic data, and acts as a central connecting point for several other components via its six Common Berthing Mechanisms. The European Columbus and Japanese Kibo laboratories are permanently berthed to two of the radial ports, the other two can be used for berthing the HTV, Cygnus and Dragon spacecraft (and previously American Shuttle Orbiters docked with the ISS via Harmony and MPLMs).

Columbus, the primary research facility for European payloads aboard the ISS, provides a generic laboratory as well as facilities specifically designed for biology, human research and fluid physics. Several mounting locations are affixed to the exterior of the module, which provide power and data to external experiments.

The Japanese Kibo is the largest single ISS module. This laboratory is used to carry out research in space medicine, biology, Earth observation, materials production, biotechnology, communications research, and has facilities for growing plants and fish. The laboratory contains a total of 23 racks, including 10 experiment racks and has a dedicated airlock for experiments.

The European-built Tranquility, or Node 3, is the third and last of the station's US segment nodes. It contains additional life support systems to recycle waste water for crew use, supplement oxygen generation and remove CO_2, as well as housing crew exercise equipment. Three of the four berthing locations are not used. One location has the cupola installed, and one has the docking port adapter installed.

The Cupola is a seven window observatory, used to view Earth and docking spacecraft. The Cupola project was started by NASA and Boeing, but cancelled due to budget cuts. A barter agreement between NASA and ESA resulted in the Cupola's development being resumed in 1998 by ESA. The module comes equipped with robotic workstations for operating the station's main robotic arm and shutters to protect its windows from damage caused by micrometeorites.

The Russian Rassvet module is primarily used for cargo storage and as a docking port for visiting spacecraft.

The Leonardo Permanent Multipurpose Module is a storage module attached to the Unity node, provided to NASA's ISS programme by Italy and considered to be a US element. In a bartered exchange for providing these containers, the US gave Italy research time aboard the ISS out of the US allotment in addition to that which Italy receives as a member of ESA.

As part of its ISS utilisation programme, ESA has developed various multi-user facilities, specialised stand-alone payloads and infrastructure elements. The following tables 7-16, 7-17 and 7-18 list the major facilities, and are divided into three major groups:

- pressurised (internal) payloads;
- external (unpressurised) payloads;
- infrastructure support equipment.

Dedicated factsheets containing overviews and technical data of these facilities can be found online: **eug.spaceflight.esa.int**

Table 7-16: ESA-sponsored pressurised (internal) facilities for the ISS Utilisation programme

FACILITY	LOCATION AT ASSEMBLY COMPLETE	ON-ORBIT DATE
BIOLAB	Columbus module	02/2008 (ISS flight 1E)
European Physiology Modules (EPM)	Columbus module	02/2008 (ISS flight 1E)
European Drawer Rack (EDR)	Columbus module	02/2008 (ISS flight 1E)
European Transport Carrier (ETC)	Columbus module	02/2008 (ISS flight 1E)
Material Sciences Laboratory (MSL)	US Lab "Destiny" module	08/2009 (ISS flight 17A)
Fluid Science Laboratory (FSL)	Columbus module	02/2008 (ISS flight 1E)
European Modular Cultivation System (EMCS)	Accommodated in an EXPRESS rack- Columbus module	07/2006 (ISS flight ULF1.1)
Muscle Atrophy Research and Exercise System (MARES)	Accommodated in NASA's Human Research Facility (HRF) – Columbus module	04/2010 (ISS flight 19A)
Pulmonary Function System (PFS)	Accommodated in NASA's Human Research Facility (HRF2) – Columbus module	07/2005 (ISS flight LF1)
Portable Pulmonary Function System (PPFS)	US Lab "Destiny" module	09/2009 (ISS flight HTV-1), new unit 07/2014 (ISS flight ATV-5)
KUBIK	Columbus module	10/2007 (ISS flight 10A) 09/2009 (ISS flight HTV-1)

Table 7-17: ESA-sponsored unpressurised (external) facilities for the ISS Utilisation programme

FACILITY	LOCATION	ON-ORBIT DATE
SOLAR	Columbus External Payload Facility	02/2008 (ISS flight 1E)
Atomic Clock Ensemble in Space (ACES),	Columbus External Payload Facility	2016
Atmosphere Space Interactions Monitor (ASIM)	Columbus External Payload Facility	2016
EXPOSE-R2	Zvezda external area	04/2014 (ISS flight 55P)
Global Transmission System (GTS & GTS2)	Zvezda external area	08/2001 (ISS flight 5P) 07/2000 (ISS flight 1R)

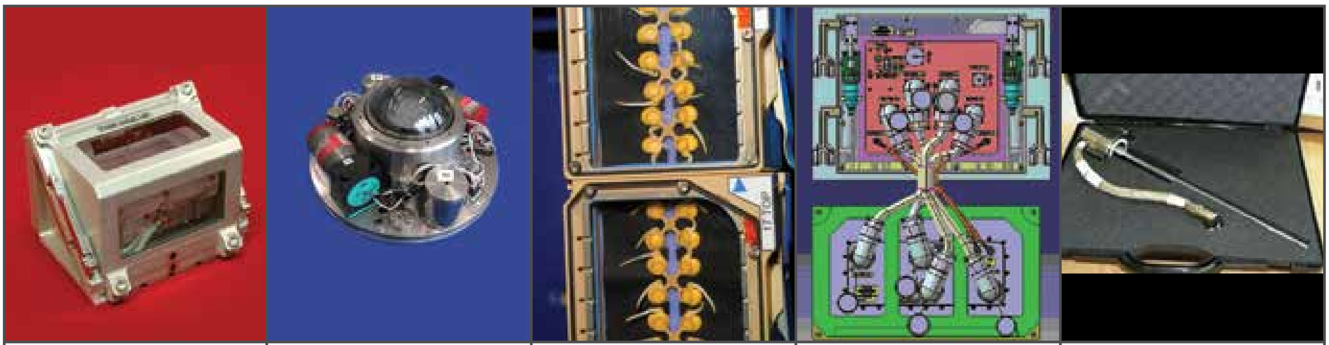
Table 7-18: ESA-sponsored infrastructure support equipment for the ISS Utilisation programme

FACILITY	LOCATION	ON-ORBIT DATE
-80 °C Freezer (MELFI 1-2-3)	Japanese "Kibo" module (2 units), American "Destiny" module (1 unit)	07/2006 (ISS flight ULF 1.1), 08/2009 (ISS flight 17A), 04/2010 (ISS flight 19A)
GLACIER (The General Laboratory Active Cryogenic ISS Experiment Refrigerator)	EXPRESS rack, Destiny Laboratory	05/2011 (ISS flight ULF6) (used for the actively conditioned samples of the whole ISS user community)
HEXAPOD		Development was finished in 2003 but currently refurbished.

Table 7-19: European Research and Accommodation Facilities

PRESSURISED (INTERNAL WITH EXPERIMENT EXAMPLES/ FACILITY MODULES)	UNPRESSURISED (EXTERNAL)	RESOURCES & SERVICES
Columbus Laboratories: • Biolab: WAICO • Fluid Science Laboratory (FSL): GeoFlow • European Modular Cultivation System (EMCS): GRAVI • European Physiology Modules (EPM): CARDIOLAB, MEEMM • European Drawer Rack (EDR): FASTER, KUBIK payload facility • European Transport Carrier (ETC) • MARES **Destiny Laboratory:** • Materials Science Laboratory (MSL)[2] in Materials Science Research Rack (MSRR): CETSOL/ MICAST/SETA	**Columbus External Payloads Facilities:** • SOLAR • ACES • ASIM • VESSEL-ID	**Resources:** Max. Power: 35 kW Average Annual Energy[1]: ~22 000 kWh Average crew time per week: ~3 hours (crew of 6) **Communication Services:** Max. data downlink rate (Ku-Band): 100 Mbps Yearly downlink data volume[3]: 250 Tbit/year Max. command uplink rate: 72 kbps Yearly uplink command volume: 0.18 Tbit/year **Transportation services (yearly average)[4]:** Pressurised upload mass: 450 - 600 kg/year Pressurised download mass: 450 - 530 kg/year Unpressurised upload mass: 80 - 115 kg/year Unpressurised download mass: 80 - 115 kg/year

1. 30kW*365*24*0.083
2. Located in US Destiny Lab
3. [(100Mbps x 365 x 24 x 3600)/10242] x 0.083
4. The values indicated are current estimates of utilisation transport capabilities (not requirements), without the Shuttle in service.



Waico in Biolab	GeoFlow in FSL	GRAVI in EMCS	FASTER in EDR	CETSOL in MSL

Image 7-3: Experiment examples

7.8.1 The International Standard Payload Rack (ISPR)

To facilitate on-orbit interchangeability between International Partner pressurised modules, internal (or pressurised) payloads are primarily accommodated within an International Standard Payload Rack (ISPR). The exception to this general statement being the Russian segment of the ISS, which does not allow the accommodation of ISPRs.

ISPRs are the largest (pressurised) individual entity that can be transported to and from orbit as logistics upload/download. The design of the racks facilitates the ready installation, removal or exchange of sub-rack units on-orbit.

There are two power ratings of ISPR, a "medium power" 6kW, and a "low-power" 3 kW. The placement of a medium-power rack (6kW) in a low power (3kW) location is not possible, but low-power racks may be placed in any location.

7.8.1.1 ISS Assembly Complete rack topology

Figure 7-24 shows the overall rack topology at Assembly Complete within all the modules of the non-Russian segment. The different colour codes distinguish between Subsystem, Stowage and Payload Racks. Users must however, keep in mind that due to the dynamic nature of the ISS programme planning, the topology shown represents the situation as of May 2014 and is subject to change.

7.8.2 The ESA Columbus laboratory and its payload accommodation

The Columbus module consists of a cylinder with an inner diameter of 4216 mm and an overall length of 6137.2 mm, closed by a truncated end cone at each end. The cross–section is double symmetric with four identical stand–off envelopes accommodating the routing of utility lines and four identical rack envelopes spaced 90 degrees apart.

As part of the ISS, ESA's Columbus module represents an element of a multi–functional, orbital infrastructure that generates and/or distributes the resources required for scientific and technological research in Low Earth Orbit (LEO). Columbus provides the capability for:

- the long–term continuous exposure of payloads to the microgravity environment and the capability for the systematic repetition and evolution of experiments;
- automatic, remotely controlled and interactive investigations involving orbit–based and ground–based crews composed of scientific, engineering and space operations personnel;
- the remote reconfiguration of the Columbus (and potentially the payloads) functional–electrical configuration based on optimised operations and redundancy concepts;
- a successive build–up and complementation of payloads based upon experiment results while using the logistics capabilities of the space transportation systems and the Columbus design features for Orbit Replaceable Units (ORU);
- in–orbit crew intervention for scientific preparatory, technical diagnostic, hardware configuration or recovery purposes when and as required.

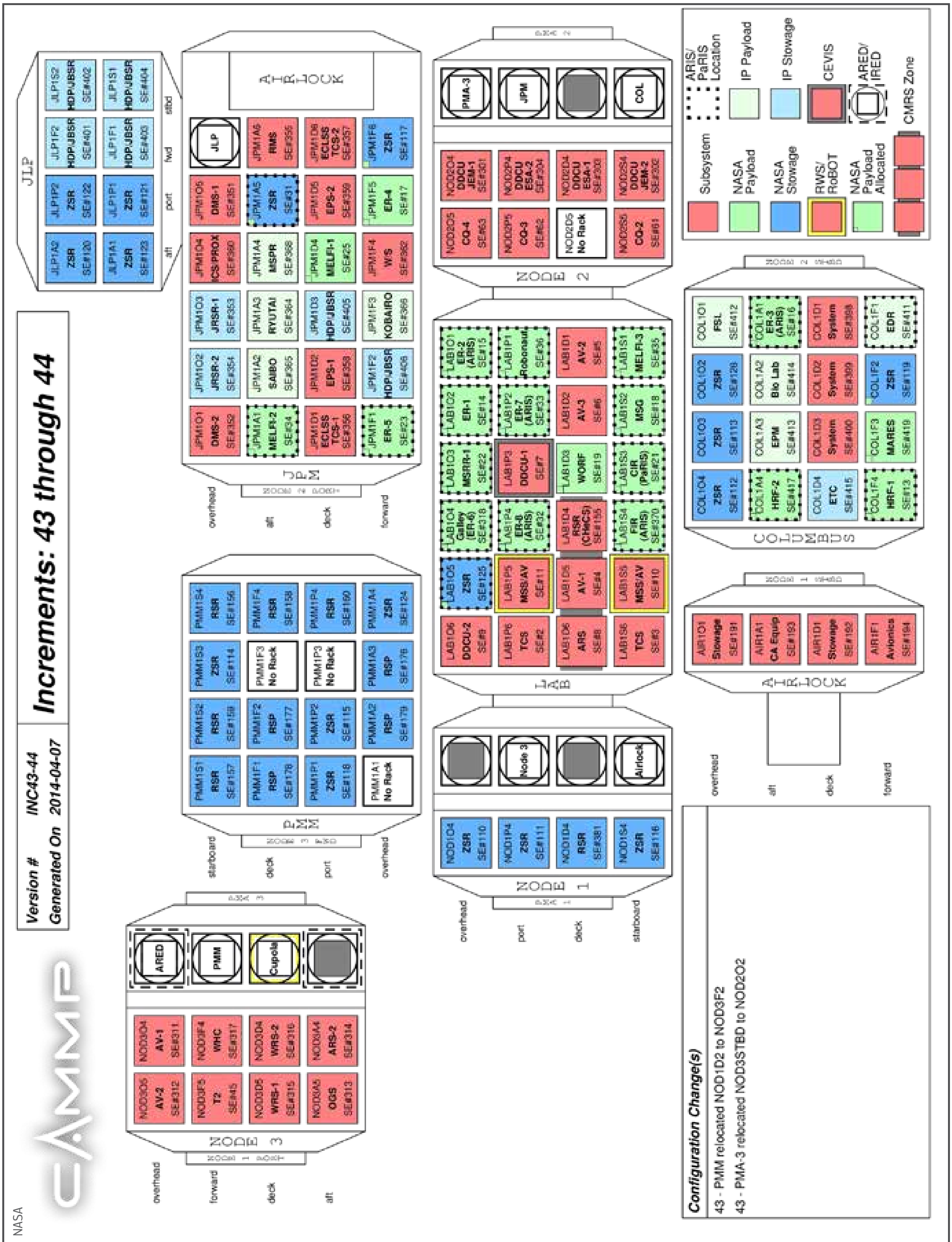


Figure 7-26: Rack configuration as of May 2014

Although aimed at basic research in the fields of material, fluid, biological and physiological sciences, the versatility and resources provided makes Columbus a suitable facility also for other fields of basic and applied sciences, process engineering and technology demonstration experiments.

7.8.2.1 Columbus internal payloads

In order to simplify the process of preparing and integrating payloads into the Columbus Laboratory, the European Space Agency - for internal purposes only - has defined three classes of user hardware, i.e. Class 1, Class 2 and Class 3 payloads. Theoretically, the following definitions are applied by ESA to both internal (pressurised) payload hardware and external (unpressurised) payload hardware. For internal payloads the definitions are very clear, for external payloads however, a precise definition is not so easy to establish. For the latter reason, the Class 1, Class 2 and Class 3 classification within this guide will only be applied to internal payloads. External payloads will be dealt with in section 7.8.2.3.

Class 1 payloads, such as the European Drawer Rack (EDR) are large multi-user facilities, which are normally developed by industry for the user(s). Class 2 payloads can be provided directly by the user, and range from an individual sample to a complete subrack level payload.

The complete payload lifecycle activities, complexity, cost and development time is significantly different for the classes of payload - although the general scope and sequence of activities is very similar in each case. The complete payload lifecycle process is generally complex and of long duration for Class 1 (~5 years), and simple and of short duration (~months to a few years) for Class 2.

7.8.2.1.1 Class 1 payloads

Class 1 payloads are any user hardware that interfaces directly with the Columbus laboratory systems at the International Standard Payload Rack (ISPR), or at the Standard Utility Panel interface in case of centre aisle payloads (see below). In general, the selection of Class 1 payloads is made at Agency Programme level and in close coordination with the Space Station partners in order to avoid duplication of hardware. Once a decision for the development of a Class 1 payload is taken, this payload will be developed by industry under contract and covered financially by the responsible Agency Programme Directorate. The final technical definition and construction of the Class 1 payload is undertaken in close interaction with the scientific and technical advisory teams of the respective User Programmes.

Within Columbus, pressurised payloads are primarily accommodated in racks. Columbus accommodates 16 racks in four segments of four racks each (Figure 7-25). System equipment requiring access or viewing by the crew is accommodated in the starboard end cone, while the remainder of the system equipment is housed around the perimeter of the port end-cone, and within three of the deck (floor) racks. The remaining 13 racks are available for payloads and storage, 10 have “plumbing and harness” to provide resources to active racks, and three provide passive stowage accommodation for payloads and system.

7.8.2.1.2 Class 2 payloads

Class 2 payloads are smaller facilities normally provided by ESA, which may be sub-units of Class 1 payloads with ISPR internal interfaces, add-on experiments, or smaller instruments accommodated in multi-user facilities (e.g. Biolab, FSL, EPM, EDR, EMCS, MSL). Specific examples of Class 2 payloads would be the Middeck Locker (MDL) and International Subrack Interface Standard (ISIS) drawer used by the EDR for containing experiments or instruments. Other types of Class 2 payloads include experiment samples, dedicated Experiment Containers and Cargo Transfer Bags. (The MDL and ISIS drawer are generally referred to as Experiment Container Modules [ECMs]).

7.8.2.1.3 Class 3 payloads

ESA is currently implementing an enhancement of the Columbus avionics and communication system that will enable bidirectional Internet Protocol communications with payloads on-board Columbus to further encourage the Columbus utilisation.

This Multi Purpose Communication and Computer enhancement, referred as “MPCC Enhancement”, would also enable a new class of payloads, sometimes referred as “Class 3 Payloads”, connected wired and/or wireless to the on-board LAN, using commercial Internet protocols, capable to be operated and be controlled remotely from

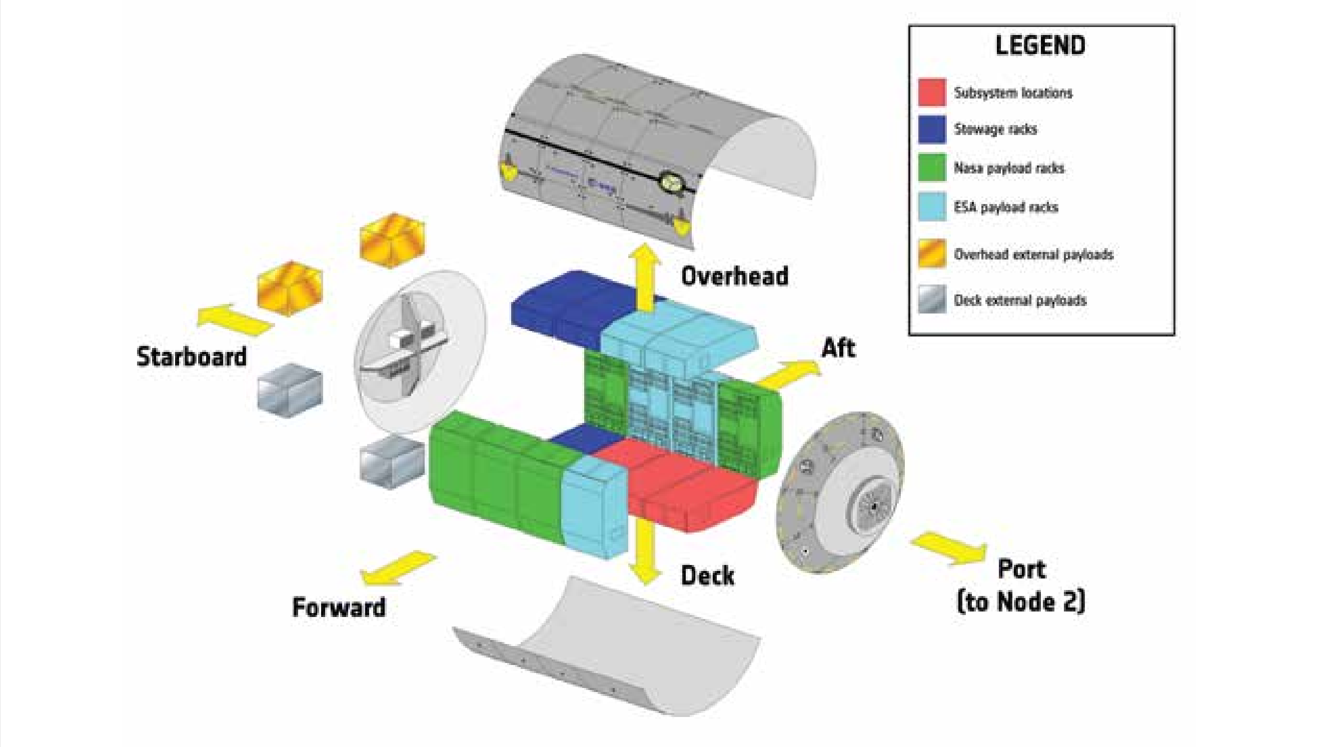


Figure 7-27: Internal layout of Columbus racks

Figure 7-28: International Standard Payload Rack (ISPR): 6-post configuration

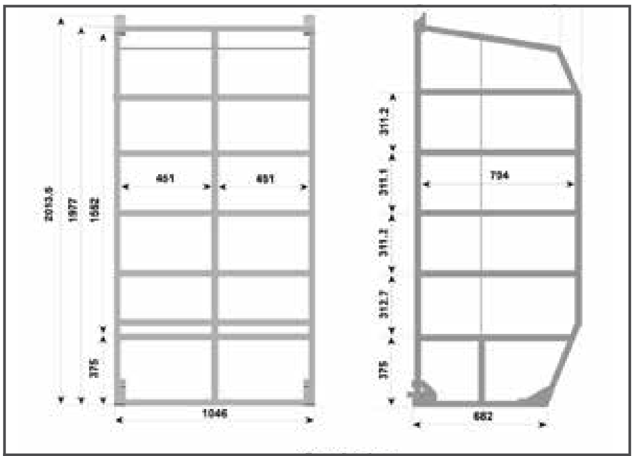


Figure 7-29: ISPR 6-post configuration dimensions – Front and Side View

the Principle Investigator(s) home base and having a short life cycle from concept to launch and on-orbit utilisation, as long as inherently safe.

The MPCC Enhancement will start to be available on-board the ISS from the second half of 2015, with full functionalities implementation by the second half of 2017. This enhancement, in its final configuration, will include the implementation of an independent Columbus Terminal allowing, even if partial, future tele-operations payloads.

7.8.2.1.4 Centre aisle payloads

Users have the possibility to mount payload equipment in the centre aisle of the Columbus Laboratory via mechanical attachment to deck rack seat tracks at the location of the deck racks (D1 – D4) of the Columbus floor (see Figure 7-29). The deck panels are removable to allow access to the stowage rack in position D4, or to any of the 3 subsystem racks - D1, D2 and D3 positions, in the under-floor area. Seat tracks are also at the ISPR front post for temporary attachment of payload equipment.

European payloads can be supplied with resources by connection to two Standard Utility Panels (SUPs) located at positions SUP1 and SUP4 in the lower stand-offs. The positions of all four Standard Utility Panels in the stand-off areas adjacent to the deck racks are shown in Figure 7-30.

The Standard Utility Panels include connectors for both payload and system equipment on the same panel. Locations SUP2 and SUP3 are available to American payloads via the United States Payload Bus (as access to the European Columbus payload bus, high rate data and smoke sensor, Emergency Warning and Caution System resources are not available at these positions).

The layout of the Standard Utility Panel is shown in Figure 7-30 and the connector allocations are reported in Table 7-20. Note that there are no water, vacuum, venting or gaseous nitrogen resources provided via the Standard Utility Panel, and any required cooling of aisle-mounted payloads should be performed by the payloads themselves.

7.8.2.1.5 Middeck Locker (MDL)

The use of standardised drawers and lockers provides users with a quick turn-around capability, and provides increased flight opportunities for the user community wishing to fly Class 2 payloads. The ISS Middeck Lockers (standard box-shaped containers) were developed by NASA to be compatible with both the Space Shuttle and the ISS. Figure 7-31 shows the basic dimensions and lay out of the MDL, while its characteristics are summarised in Table 7-21.

7.8.2.1.6 International Subrack Interface Standard (ISIS) Drawer

The ISIS Drawer (Figure 7-32) accommodation is designed to be physically compatible with the drawers of the NASA Express Rack through the adoption of a common rail installation and interface system. In the case of the EDR, the ISIS Drawers are provided by ESA and the baseline foresees the accommodation of 8-PU (8 Panel Unit) ISIS Drawers and the electrical and air cooling interfaces are spaced at 8-PU steps. The Panel Unit is used to determine the height (external) of the drawer, where 1 PU = 44.45 mm. The basic characteristics of the ISIS drawer are given in Table 7-22. The ISIS Drawer receives resources from the EDR system on the rear drawer panel where blind mate connections are implemented for both electrical and air cooling capability; some shared resources will be available in any case from the front of the rack via jumpers.

7.8.2.2 Columbus External Payload Facility (CEPF)

The Columbus module is furnished with attachment locations at the starboard end cone for integrated external payloads requiring space exposure or viewing towards nadir, zenith or the line of flight. The on–orbit attachment locations form part of the Columbus External Payload Facility (CEPF – see Figure 7-33 and Figure 7-34), consisting of two external structures mounted symmetrically and providing a total of four accommodation locations with associated sets of resources.

The accommodation locations are such that, when flying in XVV attitude, one faces towards the zenith direction (i.e. directly away from Earth), one towards the nadir direction (i.e. directly towards Earth), with the remaining two facing towards the starboard side of the ISS.

One of the accommodation structures is shown in a simple graphic in Figure 7-35, and consists of the support structure, two Mechanism Support Plates (MSP) and two passive Flight Releasable Attachment Mechanisms (FRAM).

The primary objective of the FRAM system is to provide a generic means for the accommodation of external payloads. The system consists of an active part and a passive part. The CEPF provides at each of the four locations the passive part of the FRAM, while the integrated external payload provides the active part of the FRAM. Figure 7-36 shows the interface plane between an integrated external payload and the Columbus module, with the active and passive FRAM.

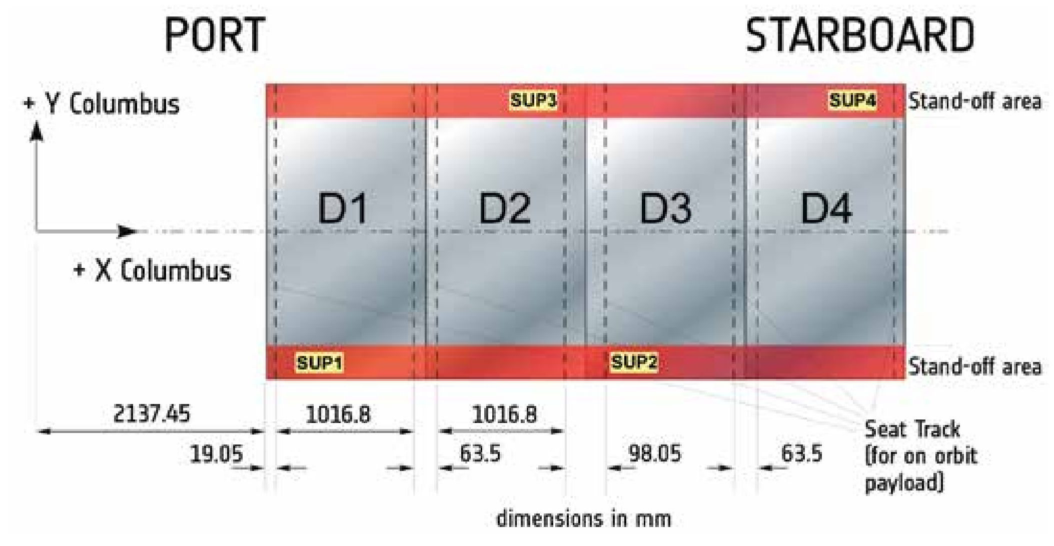


Figure 7-30: Centre Aisle Payload Attachment and Standard Utility Panel (SUP) Locations

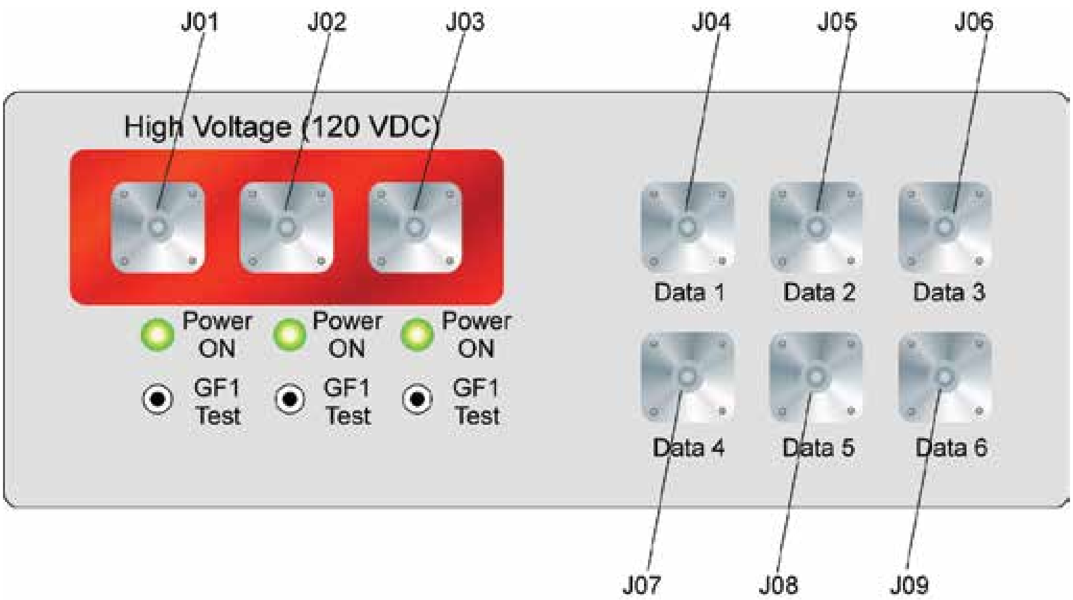


Figure 7-31: SUP panel layout

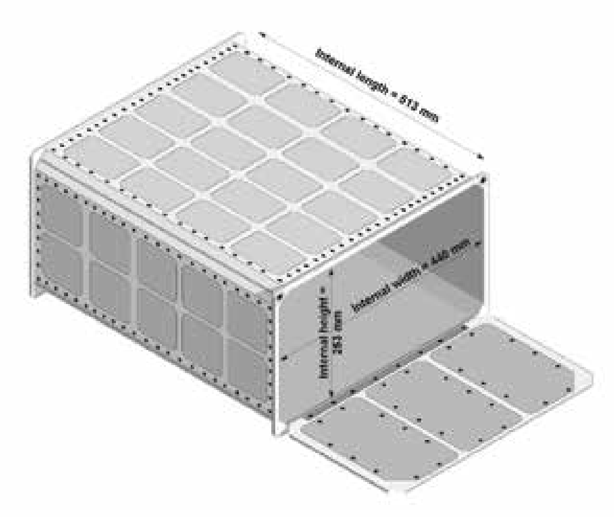


Figure 7-32: Middeck Locker (MDL) dimensions and layout

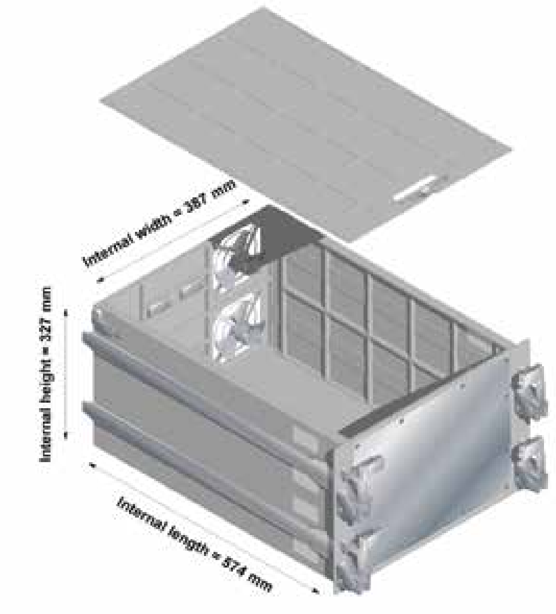


Figure 7-33: International Subrack Interface Standard (ISIS) drawer

Table 7-20: Standard Utility Panel connector allocation and function

CONNECTOR	SUP1 & SUP4 LOCATIONS	COMMENTS
J01 – Power	120 Vdc/ Crew Health Care System (CheCS) Bus	Used only by the system
J02 – Power	120 Vdc	Used only by the system
J03 – Power	120 Vdc	Provides power to aisle payloads
J04 – Data 1	Columbus Payload Bus	1533 bus for aisle payload data
J05 – Data 2	Columbus Local Area Network	IEEE 802.3 nominal line
J06 – Data 3	Video/High Rate data	Fibre optic line
J07 – Data 4	Smoke sensor/Emergency, Warning and Caution System	Smoke sensor and Emergency, Warning and Caution System
J08 – Data 5	Video Camera Assembly	This connection is only used by the Columbus system cameras (for 28 Vdc power, sync and video)
J09 – Data 6	Columbus Local Area Network	IEEE 802.3 redundant line

Table 7-21: Middeck Locker Characteristics

PARAMETER	VALUE
Maximum Volume available to users	57 litres
Internal Width	440 mm
Internal Height	253 mm
Internal Length	513 mm
Empty Mass	~5.4 kg
Net Mass available to users	28 kg

Table 7-22: ISIS Drawer Characteristics

PARAMETER	VALUE
Maximum Volume available to users	72.6 litres
Internal Width	387 mm
Internal Height	327 mm
Internal Length	574 mm
Empty Mass (including rails)	~18 kg
Net Mass available to users	40 kg

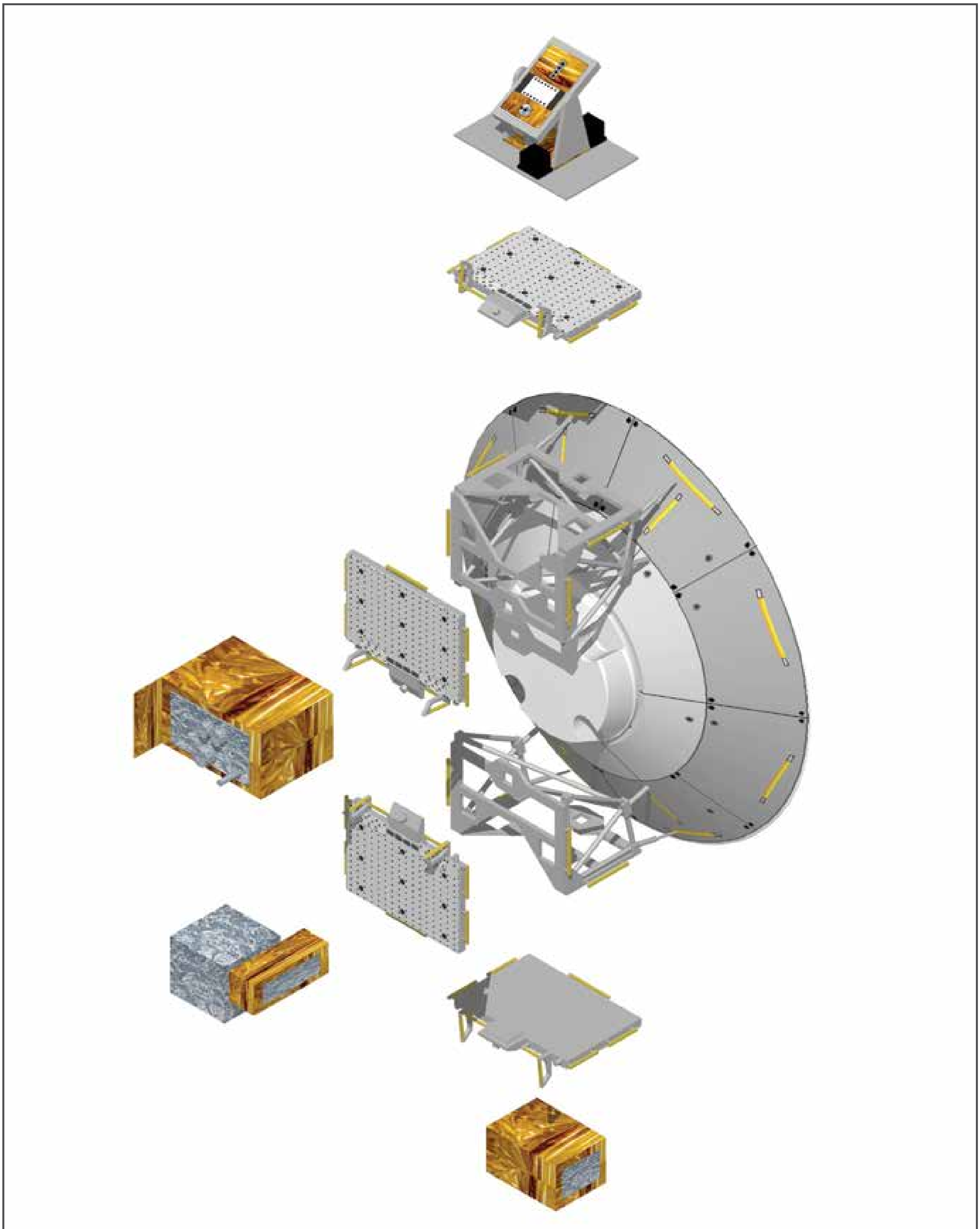


Figure 7-34: Exploded view of Columbus External Payload Facility (CEPF) on the Columbus starboard end cone

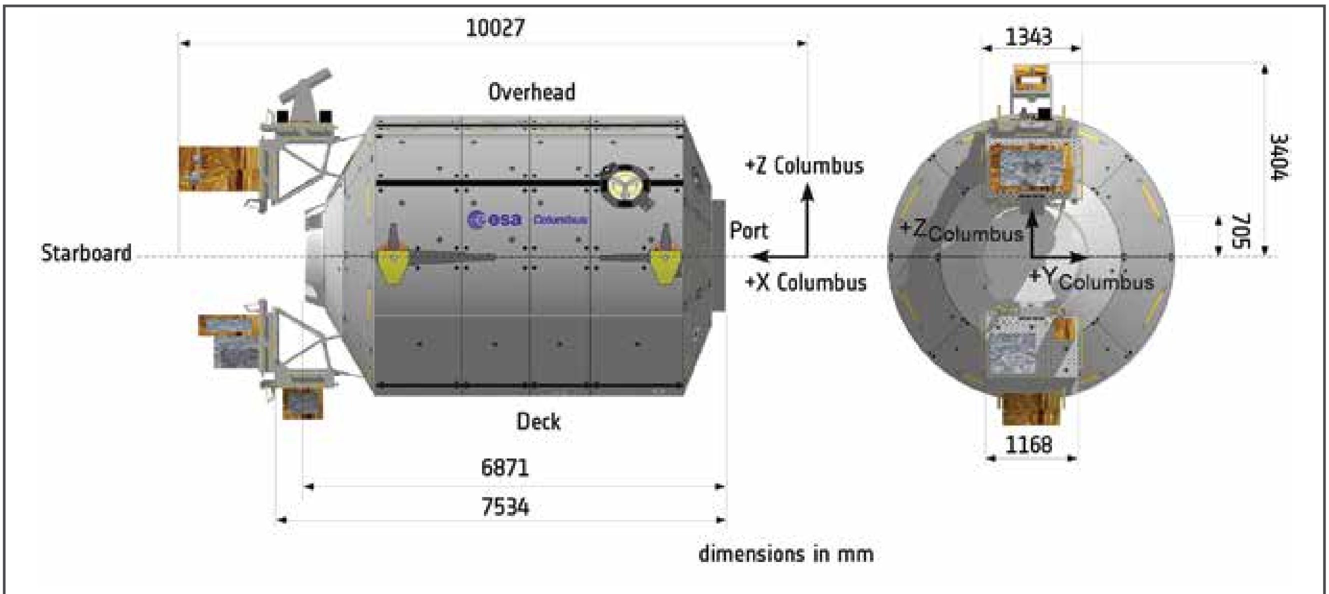


Figure 7-35: Columbus overall envelope with integrated external payloads

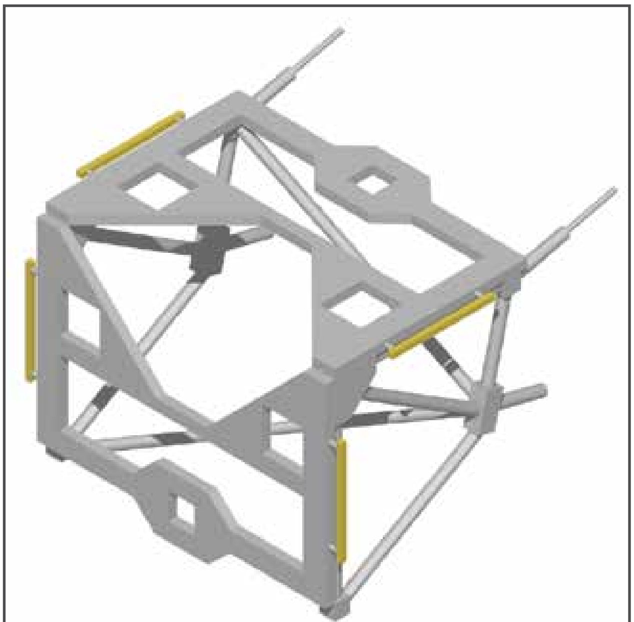


Figure 7-36: CEPF accommodation structure

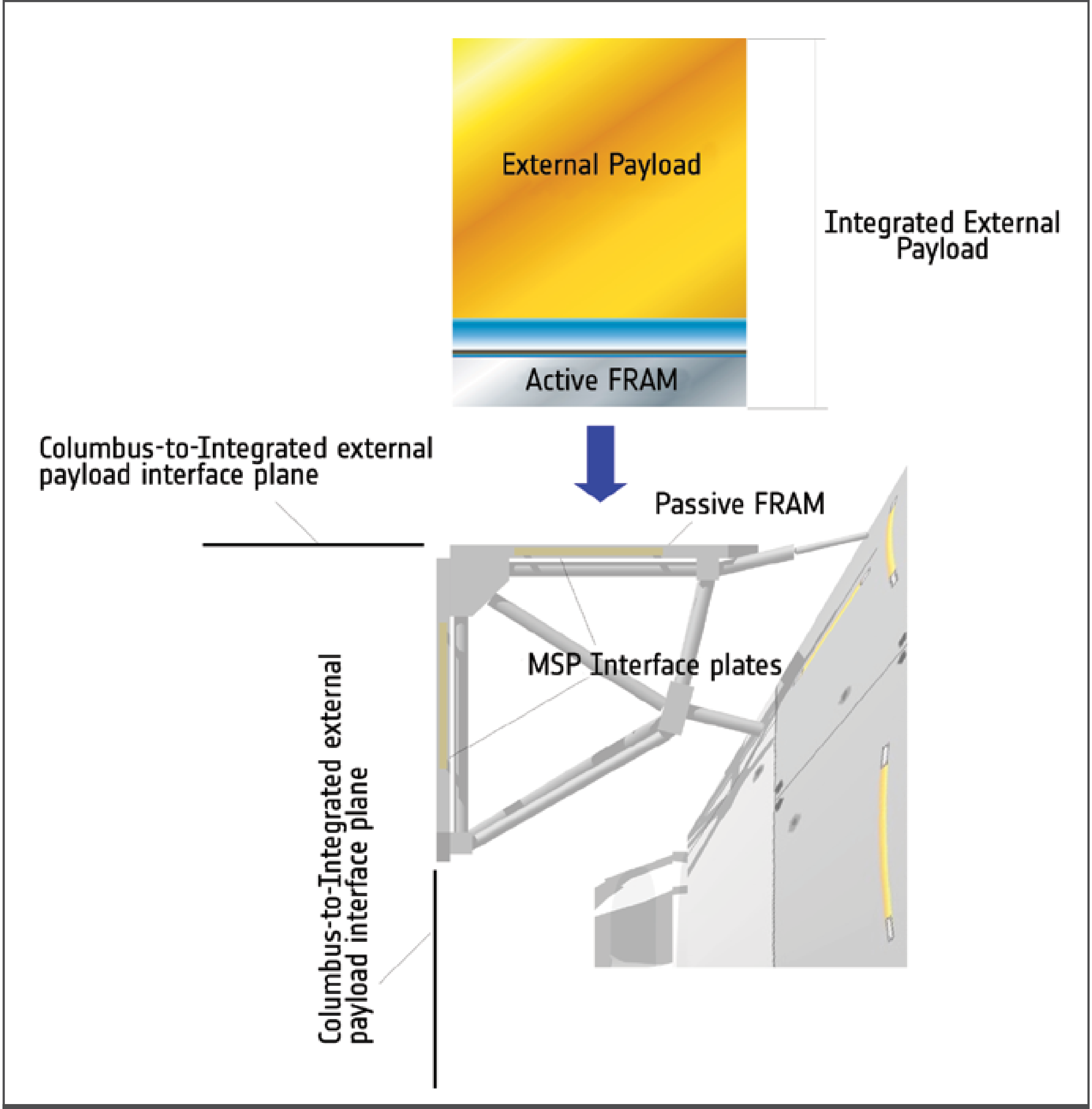


Figure 7-37: External payload/Columbus module interface plane definition

7.8.2.2.1 Columbus External Payload Adapter (CEPA)

The Columbus External Payload Adapter (CEPA) is a mounting plate for Columbus Exposed Facility (CEF) payloads and associated Flight Support Equipment (FSE). It was used in conjunction with the active Flight Releasable Attachment Mechanism (FRAM) to form the CEPA Assembly for transport and stowage aboard the Space Shuttle and Columbus module respectively. Figure 7-37 shows the CEPA Assembly. Each payload with its associated FSE is installed on the CEPA Assembly according to the requirements identified in each payload specification. The CEPA Assembly provided an interface to accommodate a wide variety of CEF payloads for transport to the ISS aboard the Space Shuttle. As the CEPA is not compatible with the SpaceX Dragon spacecraft trunk interface, future payloads will use FRAM directly. All external payloads uploaded with Dragon can only be deployed via robotic systems and CEPA is not compatible.

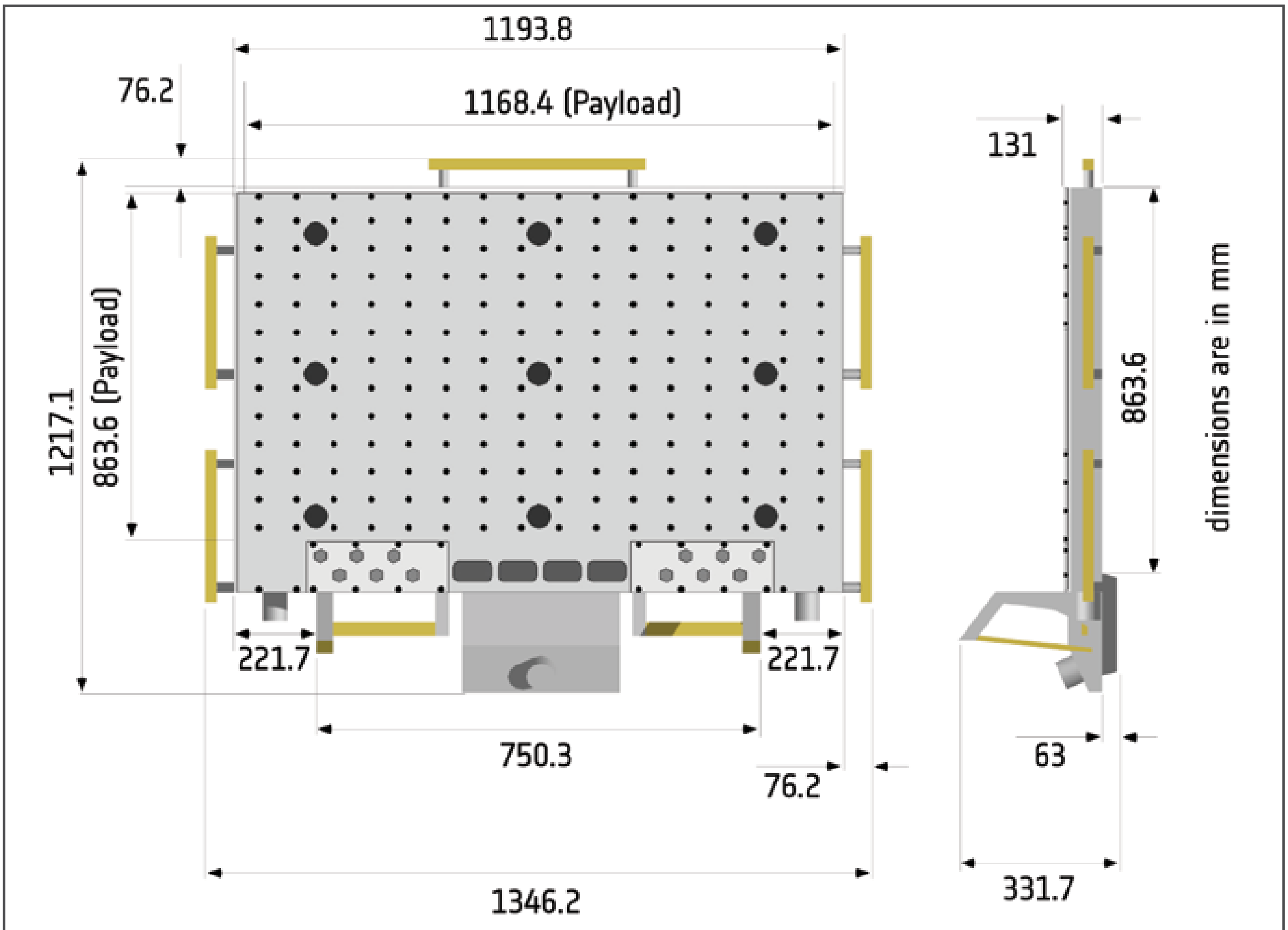


Figure 7-38: CEPA assembly envelope

Table 7-23: Columbus to external payload system interfaces

INTERFACE/RESOURCE/CONFIGURATION	DESCRIPTION
Integrated external payload on-orbit mass	≤ 290 kg (including CEPA and active FRAM)
Integrated external payload envelope, including active FRAM (Figure 7-38)	1.39 m^3 (width = 1168 mm, height = 1375 mm, depth = 864 mm)
Thermal differences	The integrated external payload shall be thermally conditioned to a temperature in a range between –62 °C to +36 °C to assure the mechanical functionality of the active and passive FRAM design during berthing and unberthing.
Power	Columbus will provide a maximum of 1.25 kW per CEPF location; the total for all four external payloads will be limited to 2.5 kW. Each CEPF location is connected to two 120 Vdc power feeders, each with a maximum allocation of 1.25 kW.
Commands to external payload	3x 28VDC Pulse Command Lines from module per EPF Location 3x 5VDC Level Command Lines from module per EPF Location
Discrete Data from external payload	3x Contact Lines to module per EPF location 3x Active Driver Inputs to module from each EPF Location
Analogue measurements	2x Analogue Signals to module from each EPF Location 2x Analogue Temperature Measurements to module Location from each EPF Location 2x Analogue Current Measurements to module from each EPF Location
Standard Payload 1553B Bus Interface	Extension of US Lab MIL–STD–1553B payload Data Buses
Specific Columbus Payload 1553B Bus Interface	Extension of Columbus Specific MIL–STD–l553B payload Data Buses supporting 2 remote terminals per payload position.
External payload computer serial interface	Connection from Payload Laptop and Programming Panel to External Payload Computer.
Columbus specific local area network (LAN)	2 x TSP (Twisted Shielded Pair cables) connections ISO/IEC 802–3 (Ethernet standard) 10Base-T (Twisted Pair wire supporting Ethernet's 10 Mbps) Columbus Payload Telemetry Payload–to–Payload communication
US Payload Local Area Network (LAN) (extension into Columbus only, non–redundant)	2 x TSP (Twisted Shielded Pair cables) connections ISO/IEC 802–3 (Ethernet standard) 10Base-T (Twisted Pair wire supporting Ethernet's 10 Mbps) US Payload Telemetry
Columbus High Rate Data Link	Connection to Columbus Video/Data Processing Unit (VDPU) to transmit payload data with rates up to 100 Mbps.

7.8.2.2.2 CEPF integrated external payload configuration, interfaces and resources

Table 7-23 summarises the principal Columbus to external payload system interfaces and characteristics. The interfaces of the CEPF include mechanical attachment and guidance mechanisms which support the interchangeability by means of Space Station Remote Manipulator System (SSRMS) operations.

There is no active thermal control capability available to External Payload Facility payloads (such capability must be provided by the payloads themselves). There is also no water, vacuum, venting, gaseous nitrogen (GN2), Emergency Warning and Caution System (EWACS) or NTSC (National Television System Committee) video capability at these locations.

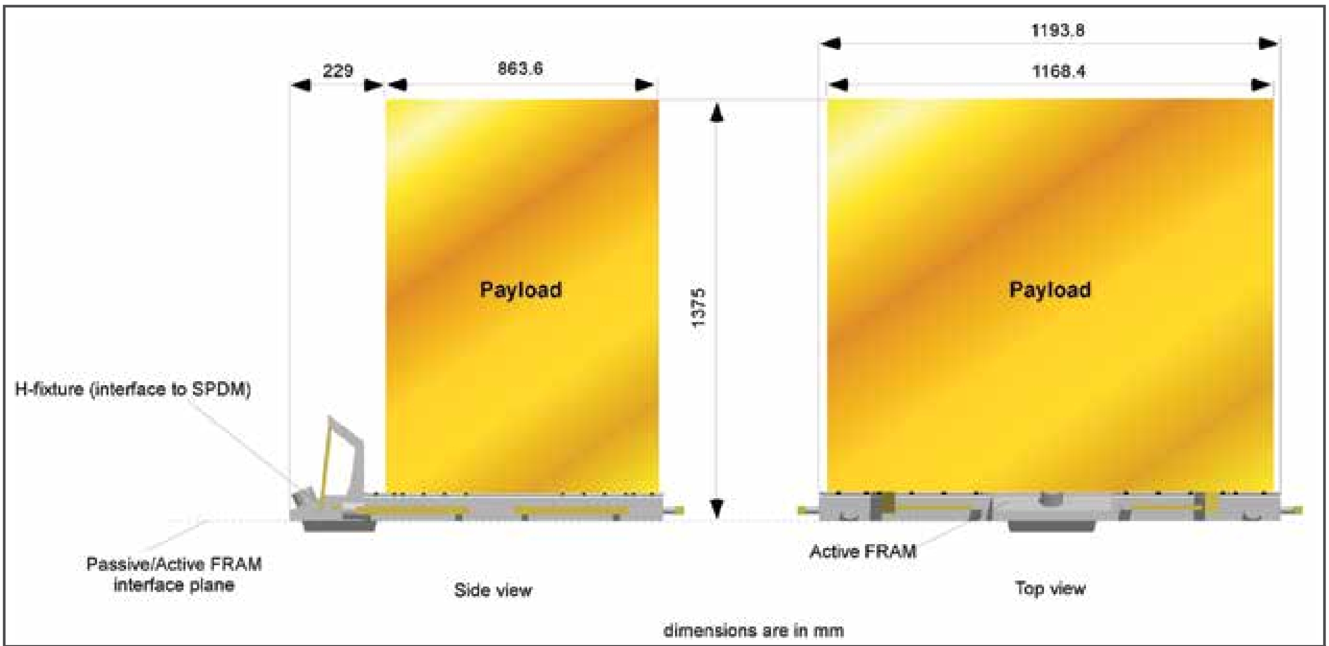


Figure 7-39: CEPF integrated external payload envelope

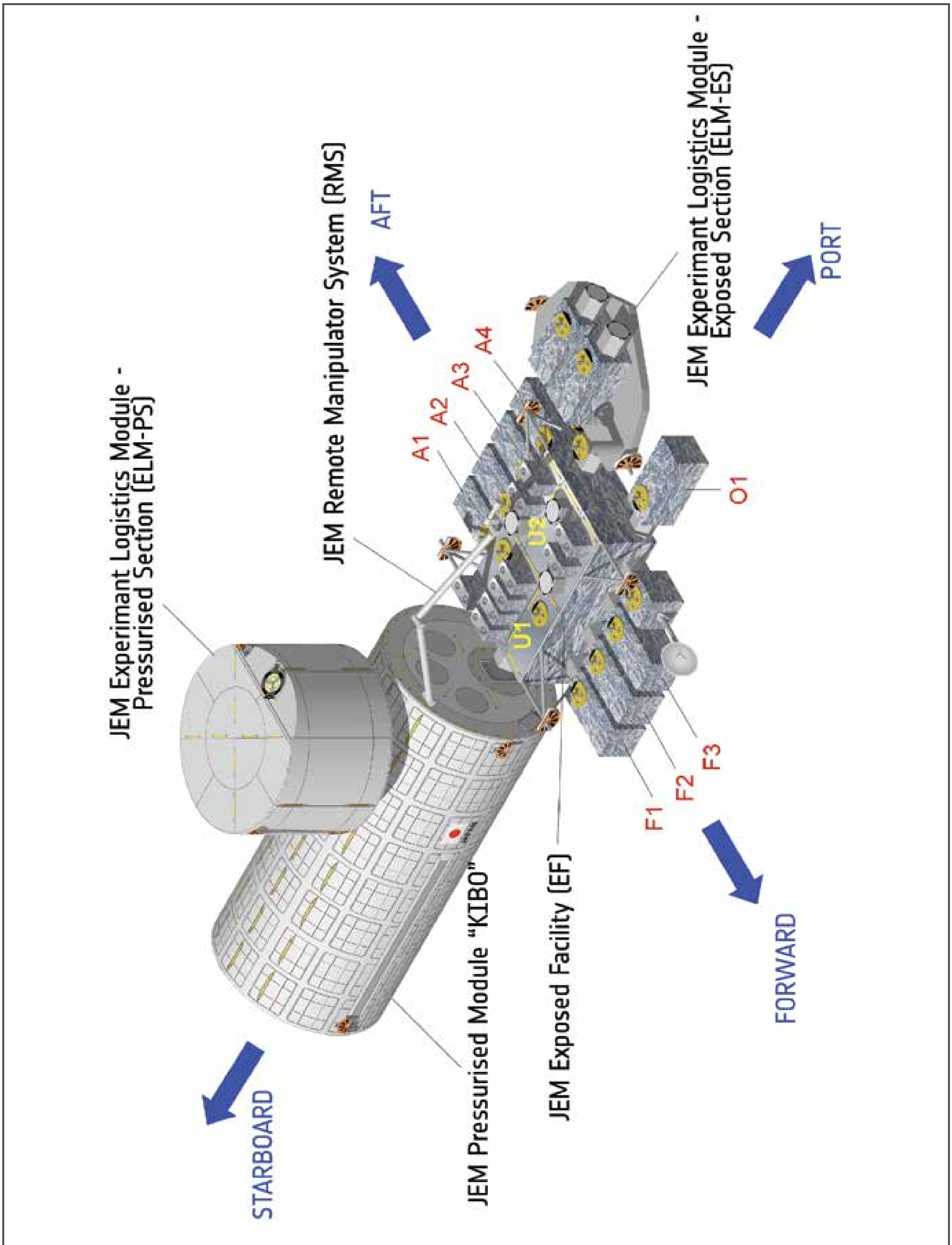


Figure 7-40: External sites configuration on the Japanese Exposed Facility (JEF)

Image 7-4: The S3/S4 Truss Assembly

7.8.2.2.3 Other partner external accommodations

Besides the European Columbus External Payload Facilities, the ISS also offers other external sites to users. There are a further 14 external sites offered by JAXA and NASA, which are the 10 sites on the Japanese Exposed Facility (F1-F3, A1-A4, U1, U2, O1 – see Figure 7-39) and the four sites on the Starboard S3 Truss (S3UI, S3UO, S3LI, S3LO). More information on the JAXA Exposed Facility can be found at the following web page:
http://iss.jaxa.jp/en/kibo/about/kibo/jef/

Users who wish to learn more about the S3 Truss external locations should refer to the following document:
SSP57021 Rev. A "Attached Payloads Accommodation Handbook" September 2002.

7.8.3 Other ISS Partner facilities

The following sections provide some basic information on the major facilities developed by Partners for utilisation on board ISS.

7.8.3.1 NASA Facilities

7.8.3.1.1 Human Research Facility (HRF)

Situated in Columbus, the Human Research Facility (HRF) is a two-rack facility designed to support life sciences investigations using human subjects. HRF Rack 1 was delivered and installed on the ISS during the STS-102 mission (5A.1) in March 2001. HRF Rack 2 was delivered to orbit during the Return To Flight Shuttle mission to the ISS (LF1) in July 2005.

The HRF 1 is a rack that provides services and utilities to experiments and instruments installed within it.

The major pieces of research equipment in HRF Rack 1 are an Ultrasound/Doppler system, a metabolic gas analyser system, a Space Linear Acceleration Mass Measurement Device (SLAMMD), a portable computer and a computer workstation for data processing and data communications. HRF-2 provides power, command and data handling, cooling air and water, pressurized gas, and vacuum to experiments. The Refrigerated

Centrifuge (RC) separates biological substances of various densities by spinning at a high rate of speed. A suite of experiment-unique radiation dosimetry equipment is also stowed in the HRF rack. Investigators using HRF will also have access to the complement of equipment in the Crew Health Care System (CheCS). As an example, the ergometer and treadmill, developed by CheCS for countermeasures, may be utilised in HRF exercise experiments.

7.8.3.1.2 Microgravity Sciences Glovebox (MSG)

The Microgravity Science Glovebox (MSG), located in Destiny, is a rack facility enabling scientists from multiple disciplines to participate actively in the assembly and operation of experiments in space with much the same degree of involvement they have in their own research laboratories. Developed by ESA and integrated by NASA, the MSG was launched to the ISS in June 2002. This facility offers an enclosed 255 litre work area and provides a 100,000 level "clean room" sealed glovebox environment that is accessible to the crew through sealed glove ports and to ground-based scientists through real-time data links and video. Because the MSG work area can be sealed and held at a negative pressure, the crew can manipulate experiment hardware and samples without the potential hazard of small parts, particulates, fluids, and gasses escaping into the open laboratory module. To date, MSG has gained the title of "most versatile and most used USOS Facility" and is undergoing an upgrade to support animal and biology research in the future.

Technical data on the MSG can be found in the dedicated factsheet on-line: **eug.spaceflight.esa.int**

7.8.3.1.3 Minus Eighty (Degrees Celsius) Laboratory Freezer for ISS (MELFI)

The Minus Eighty (Degrees Celsius) Laboratory Freezer for ISS (MELFI) provides the Space Station with refrigerated volume for storage and fast-freezing of life science and biological samples.

MELFI has been developed by ESA; two MELFI flight units were delivered to NASA and one flight unit to JAXA. The first MELFI freezer was launched to the ISS in July 2006, the final Melfi unit was flown to the ISS in 2010.

MELFI includes the cold volume, made by four separate compartments (dewars), and a nitrogen distributing system, consisting of piping and control valves. Each dewar is a cylindrical vacuum insulated container with a total capacity of about 75 litres. Its internal volume is divided in four parts by a cross structure, having two functions: the support function for the specimen containers and the heat transport function, from the heat exchanger to the specimen.

Users can design their own accommodation hardware, based on defined interface requirements and their cooling needs. MELFI is a 'contact freezer' to allow selection of the cooling speed. For fast cooling, the samples must be held against the Dewar trays and have a large, conductive surface. Conversely, samples requiring slow cooling need small, isolating interface surfaces.

Technical data on MELFI can be found in the dedicated factsheet on-line: **eug.spaceflight.esa.int**

7.8.3.1.4 Window Observational Research Facility (WORF)

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

The WORF rack provides mounting for payloads, with access to power at 120 or 28 Vdc, uplink and downlink commands at low and medium data rates, and moderate temperature cooling capability for payloads. The interior of the WORF provides for a non-reflective, light-tight environment both to minimise glare off the window, and to allow use of payloads that are sensitive to extremely low energy phenomena such as auroras. The ISS SERVIR Environmental Research and Visualization System (ISERV), deployed inside WORF, automatically takes images of Earth through a small telescope with an off-the-shelf digital camera mounted in the International Space Station's Destiny module.

7.8.3.1.5 Materials Science Research Rack (MSRR-1)

The Materials Science Research Rack (MSRR-1) is the core of materials science research in microgravity on-board the ISS, covering a wide range of fields. The rack is located in Destiny. The ESA Materials Science Laboratory (MSL) is integrated as a part of the core element of the MSRR-1.

7.8.3.1.6 Fluids and Combustion Facility (FCF)

The Fluids and Combustion Facility (FCF), in Destiny, is made up of two powered racks, the Fluids Integration Rack (FIR) and the Combustion Integration Rack (CIR). The FCF provides a permanent modular, multi-user facility to accommodate sustained, systematic research in the disciplines of fluid physics and combustion science. The two disciplines share racks and mutually necessary hardware within FCF to reduce costs and effectively use ISS resources.

The FIR is designed to be easily reconfigured on-orbit, similar to an optics bench in a scientist's laboratory. The FIR will permit a wide range of fluid investigations from microscopic imaging to particle tracking. The CIR is the only facility on-board the ISS to perform combustion research experimentation.

7.8.3.2 JAXA Facilities

7.8.3.2.1 Gradient Heating Furnace (GHF)

The Gradient Heating Furnace (GHF) is a vacuum furnace located in the Kibo module that contains three heating blocks. Their positions and temperatures can be independently controlled, and various temperature profiles can be realised. This facility will be mainly used for high quality crystal growth experiments using unidirectional solidification. GHF has an automatic sample exchange system that can accommodate up to 15 samples to reduce crew operation. The heater temperatures range from 500 °C to a maximum of 1600 °C.

7.8.3.2.2 Fluid Physics Experiment Facility (FPEF)

FPEF is a multi-user facility, located in the pressurised Kibo laboratory module, to investigate fluid physics phenomena in a micro-gravity environment. It consists of the core section and the mission section. The core section contains observation equipment, control equipment, and miscellaneous experiment support systems. The mission section, otherwise known as the Experiment Cell, is exchangeable according to the purpose of the experiment. The FPEF's observation capabilities include liquid bridge observation, three-dimensional flow field observations, surface temperature measurement, ultrasonic velocity profile measurement, and surface-flow rate observation.

7.8.3.2.3 Solution/Protein Crystal Growth Facility (SPCF)

The Japanese Solution/Protein Crystal Growth Facility (SPCF) located in the Kibo Laboratory module is comprised of two modules: the Solution Crystallisation Observation Facility (SCOF) and the Protein Crystallisation Research Facility (PCRF).

The SCOF is an in-situ observation facility containing versatile diagnostics, including a Mach-Zender interference microscope for precise measurements of growth conditions and an amplitude modulation microscope. Interfaces for control and measurement of temperature and pressure, control of the cell stage, evacuation, and N2 gas supply are available. A Michelson interference microscope and Dynamic Light Scattering are also available as options.

The PCRF contains 6 cell cartridges and allows for 4 different types of protein crystallisation, i.e. vapour diffusion, batch, membrane and liquid-liquid diffusion methods.

7.8.3.2.4 Cell Biology Equipment Facility (CBEF)

The Cell Biology Experiment Facility (CBEF), integrated in the Japanese Kibo pressurised module, has been developed for various life science experiments such as cell cultivation and plant biology. It consists of an incubator unit and a control and communication unit. The incubator unit includes a µg compartment and a centrifuge that provides gravity control levels between 0.1 and 2.0 g.

Experiment units are placed within containment canisters and installed in the CBEF. The incubator can control temperature, humidity and CO_2 concentration for cultivation, within the following ranges:

Temperature: 15 – 40 °C
Humidity: 20 – 80 % Relative Humidity
CO_2 concentration: 0 – 10 vol %

7.8.3.2.5 Clean Bench (CB)

The JAXA Clean Bench (CB) provides a closed workspace for aseptic (glovebox) operations with life sciences and biotechnology materials. All materials entering and leaving the work volume pass through a pre-treatment chamber for sterilisation if required. The CB is accommodated in a double ISPR next to the CBEF, and is located in the Kibo module.

7.8.3.2.6 Image Processing Unit (IPU)

The Image Processing Unit (IPU) receives image data from various experiment equipment in Kibo, encodes the data, and then transfers the encoded data to the Kibo system lines. The IPU also records experiment image data on tape when real-time data downlink is not available. The main functions of the IPU are to have various interfaces with the Kibo systems and experiment equipment, to receive and decode 5 channels of independent video signals simultaneously, and to record video signals on tape with five digital VCRs continuously (up to 120 minutes each).

7.8.3.2.7 Aquatic Habitat (AQH)

The Aquatic Habitat (AQH) is a sub-rack facility that accommodates freshwater and saltwater organisms (such as Medaka fish) inside the Kibo module environment. The facility is designed to accommodate experiments for up to 90 days, making it possible to conduct research ranging from early development and differentiation to individual responses in a microgravity environment.

7.8.3.2.8 Space Environment Data Acquisition Equipment/Attached Payload (SEDA/AP)

The SEDA/AP is an external payload, which is accommodated on the external Kibo Exposed Facility (EF). The objectives of this payload will be to take measurements of the space environment (neutrons, plasma, heavy ions, high-energy light particles, atomic oxygen and cosmic dust) in the ISS orbit. SEDA/AP is used to study the environmental effects of the space environment on materials and electronic devices on the Kibo EF. In parallel, the SEDA/AP will help verify the JAXA Attached Payload BUS (APBUS) technology, which provides necessary functions to payloads mounted on the Kibo EF.

7.8.3.2.9 Monitor of All-sky X-ray Image (MAXI)

MAXI is an external facility mounted on the Kibo EF and consists of highly sensitive X-ray slit cameras for the monitoring of more than 1000 X-ray sources in space over an energy band range of 0.5 to 30 keV.

7.8.3.2.10 Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES)

The SMILES external facility accommodated on the Kibo EF is a submillimeter-wave limb-sounding spectrometer operating in the 640 GHz band for observing spontaneous radiation emitted by trace gases and particles within the stratosphere. It is aimed at being a demonstration of submillimetre sensor technology based on a superconductive mixer and a 4 Kelvin mechanical cooler.

7.9 User Support and Operations Centres (USOCs)

The ISS Programme consists of two major components, which are termed “space segment” and “ground segment” respectively. The space segment refers to the on-orbit ISS elements (including the vehicles that service the ISS), and the ground segment includes all of the ground-based facilities that support the activities involved in the Payload Lifecycle. Based on a decision made by the Manned Space Programme Board in 1998, ESA decided to adopt a decentralised infrastructure for the operation of European payloads on board the ISS, based on the concept of User Support and Operations Centres (USOCs).

Under the overall management of ESA, the European USOCs carry out the majority of tasks related to the preparation and in-flight operations of multi-user facilities. USOCs are based on already existing national user centres. This approach makes the USOCs instrumental for the implementation of the ISS ground

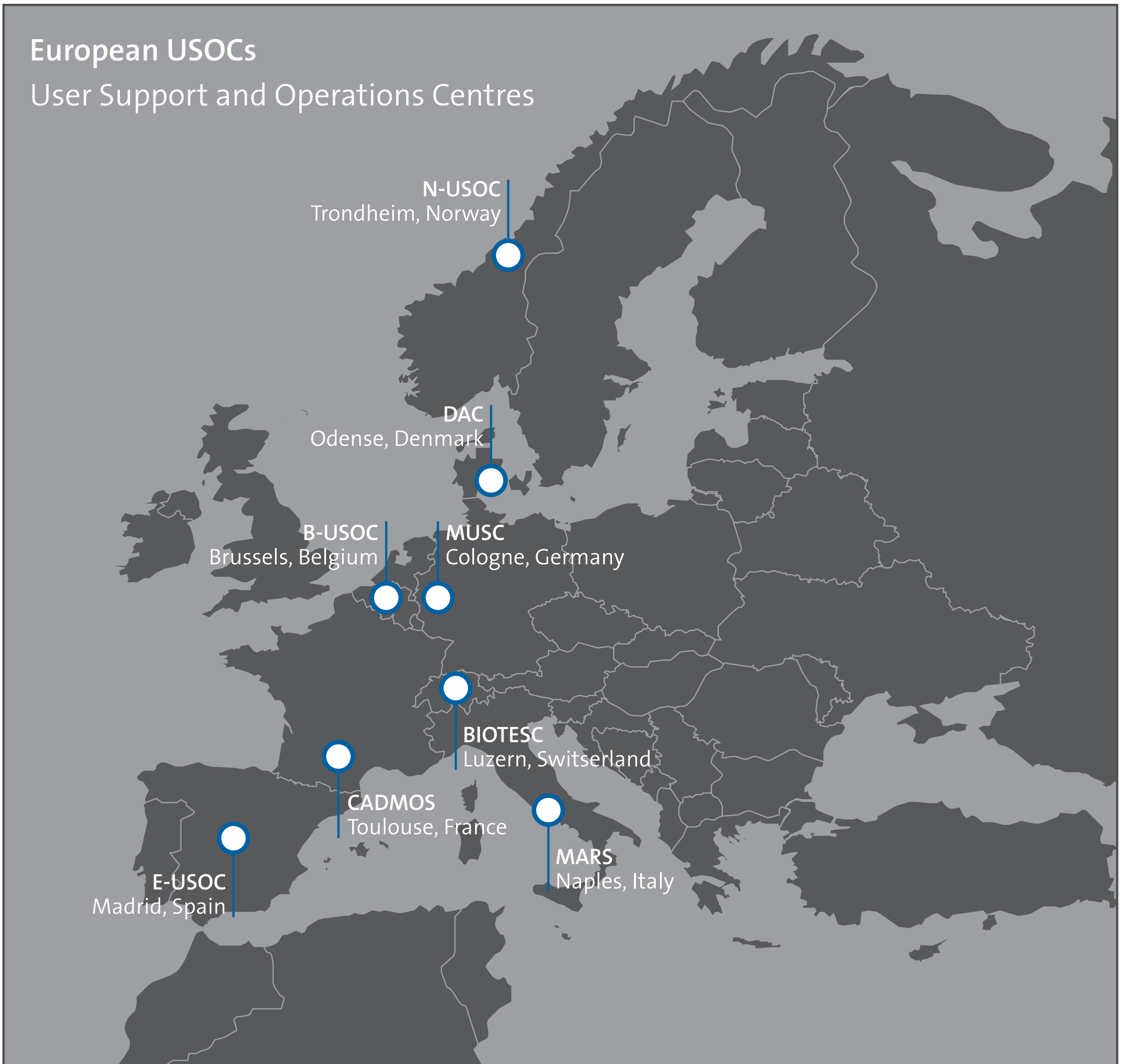


Figure 7-41: Geographical distribution of European USOCs

segment for payload operations preparation, real-time data dissemination and provision of instantaneous experiment command processing. The USOCs act as a link between the scientific user community and ESA's ISS utilisation organisation. With the discipline-oriented USOCs distributed over Europe it is ensured that focal points for the preparation and conduct of ESA payload operations are created, which are both very close to the payload operations on board the ISS and the scientific user groups on the ground.

7.9.1 Geographical distribution of European USOCs

A USOC can also be called a Facility Responsible Centre (FRC) but not all USOCs are FRCs. Being responsible for a specific facility, the USOC/FRC has the delegated overall responsibility for a specific multi-user rack level facility. Its functions focus on payload systems aspects and are related to all phases of payload operations, i.e. pre-flight activities, in-flight operations and post-flight activities. During the on-orbit operations phase, the FRC will operate the facility and assist scientists in their payload operations, and with ground control experiments.

In some cases, an FRC can be supported by another USOC, for the sake of sharing specific experiment knowledge, providing redundancy and increasing operational flexibility. Other than FRCs, USOCs are responsible for experiments and payloads to be accommodated in a multi-user level facility.

In addition, for specific experiment operations, dedicated User Home Bases (UHBs) will be set up if required. UHBs, which are the "home" locations of the scientists, are typically national institutes (e.g. universities), who need to set-up the adequate communication and data processing infrastructures that allow real-time data monitoring and control of the respective experiments (e.g. for remote operations). The establishment and verification of UHBs will typically be done on an increment basis. The FRCs will coordinate and support this setup, and be the focal point for the operations preparation activities for the UHB, in particular for the definition of experiment operations requirements, the specifications of hardware and software, and the connectivity requirements of the UHB to the ISS ground segment.

7.9.2 USOC Assignments

Table 7-24 summarises the USOCs (FRCs and Facility Support Centres [FSCs] only) and their current assignment of facilities as of July 2014.

7.9.3 USOC Tasks and Responsibilities

The tasks for which the USOCs are responsible can be summarised as follows:

- eisseminate information and data on the facility/equipment under their responsibility, for the sake of increasing the knowledge by the scientific community of the ISS and the ESA equipment;
- facility and experiment operations preparation, validation, and execution;
- payload increment planning and inputs to the overall mission/increment/partner plan;
- operations feasibility and science samples bread-boarding with the Scientific Reference Model (SRM), collecting science requirements for experiment and payload upgrades;
- scientific experiment preparation and operation validation on SRM/EM (Engineering Model) including validation of payload increment timelines, increment procedures and payload data base;
- consolidated planning in coordination with Industry for ground model utilisation (SRM/EM/EGSE) for increment preparation;
- provision of science/sample based parts to experiment safety data packages, experiment qualification and validation testing, experiment ground and launch site processing;
- update of the Payload Operations Data File (PODF), operations scenarios with associated centres, validation and interface testing of ground segment (in particular with the Columbus Control Centre [Col-CC]), experiment ground operations products for launch items;
- experiment training requirements and procedures, astronaut training support for experiment operations (including instructors), familiarisation of scientists;
- ground rules and constraints, issue of planning and re-planning requests, inputs to short-term-plan, timeline and ground data flows;
- real-time operations management and re-planning for payload and experiment execution,

Table 7-24: Assignment of USOCs to Payloads

FACILITY	FACILITY RESPONSIBLE CENTRE (FRC)	SUPPORTING USOC
Pressurised Rack Level Facilities (Class 1)		
BIOLAB	MUSC (Cologne)	BIOTESC (Luzern)
EDR	MUSC (Cologne)	
EPM	CADMOS (Toulouse)	
FSL	MARS (Naples), transferred to B-USOC (Brussels) in 2014	E-USOC (Madrid)
MARES	CADMOS (Toulouse)	
Pressurised Sub-Rack Level Facilities (Class 2)		
EMCS	N-USOC (Trondheim)	
EML	MUSC (Cologne)	
MSL	MUSC (Cologne)	
PFS/PPFS	DAC (Odense)	
PK-4	CADMOS (Toulouse)	MUSC (Cologne)
External (Unpressurised) Facilities		
SOLAR	B-USOC (Brussels)	
ACES	CADMOS (Toulouse)	
ASIM	B-USOC (Brussels)	

payload team co-ordination, flight anomalies reporting, console logs, payload data processing, ground based (parallel) experiments on SRM/EM;
- configuration control of experiment ground models (e.g. ground experiment containers), SRM configuration control.

7.9.4 ESA Payload Data Centre

The ESA Payload Data Centre has been active for operations since September 2014.

The main goals of the Payload Data Centre (PDC) are:

- centralise server functions and maintenance to provide implementation flexibility;
- virtualize the physical decentralized servers;
- re-balance workstation vs. server performance to provide the users an enhanced system for an improved operational usage;
- unify UHB (User Home Base) Terminal and workstation user functions and security scheme to allow secure connectivity.

Currently, all ESA ISS Science data is required to be stored locally at each USOC site, which in many cases uses the existing servers. The PDC will provide the mechanism to request/access/store all science data in one centralized/redundant archive with access rights based on user credentials. Users can request access to science data via the payload responsible USOC.

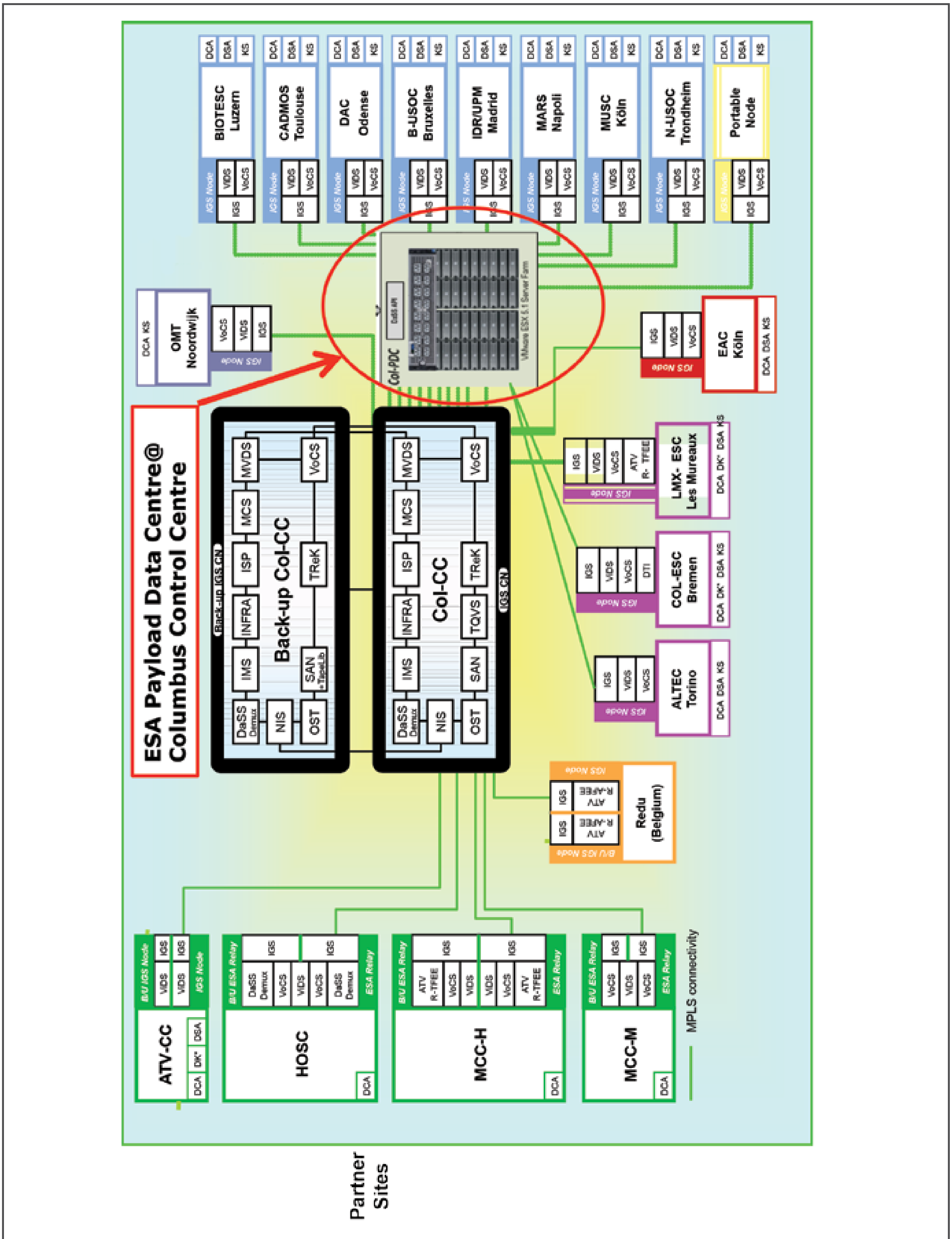


Figure 7-42: Graphical structure of ESA Payload Data Centre

7.10 Product and safety assurance

Like in no other space project, developers of microgravity payloads have to deal with a wide variety and combination of environments. The payloads have to survive ground and launch, space external or pressurised environments. They have to be light, compact and reliable in order to be stored and operated in the existing facilities on board the ISS, and sometimes returned to ground for scientific or logistic purposes. They are often developed with relatively limited budgets and in a short time in order to meet ISS Utilisation time lines. These aspects have a deep influence on the development of microgravity payloads and they have been reflected in the Agency's Product Assurance (PA) approach for Microgravity payloads. A set of modular PA requirements have been tailored to cover all possible mission scenarios. Materials and processes requirements have been tailored in consideration of all possible mission types. For example, fluid compatibility, fungus resistance and ageing phenomena are more relevant to long duration missions, whereas out-gassing and resistance to UV or atomic oxygen are important for ISS external payloads.

Based on self-standing modules of the European Cooperation for Space Standardization (ECSS) mission-tailored requirements, the current approach has been successfully applied in the development of ESA microgravity payloads since 1995. It consists of a number of basic Quality and Product Assurance requirements (GPQ-10 "Product Assurance Requirements for Payload Projects"). These basic requirements are systematically applied to each payload development activity and are complemented with a "module" of requirements depending on the mission type. The modules cover the requirements for materials, safety, reliability and maintainability. They are called Project Specific Annexes (PSA). Each PSA is specific to a certain mission type and it is made applicable in Statements of Work. Mission types are defined based on the following criteria:

- mission duration, ranging from years (long) to minutes of microgravity (very short);
- mission on board inhabited modules (ISS) or automated systems (e.g. Sounding Rockets);
- mission environment: pressurised or exposed to space (e.g. ISS external payloads);
- payload size and type: facilities (ISS payloads providing support functions to a number of experiments) or individual experiments.

This modular approach suits the large number of projects and their differences well. In this respect, consistency of implementation across the projects is considered of paramount importance.

7.10.1 Materials and mechanical parts

The selection of materials and mechanical parts is driven by reliability and safety. Materials are selected from those that are proven to withstand the mission environment without unacceptable degradation. Requirements for materials vary depending on the type of mission. Requirements that apply to materials selection are:

- stress corrosion (metallic materials used in structural applications);
- off-gassing (organic materials in inhabited modules);
- toxicity (particularly relevant to Safety);
- out-gassing (materials exposed to vacuum);
- radiation (for long duration missions);
- flammability (materials used in human spaceflight missions);
- other requirements such as chemical compatibility, for fluidic systems or experiment hardware, or moisture and fungus growth, for long duration missions in inhabited modules, apply to specific cases.

The applicable requirements for Materials and Safety are defined in the following documents:

- GPQ-010-PSA-101 "Safety and Materials Requirements for ESA Payloads on ISS";
- GPQ-010-PSA-106 "Safety and Materials Requirements for ESA Payloads on ISS (Space-exposed Payloads)";
- GPQ-010-PSA-111 "Safety and Materials Requirements for ISS Payloads (Short/Medium Duration Missions)".

7.10.2 Commercial, aviation and military equipment

Scientific experiments often require the use of a large variety of equipment to perform specific functions. Such equipment can be for example Peltier elements, data acquisition cards, video cameras, x-ray sources, portable computers etc. This equipment cannot be specifically developed for microgravity applications. Instead, it has originally been developed and qualified for non-space applications and manufactured according to sound industrial practice. It falls within the definition of Commercial, Aviation and Military equipment (CAM). CAM equipment, widely used in microgravity payloads, is subjected to a number of verifications involving engineering assessments, testing and inspections, the extent of which depends on the mission duration and whether it is used to perform reliability-critical functions or not. In any case, CAM equipment cannot be used to perform safety critical functions.

7.10.3 Reliability and maintainability

While Safety remains a top priority for microgravity payloads, reliability and maintainability are also considered essential for the success of a mission. ESA's Reliability and Maintainability approach for facility class payloads can be summarised as follows:

- equipment that may potentially malfunction should be designed as on-orbit replaceable unit;
- facilities are designed to be able to detect, isolate failures at ORU level and verify system recovery;
- the likelihood of malfunctions that cannot be recovered through on-orbit maintenance is minimised by design, for example in terms of quality levels of Electrical, Electronic, Electromechanical (EEE) components, and by applying Quality and Product Assurance methodologies such as selection of qualified processes, traceability of parts and materials, inspections etc.;
- external payloads are designed to be maintenance-free on-orbit. Quantitative reliability targets are used to guide the payload design.

The reliability and maintainability requirements applicable to facility class payloads and external payloads are, respectively:

- GPQ-010-PSA-102, "Reliability and Maintainability for ESA Research Facilities on ISS";
- GPQ-010-PSA-107, "Reliability and Maintainability for ESA Payloads on ISS (On-orbit non-maintainable)".

ESA's Reliability and Maintainability approach for experiment class payloads is based on:

- the prevention by design of failure propagation outside the experiment;
- risk of on-orbit malfunction minimised by design (e.g. selection of EEE parts) and by applying Quality and Product Assurance methodologies;
- limited on-orbit maintenance.

The Reliability and Maintainability requirements applicable to experiment class payloads are detailed in:

- GPQ-010-PSA-103, "Reliability and Maintainability for ESA Research Payloads (Short/Medium Duration Missions)".

ESA's Reliability and Maintainability approach for very short mission duration, such as Sounding Rockets, consists of the application of Quality and Product Assurance methodologies as detailed in GPQ-010 "Product Assurance Requirements for Payload Projects", and of aerospace industrial processes as well as industrial best practice. As Sounding Rockets missions are suborbital missions no space requirements (e.g. for radiation, out-gassing, hi-rel EEE parts) are applied to parts and materials.

7.10.4 Safety assurance

Safety Assurance is an important area under the Microgravity Product Assurance Manager's responsibility. It has the main objective of verifying that the final product is as safe as it should be by design. Typical Safety Assurance activities involve performance hardware inspections to check as-built configuration and workmanship aspects which are relevant for safety such as sharp edge inspections, and supports the safety verification activities.

ESA requirements for microgravity payloads can be found on the Microgravity Product Assurance and Safety Office webpage **paso.esa.int**

For further information regarding Product and Safety Assurance of microgravity projects, users should contact the ESA Microgravity Product Assurance responsible:

Giancarlo Bussu
ISS Utilisation PA&S Office (HSO-UQ)
ISS Utilisation and Astronaut Support Department
European Space Agency
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands
Tel: +31 71 565 3140
Fax: +31 71 565 6132
E-mail: giancarlo.bussu@esa.int

7.11 ISS safety

The payload safety certification process is aimed at ensuring that the payload does not endanger the crew, the ISS, the transportation vehicle/launch vehicle, ground personnel or ground facilities, or any other payload. Successful completion of the associated safety reviews is mandatory to achieve certification of the payload for flight.

The user is responsible to implement the safety programmatic and technical requirements and to document compliance. The safety programmatic requirements are defined in the GPQ documents and in SSP 30599 "Safety Review Process". Safety analyses, including definition of hazard categories, shall be implemented as required by SSP 30599.

As a guideline users should also refer to NSTS/ISS 18798 Rev B, "Interpretation of NSTS/ISS Payload Safety Requirements".

The Hazard Report form provided in SSP 30599 shall be used to document hazard control measures and verifications, as necessary.

The payload safety technical requirements are defined in SSP 51700 , "Payload Safety Policy and Requirements for the International Space Station. Structural designs shall comply with SSP 52005, "Payload Flight Equipment Requirements and Guidelines for Safety Critical Structures".

Hazard identification and relevant controls must be identified and described in (Ground and Flight) Safety Data Packages. These packages are prepared by the user (or payload developer), with the assistance of the ESA Safety and Product Assurance Office, and submitted for assessment to the safety review process.

Individual payload safety certification reviews are closely associated with the payload design and development milestones. There are three levels of review termed 0, I, II and III, and their development and delivery schedule is linked to the Preliminary Design Review, Critical Design Review and Preliminary Acceptance Review, respectively. During these reviews, the user (or payload developer) presents a brief description of the payload, support equipment and operation, followed by data that is unique to the particular level of review. The depth of the review depends upon the complexity, technical maturity and hazard potential of the payload.

7.11.1 Safety reviews

The schedule of safety reviews shall be established by the Project Master Schedule approved by ESA, in compliance with the requirements in SSP 30599 "Safety Review Process". Post Phase III Safety Verifications Process shall be completed at least 30 days prior to delivery of flight hardware and/or ground support equipment (GSE). The detailed submittal schedule of safety data packages shall be established by the relevant project review plan. In consideration of the importance of safety both in terms of design compliance with safety requirements and product conformity to the design, the user shall take full responsibility for the following activities:

- preparation of Flight and Ground Safety Data Packages (SDP) of good quality and their presentation at Safety Reviews.
- corrective measures or action items identified as necessary by the safety review panel shall be readily implemented;
- performance of the complete safety verification process, including checking and approval of analysis carried out at lower integration level and verification of product conformity to the design and approved configuration. In particular, the user's PA and Safety Organisation shall witness and/or check the safety-related tests and inspections performed either internally or at lower integration level, to ascertain adherence to the requirements, implementation of prescribed conditions and acceptability of results;
- preparation and submittal of Fracture Control Plan and Structural Verification Plan in accordance with SSP 52005 and ECSS-EST-32-01C (or latest revision),, "Fracture Control". Delivery at Safety Review Phase III of a Fracture Control Report;
- all safety-related tests (e.g. flammability, off-gassing, out-gassing, etc.) shall be performed at facilities acceptable to ESA;
- the payload design shall allow safe maintenance on ground;

- the ground SDP shall cover flight hardware, GSE and planned ground operations at launch and landing sites. The Ground Safety Data Package shall also cover ground safety for any other site where it is planned to operate the flight hardware and/or its GSE after acceptance by the Agency;
- performance of the safety assessment of units/ models to be operated on ground (e.g. ground unit) and demonstration of compliance with safety regulations that apply at the site of use.

All the ECSS series of documents referred to in the previous paragraphs can be downloaded from the European Cooperation for Space Standardisation (ECSS) website. (**http://www.ecss.nl**)

For any further information regarding safety aspects, users should contact the ESA ISS Safety Responsible:

Rosario Nasca
Independent Safety Office (TEC-QI)
Product Assurance and Safety Department
European Space Agency
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands
Tel: +31 71 565 4935
Fax: +31 71 565 6839
E-mail: Rosario.Nasca@esa.int

7.12 ISS utilisation and payload planning

The planning includes all the preparation activities in which the user's research objectives are defined and coordinated with other research payloads and the ISS systems and operations, as well as the ISS multilateral processes in place today.

Before discussing the ISS planning process, it is important to be familiar with the terms that are used to reference planning timeframes. These terms are as follows:

- Increment (I) - a period of time that spans between two consecutive returns of Soyuz vehicles, serving as crew-tended vehicles. Soyuz vehicles are qualified to remain docked to the ISS for a period of 6 months, and can carry up to 3 crew members. With the current ISS logistics and corresponding Soyuz vehicles rotations, one gets Increments of 2 months and of 4 months.
- Planning Period (PP) - this period spans approximately 1 calendar year, but is tied to the ISS increments as defined above, the ISS Planning periods cover periods between European spring to fall and European fall to spring. Each planning period includes a sequence of 4 Increments, 2-/4-/2-/4-month periods.
- Expedition - an ISS Expedition is defined as the period during which a given Soyuz vehicle is launched, docked to and returned from the ISS. Thus it corresponds to the on-orbit duration of a given set of crew members sharing the same Soyuz vehicle. Per Soyuz qualification, this corresponds to approximately 6-months.
- Launch (L) – as it suggests, this refers to the day of launch of a payload.

The ISS planning cycle is made up of four phases:

- multi-increment planning (or strategic planning);
- tactical planning;
- pre-increment planning;
- increment execution planning (or execute level
- planning).

7.12.1 Multi-Increment planning

Multi-increment planning (also referred to as strategic planning) provides the long-range planning for the ISS Programme and begins approximately one year prior to the release of the Consolidated Operations and Utilisation Plan (COUP). The COUP document is a 5-year plan for the United States On-orbit Segment (USOS) community of the Space Station. This planning document compares the capabilities of the Space Station with utilisation objectives of NASA, JAXA, CSA and ESA planned for the ISS in the long-term future. The planning process begins by performing integrated traffic planning to define the transportation support to the ISS for crew support, maintenance and logistics, utilisation, and consumables re-supply of the ISS. This information is combined with the PP resources, supporting services, and accommodation capabilities of the ISS to develop the Operations Summary Document (OSD). The OSD serves as the basis for the development of the Composite Operations Plan (COP) and the Composite Utilisation Plan (CUP). The COP and CUP are then used to develop the COUP. In summary, for each Planning Period the COUP establishes the amount of resources and accommodations allocated and subscribed to each system and each Partner for utilisation. It also reflects the planned amounts of supporting services from other programmes that are available and subscribed. The COUP also provides specific direction and guidance to tactical planning regarding COUP implementation. The COUP includes a high-level manifest of major items planned for each planning period and is written by the ISS Programme Office. This document finally provides a feedback loop in form of a comparison between actual accomplishments for the just-finished Planning Period of ISS USOS activities and the previous strategic predictions for the same Planning Period.

7.12.2 Tactical planning

Tactical planning and manifesting is performed per Increment pair, i.e. a sequence of one 2-month Increment and one 4-month Increment. The multilateral process nominally begins 1.5 year prior to the start of an Increment pair. Tactical planning and manifesting is a multilateral process, which defines the resources, allocations, research objectives, priorities, and manifests for each Increment pair and ISS Expeditions crews. It also continues the integrated traffic planning begun in the

multi-increment planning phase. These requirements are documented in the Flight Programme (FP) and the Increment Definition and Requirements Document series and annexes for a specific increment.
The FP defines the ISS tactical programme content and flight definition required to allow consistent planning and resource control. It also documents ISS FP definition history.

The Increment Definition and Requirements Document (IDRD) for Increment X, defines Increment pair boundary conditions, resources and requirements as well as flight and stage objectives. This document also consists of several annexes including Annex 1: Station Manifest, which contains the detailed manifest for all transportation vehicles in the increment; and Annex 5: Increment X Payload Tactical Plan, which provides the Increment Definition and Requirements Document (IDRD) used to provide programme direction and initialise development of the cargo/payload integration and execution planning products.

7.12.3 Pre-increment planning

The pre-increment planning process begins around 12 months prior to Increment pair start and takes the increment requirements and mission objectives as defined by the relevant Increment Definition and Requirements Document (IDRD), and translates them into a number of timelines which govern the on-orbit and on-ground activities associated with a particular increment.

The initial phase of pre-increment planning is the Basic planning cycle, which occurs from I-12 months to I-6 months. The Basic cycle places emphasis on the initiation and integration of operations planning for payloads. The last phase of pre-increment planning is the Final planning cycle, which occurs from I-6 months to I-1 month. The Final cycle places emphasis on the integration of payload and systems operations planning.

The main product of the pre-increment planning process is the On-orbit Operations Summary (OOS), which is a high-level activity plan for an entire increment. High-level activities are planned for a specific day of the increment but are not (yet) scheduled for a specific time on that day. The OOS establishes the basis from which actual distribution of ISS resources is to be made by providing expected resource availability and environmental conditions throughout an increment, and by identifying constraints and critical events or time periods during an increment. The OOS is also the foundation for the development of the detailed schedules produced during the increment execution planning process.

7.12.4 Increment execution planning

The increment execution planning process (also known as execute level planning) begins 1 month to 3 weeks before the start of an Increment pair and consists of three phases:

- short-term planning;
- real-time planning;
- real-time re-planning.

7.12.4.1 Short-Term planning

This is the process through which weekly and daily schedules of systems and payload operations activities are developed and, if necessary, the long-range plan of activities through the rest of the Increment pair is updated. It is performed by an international team of systems and payload planners. The schedule developed during this process is used to define in detail the activities to be performed during the planning cycle. The long-range plan, which, if necessary, is updated during this process, is used as the basis for generating future detailed plans, and covers the time frame from the end of the next detailed schedule through the end of the increment.

The main products of short-term planning are the Weekly Look-ahead Plan (WLP) and the daily Short-Term Plan (STP). The WLP is the detailed integrated schedule of activities to be performed during one week of Station operations. The WLP includes all ISS activities, including International Partner (IP) systems and payload activities. The WLP is then further refined into daily schedules called STP. In addition to crew activities, STP timelines also include automated onboard activities and ground controller activities, as well as ancillary data such as Station attitude and communications coverage data. Activities in the STP include all the information necessary for execution, including a reference to the procedures associated with each activity. The STP is developed the week prior to its execution and is based on the OOS that was developed during the pre-increment planning phase, as well as the WLP. Development of the STP is performed by a team called the International Execute Planning Team, which consists of planning personnel from the IPs.

7.12.4.2 Real-time planning

This is the process through which the onboard and ground detailed schedules are developed. It is performed by the international team of systems and payload planners. The detailed schedules developed during this process are used by the ground crew, the onboard crew, and automated systems to identify and control the segment-specific and station-wide payload and systems activities to be performed during the planning cycle. This process generates the Onboard Short-Term Plan (OSTP), which is the integrated plan that is viewed and executed onboard the Station. Since it is derived directly from the STP, the OSTP contains all activities to be executed, including crew, ground, and automated activities for the IP segments. Uplinking of new activities to be included in the OSTP occurs daily.

7.12.4.3 Real-time re-planning

This the process through which the detailed schedules are updated in real-time to reflect desired or required changes to systems or payload operations. It is performed by the on-console teams in the Space Station Control Centre (SSCC), the Payload Operations Integration Centre (POIC), the IP Control Centres and the Russian TsUP Control Centre. The detailed schedules developed during real-time planning are updated by the real-time re-planning process in response to required or desired changes. Updates to the schedule will be performed on a 365/24/7 basis to maintain a safe and functional ISS or in response to desired payload operations changes.

7.13 Legal aspects

This section summarises the main legal issues concerning the utilisation of the International Space Station.

7.13.1 Legal framework

7.13.1.1 General principles

Space law regulates the conduct of the activities of humankind in outer space by both governments and private individuals. Generally speaking, the law of outer space can be divided into two interactive areas:

- the international space law, which governs the activities of states and international intergovernmental organisations;
- the national space law, which governs the activities of individual countries and their nationals.

Since the establishment of the United Nations Committee on the Peaceful Uses of Outer Space in 1958, five major international treaties and conventions have been negotiated and ratified by countries around the world. A growing number of bilateral and multilateral treaties also address space activities.

One of the most important principles of space law is the fact that no part of space is subject to national appropriation. The United Nations space treaties specifically declare space to be open to all countries, similar to the high seas or the deep seabed. This means, in effect, that no one can own any portion of space.

Another important principle of space law provides that any object sent into space (e.g. launcher, station parts, etc.) keeps the nationality of its owner. Each Soyuz for instance, is registered as a Russian object each time a Soyuz is launched.

In the case of the International Space Station, we have a unique assemblage of national objects in space. The American components of the station (e.g. Destiny laboratory) are linked with European, Russian, Canadian and Japanese components, all of which will keep their nationality, according to international space law.

7.13.1.2 Space Station agreements

The five Space Station Partners - who are the United States, Europe, Canada, Japan and Russia - have come up with a unique legal framework to work together while protecting each other's interests. They have not created a new set of laws applying in outer space, they have rather made links between the Station and their territory so as to authorise the application of their national law to a given situation. The Space Station Partners have created three different types of agreements:

First, the governments involved in the Space Station project have signed an international treaty on 29 January 1998, formalising their participation. The Space Station Intergovernmental Agreement often referred to as "the IGA" establishes "a long term international co-operative framework on the basis of genuine partnership, for the detailed design, development, operation, and utilisation of a permanently inhabited civil Space Station for peaceful purposes, in accordance with international law" (Article 1). The Intergovernmental Agreement is the main legal document concerning the International Space Station. It creates a unique legislative regime, constituting a set of rules, which recognise and link the national jurisdiction of the Partner States on the Space Station. National laws can therefore be applied to a given situation, in such areas as liability issues, the protection of intellectual property rights, the exchange of goods and data and even criminal matters.

A second level of agreements in the Space Station legal framework involves the space agencies of the participating governments. The governments who have signed the Space Station Intergovernmental Agreement have delegated responsibilities to their respective space agencies to do the actual co-operative work of building, operating and utilising the Space Station. NASA as the Space Station coordinator, has signed bilateral agreements with each co-operating Agency (ESA – representing Europe, CSA – representing Canada, RKA now Roscosmos – representing Russia, and NASDA now JAXA – representing Japan). These four bilateral agreements, called Memoranda of Understanding (or "MoU"), describe in detail the roles and responsibilities of the agencies in the design, development operation and utilisation of the Space Station. In addition, those documents serve to establish the management structure and interfaces necessary to ensure effectively the operation and utilisation of the Space Station. The space agencies have also agreed to use, when necessary, barter agreements. These bilateral agreements allow the exchange of Space Station resources between the Partners under certain conditions.

Finally, the co-operative space agencies have created a third level of Space Station agreements. This level is constituted by various bilateral implementing arrangements between the space agencies, which have been created to implement the Memoranda of Understanding. They distribute concrete guidelines and tasks among the national agencies.

7.13.1.3 Extension of national jurisdiction to the Space Station

As mentioned above, international space law provides that any object sent into space (e.g. launcher, station parts, etc.) keeps the nationality of its owner. For the Space Station the jurisdiction relating to the activities conducted on the Station is determined by the nationality of the module in which the activity takes place. Basically, the Intergovernmental Agreement allows the Space Station Partner States to extend their national jurisdiction into outer space, so the elements they provide (e.g., laboratories) are assimilated into the territories of the Partner States.

The basic rule is that "each partner shall retain jurisdiction and control over the elements it registers... and over personnel in or on the Space Station who are its nationals" (Article 5 of the Intergovernmental Agreement).

This means that the five owners of the Space Station are responsible for the respective elements they provide. The extension of the national jurisdiction of the countries they represent, determines what laws are applicable for activities occurring on their elements of the Space Station (e.g. American law in the American Destiny module). The European Partner States are being treated as one homogenous entity, called the European Partner on the Space Station. But any of the European Partner States may extend their respective national laws and regulations to the European elements, equipment and personnel.

7.13.2 Intellectual property

7.13.2.1 Protection

One of the most delicate legal matters concerning the utilisation of the Space Station is the protection of intellectual property rights. The main objective of the Space Station Partners concerning property rights is to avoid the infringement of rights owned by another Partner or their affiliates (e.g., industrial contractors, customers).

In order to mitigate the risk of potential infringement, the Space Station Partners have agreed to create specific marking procedures to protect the proprietary and confidentiality of each other's data and goods. But the Space Station customers should be aware that those procedures have to take into account the obligation the Partners have to exchange specific technical data and goods, when necessary, to operate and utilise the Space Station in a safe manner (Article 19 of the Intergovernmental Agreement). Therefore, each space agency and its affiliates - any industry or academic institution under contract - have the obligation to mark their technical data or goods with a notice that indicates any specific conditions regarding how those data or goods may be used by other agencies, their contractors and subcontractors.

Basically, a Space Station customer under contract with the European Space Agency has the right to confidentiality and will benefit from the marking procedures. The rules take also into account the protection of third-party intellectual property rights. Any third party proprietary data, which may be required in order for the Partners to carry out their responsibilities, or which may be derived from an experiment, will also be properly marked and protected. The following guidelines have been agreed on by the Partners in order to protect intellectual property rights:

Space transportation: each Partner has to respect the proprietary rights and the confidentiality of properly identified and appropriately marked data and goods to be transported on its space transportation systems (e.g., Soyuz) (Article 12 of the Intergovernmental Agreement)

Communications: Each Partner has to respect the proprietary rights of the utilisation data passing through its communication systems, including its ground network and the communication system of its contractors, when providing communication services to another Partner (Article 13 of the Intergovernmental Agreement).

Regarding crew, a “Crew Code of Conduct” has been agreed on by the Partners in September 2000. It sets specific rules and a chain of command for the astronauts and cosmonauts of International Space Station crews. Some specific regulations concerning the handling of data and goods by the astronauts have been included in the Code of Conduct, which contribute to protect the intellectual property rights of Space Station customers. According to the Code of Conduct, crew members are required to:

- protect marked proprietary data;
- limit the use and disclosure of any technical data and goods to the purpose of performing their assigned tasks;
- use confidential information obtained in the course of performing their duties only for official purposes and not to further private interest.

If anyhow an infringement of intellectual property were the cause of a claim for damages, legal proceedings would have to be taken against the infringing party. Those claims would be made according to the current international regime for intellectual property and the respective contractual arrangements made between the space agencies and their customers. Because of the particular situation of the European Partner, and to prevent simultaneous claims in multiple European countries, it is provided in the Space Station legal framework that:

- *if* an infringement of intellectual property rights relating to a European Space Agency-registered element occurs *and* the owner of that intellectual property has protected his rights in multiple European countries (e.g., through patent and licences), *then* the owner may not recover in more than one European State for the same act of infringement (Article 21 of Intergovernmental Agreement).

7.13.2.2 Ownership and exploitation

In order to conduct activities using the facilities offered by the Space Station, a contract will be established between the users and the European Space Agency. The ownership of the invention and the type of licensing of any intellectual property - data or product - resulting from the Space Station utilisation will be dependent on the contractual framework.

Generally, the European Space Agency, as an international organisation financed by public funding, is responsible for securing rights for inventions resulting from the contracts it places, and is also responsible for disclosing its own invention to Members States (Article III of the European Space Agency Convention). Therefore whenever an experiment is performed through a contract with the European Space Agency, participants have usually specific obligations concerning patents and licensing issues.

Two main Agency regulations concerning intellectual property that may apply to Space Station customers are:

- ownership of invention: A contractor (e.g., European customer under contract with the European Space Agency) is deemed to be the owner of any invention made in the course of or resulting from work undertaken for the purpose of an ESA contract. He shall be entitled to protect his invention, generally by filing for a patent (Article 37.1 of the General Clauses and Conditions for European Space Agency Contracts);
- licensing: The European Space Agency and its Member States (or Participating States) are entitled to a free of charge, non-exclusive irrevocable licence to use the invention for their own requirements in the fields of space research and technology and their space applications, and are allowed to grant sub-licences for these purposes within the territory of the Member States (or Participating States). (Article 37.2 of the General Clauses and Conditions for European Space Agency Contracts).

Therefore, the ownership of the data resulting from work done on the Space Station and the possibility to get exclusive licenses will be defined by the specific collaboration scheme agreed on by the European Space Agency and its customers.

In the event an invention occurs on the Space Station, the country of inventorship will be determined by the ownership and registry of the Station's element in which the invention has taken place (Article 21 of the Intergovernmental Agreement). For example, an invention made on a US element (e.g., Destiny Laboratory) will be deemed to have occurred in the United States.

This does not impact the ownership of the invention, nor does it preclude the right to file for a patent in multiple countries. An inventor may file for a patent in any country he chooses. For example a European researcher inventing a process resulting from his experiment in the Destiny Laboratory (= American territory), may file for a patent anywhere in the world to protect his invention. The purpose of the territorial approach (e.g., American components of the Station = United States territory) is only to determine the location and country where the invention took place.

With respect to the European elements (e.g., Columbus Laboratory), any European Partner State may extend its national law to the European elements and elect to deem the activity to have occurred within its territory. In theory, an invention occurring in the European Laboratory could then be deemed to have occurred in France or Germany. An inventor having used the European Columbus Laboratory facilities may file for a patent anywhere in the world to protect his invention, but he will need to choose one of the European Partner States' territories to determine where his invention originally took place.

7.13.2.3 Liability

Whenever an incident occurs in any field, it is important to be able to determine the responsibilities of the actors involved. Some international legal texts already edict fundamental liability rules concerning space activities (i.e., Liability Convention, 1972), but the Space Station legal framework itself goes a bit further.

The Intergovernmental Agreement establishes a "cross-waiver of liability" which prohibits any of the five Partners or their related entities (contractor, subcontractor, national) to claim against another Partner (or its related entities) for damage sustained as a result of International Space Station activities (Article 16 of the Intergovernmental Agreement).

Each Partner is required to implement this obligation in the contracts with its own contractors and subcontractors. Basically, each Partner and its affiliates, including customers, should assume its own losses with a few exceptions, such as patent infringement.

Any claims arising between a Partner State and its own related entities, will be covered by contracts or subcontracts that will not implicate the other International Partners.

In practice, the Space Station customers will be asked to agree to an inter-party waiver of liability as part of their contract with the European Space Agency, stating that each party will not bring claims in arbitration or sue the other party as a result of International Space Station activities.

In any case, issues such as the applicable law for disputes and the detailed procedures in case of arbitration will be decided mutually by the Space Station customers and European Space Agency. The contract will specify the country where the Arbitration Tribunal shall sit, normally in the country where the customer has his legal seat or where the contract is to be executed.

7.13.2.4 European Space Agency Human Spaceflight data policy

In line with the Resolution on Information, Data and Intellectual Property (ESA/C/CLV/Res. 4 [Final] of December 2001) the Data Policy makes a distinction between:

- raw and calibrated data, resulting from the
- implementation of the experiments; analysed data, produced by either the investigator or the Agency;
- commercial projects.

In the event that the the experiments or commercial projects are implemented on a flight opportunity or a ground facility not belonging to the Agency, the Agency may enter into arrangements with the supplier of the flight opportunity or the ground facility for the implementation of the experiments or commercial projects respectively. In such cases the Agency shall make its best efforts to negotiate conditions set forth in this data policy. In the case that such arrangements are of a cooperative nature involving cost sharing between the parties, the Agency may also negotiate the sharing of the resulting data.

In the case that the flight hardware for an experiment, implemented on an Agency flight opportunity, is provided in part or in full by the investigator or an organisation such as a national space agency, the Agency and the investigator or organisation which provides the flight hardware, shall enter into an arrangement setting out their respective rights and obligations in line with this data policy.

The Agency will ensure that the access to, and storage of, the raw and calibrated data and the analysed data will follow the appropriate rules in case of restrictions such as confidentiality and propriety rights (e.g. for medical data).

7.13.2.4.1 Raw and calibrated data, resulting from experiments

Raw and calibrated data in the context of this data policy are defined as information, data and samples obtained as a direct result of the implementation of the experiment delivered or transmitted in any form of carrier, including: photo materials; films; audio and video tapes; samples (e.g. biomedical or physical materials); diskettes; and telemetry data. Such data will be provided to the investigator for analysis and for publication of the scientific results of the experiment.

The raw and calibrated data are governed by the provisions detailed below:

Ownership and use by ESA

The Agency shall be the owner of all the raw and calibrated data directly resulting from the experiments implemented in the frame of the Human Spaceflight, Research and Applications Programme Board (ESA/PB-HSR) Programmes.

The Agency shall be entitled to use the raw and calibrated data resulting from the experiments for its own purposes in the field of space research and technology and their space applications.

The ownership of raw and calibrated data, as well as exclusive access to, use of and the right to disseminate data resulting from experiments related to applications proposals from industry, including those forwarded by the Participating States directly, may remain with the industry concerned if deemed necessary by the industry and considered, by the Programme Board, to be essential for the promotion of industrial utilisation of the ISS.

Intellectual Property

In the event that it is legally possible to protect the raw and calibrated data, the Agency shall be entitled to protect the raw and calibrated data directly resulting from experiments through any form of Intellectual Property title that may be appropriate to protect such data. In the event that an Intellectual Property title is obtained by the Agency, Participating States and persons and bodies under their jurisdiction shall be entitled to free of charge, non-exclusive and non-commercial access and use.

Prior access

The Agency shall grant the investigator an exclusive right of prior access to the raw and calibrated data.

The duration of the exclusive right ("Period of Prior Access") shall be one year from the provision by the Agency of the data to the investigator in a form suitable for analysis.

The exclusive right of prior access shall be granted to the investigator under the condition that the investigator shall:

- undertake to furnish the Agency with an analysis of the results obtained and shall take all reasonable steps to publish such results or, alternatively, shall authorise the Agency to do so (such publication shall include a suitable acknowledgement of the services afforded by the Agency); and
- provide the Agency, free of charge, with an agreed number of copies of the publication and, notwithstanding the provisions of the paragraph above, the Agency shall have the right

to reproduce and disseminate results that have already been published.

Any change to the duration of the Period of Prior Access shall be dealt with in accordance with section Exceptions, taking into account, inter alia:

- the extent and nature of the involvement of the investigator in the development of the experiment;
- the type and complexity of the data to be received from the experiment.

Access

Participating States, or persons or bodies under their jurisdiction, may request access to the raw and calibrated data from the Agency. The Agency shall grant such access on the following conditions:

- the access shall commence upon the expiry of the Period of Prior Access;
- the investigator may express his views on the conditions on which such parties may be granted access to the raw and calibrated data, for the Agency's consideration and decision; however, unless there are specific reasons of commercial interest, such conditions should normally provide for unrestricted access; and
- the access to, and dissemination of, the raw and calibrated data, shall, in principle, be subject to the payment of the cost for the copying and other administration fees reasonably incurred by the Agency for the dissemination of such raw and calibrated data, the Director General of the Agency shall have the right to waive such fees.

Persons or bodies under the jurisdiction of other Agency member states may request from the Agency access to the raw and calibrated data. Any such access to the raw and calibrated data shall be subject to the conditions to be determined by the Participating States, with due consideration for the views expressed by the investigator. Unless there are specific reasons of commercial interest, acceptable to the Participating States, such conditions should normally provide for unrestricted access.

Access to the raw and calibrated data by persons or bodies under the jurisdiction of non-member states or by international organisations shall be given consistent with the relevant provisions of applicable arrangements concluded by the Agency, and taking into account the conditions to be determined by the Participating States, with due consideration for the views expressed by the investigator.

Commercial use

The commercial use of the data resulting from experiments may be allocated by the Agency to third parties, on conditions to be approved by the Participating States to the applicable HSR Programme. Such conditions shall take account of any investment made, or to be made, by a third party and shall afford the necessary protection to any Intellectual Property created by the third party at its own expense. Any such commercial use shall be dealt with as a commercial project described below.

Storage

The Agency shall take the necessary actions, subject to budget availability and feasibility constraints (e.g. biological samples), to arrange for the storage of the raw and calibrated data for a period of ten years or such additional period as the Agency may deem necessary and in line with applicable laws and regulations. The Agency will ensure storage in an appropriate manner, as required by the nature of the data (e.g. biological samples), implementing the applicable policies.

The Agency shall ensure that the Participating States or persons or bodies under theirjurisdiction have access to the stored raw and calibrated data. In that respect, the Agency will maintain a database in the Erasmus Experiment Archive ("EEA"), the former Agency Microgravity Database ("MGDB"), which will contain the main characteristics of the experiments and data.

The Agency will provide to the User Support and Operations Centres (USOCs) the means to process, store and to provide access to raw and calibrated data from ISS utilisation.

7.13.2.4.2 Analysed data, resulting from experiments

Analysed data in the context of this data policy shall mean the information and data produced by the investigator or the Agency, based on, and after the analysis of, the raw and calibrated data. Depending on whether the investigator or the Agency produces such analysed data, different rights and obligations will be applicable to the analysed data.

The analysed data are governed by the provisions detailed below.

Ownership
- analysed data produced by the Agency;
- any information, data and Intellectual Property produced by the Agency based on, and after the analysis of, the raw and calibrated data resulting from the experiments, shall be owned by the Agency;
- analysed data produced by the investigator.

Any information, data and Intellectual Property produced by the investigator based on, and after the analysis of, the raw and calibrated data resulting from the experiments, shall be owned by the investigator, subject to the following provisions:

- the investigator shall notify the Agency of any application for an Intellectual Property title within two months from the date the application is filed and the Agency shall treat such information as confidential, as long as the application has not been published in accordance with the relevant law, or has not been published for at least a period of eighteen months from such notification; and
- the Agency shall have the immediate right to use the information and data free of charge for its own requirements in the field of space research and technology and their space applications, ensuring the non-dissemination and non-disclosure of the information and data.

Obligations of the investigator
The investigator shall:

- undertake to furnish the Agency with an analysis of the results obtained and shall take all reasonable steps to publish such results or, alternatively, shall authorise the Agency to do so (such publication shall include a suitable acknowledgement of the services afforded by the Agency); and
- provide the Agency, free of charge, with an agreed number of copies of the publication, and notwithstanding the provisions of the paragraph above, the Agency shall have the right to reproduce and disseminate results that have already been published.

7.13.2.4.3 Access and dissemination

Dissemination of Agency-owned analysed data
Participating States, or persons or bodies under their jurisdiction, may request from the Agency access to Agency-owned analysed data. The Agency shall grant such access on the following conditions:

- the investigator may express his views on the conditions on which such parties may be granted access to the Agency-owned analysed data, for the Agency's consideration and decision; however, unless there are specific reason of commercial interest, such conditions should normally provide for unrestricted access; and
- the access to and dissemination of the analysed data shall, in principle, be subject to the payment of the costs for the copying and other administration fees reasonably incurred by the Agency for the dissemination of such Agency-owned analysed data; the Director General of the Agency shall have the right to waive such fees.

Persons or bodies under the jurisdiction of other Agency member states may request from the Agency access to Agency-owned analysed data. Any such access to Agency-owned analysed data shall be subject to the conditions to be determined by the Participating States, with due consideration for the views expressed by the investigator. Unless there are specific reasons of commercial interest, acceptable to the Participating States, such conditions should normally provide for unrestricted access.

Access to Agency-owned analysed data by persons or bodies under the jurisdiction of non-member states or by international organisations shall be given consistent with the relevant provisions of applicable arrangements concluded by the Agency, and taking into account the conditions to be determined by the Participating States, with due consideration for the views expressed by the investigator.

Dissemination of publications of the investigator on experiment results

The Agency shall have the right to reproduce and disseminate publications of the investigator on experiment results.

Storage

The Agency shall take the necessary actions, subject to budget availability, to arrange for the storage of the Agency-owned analysed data for a period of ten years or such additional period as the Agency may deem necessary and in line with applicable laws and regulations.

The Agency shall ensure that the Participating States or persons or bodies under their jurisdiction have access to the stored Agency-owned analysed data.

The Agency shall also store the publications of the investigators in the EEA and shall ensure that the Participating States or persons or bodies under their jurisdiction have access to these publications.

7.13.2.4.4 Commercial projects

Commercial projects in the context of this data policy shall mean projects based on a commercial proposal that is carried out in the frame of the relevant HSR Programmes.

The commercial projects are governed by the provisions detailed below:

- the applicable Agency rules, contained in the Resolution, anticipate that commercial projects will require the conclusion of specific arrangements between the Agency and the commercial user concerned. Such arrangements will need to reflect, in particular, the parties' technical, scientific, economic and financial interests and contain corresponding provisions for the ownership, access and use of information and data and Intellectual Property resulting from the commercial project.

In this connection:

(a) the commercial user paying the totality of the utilisation costs will have the exclusive ownership, access and use of the information and data and Intellectual Property resulting from that commercial project; and

(b) in the event that the Agency partially funds the utilisation costs, or is otherwise involved in the commercial user activities, the access to and use of the information and data and Intellectual Property to be reserved for use by the Agency will be negotiated in accordance with the applicable policy, with a view to securing payment to the Agency of royalties from the exploitation of information and data and Intellectual Property or fees relating to the provision by the Agency of services or financial support.

Exceptions

In case of specific reasons of interest to the Agency or Participating States, either the Agency or the Participating States can request the Programme Board to grant exceptions to this data policy.

7.14 Payload life-cycle and major milestones

The integration process of a payload and its accompanying milestones will differ according to whether a payload flies on the Russian segment (using Russian resources) or whether it flies on the United States On-orbit Segment (USOS) (i.e. NASA, ESA, CSA, JAXA). These two processes are discussed separately in the following sections.

7.14.1 Russian segment payloads

Between 2001 and 2005, ESA has had several opportunities to fly astronauts and payloads to the ISS by means of the Russian Soyuz and Progress vehicles. In most cases, ESA payloads have also been integrated in the Russian Segment of the ISS.

There exist healthy prospects for future collaboration between ESA and Russia with regards to ISS utilisation and therefore it is necessary to provide users with a general overview of the integration process involved, which differs from that implemented in the USOS. The experience gained by ESA during collaborative missions with Russia has paved the way towards full European utilisation after the Columbus module was launched. Users must however bear in mind that the utilisation process for Russian segment payloads can be subject to minor changes on a mission-to-mission basis. See Figure 7-43 for a typical payload operational cycle.

For the most up-to-date information, please contact the European Space Agency representatives listed in chapter 2 of this guide.

7.14.2 USOS payloads

For payloads accommodated in/on the USOS (i.e. NASA, ESA, JAXA, CSA) segment of the ISS, the payload life cycle includes the following:

- payload development;
- payload integration;
- payload training;
- operations preparation and integration;
- certification of flight readiness;
- ground processing;
- on-orbit operations;
- post-flight processing.

The overall process is schematically represented in Figure 7-43 and is summarised in the following paragraphs. The figure also displays the documentation that accompanies the various reviews and milestones. Users must keep in mind that the timeline given is meant as a guide to users and that it represents a generic case: in most situations the actual milestones will vary on a payload-to-payload basis. The timelines in Figure 7-43 are given in months with respect to a an Increment (I) and the Launch (L). This particular example represents a case where the launch date coincides with the increment start date, which in turn begins 4 months after the start of the planning period.

A simplified overview of the development and integration processes is also presented in Table 7-25.

7.14.2.1 Payload development

Starting from a set of scientific requirements, documented in the ESR (Experiment Scientific Requirements), the developer team initiate the payload development, which is usually following the classical Phase A, B and C/D process, where:

- phase A is the feasibility study phase, to assess the programmatic, technical and financial feasibility of a given payload prior to submission to the relevant committee (e.g. an ESA Programme Board) to become an official ESA project;
- phase B is a more advanced study of the design, transforming conceptual ideas (feasibility study) into engineering data and design. Compatibility with the scientific requirements is better assessed and confirmed. Output of the Phase B are also the main resources necessary to operate the payload, as mass, power, data, crew interfaces;
- phase C/D is the development and manufacturing phase, with the phase C focusing mainly on the provision of manufacturing design and manufacturing of ground Unit(s) and the Phase D devoted to the manufacturing and acceptance of the flight unit(s);
- once the Phase C/D has started, the integration team can initiate the allocation of the experiment to an increment. For a complex experiment the time between start of phase C/D and actual flight, can last up to 5 years, while for a simple payload such a time can be reduced to about one year.

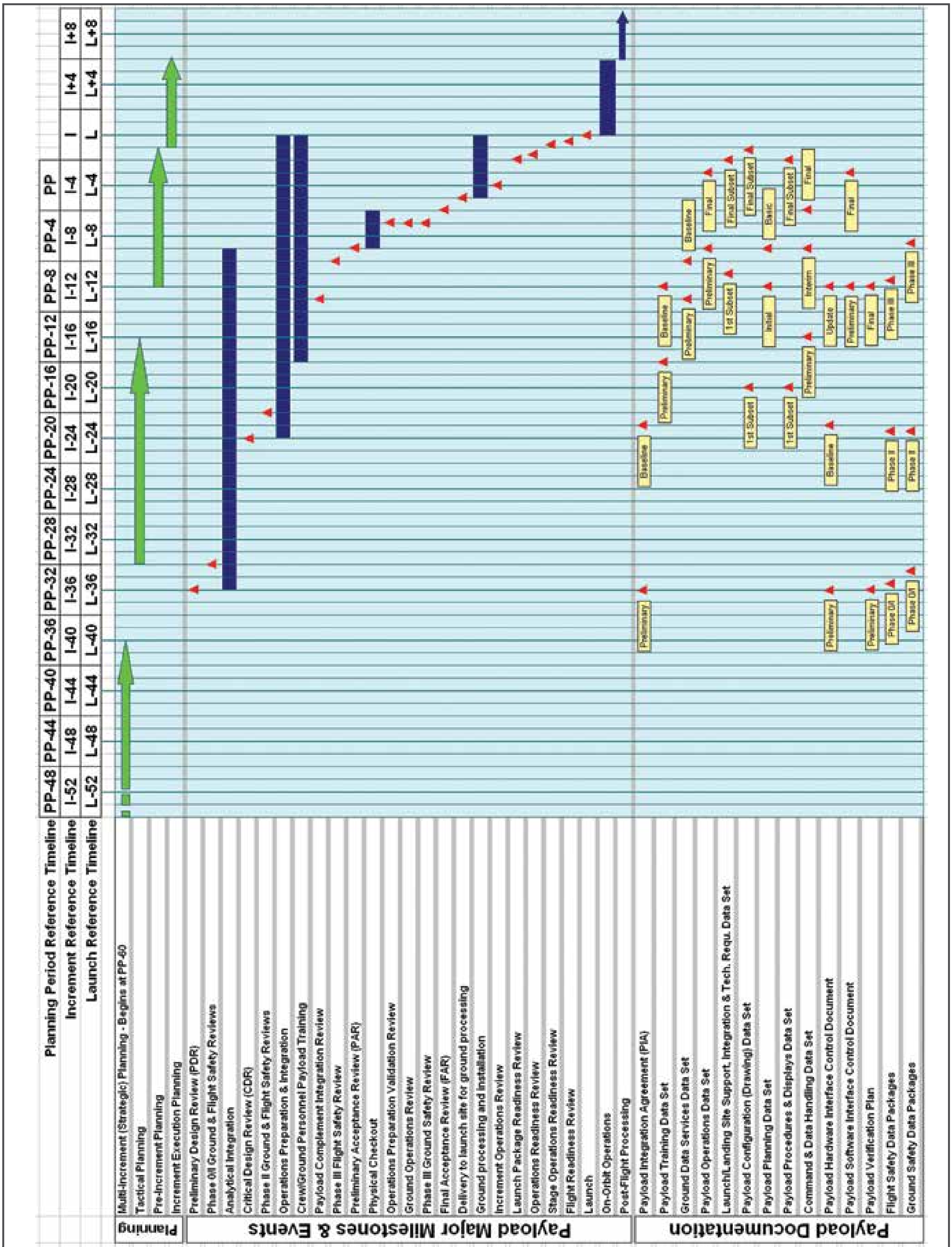


Figure 7-43: USOS timeline

7.14.2.1.1 Payload integration

The term "integration" applies to all the ground-based activities necessary to ensure that all aspects, items and products necessary to successfully operate the experiment in orbit are available in good time, are of the adequate quality and are in accordance with the overall ISS scenario and requirements. Overall, the major outcome of the integration process is the synchronization of the products provided by the several parties contributing to the performance of the experiment in orbit, complemented by the assessment that the experiment will be successfully performed in orbit.

Part of the overall integration process is also the analytical and physical integration and ground processing of the payload, which covers all of the activities required to physically interface the payload to the ISS System and the vehicles transporting the hardware to the ISS. This process includes verification of the applicable interface requirements, encompassing the necessary testing activities. The precise activities of this phase depend heavily on the payload class and characteristics.

7.14.2.1.2 Major reviews

The major reviews associated with payload integration are:

<u>Preliminary Design Review (PDR)</u>

The major focus of the Preliminary Design Review is the assessment of the preliminary design and compatibility of the scientific requirements and overall design requirements in terms of interfaces, resources and safety. A key outcome of the PDR is the project development schedule, which will then drive the complete integration process up to launch. The major objective of the PDR is the starting of the production of the manufacturing drawings, and the release for engineering model (if applicable) manufacturing. The PDR is the completion activity of the classical project development Phase B, and demonstrates and baselines a feasible and credible design that will accomplish the stated goals within the constraints imposed by the fiscal and operating environment.

<u>Critical Design Review (CDR)</u>

During the Critical Design Review, the Payload Data Package is reviewed to demonstrate that the payload is compatible with its scientific and functional requirements, with its external physical and functional interfaces and with the applicable safety requirements. If applicable, the results of the testing on the engineering unit are part of the CDR data package and provide evidence of the quality and performance of the design. All analysis shall be completed by the CDR, and therefore the CDR shall allow close out of those requirements to be verified by analysis. Major objective of the CDR is the release for manufacturing of the flight unit. The CDR is the completion activity of the project Phase C, and freezes the design, allowing then manufacturing and verification.

<u>Acceptance Review (AR)</u>

The Acceptance Review is held following the successful termination of all acceptance activities. The review consists on the verification that all applicable requirements have been properly and successfully verified.

Part of the AR is also the review of the documentation certifying the configuration of the payload. The AR will also assess the completeness of the data package, to ensure that all documents necessary for the future operations of the payload are available and complete. On this respect, the operational manual is delivered, in its final form, as part of the AR data package.

With the AR, ESA assesses the fulfillment of all contractual obligations and, upon successful review; the ownership of the payload is transferred from industry to ESA.

Members of the integration team, encompassing operation, engineering, training, ground segment expertise, participate to the above major reviews, and ensure that indeed all integration aspects are well assessed and the payload can be successfully operated on the ISS. The work of the integration team is coordinated by the Payload Integration Manager (PIM) who is familiar with all aspects of integration, and related requirements and due dates, and coordinates as well the work with assigned USOCs.

Table 7-25: Example of payload development and integration steps

Review/Event	Main objectives
RR - Requirements Review I-27 months (I = ISS Increment)	• Definition of mission goals • System & operational requirements definition • Accommodation on ISS • Interfaces definition • Review of safety aspects (Phase 0+1) • Schedule + ESA involvement definition • Experiment Science Requirements (ESR) doc. development initiated
UIB (Utilisation Implementation Board) I-21 months	• Approval of ESR (review of ISS resources)
EUB (European Utilisation Board) PB-HME (ESA programme Board for Human Spaceflight, Microgravity and Exploration)	• For information / endorsement / approval
DR: Design Review I-20 months	• Fix requirements and interfaces • Fix the design • Fix the schedule • Review safety aspects (Phase 2) • Establish training concept
FA (Feasibility Assessment) & JMMT (Joint Mission Management Team)	• Feasibility assessment by ESA and its industrial ISS operator • Assignment of experiment to an ISS Increment • Decision on approach for experiment execution
IDRD - Increment Definition & Requirements Doc + annexes (multilateral document) I-12 months	• Definition of ISS increment content, release of Interface Requirements Document (IRD) (ESA document) and multilateral requirements coordination
ICMs (Increment Coordination Meetings) & JMMT Joint Mission Management Team	• Monitoring of status of ISS increments preparation • Assignment of increment manifest
FAR (Flight Acceptance Review) I-4 months	• Review of payload and declaring it finished (stand alone) • Review of safety aspects (Phase 3) • Interfaces frozen and verified • Experiment System Tests successfully completed • Crew trained or on-board training ready • Acceptance of Ground Models and Crew Training Models
COFR (Certificate of Flight Readiness) I-2 months	• Declare item ready for flight

7.14.2.1.3 Analytical integration

In parallel with the initiation of the payload development activities, the analytical integration process can begin. In this process, each payload is analysed in detail to ensure compatibility with the Columbus Laboratory system (or alternative internal or external accommodation sites on the ISS). Compatibility with other payloads within the payload complement being flown on the allocated increment is also verified. ESA, through the Payload Integration Manager, will perform the analytical integration activities in support of the user. For Class 2 payloads, this typically takes place between L-36 and L-9 months.

7.14.2.1.4 Physical checkout

As part of the overall acceptance process, the payload shall undergo an interface test. If the payload interfaces directly with Columbus, then the testing is performed at the Rack Level Test Facility, which simulates the Columbus interfaces.

If the payload interfaces with a rack already in orbit, the interface is verified with the relevant Engineering Model (or Ground Reference Model) normally located at the relevant Facility Responsible Centre (FRC). In this case, the payload will not be subject to testing on the Rack Level Test Facility. After completion of the acceptance process, the payload is now ready for shipment to the designated launch site.

7.14.2.2 Payload training

Payload training is aimed at ensuring ground personnel and flight crew involved in payload operations perform safely and effectively under both nominal and off-nominal operations situations.

Individual payload facilities training for ESA payloads is performed at the European Astronaut Centre in Cologne, using a training model of the payload in question. All ISS crew members receive training and certification on Columbus and ESA payloads at EAC. Following crew assignment to a specific increment, each astronaut receives dedicated training on the experiment that he/she will be performing on the ISS. During Integrated Training (i.e. the last six months prior to increment start), travelling of the crew is restricted and the training schedule is strictly controlled. Therefore, as part of the integration process, it shall be ensured that all hardware, documentation and operational products are available in due time for the allocated crew training slots.

7.14.2.3 Operations preparation and integration

Operations preparation and integration relates to the development and/or updating of those data products used to operate the Columbus Laboratory and its payloads. The outputs of pre-increment and increment execution planning are used to develop operations products to enable real-time increment operations, and ensure that all involved entities (i.e. ground controllers and facilities, and crew) are adequately prepared for an increment. Operations products refer to all data-related items required to directly operate the Columbus Laboratory and its payloads throughout an increment, under both nominal and contingency conditions. Operations products can be located on-orbit or on ground and may be in electronic and/or physical formats.

Class 1 payloads will normally remain on-orbit for several years, maintained and upgraded as required, so the operations products will likewise be updated to reflect these changes, together with any lessons learned. Class 2 payload operations products are, by their nature, associated with Class 1 operations products, and thus any changes to an existing Class 2 payload or the installation of a completely new Class 2 payload will be reflected in the associated Class 1 operations products. Inputs to the on-board operations products are part of the Acceptance Data Package required for acceptance of the payload. The operations team will then use those inputs to develop the final operational products, in line with the applicable standard and taking into account the specific needs of the payloads and the increment in which the payload will be operated.

7.14.2.4 Certification of Flight Readiness

The Certification of Flight Readiness (CoFR) process is a formal certification process to ensure the safety and operational readiness of the user payload for flight to the ISS and operation on the ISS. The ESA CoFR process is a means for ESA management to systematically assess and certify the successful completion of all programme activities required to ensure the success of every ESA-managed ISS activity. This includes (but is not limited to) certification of safety, integration, and operational readiness, including crew training, of all of ESA's ISS-bound and ISS-supporting hardware and software, facilities, and personnel involved with pre-launch, launch and/or return, on-orbit assembly, operations, and utilization activities.

ESA (with appropriate support from NASA and other IPs, as necessary) performs a detailed "readiness review," called the Operations Readiness Review (ORR) to demonstrate their readiness to support the launch and/or undocking of an ISS Transportation Vehicle, and ESA's subsequent on-orbit activities.

During the ORR, each ESA Certifying Organisation presents the status of its mission responsibilities according to a pre-defined CoFR presentation template. At the end of a successful ORR, the ESA Mission Manager and the associated ESA CoFR Board, decide to certify the readiness of all, a portion of, or none of ESA's planned ISS launch, return, and on-orbit activities for the Increment by signing the ESA CoFR Certificate.

The ORR typically takes place two to three weeks prior to the Stage Operations Readiness Review (SORR), which in turn takes place about three weeks before the start of an increment.

7.14.2.5 Ground processing

Payloads to be transported to the ISS using the American commercial vehicles are shipped to the launch site at about 2.5 months prior to the scheduled upload launch. At the launch site, the NASA Payload Mission Integrator receives the payload and carries out the necessary processing activities to install the payload within the Cargo vehicle. Payloads to be transported using Russian vehicles will follow dedicated integration schedule, which are usually defined on a case-by-case basis.

7.14.2.6 On-orbit operations

When the payload arrives at the ISS, it is transferred to its allocated internal or external accommodation site or temporary stowage location. It is then installed and a short activation checkout test performed to verify readiness for on-orbit operation. Payload operations include nominal operations to achieve the research objectives of the payload, together with any nominal servicing and maintenance that is required. Users monitor and interactively control their experiment from the assigned User Support and Operations Centre or User Home Base. On completion of on-orbit operations, the payload is removed from its location, trashed or in exceptional cases, returned to Earth. The operation teams follow all Columbus system and payload operations in real-time, ensure the correct functionalities of all Columbus systems and payloads, and react as necessary to all off nominal situations. Part of the tasks of the operation teams is the planning of the ESA operations, ensuring that ESA operations are performed within the required planning constraints.

7.14.2.7 Post-flight processing

Users requiring early retrieval access to the flown samples will have access to the returned samples usually within 4 days after landing. ESA and NASA will define the planning for returning of the samples to the users/scientists.

The User Support and Operations Centre (or Facility Responsible Centre) associated with the operation of the user's payload will also provide the user with acomplete history of all the tele-commands sent to, and telemetry data received from the payload during the increment. The final step of the payload lifecycle is the publishing of the research resulting from the onboard operations of the payload on the ISS.

7.14.3 Payload documentation

The documentation that will be developed during the integration process of a payload will differ according to whether the payload flies on-board the Russian segment of the ISS or the USOS (i.e. NASA, ESA, JAXA, CSA) segment. The inputs required from the users to develop these documents as well as the format of the documents will be different for the two segments of the ISS. The PIM will guide the users and developers through both processes.

7.14.3.1 Launch/Landing site support, integration and technical requirements data set

This data set contains the requirements for integration and ground processing, together with launch/landing-site requirements, and include verification, inspection/test activities, assembly, installation and test requirements, payload physical integration, site interfaces and resources, deliverable items lists, support services and equipment, ground processing, access and contingency activities. Also included here are any payload equipment items that are to be launched/returned from the relevant increment, and any late-access or post-landing early retrieval requirements. Typically, the first preliminary subset of this data set is submitted approximately 6 months prior to the payload being on-dock, i.e. delivered to the launch site, while the last baselined subset will be submitted around 2 months before launch (L-2).

7.14.3.2 Payload Planning data set

The Payload Planning data set provides the detailed pre-increment and real-time planning and payload resource requirements for the International Space Station (ISS) Programme. The user/payload developer provides the detailed payload planning and resource requirements specifications to the ISS planners based on the types of inputs described within the payload data sets blank book.

The payload planning requirements are used for modelling the user's requirements for onboard activities, and also defines the products, activities, roles, responsibilities, and interfaces required for the provision of payload planning during Payload Operations.

The Payload Planning data set collects detailed planning requirements for ascent/descent, and Station onboard resources such as crew time, power, thermal, commanding, and data and video downlink requirements. The ISS Mission Planners utilise these requirements to develop planning products such as the On-Orbit Operations Summary (OOS), Weekly Look-Ahead Plans, Short-Term Plan (STP) and the Onboard Short-Term Plan (OSTP).

Typically, two versions of the Planning Data Set are submitted:

- initial version – this first version of the planning data set is submitted approximately 12 months before the start of the payload increment (I-12);
- basic version – this is submitted around 3 months after the initial version, i.e. at I-9 months.

Payload Procedures and Displays data set

The Payload Procedures and Displays (PPD) data set includes the requirements for crew, automated, and ground command procedures and related information, onboard crew displays, and payload messages, supporting on-board operations. There are several subsets of the PPD data set that are submitted during the life-cycle of a payload, the first subset being delivered in draft form at the time of the CDR. The complete planning will be elaborated by the PIM, based on the payload specific features.

7.14.3.4 Command and Data Handling Data Set

The Command and Data Handling (C&DH) data set is the method by which a user/payload developer defines the payload requirements for use of the International Space Station (ISS) flight and ground C&DH systems. Three versions of this data set will be submitted during the life cycle of a payload:

- preliminary version – delivered around 16 months prior to the launch of a payload (L-16);
- interim version – submitted 9 months before launch (L-9);
- final version – submitted 6 months before launch (L-6).

7.14.4 Interface control documents

7.14.4.1 Interface Requirement Document

The Interface Requirement Document (IRD) defines the physical and functional interface requirements between payload and system, and acts as a guideline to establish commonality with the respect to analytical approaches, models, test methods and tools, technical data and definitions for integrated analysis.

Considering the requirements given in the IRD, the user, together with the integration engineer will define the Payload-unique hardware Interface Control Document (ICD), which includes a description of the payload and document the specific interface requirements applicable to the payload together with the relevant verification methods.

7.14.4.2 Payload Hardware Interface Control Document

The unique payload hardware Interface Control Document (ICD) defines and controls the design of the interfaces between the payload and the system that accommodates it, including unique interfaces, constraints, definition of selectable parameters, and stage unique constraints. The unique ICD provides specific design data and defines the engineering analyses applicable to the interfaces and optional/ special services.

7.14.4.3 Payload Software Interface Control Document

The Payload Software Interface Control Document (ICD) is developed to define the flight unique software interface requirements between the payload systems and the ISS flight data handling elements (low, medium and high rate data links). The user will determine the number and type of interfaces based on the requirements of the unique payloads.

7.14.4.4 Payload Verification Plans

A payload unique Payload Verification Plan (PVP) is developed together with the Payload ICDs, and is used to define the complete set of verification activities necessary to ensure compliance with the payload design requirements identified in the ICDs. The PVP will contain Verification Data Sheets providing instructions, definitions, references and guidelines for the verification activities associated with each payload design requirement. The submission of the PVPs will take place together with that of the Payload Hardware ICD, i.e. a preliminary version around the PDR and a final version is due around the CDR.

7.14.4.5 Safety Data Packages

The safety process is a key element of the development and integration activities. Safety on board the ISS is paramount and safety requirements shall be considered at the very early stage of the development process, considering not only the design of the payload but also its operations.

The safety data packages shall be elaborated in accordance with the applicable requirements. Typically, the milestones for the submission of the data packages are as follows:

7.14.4.5.1 Flight and Ground Safety Data Packages

- phase 0/I Data Package – approximately 45 days prior to the Phase 0/I Safety Review, which takes place around the PDR time frame;
- phase II Data Package – approximately 45 days prior to the Phase II Safety Review, which takes place around the CDR time;
- phase III Data Package – approximately 45 days prior to the Phase III Safety Review, which shall be completed to ensure successful AR.

7.15 Operational cycle of an ISS payload

7.15.1 Russian Segment payload operational cycle

Table 7-26 provides a general outline of the major events that take place during the operational cycle of a payload flying to and being accommodated on the Russian segment of the ISS. Scientists should use this as a reference and should keep in mind that the list below may vary from payload to payload. For a generic case, the table refers to the timeline of a Soyuz launch campaign. ("L" refers to the time of launch of the Soyuz spacecraft and "R" refers to the time of landing of the Soyuz capsule). Figure 7-44 graphically summarises the sequence of events during a Soyuz launch campaign.

7.15.2 USOS payload utilisation/operational cycle

The timeline and utilisation/operational cycle of payloads accommodated on the USOS of the ISS have been described in section 7.14.

For more information on the International Space Station please visit the following web pages:

www.esa.int/Our_Activities/Human_Spaceflight/Research/International_Space_Station

Table 7-26: ESA-sponsored pressurised (internal) facilities for the ISS Utilisation programme

TIME	EVENT
L-1 month	Payloads delivered to Baikonur launch site.
L-30 to L-20 days	Pre-integration inspections at Baikonur (in most cases scientists and payload developers will be present).
L-20 to L-12 days	Payload physical integration into Soyuz spacecraft.
L-8 to L-5 days	Spacecraft integration with launcher. Upon request, final stowage of limited additional cargo is possible.
L-1 day	Soyuz launcher rolled-out to launch pad.
L-7 days to L-12 hours	"Late Access" of limited size kits possible through side hatch of Soyuz spacecraft.
L	Launch of Soyuz vehicle.
L + 6 hours	Spacecraft docks with ISS.
L to L+6 months	Execution of scientific programme of mission.
L to L+6 months	Users located at: the User Support and Operations Centres (USOC) or a User Home Base (UHB).
L+6 months	Undocking and landing of spacecraft.
L+6 months	Payload and data retrieval.
R to R+15 days	Payloads and experiment data handover to scientists/payload developers.
R+40 days	Final project review.

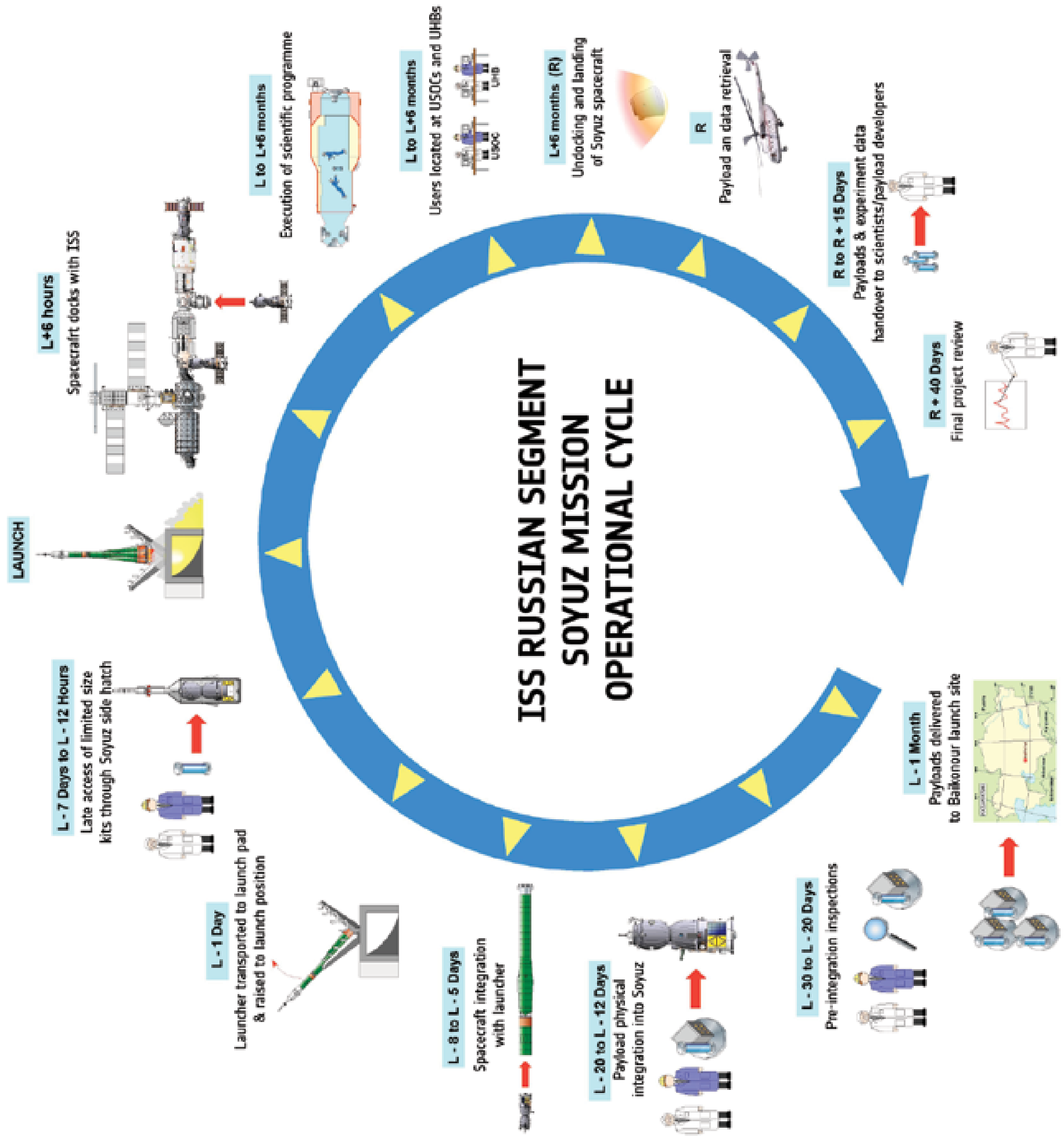


Figure 7-44: Operational cycle for a Soyuz-transported ISS payload

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