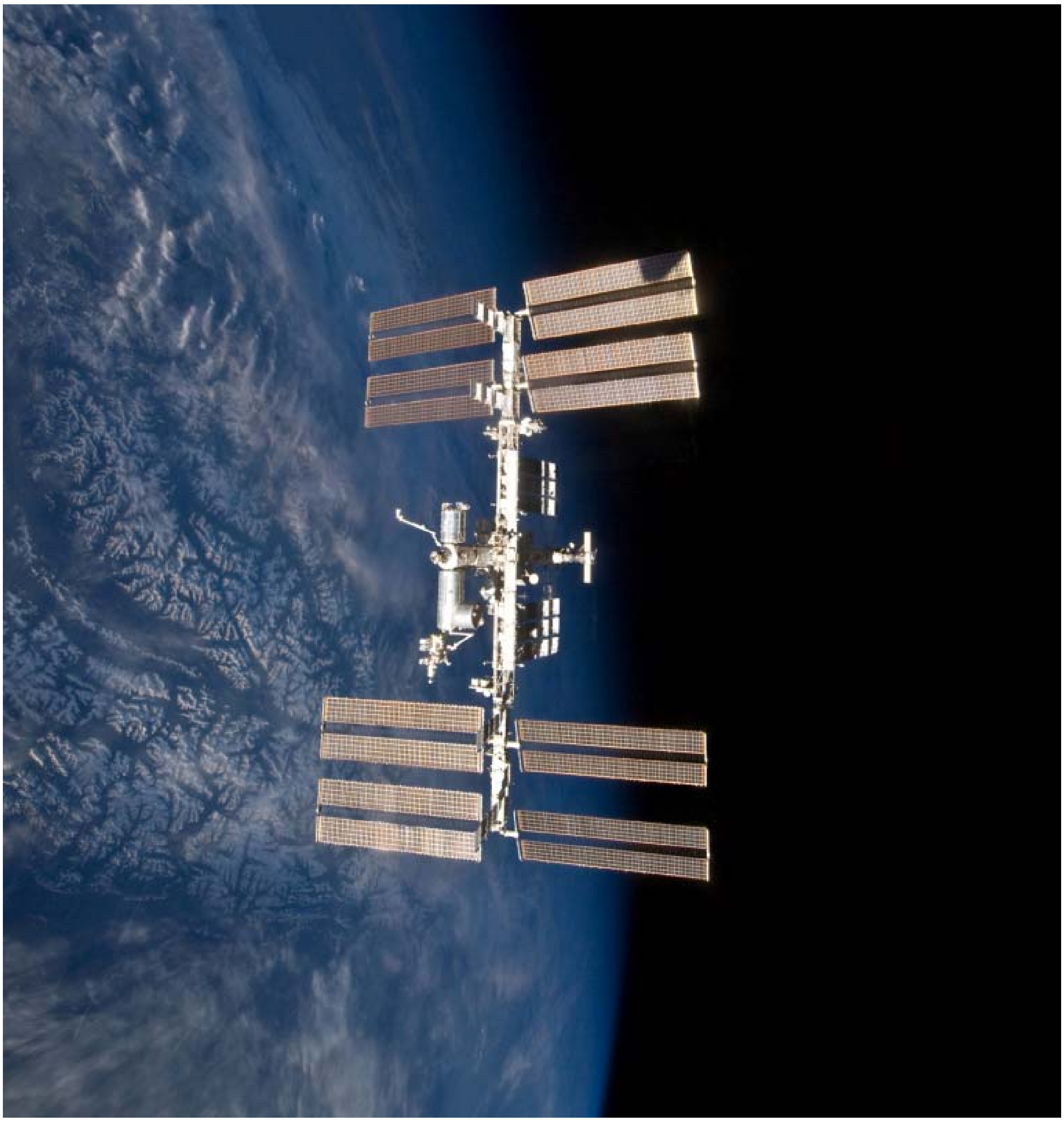
Annex 1: Additional technical Information on ISS capabilities and background information



Research Announcement for ISS Experiments relevant to study Global Climate Change

Figure 1: ISS Elements

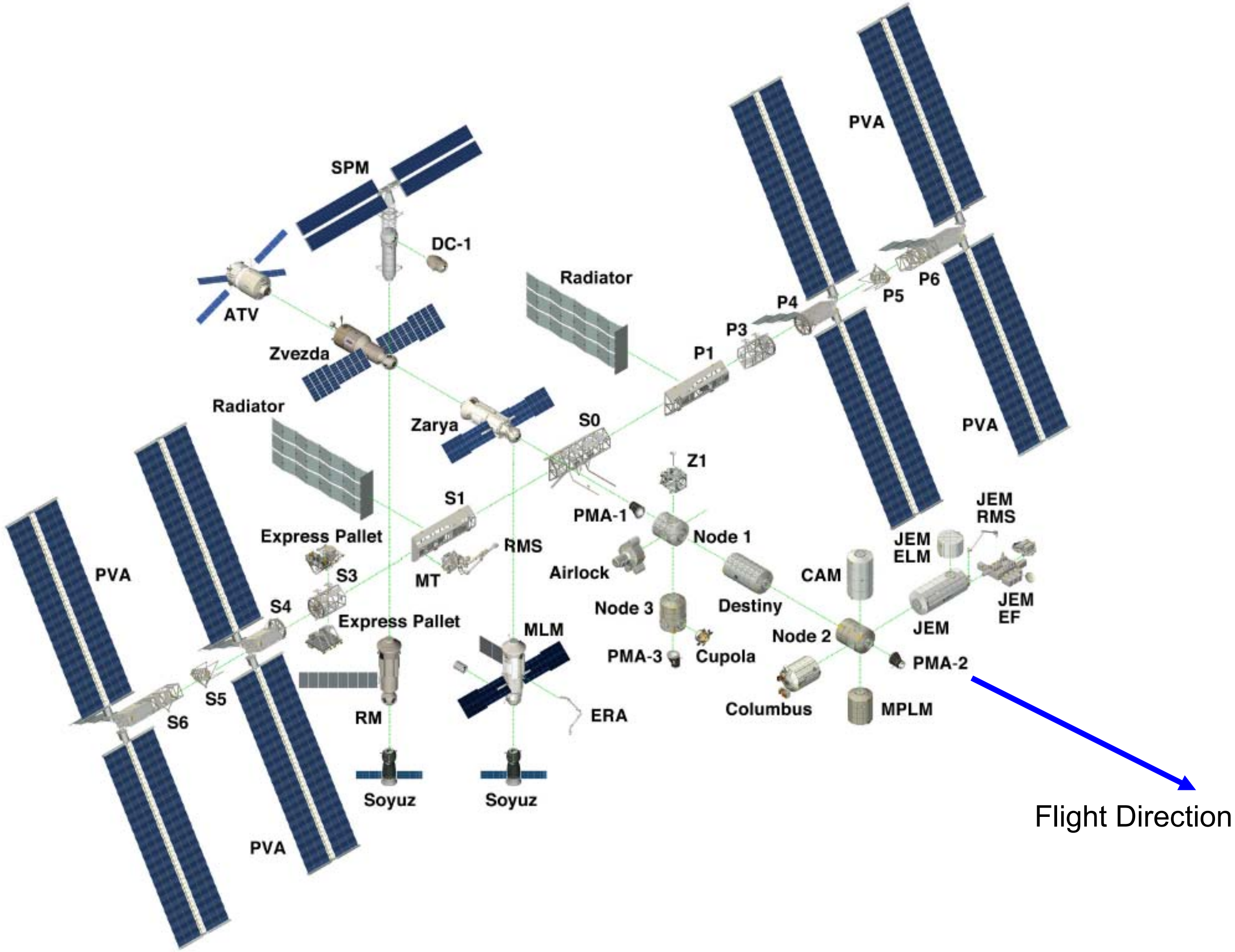


Table of Content

1 Reference Documents

RD-1	European Users Guide to Low Gravity Platforms, Ref: UIC-ESA-UM-0001 Issue 2-0. Sept. 2005: http://www.esa.int/SPECIALS/HSF_Research/SEMG2W4KXMF_0.html
RD-2	NASA Reference Guide to the International Space Station http://www.nasa.gov/mission_pages/station/news/ISS_Reference_Guide.html
RD-3	NASA ISS Interactive Reference Guide http://www.nasa.gov/externalflash/ISSRG/
RD-4	Columbus Payload Accommodation Handbook (CPAH): Attached Pressurized Module (APM), Ref: COL–RIBRE–MA–0007–00, Issue 1/A, 23 Feb 2009 (Available on Request – iss-climatechange@esa.int)
RD-5	NASA webpage: Earth and Space Science using ISS as a platform http://www1.nasa.gov/mission_pages/station/science/nlab/platform.html
RD-6	Overview of attached payload accommodations and environment on the international space station http://www1.nasa.gov/pdf/190373main_TP-2007-214768.pdf
RD-7	The changing earth: New scientific challenges for ESA's living planet programme. ESA SP-1304. July 2006 http://esamultimedia.esa.int/docs/SP-1304.pdf
RD-8	Small Explorer (SMEX) missions of opportunity solicitation technical interchange meeting: ISS unpressurized payload accommodations presentation http://www.nasa.gov/pdf/206852main_SMEX_Presentations_website.pdf
RD-9	Kibo Exposed Facility description http://kibo.jaxa.jp/en/about/kibo/jef/
RD-10	Space Environment for JEM Exposed Facility Payload http://idb.exst.jaxa.jp/edata/02110/199810K02110020/199810K02110020.html#1
RD-11	ISS PIMS microgravity data webpage; http://pims.grc.nasa.gov/pims_iss_index.html
RD-12	ISS PIMS data examples of actual disturbances; http://pims.grc.nasa.gov/pimsdb/index.cfm?method=Handbook.pimslist
RD-13	NASA Window Observation Research Facility http://www.nasa.gov/mission_pages/station/science/experiments/WORF.html
RD-14	NASA International Space Station Capabilities and Payload Accommodations http://www.nasa.gov/pdf/462947main_2010_June_Jones_ISS%20Accomodations 1.2a.pdf

2 Acronyms

AD	Applicable Document
AOS	Acquisition of Signal
ASIM	ESA Air Space Interactions Monitor payload
ATV	ESA's Automated Transfer Vehicle
CEPA	Columbus Externals Payloads Adaptor (CEPA)
CEPF	Columbus External Payloads Facility (CEPF)
DPU	Data Processing Unit
EF	External Facility
ELC	Express Logistics Carrier
EPF	External Payloads Facility
ESA	European Space Agency
EUTEF	ESA European Technology Exposure Facility
EVA	Extra-Vehicular Activity
EXPRESS	EXpedite the PRocessing of Experiments to the Space Station
FM	Flight Model
FRAM	Flight Releasable Attachment Mechanisms
GM	Ground Model
GSE	Ground Support equipment
H2B	JAXA H2B Launch vehicle (for HTV)
HCOR	High Rate Communications Outage Recorder
HICO	NASA Hyperspectral Imager for the Coastal Ocean
HREP	NASA HICO and RAIDS Experimental Payload
HTV	JAXA H2B Transfer Vehicle
H/W	Hardware
IR	Infrared
ISS	International Space Station
kPa	Kilopascals
JAXA	Japanese Aerospace Exploration Agency
JEM	Japanese Experiment Module (known as *Kibo*)
JEM-EF	Japanese Experiment Module Exposed Facility (also known as *Kibo*-EF)
LAN	Local Area Network
LOS	Loss of Signal
LVLH	Local Vertical Local Horizontal (an ISS attitude mode)
MPLM	Mini Pressurised Logistic Module
MSP	Mechanisms Support Plate
NASA	National Aeronautics and Space Administration (USA)
P3	Port location on US Truss for external instruments
RAIDS	NASA Remote Atmospheric and Ionospheric Detection System
RD	Reference Document
RS	Russian Segment (of ISS)

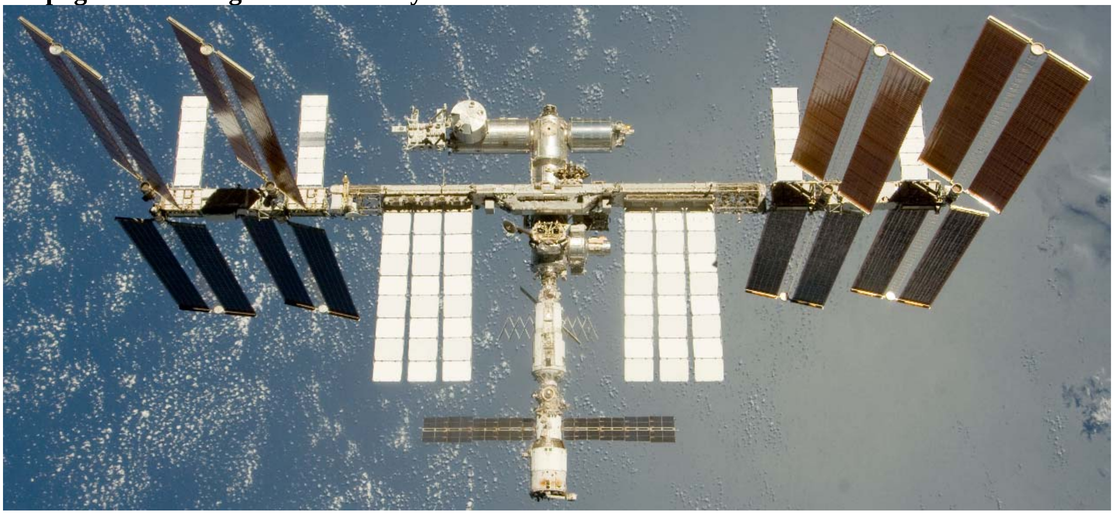
S3	Starboard location on US Truss for external instruments
SMILES	JAXA Superconducting Submillimeter-Wave Limb Emission Sounder
TEA	Torque Equilibrium Attitude (An ISS attitude mode)
TBC	To Be Confirmed
TBD	To Be Defined
TDRSS	NASA Tracking and Data Relay Satellite System
URM-D	Zvezda Portable Multipurpose Workstation
USOS	United States Operating Segment (includes Columbus & Kibo modules)
UV	Ultraviolet
VDPU	Video Data Processing Unit
W	Watts
WORF	Window Research Facility (in NASA *Destiny* module)

2.1 Overview: The ISS as an observation platform for climate change studies

2.1.1 Key Characteristics of ISS

The International Space Station (ISS) is a permanently manned orbital platform with six crew, with the assembly of the primary elements completed in 2010, offering a multipurpose research facility in low Earth orbit. Potentially, the ISS can be used as an observation platform for instruments and experiments, supplementing on-going and planned climate change and Earth observations from dedicated satellite, airborne and terrestrial platforms.

Figure 2: Current configuration of ISS (August 2009). This shows the space station in the normal local vertical / local horizontal (LVLH orientation). The direction of motion is towards the top of the page Refer to Figure 1 to identify individual modules



Specific parameter constraints of the ISS platform, relevant to Earth observation instruments, are summarised below;

- **Orbital inclination: 51.6°**
    - The characteristics of the ISS orbit are such that it flies over approx. 85 % of the surface of the globe, an area which includes approx. 95 % of the Earth's population.
    - Ground track precesses westward, such that the daily equatorial crossing time (UTC) is approximately 20 minutes earlier each day
    - Varying solar illumination conditions
- **Orbital altitude varies between 330 km and 460 km (typically maintained in the 340-385km altitude range) , with an orbital period of between 90 and 94 minutes.**
    - The orbital altitude gradually decays due to aerodynamic drag, requiring reboosts on average every 3 months

- **Normal operations are interrupted by arrival and departure of resupply vehicles, as well as crew extra-vehicular activities and reboosts**
    - On average two periods of undisturbed activity of approximately 30 days per reboost cycle are available.
- **Variable spacecraft attitude**
    - ISS is maintained close to Local Vertical Local Horizontal (LVLH) attitude.
    - The Node 2 (Harmony module) docking port is facing in the direction of motion (see section 3.2)
    - Attitude can vary up to +/-15° per axis. However, variations are typically around 1° per axis per orbit (maximum 3.5° per orbit)
    - Fine pointing cannot be provided by ISS, it must be provided at the payload level. Also post processing techniques for image stabilisation can be considered to provide highest performance
- **Microgravity environment**
    - Minor quasi-steady accelerations ($<10^{-5}$g) due to air drag
    - Vibratory accelerations, varying with crew and ISS operations
        - Better than 10^{-5}g (integrated over 10 s)
        - Transient up to 10^{-3}g (>100Hz, see Annex 1, section 3.3 for detailed descriptions of variation of g-level with frequency)
- **Crew operation / intervention in instrument operation is possible, but total crew time is limited and shared with other payloads / operations**
- **Data transmission rates and volume are limited (see Annex 1 section 3.7)**
    - Data transmission is shared resource with other ISS instruments and systems (See Section 3.7 of this document ISS data transmission capabilities)
    - Data transmission are made in prescheduled blocks See Section 3.7 of this document for typical examples)
    - Payloads should have capacity to store data until scheduled transmission, as no data storage capacity is available from ISS
    - Data transmitted from payloads during gaps in coverage from TDRSS communication satellites each orbit is stored in a buffer in the ISS data management system until reacquisition of signal
    - Some compression within the experiment may be needed for transmission of high volumes of data
- **ISS orbit and attitude estimation accuracy limitations**
    - Measured position accuracy to better than 75m in each axis, velocity better than 0.2m/s and attitude +/-3° using differential GPS
    - Higher resolution position and attitude information requires dedicated star tracker/rate gyros
- **Thermal constraints**
    - Columbus external payloads can only dissipate heat by radiation
    - Near LVLH attitude of ISS results in one side of instrument constantly facing Earth and the other side constantly facing space

- Angle between plane of ISS orbit and solar vector varies between +75° and -75° resulting in varying solar illumination on instruments

Detailed technical details of the ISS platform and constraints can be found in Section 3 of this document.

2.1.2 Instrument accommodation

Instruments can be mounted either externally on the ISS (i.e. exposed to the direct space environment) or internally viewing through windows. Most windows provide transmission in the visual and short wave Infra-Red region, the detailed specifications and transmission curves of these windows is given in Section 3.6 Potentially, simple instruments may be developed and flown with relatively short lead times. Possible locations for instruments are indicated on Figure 3. These are summarised below;

External instrument mounting locations

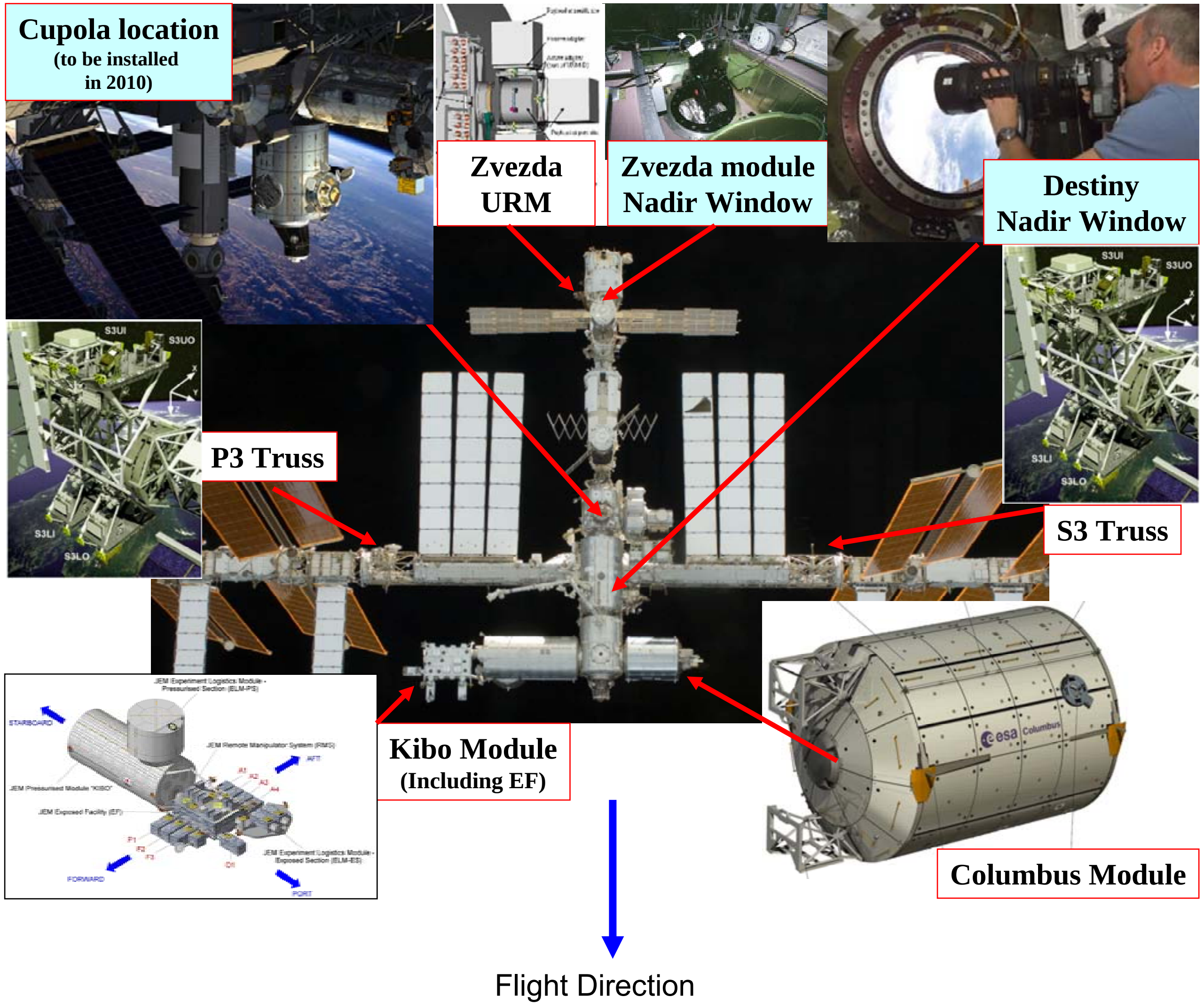
- **ESA Columbus External Payloads Facility (CEPF**). The Columbus facility is fitted with an external mounting structure which can carry up to 4 large payloads. The attachment sites permit nadir, starboard (limb) and zenith viewing. Data and power connections are provided to the payload attachment locations. The nadir location will be used for the ESA Atmosphere Space Interactions (ASIM) payload from 2013 onwards and the ESA EUTEF multi-instrument payload was operated on one of the starboard facing attachment points from February 2008 to August 2009. The location of Columbus at the end of the ISS complex, gives a good unobstructed view towards the Earth's limb in the forward direction of motion.
- **JAXA Kibo Exposed Facility (Kibo-EF)**. The Japanese Kibo facility has an external facility which can carry several instruments or payloads. Two Earth observation payloads were recently installed on the Kibo-EF, the JAXA SMILES (sub-millimeter wave limb sounder) and NASA HREP (a sea hyperspectral visible/near-IR imager and an upper atmosphere airglow optical sensor)
- **US Truss**. The US Truss has a total of 6 mounting locations for large instrument payloads, next to the main solar arrays.
- **Russian Segment URM-D**: The Russian segment has an external mounting platform (URM-D) on the side of the Zvezda module, with nadir, limb and zenith pointing mounting locations. The ESA EXPOSE-R exobiology facility is currently mounted on the zenith facing plate of the URM-D

Internal instrument mounting locations

- **NASA Destiny Module Nadir Window**. This is a 51-cm high quality optical window transparent from the near ultraviolet (>350 nm) to beyond 2 μm in the near infrared. In 2010 observations through the window will be enhanced with the addition of a dedicated rack facility (Window Research Facility: WORF), providing instrument mounting points, power and data connections.
- **NASA Cupola Module**. This is a dedicated module for external observation by the crew and instruments of the Earth, space, the ISS structure and visiting vehicles. A total of seven windows provide nadir and limb viewing, with similar transmission characteristics to the Destiny module window. Mounting points are provided for optical instruments and data transmission from instruments to the ISS data management system can be made through a wireless connection.
- **Russian Segment Zvezda Windows**. The Zvezda module has several nadir and limb facing windows.

Additional technical information on instrument mounting locations and associated facilities can be found in Section 3.4and 3.6 .

Figure 3: Underside view of ISS showing possible locations for Earth observation instruments. Internal mounting locations are highlighted



3 Detailed technical information on ISS capabilities and background information

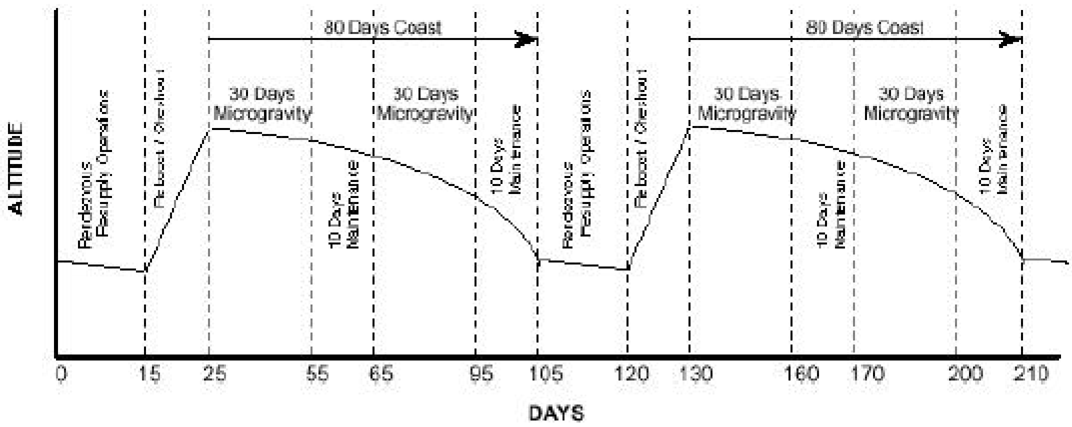
3.1 ISS Overview

The International Space Station (ISS) is a permanently manned orbital platform with six crew. It will reach the fully assembled configuration in 2010, offering a multipurpose research facility in low Earth orbit (Figure 1: ISS Elements). Potentially, the ISS can be used as an observation platform for instruments and experiments, supplementing on-going and planned observations from dedicated platforms.

The rotation of crews to / from the ISS will be performed by Soyuz vehicles for the foreseeable future, eventually supplemented by the U.S. Orion crew transport vehicle in the middle of the next decade. Resupply of the station with consumables and equipment (including payloads and instruments) is performed periodically by a variety of vehicles including the Russian Progress, European Automated Transfer Vehicle (ATV), Japanese H-IIB Transfer Vehicle (HTV) and U.S. commercial resupply vehicles.

During normal operations the ISS is in a stable attitude (see section 3.2 below), and the crew are able to perform operation of science experiments and payloads. It should be noted that the amount of crew time available for any one experiment is limited and some flexibility in scheduling activities is preferable. Command uplink and telemetry downlink shared with other payloads is available via the TDRSS (geosynchronous satellite) system, although there are some periods during each orbit when coverage is not available. Normal operations are interrupted during the arrival and departure of vehicles to the station and the period during crew exchanges, unloading of cargo vehicles and extravehicular activities often results in modified operations schedules (Figure 4: ISS operations and altitude profile)

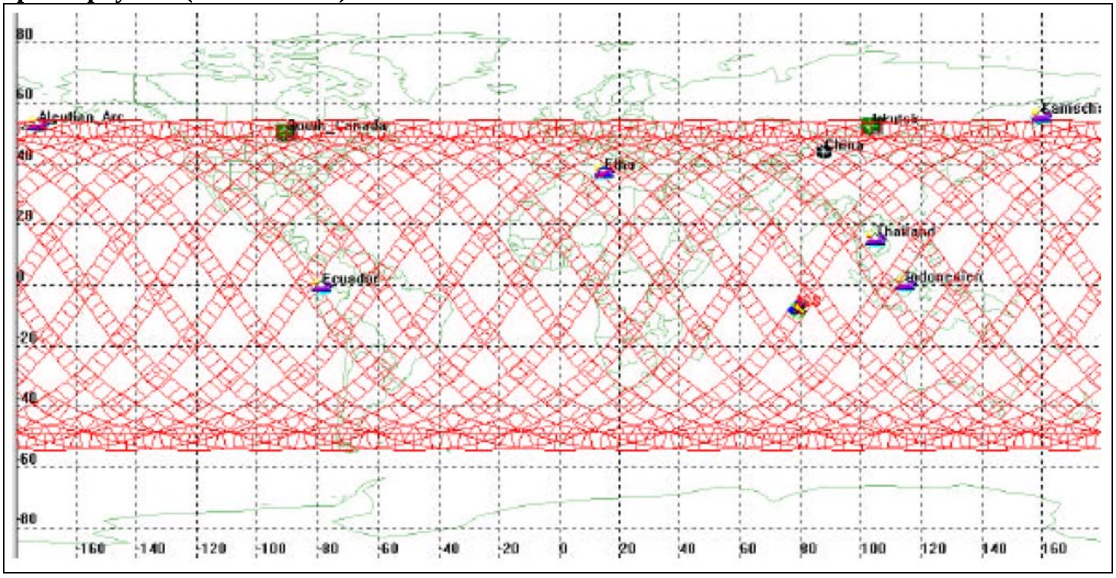
Figure 4: ISS operations and altitude profile (Source: RD-1)



3.2 ISS Orbital and attitude characteristics

The International Space Station (ISS) has a nearly circular orbit inclined at 51.6° to the equator with an average altitude range that is maintained between approximately 330 km and 460 km (typically maintained in the 340-385km altitude range), with an orbital period of between 90 and 94 minutes. The characteristics of the ISS are such that it flies over approximately 85 % of the surface of the globe, an area which includes approximately 95 % of the Earth's population.

Figure 5
Mercator projection of ISS coverage in 24 hour period for a 70 degrees swath nadir pointing optical payload (Source: ESA)



The angle between the ISS orbit plane and the solar vector, known as the beta angle, can vary between a maximum of +75 degrees and minimum -75degrees. This results in varying illumination conditions for Earth observation and changing geometry for occultation of the sun by the Earth's limb (Figure 6) Seen from any one point on the Earth the ground track precesses, with the daily pass of ISS occurring approximately 20 minutes earlier each day (Figure 7)

Table 1
Example orbital parameters and ranges for ISS (1:19UT Wednesday 7th October 2009)

Parameter	Actual data (1:19UT Wednesday 7th October 2009)	Acceptable Range
Eccentricity	0.0008103	Maintained near circular
Inclination	51.63°	51.6°
Perigee height	340km	300-460km
Apogee height	351km	300-460km
Revolutions per day	15.746	15.3 – 15.8
Orbutal period	91.45 minutes	91-94 minutes

Figure 6
Example variation of solar beta angle for the ISS (when assembly complete) during 1 year (source: RD-10)

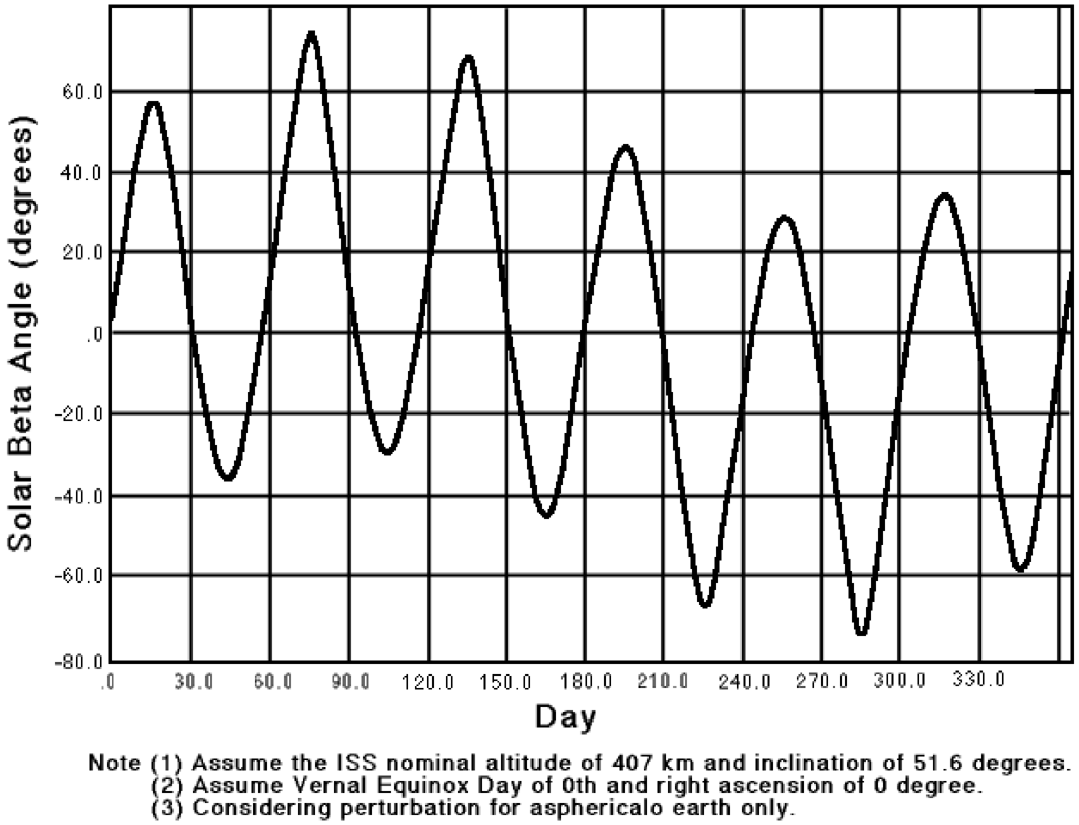
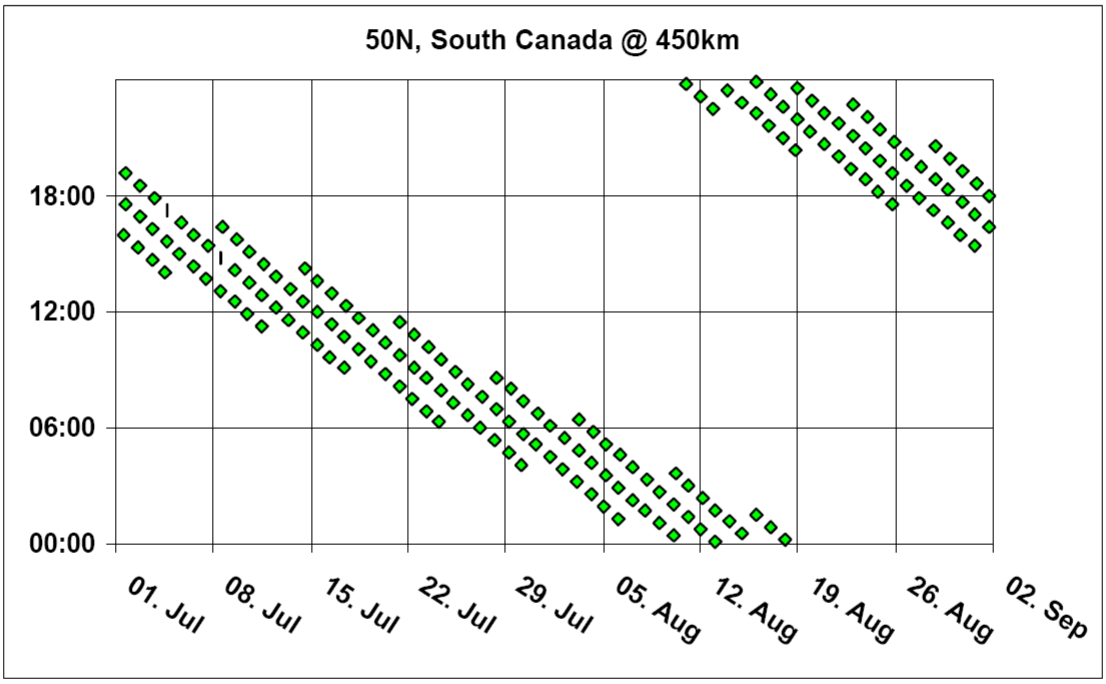


Figure1.1.1-3 An Example of The Annual Solar Beta Angle Variation for ISS Orbit

Figure 7
Example of evolution of local time of ISS ground track crossing of a given region over a 60 day period (precession cycle). Source ESA



The ISS orbit will decay due to atmospheric drag. The lowest limit of the ISS altitude, for its survival in orbit, is taken as 278 km. Therefore, the operational altitude should ideally be kept higher than 350 km, from where the orbital decay takes 120 days to reach such limit with an average decay of 0.6 km/day. Periodic boosting by using onboard thrusters must be carried out to maintain the ISS altitude within 330 – 460 km. This variation is a direct consequence of the 11-year solar activity cycle that causes the atmospheric density profile to vary (expanding the atmosphere at solar maximum). The reboost period itself requires 1-2 orbits (1.5 - 3 hours) and represents a certain, but temporary, interruption in the maintenance of the ISS microgravity and pointing specifications. Periodic reboost is carried out approximately every 10 to 45 days. An example of actual ISS altitude history is given in Figure 8 and projected ISS altitude is in Figure 9: Long term projection of ISS orbital altitude (Source: ESA RD-1).

Figure 8
ISS altitude history November 1998 – May 2005 (Source: ESA-RD-1 / NASA)

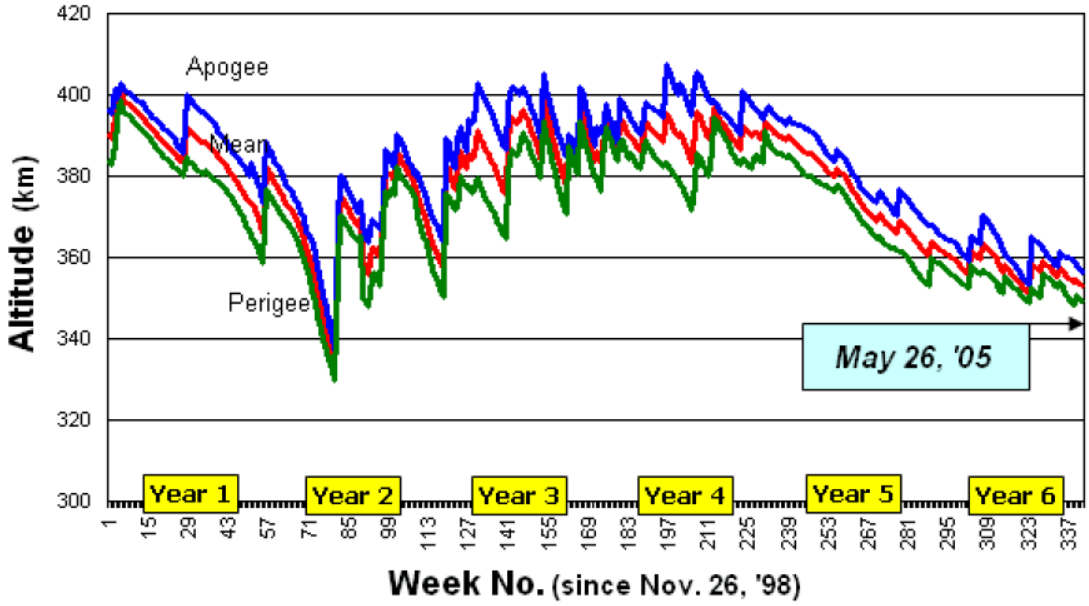
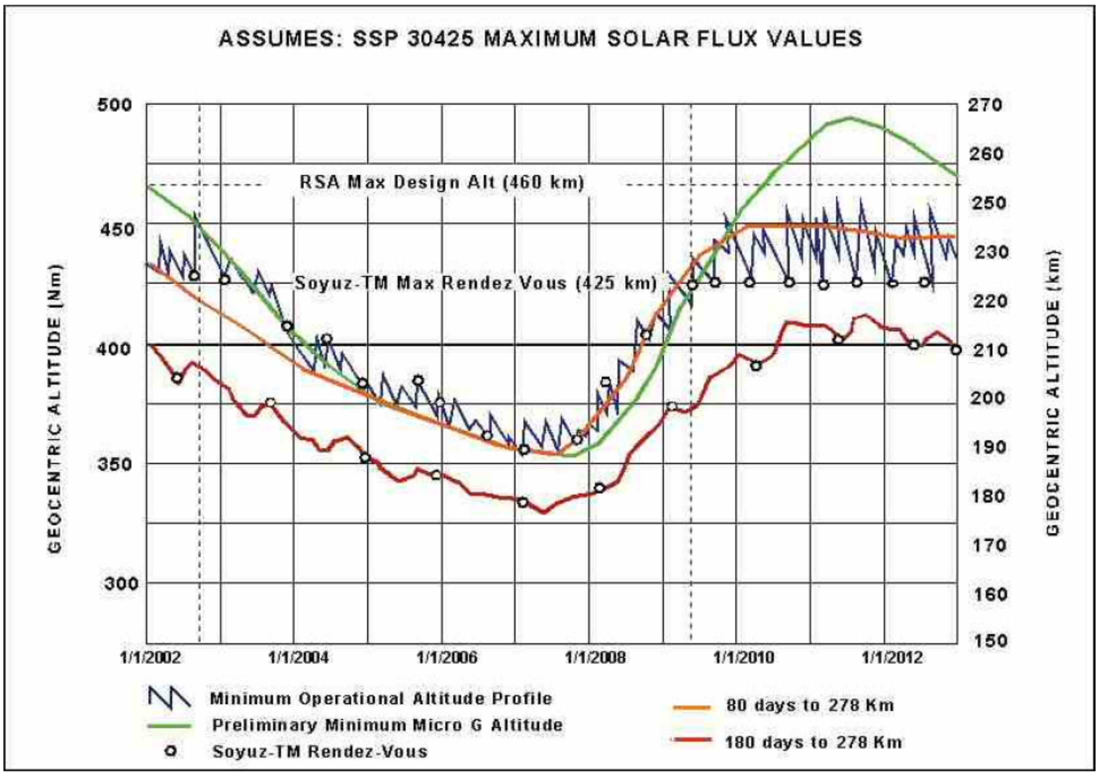
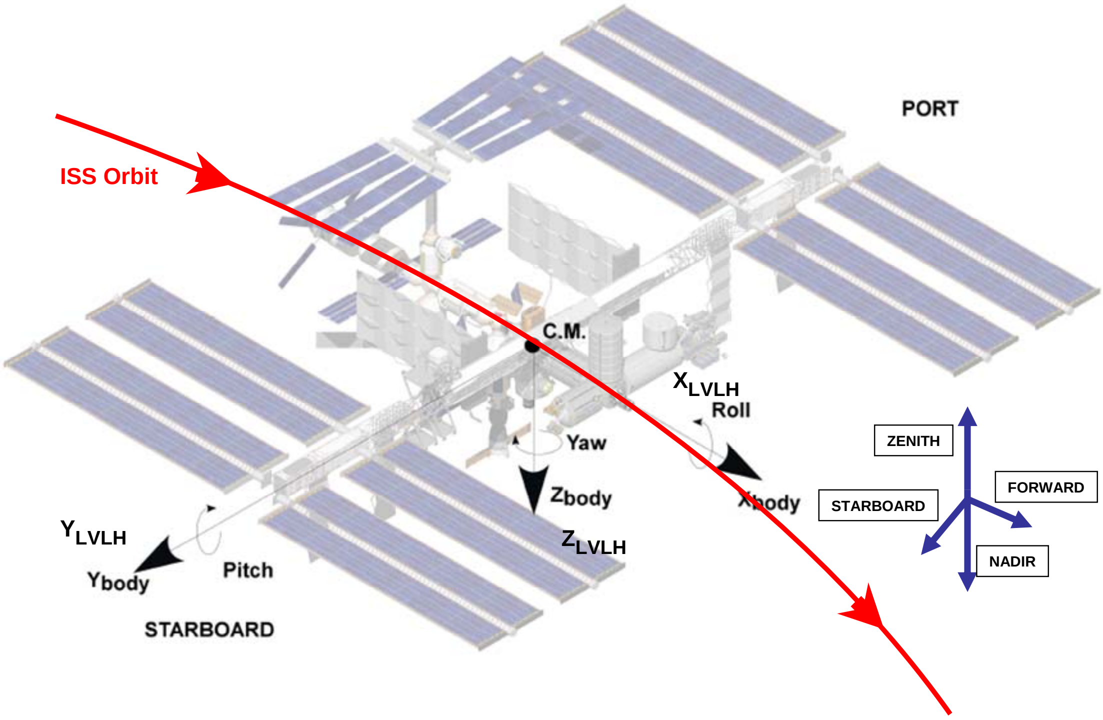


Figure 9: Long term projection of ISS orbital altitude (Source: ESA RD-1)



The ISS attitude is expected to be maintained in Torque Equilibrium Attitude (TEA) mode during normal operations. In this mode utilisation of attitude control thrusters and control moment gyros is minimised by allowing the ISS to establish an attitude that balances external torques such as aerodynamic drag and gravity gradient. The actual ISS attitude in TEA normally will be close to and vary around the Local Vertical Local Horizontal (LVLH) attitude. In LVLH attitude the ISS appears to maintain a fixed attitude relative to a position immediately below the ISS (i.e. the local horizon), with the Node 2 (Harmony) docking port pointing into the direction of orbital motion (see Figure 10)

Figure 10 Local Vertical, Local Horizontal ISS attitude (Source: ESA)

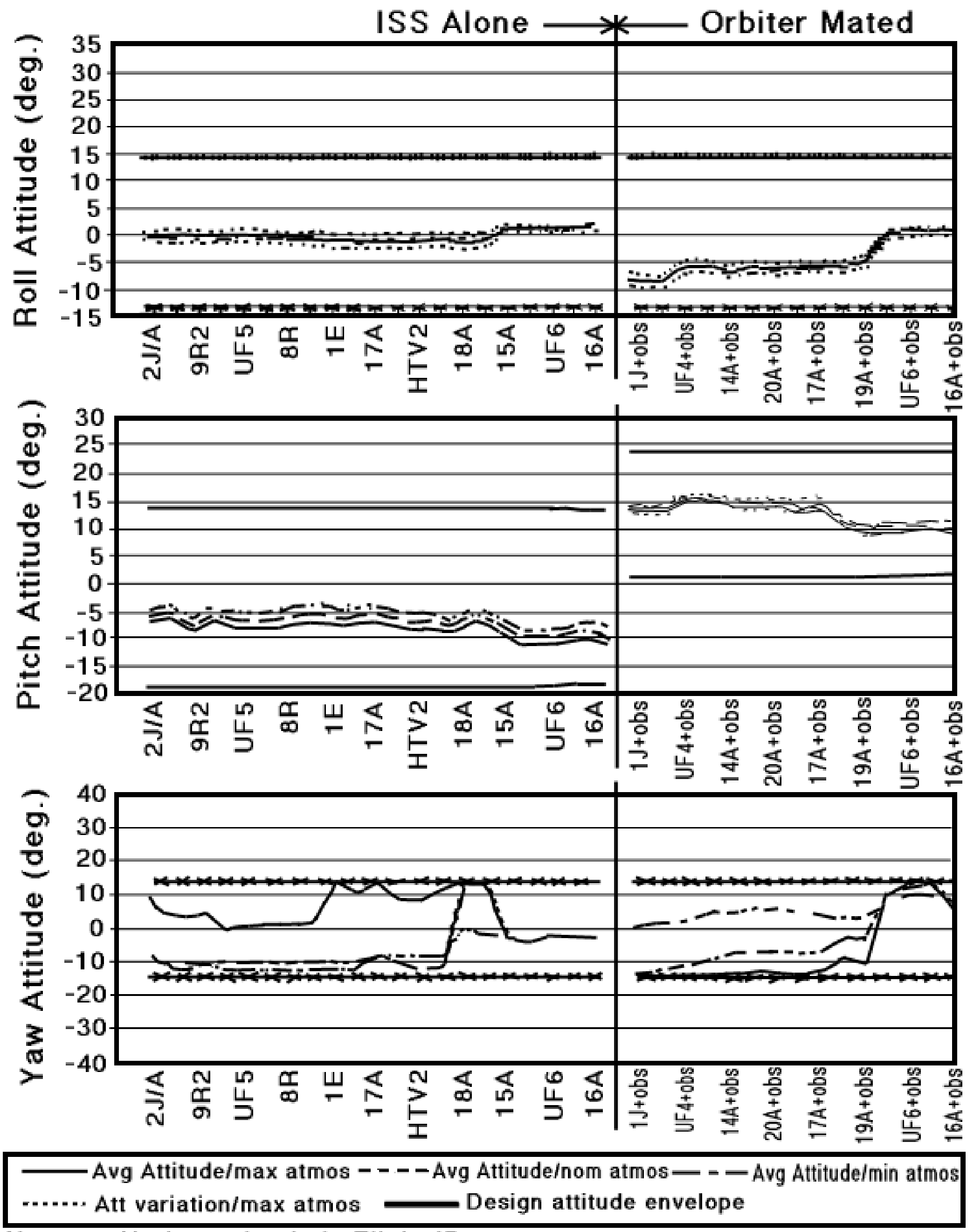


The maximum specified variations of ISS attitude in TEA relative to LVLH are between +15 and -15 degrees for the roll and yaw axes, and between +15 and -20 degrees for the pitch axes. Across one orbit the stability of the attitude is better than 3.5 degree/axis/orbit and the rate of change of attitude is less than 0.002degree/s/axis. This is summarised in Table 2. For a particular ISS configuration it is expected that the long term variation of pitch and roll attitude is about +/-3 degrees, although yaw may vary over a much wider range. Arrival / departure of a visiting vehicle is likely to result in a change in the mean attitude (Figure 11).

Table 2

Parameters	*Characteristics*
Nominal Attitude	XVV (station x-axis toward the velocity vector)
Range of Operational Attitude	Roll, Yaw : +15 deg to -15 deg Pitch : +10 deg to -20 deg
Attitude Control Accuracy	+/- 5 deg per axis (compared with the commanded values) +/- 3.5 deg per axis (controlling to TEA)
Attitude Change Rate	Within +/- 0.02 deg/s per axis (except during microgravity operations) Within +/- 0.002 deg/s per axis (during microgravity operations)
Attitude Estimation Accuracy	0.5 deg per axis (3 σ) 0.01 deg/s per axis (3 σ)
(Knowledge Accuracy)	(at the NASA navigation base) 3.0 deg per axis (3 σ) (at attached payload)
Attitude Prediction Accuracy	TBD
Continuous Period in the TEA	30 days

Figure 11
An Example of Long Term Variation of the ISS Attitude Profile
(Source: RD-10)



Note (1) Horizontal axis is Flight ID.
1J: August 2001(JEM-PM, JEMRMS launched)
2J/A: February 2002 (JEM-EF experiment payload launched at the first time)
14A: May 2002
UF5: June 2002
1E: October 2002
17A: November 2002
HTV2: February 2003
15A: July 2003
UF6: August 2003
16A: December 2003 (Assembly Complete)

Note (2) ISS configuration stage of Rev. C assembly sequence (Currently Rev. D)
Note (3) This analysis assumed 1 CMG failed out of 4 for the unmated stages (i.e. ISS alone).

Measurements of ISS attitude by star tracker instruments mounted on external payloads, show that during normal operations the attitude stability is typically quite better than the specifications, with a smooth sinusoidal variation with an amplitude of less than 1 degree in each axis over one orbit. The behaviour over multiple orbits is such that the variation does not exceed approx. 2 degree when the ISS configuration is not changed (e.g. by a visiting vehicle docking).

Furthermore, in normal operations the attitude can be predicted using payload star tracker data to better than 0.2 degree accuracy for a few days (predictions using the standard measurements of attitude data may be less accurate, since this data is of lower resolution).

The arrival or departure of a visiting vehicle, such as Soyuz, can result in irregular variations of attitude of 3-4 degree per axis, which may take a few orbits to damp down. Similarly, re-boosts cause transient variations in attitude of 2-3 degree.

Ephemeris of predicted ISS orbit and attitude are generated at regular intervals. Four GPS receivers at different locations on the ISS are used to measure position and calculate attitude by differential GPS measurements. The specification of the predicted and measured ephemeris are as follows;

Predicted position, velocity and attitude:

- Position better than 1 km in each axis
- Velocity better than 0.9 m/s in each axis.

Measured position, velocity and attitude:

- Position better than 75 m in each axis,
- Velocity better than 0.2 m/s.
- Attitude is determined from differential GPS measurements to +/-3 degree accuracy.

The predicted and measured trajectory and attitude data is available to payload operators.

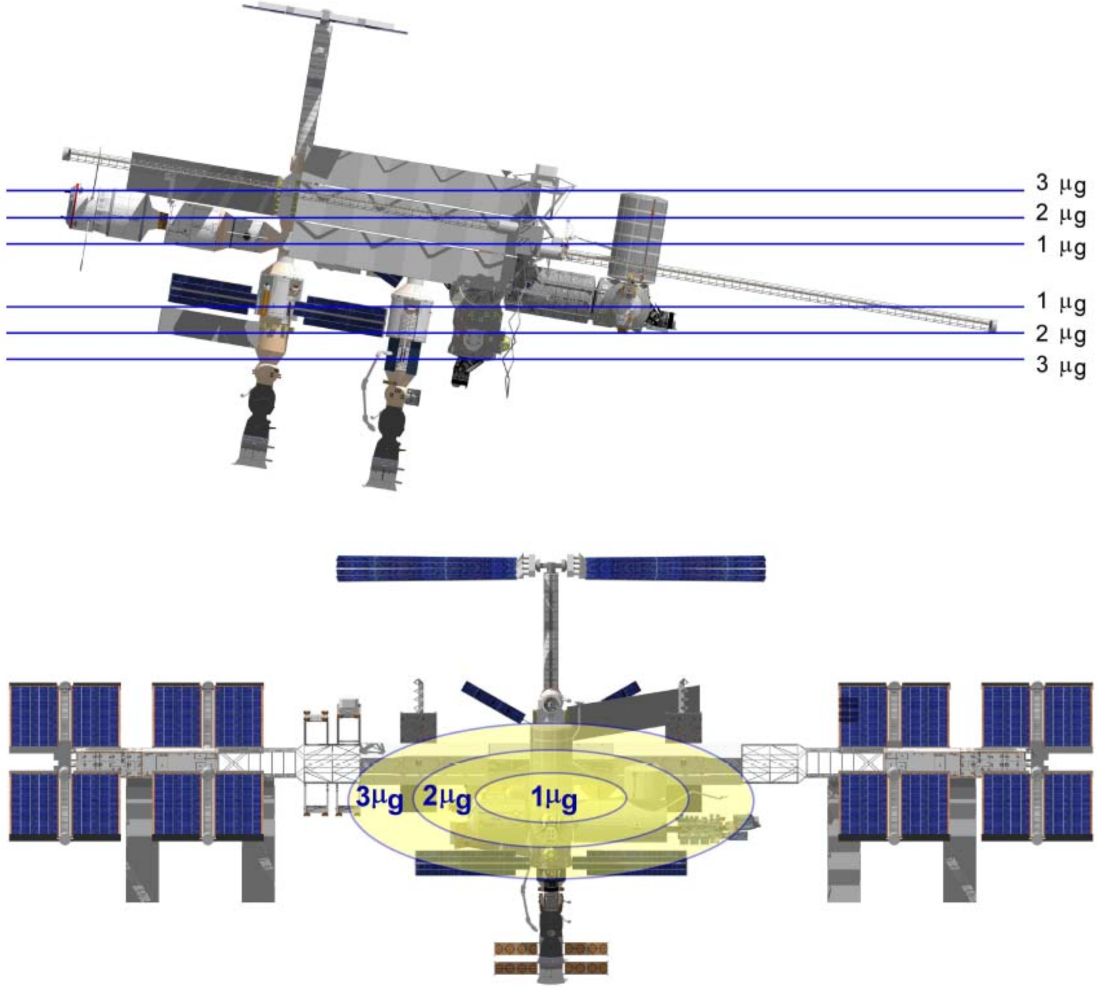
Some facilities onboard of ISS are able to provide high resolution attitude measurements. The JAXA Kibo module external platform ICS system can determine attitude to better than 0.3 degree, providing this information to other Kibo-EF payloads. Additionally, individual payloads using star trackers and gyroscopes have demonstrated attitude measurement capability with better than 0.1 degree accuracy.

3.3 ISS vibration and residual acceleration

The ISS is subject to a number of perturbing forces, including air drag, as well as accelerations induced by the crew, equipment or intentional manoeuvres (e.g. reorientation reboost, visiting vehicle dockings). As a result instruments and payloads are subject to a residual acceleration “microgravity environment” environment, rather than “zero gravity” due to a combination of quasi-steady accelerations and vibrations. Quasi-steady accelerations (e.g. at a frequency less than 0.01 Hz) are mainly the result of air drag on the ISS, as well as the gravity gradient across the large structure of the space station (Figure 12).

Vibrations are generated by a number of sources, particularly crew activities but also equipment operations may contribute.

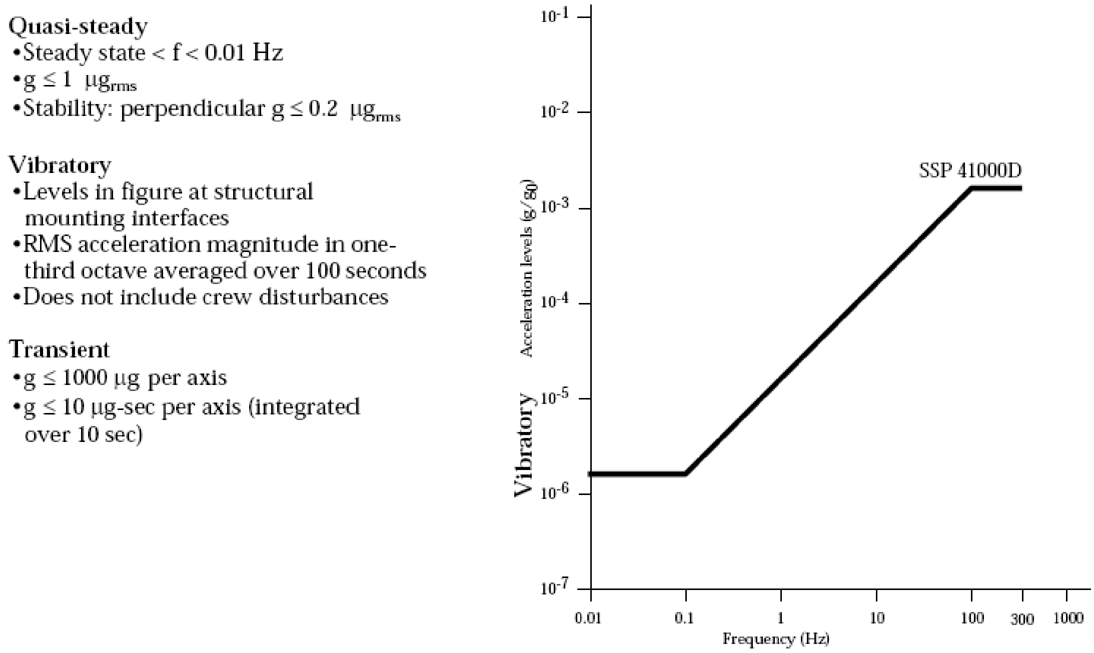
Figure 12
Quasi steady accelerations contours for ISS assembly complete (RD-1)



The vibration and residual acceleration environment of the ISS needs to be taken into consideration for Earth observation instruments, particularly if some measurements have a strong sensitivity to certain frequencies of vibration.

The ISS microgravity environment requirements are summarised in Figure 13: Summary of ISS microgravity requirements .

Figure 13: Summary of ISS microgravity requirements (source: NASA /RD-1)



Further details of measurements of actual microgravity levels and disturbances on ISS can be found at the NASA PI Microgravity Services (PIMS) website;
ISS PIMS microgravity data webpage (RD-11);
http://pims.grc.nasa.gov/pims_iss_index.html
Examples of actual disturbances (RD-12);
http://pims.grc.nasa.gov/pimsdb/index.cfm?method=Handbook.pimslist
Additionally, RD-6 (Overview of attached payload accommodations and environment on the international space station http://www1.nasa.gov/pdf/190373main_TP-2007-214768.pdf) gives expected microgravity disturbance spectrum at different external platform locations.

3.3.1 ISS visiting vehicles traffic

The ISS is regularly visited by various vehicles which transport the crew to and from the ISS, as well deliver supplies and equipment to the station and remove waste when departing. Assembly of the ISS is essentially complete, therefore the visiting vehicle traffic is expected to be primarily dedicated to ISS operations during the next decade.

Figure 14: shows a typical traffic flow which may be expected during ISS operations in the coming years, while Figure 15 shows the various vehicles. The key points to note are;

- Visiting vehicles dock at various docking ports on the station. Usually any of the main docking ports are only left unoccupied for a short time after the departure of one vehicle and the arrival of a new vehicle
- The nominal number of crew members is six, with crew being rotated on Soyuz vehicles. Each Soyuz can carry three crew members, so that crew members are rotated in blocks of three crew. As a result there are

short periods when there may only be three crew members aboard in the time between

- There are an average of 4 Soyuz launches to ISS per year. Each Soyuz spends 5-6 months docked per station, so that two different docking ports on the Russian segment are used for Soyuz vehicles
    - Soyuz can carry payloads to the station inside the pressurised volume of the vehicle
    - Soyuz can return a small amount (>50kg total) of cargo from the ISS inside the pressurised volume of the vehicle
- Russian Progress vehicles deliver supplies to the Russian segment with 4 to 5 vehicles being launched per year, each Progress remaining attached for between 2 – 6 months.
    - Progress can carry payloads to the station inside the pressurised volume of the vehicle
    - Occasionally Progress vehicles
- The ESA ATV docks to the aft port of the Russian service module, with a flight frequency of 12-18 months. Typically, ATV remains attached for up to 6 months.
    - ATV can carry payloads to the station in the pressurised volume of the vehicle
- The Japanese HTV docks on the US segment, with a flight frequency of one vehicle every 12 months. The docked phase lasts up to 1 month.
    - ATV can carry payloads to the station in both the pressurised volume of the vehicle and an external upressurised cargo compartment
    - External payloads can be transferred from the HTV unpressarised cargo compartment to the external ISS mounting locations using the ISS mobile servicing system (MSS, which includes the USOS robotic arm systems)
    - External payloads can be transferred to the external cargo compartment of HTV at the end of the operational life of the payload, for disposal during the destructive reentry of HTV
- The NASA commercial resupply vehicles (CRS) will dock on the US segment of the ISS. It is anticipated that these vehicles will fly approx 3-4 times per year and remain docked up to 1 month.
    - The OSC Cygnus vehicle can carry payloads to the station in the pressurised module of the vehicle. Alternatively, the pressurised module can be replaced with an ExPRESS Logistics carrier for unpressurised external payloads
    - The SpaceX Dragon Vehicle can carry payloads in both the pressurised capsule or the unpressurised external payloads module of the vehicle.
    - External payloads can be transferred from the CRS unpressarised cargo compartment to the external ISS mounting locations using the ISS mobile servicing system (MSS, which includes the USOS robotic arm systems)
    - External payloads can be transferred to the external cargo compartment of CRS at the end of the operational life of the payload, for disposal during the destructive reentry of the non-reusable compartments of the CRS vehicle

  - The SpaceX Dragon vehicle can return payloads inside the pressurised compartment of the Capsule.
- Sometimes there are repositioning of vehicles from docking one port to another (particularly Progress and occasionally Soyuz) to permit a new arriving vehicle to use one port.
- The crew rotation plan may alter in the middle of the decade if new US commercial crew transport vehicles are available.

During docking and undocking operations, some disturbance of the ISS attitude and operations are expected. In addition, there is the possibility of impingement of attitude control thruster exhaust on the ISS environment which may require some sensitive instruments to be protected.

A general overview of the ISS visiting vehicles may be found in the NASA ISS Reference Guide;
http://www.nasa.gov/pdf/508318main_ISS_ref_guide_nov2010.pdf

Further details of individual vehicles can be found at the respective agency websites;

ESA ATV;
http://www.esa.int/SPECIALS/ATV/index.html

JAXA HTV;
http://iss.jaxa.jp/en/htv/

NASA CRS SpaceX Dragon;
http://www.nasa.gov/pdf/478108main_Day2_P11r_IP_SpaceX_Beck.pdf

NASA CRS OSC Cygnus;
http://www.orbital.com/HumanSpaceExplorationSystems/COTS/

Figure 14:
An example of a typical traffic flow to/from the ISS along with the crew rotation. The period when each crew member is onboard the station is noted in the upper part of the timeline. The middle part of the timeline shows the vehicles which are occupying the various ISS docking ports. The MRM2, MRM1, DC-1and SM-Aft ports are on the Russian segment, these can accept the Soyuz, Progress and ATV vehicles. Node2 and PMA-2 are on the US operating segment and can accept the HTV and new American commercial resupply vehicles. Target launch dates for each visiting vehicle is given on the lower part of the timeline (Source: NASA)

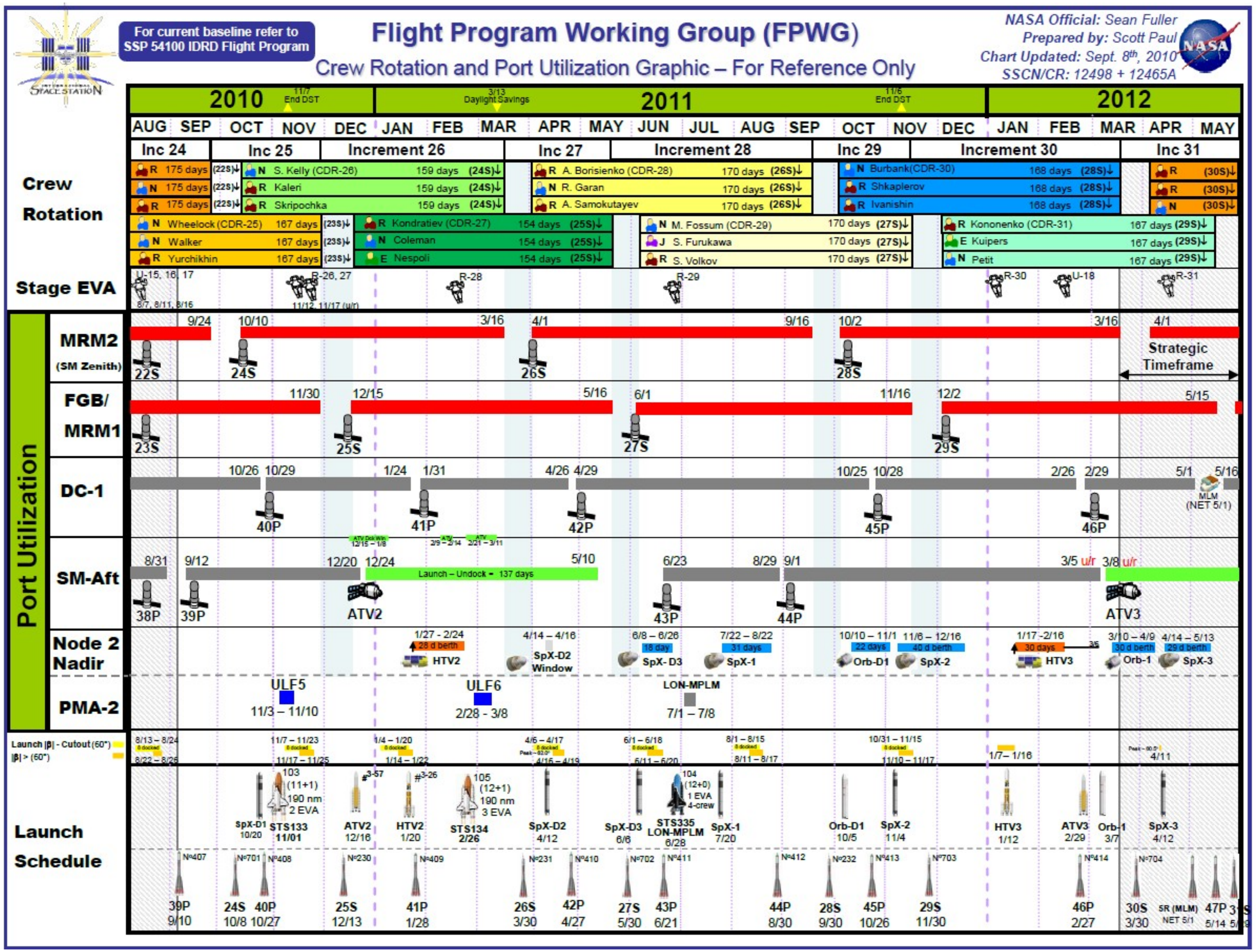
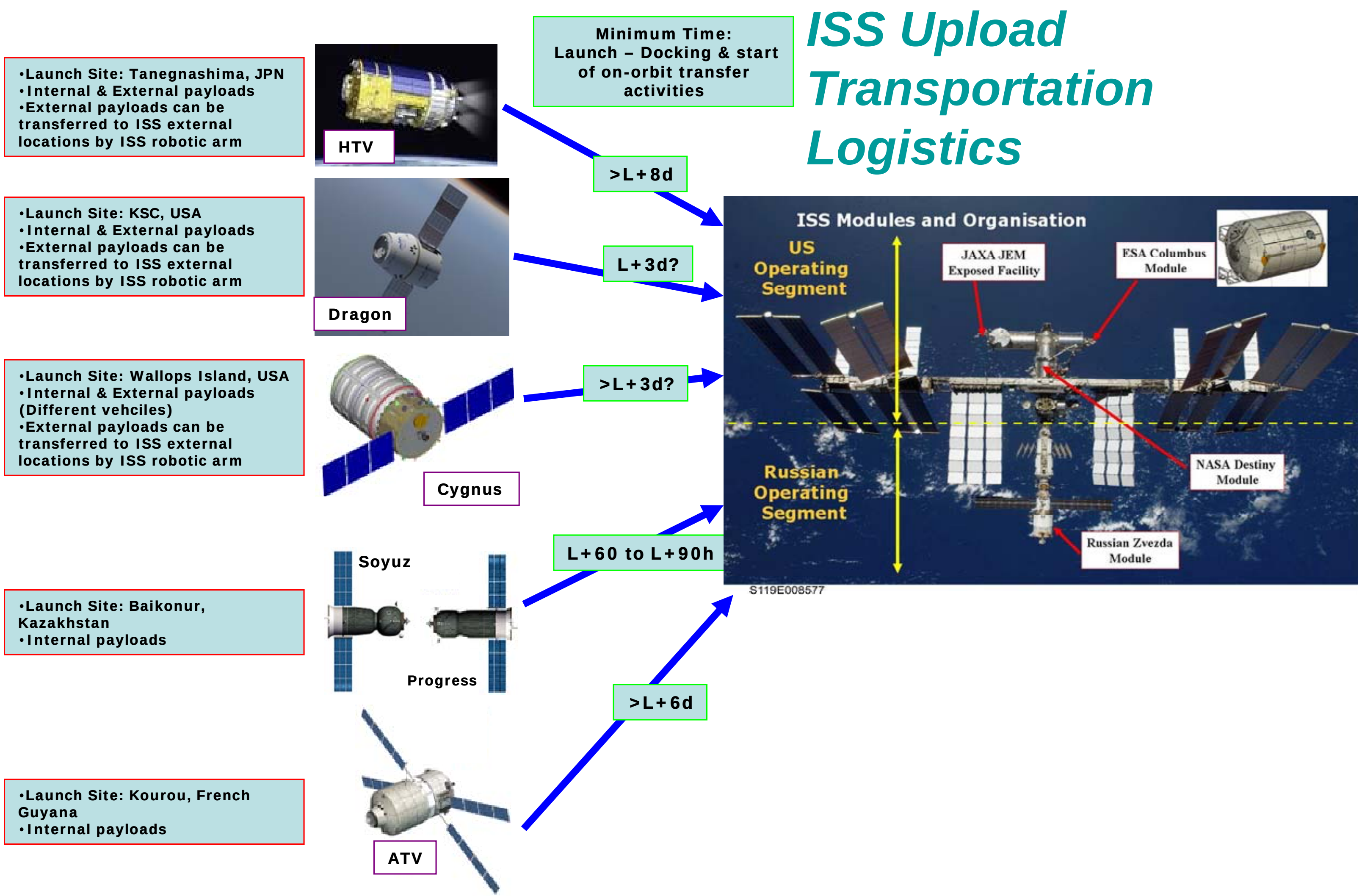


Figure 15


ISS Upload Transportation Logistics
Minimum Time: Launch – Docking & start of on-orbit transfer activities
•Launch Site: Tanegnashima, JPN
•Internal & External payloads
•External payloads can be transferred to ISS external locations by ISS robotic arm
HTV
>L+8d
•Launch Site: KSC, USA
•Internal & External payloads
•External payloads can be transferred to ISS external locations by ISS robotic arm
Dragon
L+3d?
•Launch Site: Wallops Island, USA
•Internal & External payloads (Different vehciles)
•External payloads can be transferred to ISS external locations by ISS robotic arm
Cygnus
>L+3d?
•Launch Site: Baikonur, Kazakhstan
•Internal payloads
Soyuz
Progress
L+60 to L+90h
•Launch Site: Kourou, French Guyana
•Internal payloads
ATV
>L+6d
ISS Modules and Organisation
US Operating Segment
Russian Operating Segment
JAXA JEM Exposed Facility
ESA Columbus Module
NASA Destiny Module
Russian Zvezda Module
S119E008577

3.4 External instrument accommodation locations

3.4.1 General overview:

The ISS has a number of external locations that can be potentially used for deployment of instruments and payloads. These include the ESA Columbus External Payloads Facility (CEPF), the US Truss assembly, the JAXA Kibo JEM Exposed facility and locations on the Russian segment. The locations of these points are indicated in Figure 16. For European payloads the preference would be to use European elements of the station (e.g. CEPF), but it is also possible through interagency agreements to use other external locations on the ISS.

The external environment of the ISS is a combination of the natural space environment and the effect of the interaction of the space station with this environment (Induced environment).The characteristics of the ISS external environment are given in Table 3 ISS External Environment parameters (Source: RD-1)

Figure 16
Location of external attachment interfaces for instruments and payloads on the ISS

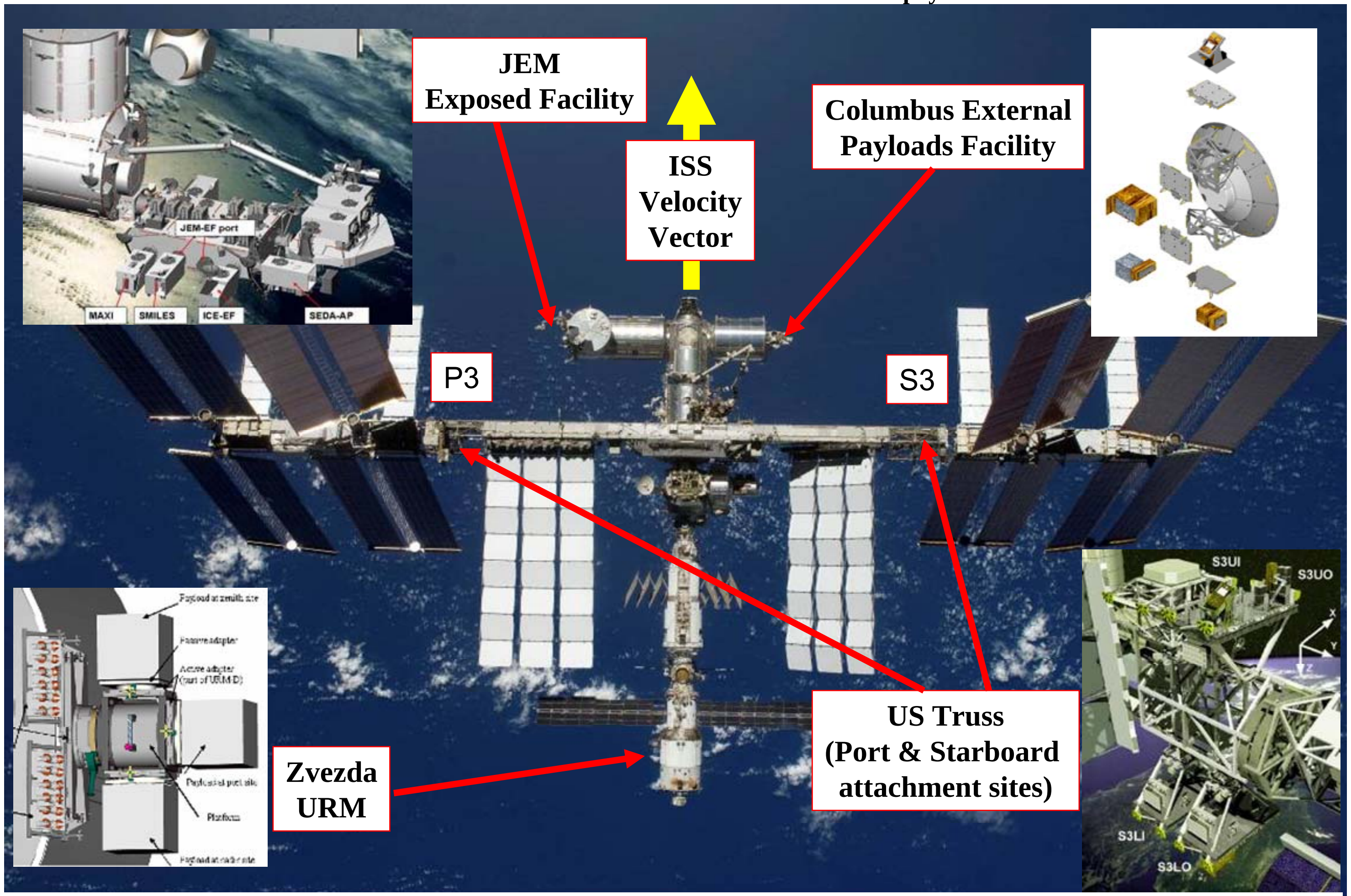


Table 3 ISS External Environment parameters (Source: RD-1)

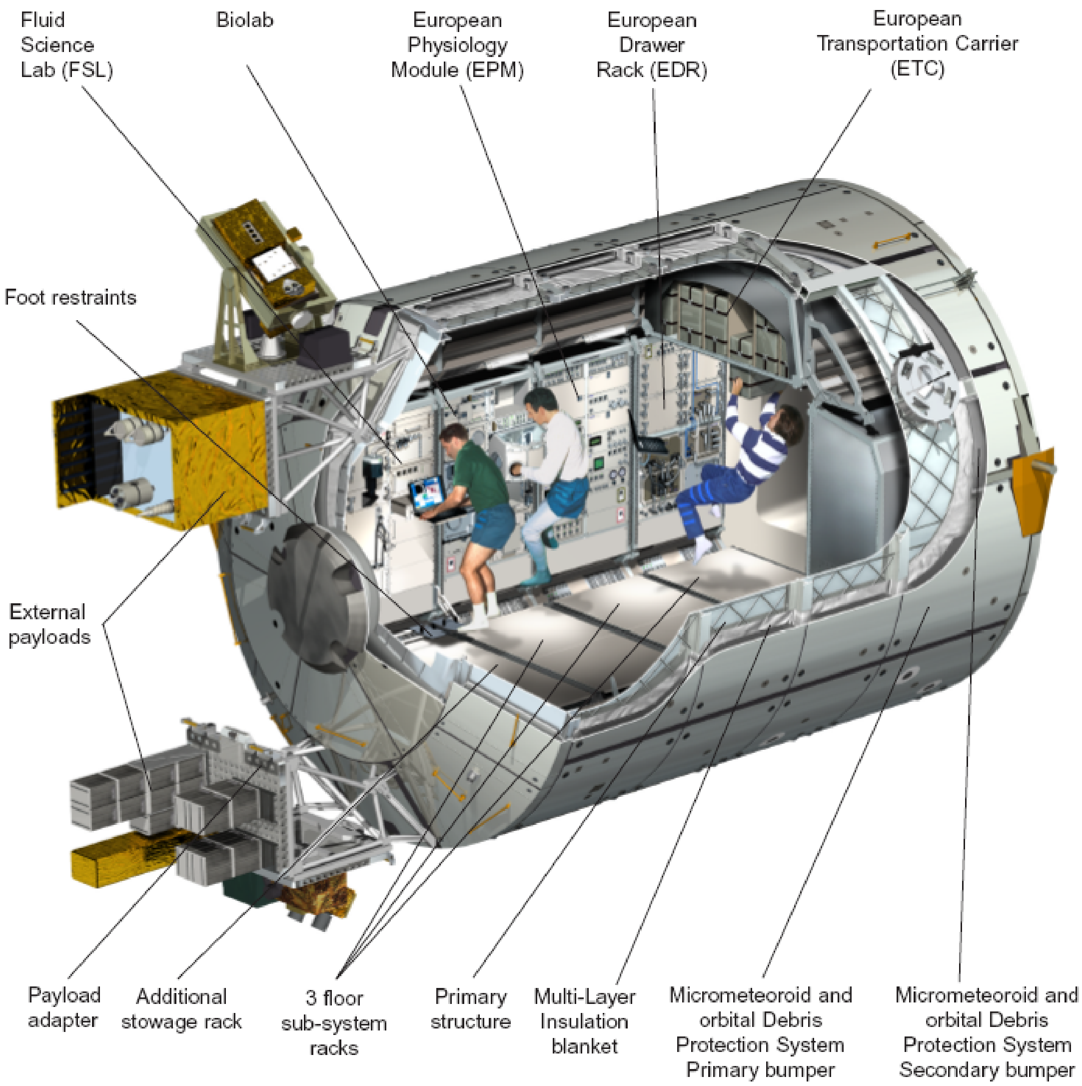
Natural External Environment	
Parameter	Value / Remarks
Atmospheric Pressure	~3.6×10^{-11}kPa
Thermal Environment	Max: ~+120°C Min: ~ -120°C
• Cold Natural Thermal Environment	Solar Constant: 1321 W/m^2 Earth Albedo: 0.2 Earth OLR*: 206 W/m^2
• Hot Natural Thermal Environment	Solar Constant: 1423 W/m^2 Earth Albedo: 0.4 Earth OLR*: 286 W/m^2
Humidity	0% relative humidity
Atomic Oxygen	Up to 4.4x1019 atoms/cm^2/day
Electromagnetic radiation spectrum	Exposure to full electromagnetic spectrum from X-rays to long wave radio. Intense solar ultraviolet radiation
Plasma	Plasma environment of ionosphere. ISS surface has an equilibrium potential of a few negative volts with respect to external plasma environment
Ionizing radiation	Trapped electrons, protons, solar and galactic cosmic rays
Meteoroids and orbital debris	Weak flux of small orbital debris and micrometeroid particles which cause cumulative surface damage and degradation over time
Induced External Environment	
Quiescent periods = standard operations outside of visiting vehicle operations and reboosts	
Molecular Column Density from ISS contamination sources	1x 10^{14} molecules/cm^2 (Excludes ram wake effects)
Particulate background	Limited 1 particle (<100μm) per orbit
Molecular disposition	Less than 1x10-^{14}g/cm^2
Non Quiescent periods *(e.g. docking / undocking of visiting vehicles, reboosts)*	
Molecular disposition	Less than 1x10-^{6}g/cm^2
Plume Impingement	Maximum 0.16kPa direct, Maximum 0.038kPa indirect (shear)

* Earth Outgoing Long-Wave Radiation

3.4.2 Columbus External Payloads facility CEPF

The Columbus module is fitted with an external payloads facility (CEPF) which consists of two mounting structures. Each mounting structure has two adaptor plates for payloads, providing a total of four attachment sites – one nadir facing (SDN), one zenith facing (SOZ) & two starboard facing (SOX and SDX). Each attachment point is compatible with the EXPRESS pallet adaptor system or custom adaptors. The general configuration of Columbus and the CEPF are shown in Figure 17.

Figure 17
General Arrangement of Columbus module



The key specifications of each attachment point are given below and in Table 4;

- **Mass:** Total mass of up to 290 kg (including EXPRESS pallet adaptor and attachment mechanism
- **Dimensions:** Maximum dimensions of the payload are 864mm x 1168mm x 1245mm
- **Power:** up to 1.25kW of power (at 120VDC). Note: equipment can only be radiatively passively cooled
- **Data:** Commanding and data transfer of up to 1.55Mbps via Ethernet data line. High data rate with interface to video processing unit of up to 32.426Mbps

The nadir pointing and starboard pointing attachment sites are most suitable for Earth observation payloads. Currently the Solar payload is mounted on the zenith facing port (SOZ), the Nadir port is currently occupied by a NASA payload which will be exchanged for the ESA ACES payload in 2013. One of the starboard attach points (SDX) will be used for the ESA ASIM payload in 2013, while the other (SOX) is currently empty, previously being used for the ESA EUTEF payload. Details and dimensions of the CEPF, attachment structures and interfaces are given in the figures below

In addition to the CEPF, potentially additional external payloads could be potentially attached to the sides of the Columbus module, using the launch trunnions facing towards the limb in either the ram direction (+x) or trailing direction. This would permit nadir, limb and zenith observations to be made with externally mounted instruments. No decision has yet been made by ESA to implement instruments along the side of the Columbus module.

Figure 18
Columbus overall envelope with CEPF (ESA-RD-1)

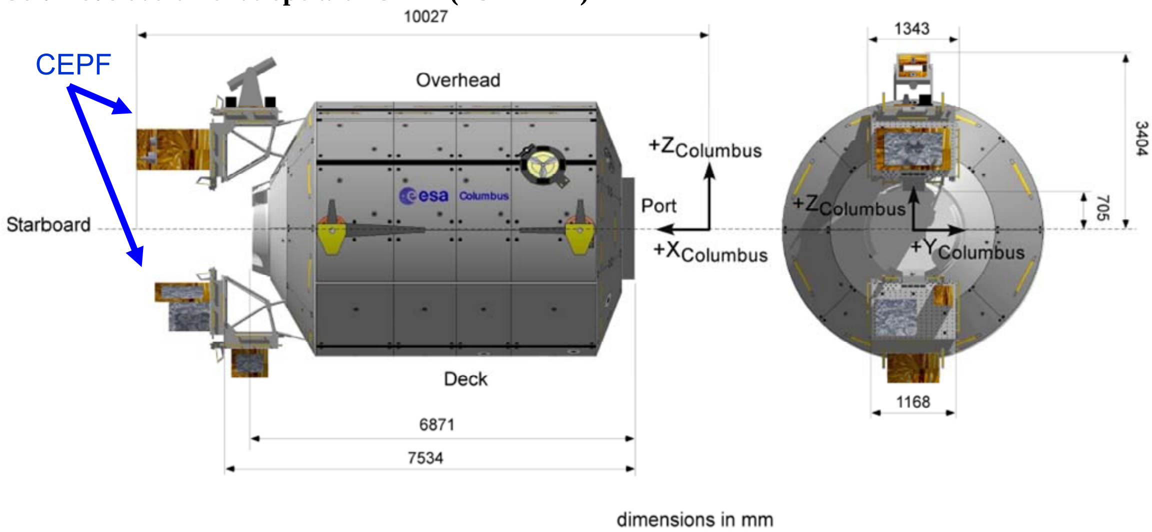


Figure 19
Columbus CEPF configuration with orientation indicated

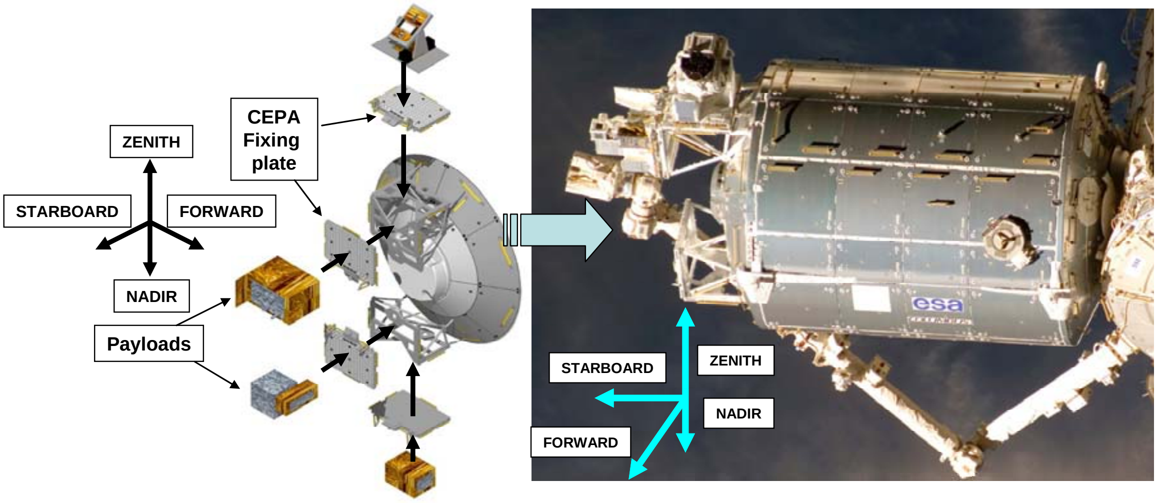


Figure 20
Columbus External Payloads Adapter (CEPA) assembly (ESA RD-1)

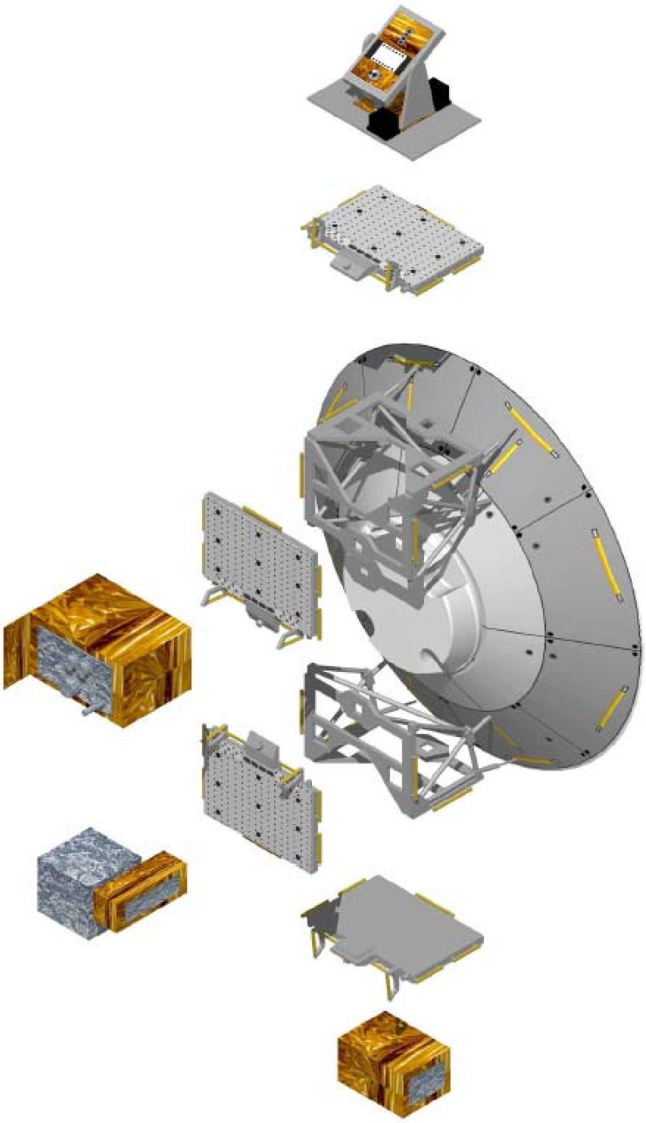


Table 4
Columbus to external payloads system interfaces

INTERFACE/RESOURCE/CONFIGURATION	DESCRIPTION
Integrated external payload on-orbit mass	≤ 290 kg (including CEPA and active FRAM). Mass available for payload up to 226.5kg
Integrated external payload envelope, including active FRAM (Error! Reference source not found.)	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 status 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 Mb/s) ❑ 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 Mb/s (currently limited to 32Mb/s)

Figure 21
External payload / Columbus module interface plane definition

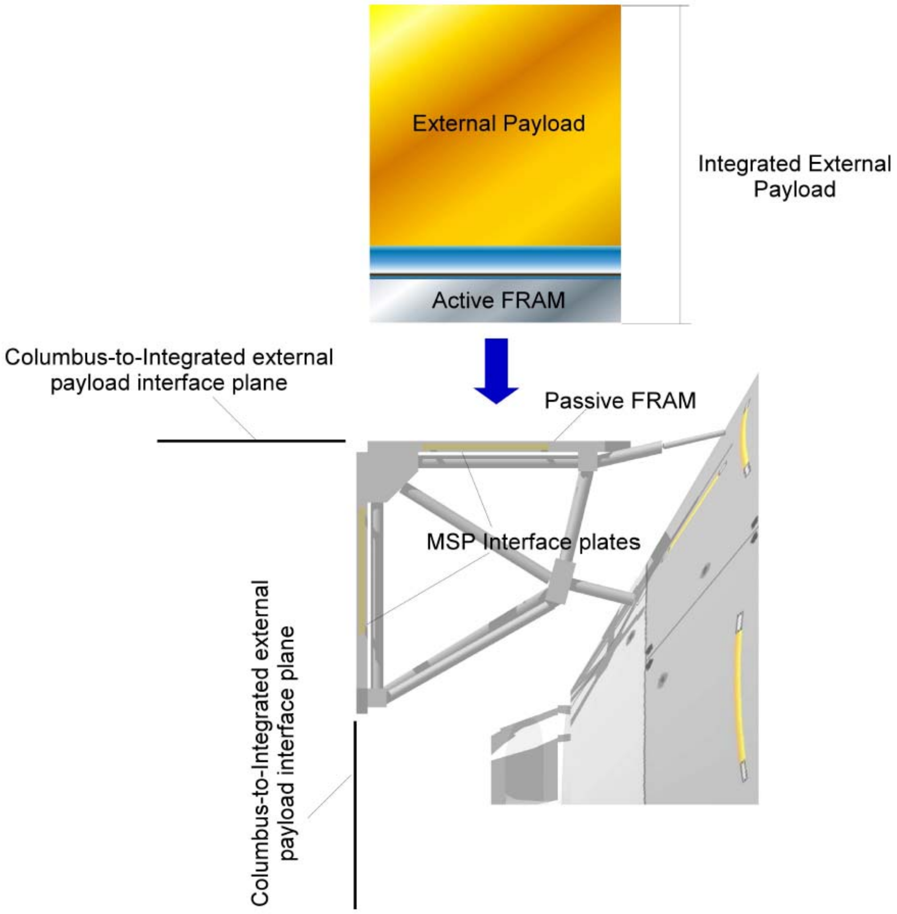


Figure 22
Detailed view of CEPF accommodation with passive FRAM and MSP (ESA: RD-1)

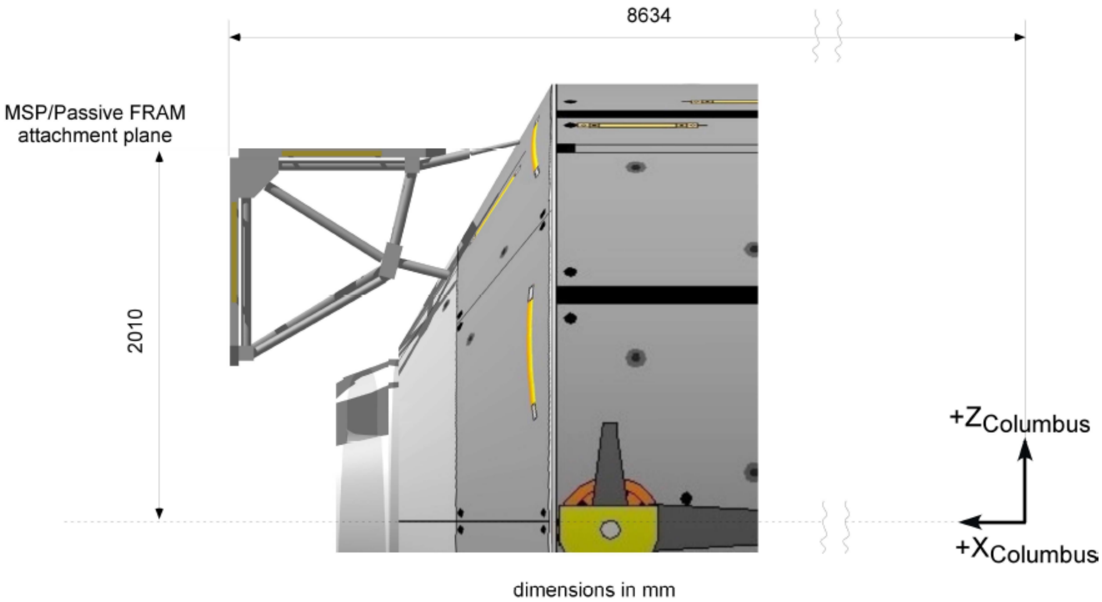


Figure 23
CEPA assembly envelope (ESA RD-1)

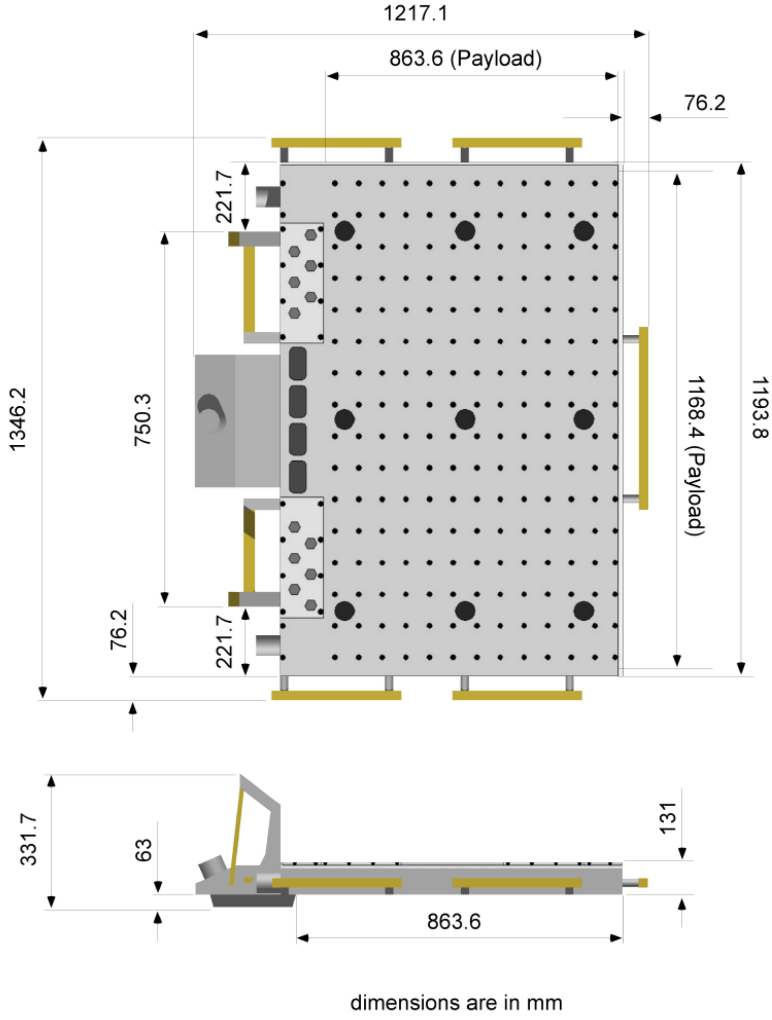
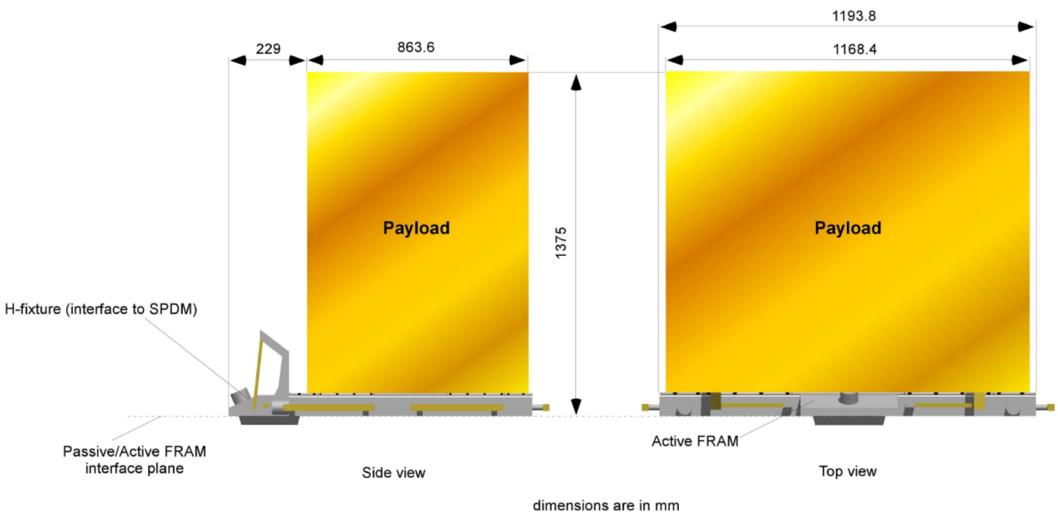


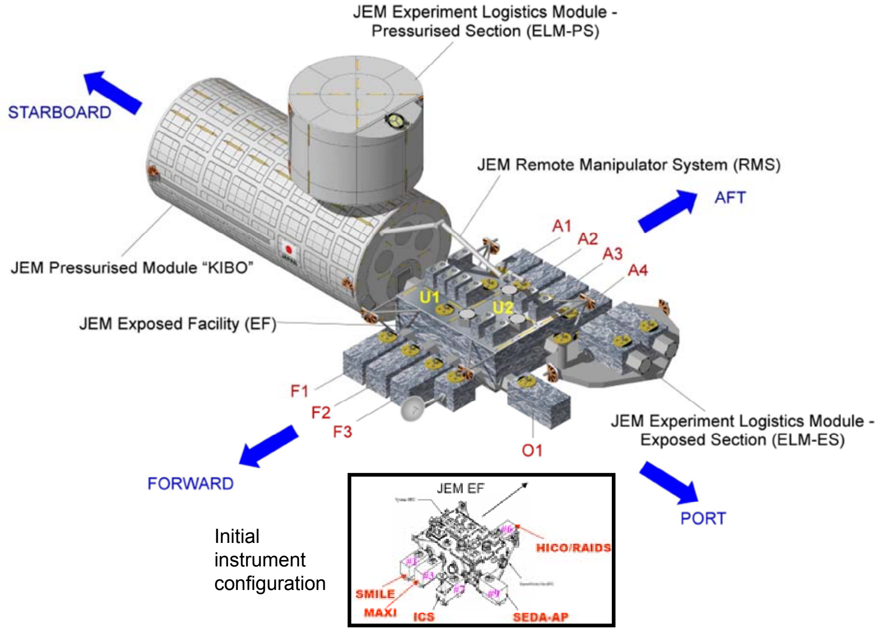
Figure 24
Columbus to external payloads interfaces (source ESA RD-1)

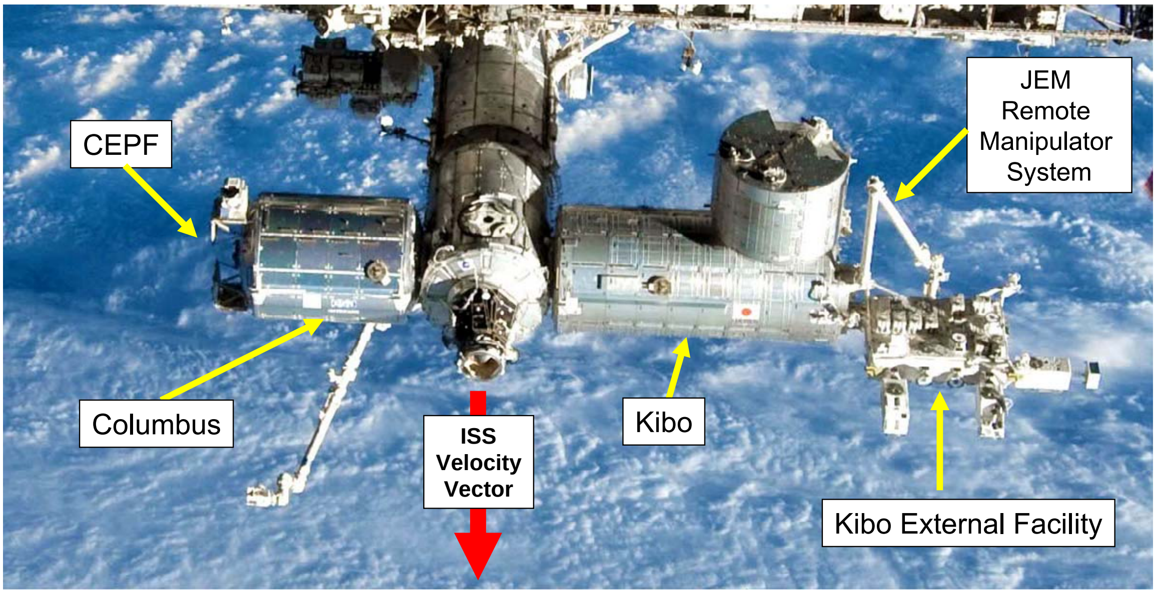


3.4.3 Kibo Exposed facility (Kibo-EF)

The Japanese Kibo module consists of a pressurised module and an external exposed facility (RD-9).The exposed facility can carry up to 12 payloads in a variety of different configurations. This includes a experiment logistics module exposed section, carrying three payloads, mounted at the end of the Kibo-EF as well as individual exposed payloads mounted on either side of the Kibo-EF (See Figure 25 and Error! Reference source not found.). New payloads can be installed on the Kibo-EF in two ways; Directly from the external pallet of HTV using a Kibo and ISS robotic arms (i.e externally transferred) or for small payloads transferred from the pressurised module via the Kibo airlock and externally installed using the Kibo robotic arm.

Figure 25 Kibo External facility general arrangement (Source ESA: RD-1 and NASA)





3.4.4 US Truss and ExPRESS Logistics Carrier

External payloads can be mounted on the US segment truss (see Figure 1: ISS Elements) by using an ExPress Logistic's Carrier (ELC), which provides power and data connections to instruments. Several instruments can be accommodated on each ELC, with on-orbit installation / removal being achieved either by an EVA or the ISS robotic arm .
The Starboard (S3) Truss can accommodate up to four ELC's while the Port Truss (P3) can accommodate up to two ELC's as shown in Figure 27.

Figure 26 ELC locations and payloads on the US Truss in 2011 (source: NASA)

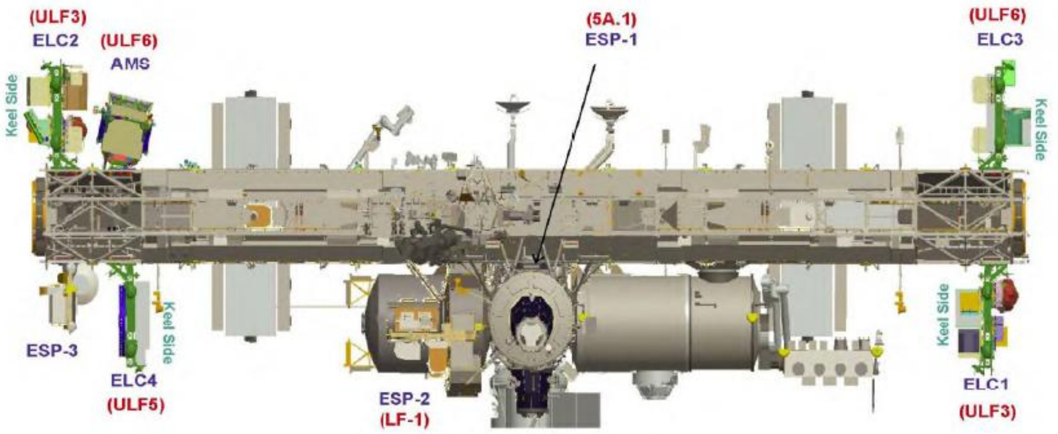
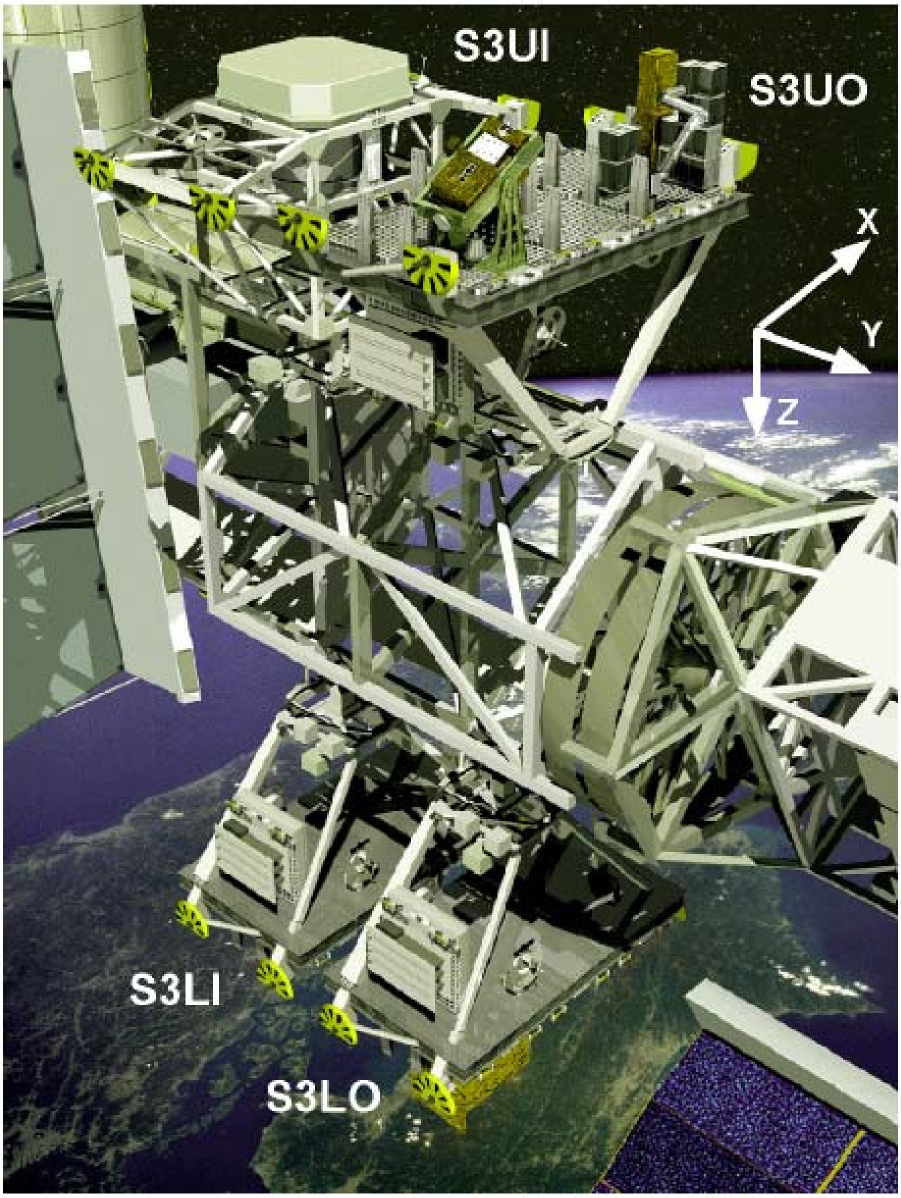


Figure 27
External payloads configuration on S3 Truss (RD-1)



Further Information on the ExPRESS Logistics Carrier (ELC) can be found on the NASA webpage;

http://www.nasa.gov/mission_pages/station/research/experiments/ELC.html

3.4.5 Zvezda URM

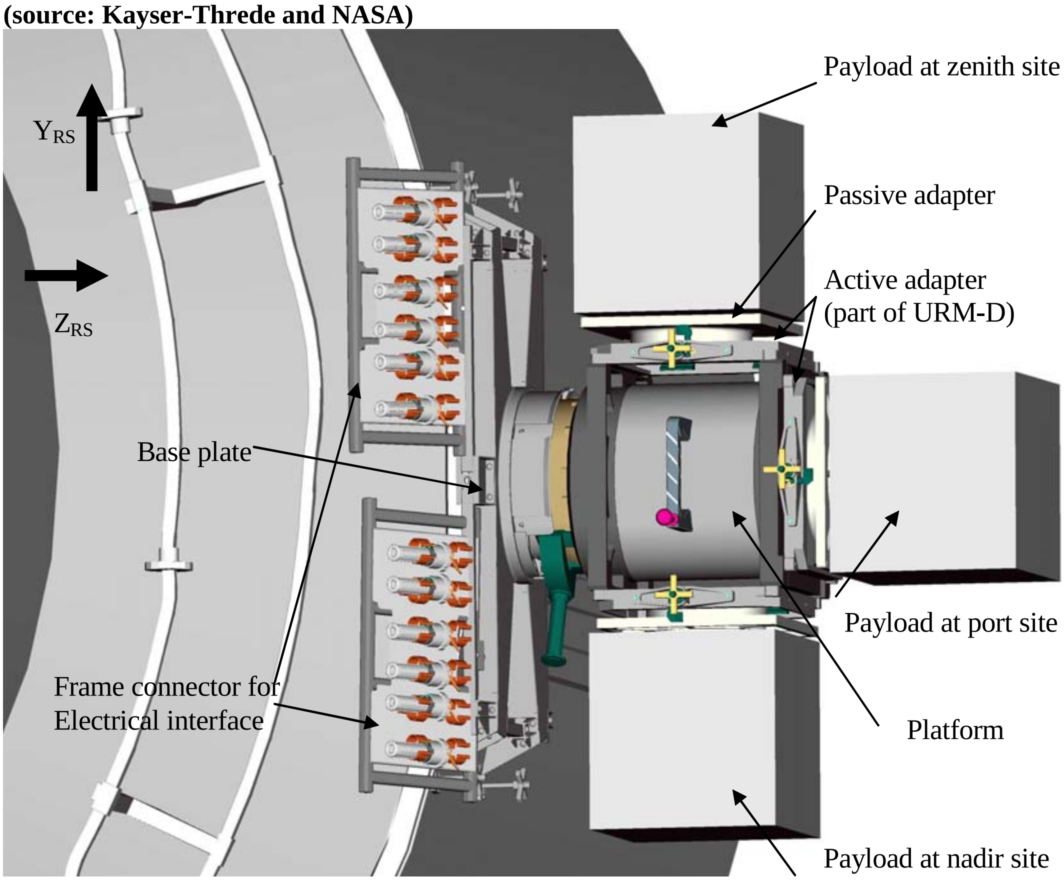
The Portable Multipurpose Workstation (URM-D) is an external mounting structure on the port side of the Russian Service Module (Zvezda). There are three payload attach points; a Nadir facing, port facing and zenith facing payload. The URM-D provides power and data connection to the payloads. Payloads are installed and removed by the crew during an EVA. Currently, the ESA EXPOSE-R payload is mounted on the Zenith port of URM-D. The general configuration of URM is shown in Error! Reference source not found.

3.4.6 External Platforms Field of View

Diagrams showing simulated fields of view and obstructions by ISS structure for the main USOS external instrument mounting locations can be found in the RD-6: “Overview of attached payload accommodations and environment on the international space station”
http://www1.nasa.gov/pdf/190373main_TP-2007-214768.pdf

Figure 28

General configuration of URM-D and photo of EXPOSE-R deployed on URM-D in Dec 2008 (source: Kayser-Threde and NASA)



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3.5 Installation of external instruments

External instruments may be installed either via a crew Extravehicular Activity (EVA or "spacewalk") or by use of one of the space station robotic arms. It is preferable to use robotic installation and de-installation of instruments, as EVA's require significant crewtime hours to prepare and perform.

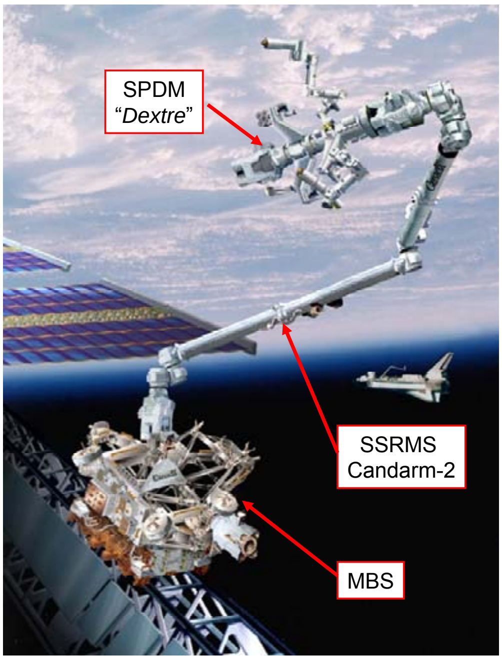
The Japanese HTV vehicle, as well as the NASA commercial resupply vehicles Space X Dragon and OSC Cygnus (in one configuration) can carry payloads in an unpressurised compartment which can be retrieved by the ISS robotic arm system, described below.

Payloads launched inside the pressurised volume of resupply vehicles can be transferred to the exterior by the crew during an EVA, with the possible exception of transfer of small payloads via the Kibo airlock described below.

3.5.1 USOS Mobile Servicing System, including Canadarm 2, Mobile Base System and Dexterous Manipulator

The Mobile Servicing System (MSS) consists of several elements which work with a large robotic arm, known as the Space Station Remote Manipulator (SSRMS or Canadarm 2) which can move around the exterior of the ISS. The Canadarm 2 can self location from one position to another, using interfaces (Latching End Effectors, LEE's) on both ends of the arm to connect to power data grapple features (PDGF's). The system is operated by the crew from one of two workstations (one in the destiny module, the other in Cupola) inside ISS. An overview of the system can be found at the following links;

Fact sheet:
http://esamultimedia.esa.int/docs/hsf_research/ISS_User_Guide/MSS_Datasheet.pdf
NASA MSS Website:
http://www.nasa.gov/mission_pages/station/structure/elements/mss.html
CSA MSS Website;
http://www.asc-csa.gc.ca/eng/iss/mss.asp



Left: The general arrangement of ISS MSS (source CSA)

The Canadarm2 can attach to the Mobile Base system (MBS) which is a multipurpose platform. The MBS can sit on a mobile transporter which can run along rails on the US Truss. The MBS has four PDGF's which allows the Canadarm-2 to connect, as well as payloads, the Dextrous manipulator or even a crew member during an EVA.

The Special Purpose Dextrous Manipulator (SPDM, nicknamed *Dextre*) consists of two robotic arms, connected by a pivoting centre section which can be connected to Canadarm-2. *Dextre* is designed to perform many tasks that would otherwise require an EVA and has a number of tools and adaptors which can be connected to the robotic arms. A good overview of the SPDM capabilities can be found in the following article

Coleshill et al Dextre: Improving maintenance operations on the International Space Station Acta Astronautica Volume 64, Issues 9-10, May-June 2009, Pages 869-874

3.5.2 JEM Remote Manipulator System (JEM-RMS)

The Japanese Kibo module has a robotic for servicing of payloads on the Kibo External Facility (JEM-EF). This consists of a large robotic arm, as well as a smaller arm which can perform fine manipulations which attaches to the end of the main arm. This combination can be used to install and remove payloads from the JEM-EF, from external locations such as the HTV Unpressurised Logistics Carrier (UPLC) working in combination with the USOS Mobile Servicing Systems. In addition, the smaller arm can be used to transfer small payloads to / from the interior of the ISS via the Kibo module airlock.

3.5.3 European Robotic Arm (ERA)

The European Robotic Arm (ERA) is mounted on the Russian Multipurpose Laboratory Module (MLM) which will be launched to the Space Station in early 2012. ERA will be able to transfer small payloads from inside the Russian airlock to locations on the exterior of the Russian segment of the ISS. Further information on ERA can be found at the following links;

ERA General Description:

http://www.esa.int/esaHS/ESAQEI0VMOC_iss_0.html

ERA Fact Sheet:
http://www.spaceflight.esa.int/users/downloads/factsheets/fs008_11_era.pdf

3.5.4 Upload of external payloads in vehicles providing direct access to the ISS robotic arm system

External payloads can be uploaded in three vehicles as an unpressurised compartment of the vehicle, which can be accessed directly via the ISS robotic arm system. These vehicles are the JAXA HTV, the NASA CRS Dragon vehicle and a variant of the NASA CRS OSC Cygnus spacecraft configured to carry an ExPRESS logistics carrier. The payload accommodation characteristics of these vehicles are as follows ;

The JAXA HTV: External Payloads are accommodated in the Unpressurised Logistics Carrier (ULC) of the HTV, carried on a dedicated Exposed Pallet (EP) (See Figure XX). The characteristics of the EP are the following;

- The EP can carry up to a total of 1500kg of payload
- Power to the payloads on the palette can be provided to 4 weeks before launch.
- No power available after HTV fuelling (eg. From a few hours prior to launch)
- Dual string 50V (70W) heater power (passive devices) supply during HTV solo flight and Node 2 berthing
- .Dual string 120V (180W) heater power (passive devices) supply during MBS/POA berthing.
- Dual string 120V heater power (passive devices) supply during SSRMS handling
- No unpressurised payload return – payloads can be removed from ISS and disposed of during the destructive reentry of HTV

HTV has flown two missions to the ISS, with the first mission (HTV-1) in September-November 2009 delivering the SMILES and HICO/RAIDS instruments to the JEM-EF

Figure 29 General Configuration of the HTV, showing the Unpressurised Logistics Carrier which can carry external payloads on an Exposed Pallet (source: JAXA)

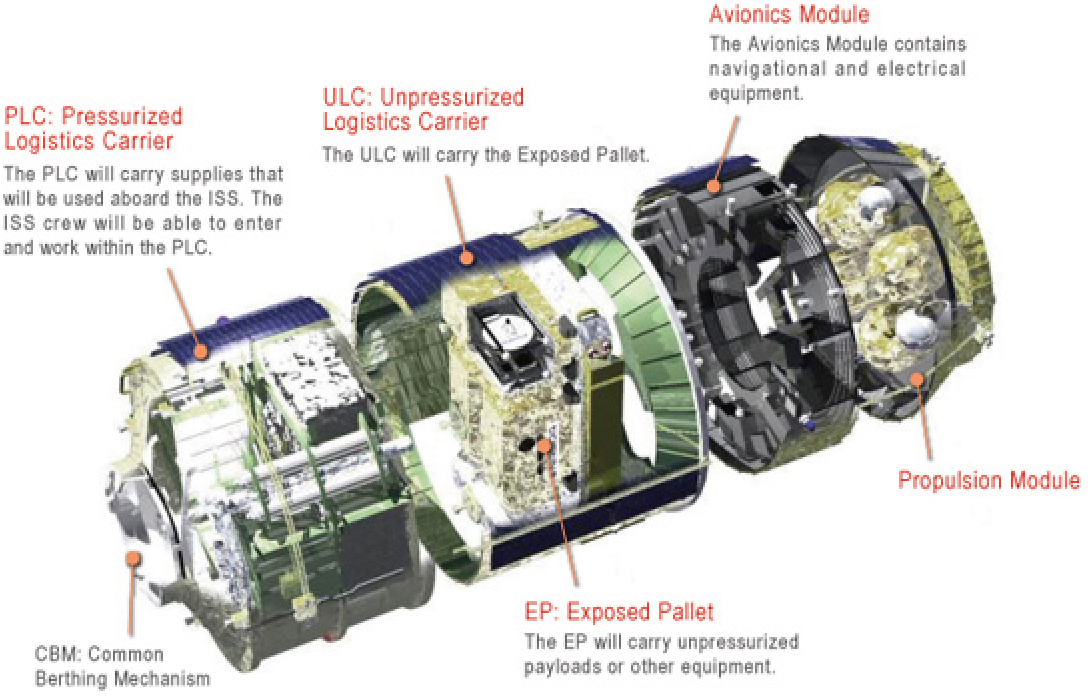


Figure 30: General configuration of the HTV Exposed Pallet. Left, a Type I pallet used for payloads, Right, a Type III pallet used for delivery of ISS spare / replacement items (source JAXA)

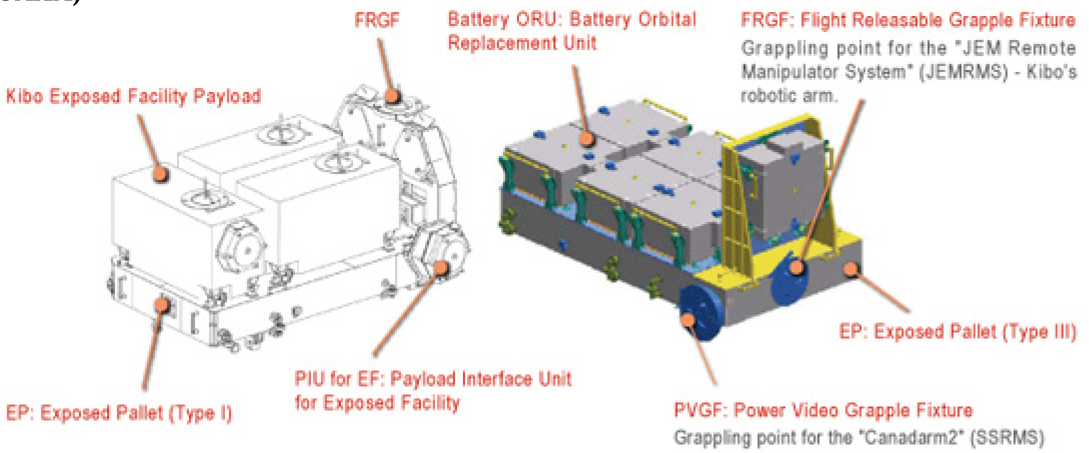


Figure 31: Installation of an Exposed Pallet into HTV

NASA CRS Space X Dragon: External Payloads are accommodated in an unpressurised trunk behind the pressurised capsule. Payloads can be mounted on standard external payload interfaces (eg. FRAM). Preliminary characteristics of external payload accommodation of Dragon are as follows;

- 120 Vdc(2x100W) cont. regulated
- RS-422 (2x100kbps) connections
- Late load possible via access doors in the trunk wall
- No unpressurised payload return payloads can be removed from ISS and disposed of during the destructive reentry of unpressurised trunk

Figure 32: General Configuration of SpaceX Dragon (Source SpaceX)

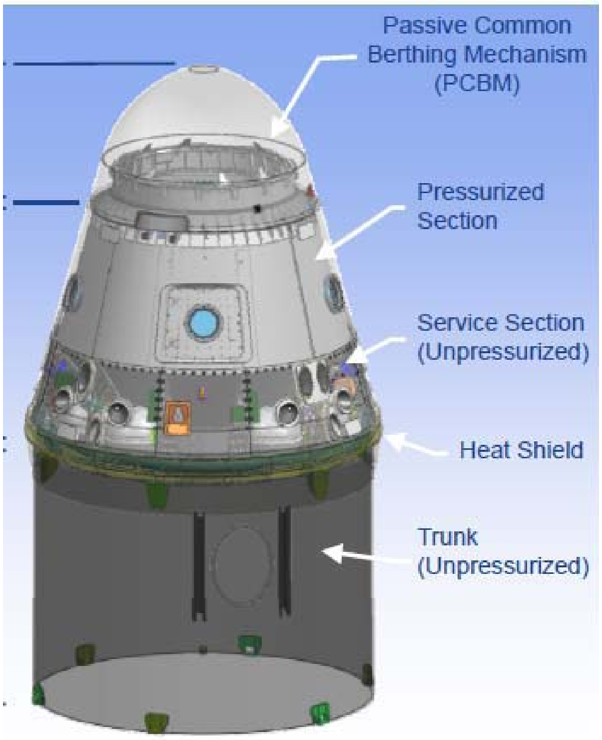
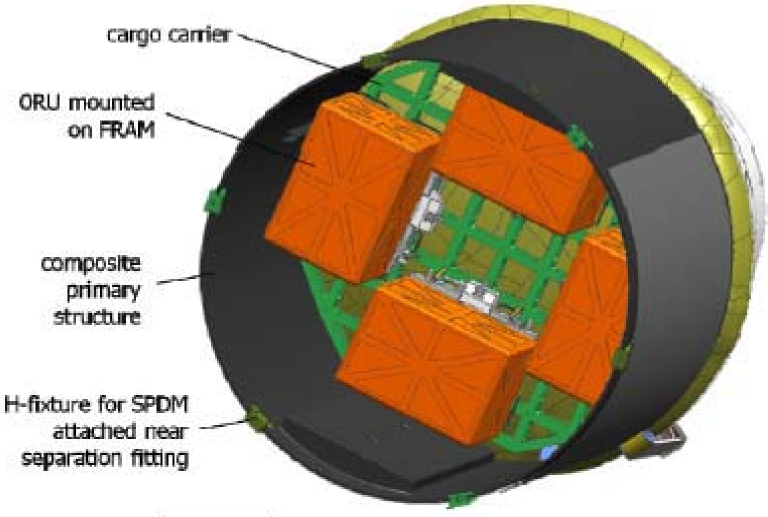


Figure 33: General Configuration of Space X Dragon trunk with FRAM based External Payloads (Source: SpaceX)



NASA CRS Orbital Science Corporation Cygnus : The Cygnus spacecraft can carry two cargo modules – either a pressurised cargo module or an unpressurised cargo module. Only one type of cargo module can be carried on one flight. The unpressurised cargo module is based on the NASA ExPRESS Logistics carrier (ELC).

3.5.5 Robotic Installation of Payloads

Robotic transfer of payloads from HTV or the unpressurised trunk of the SpaceX Dragon are performed by the SSRMS (Canadarm-2) and if required in combination with the SPDM (*Dextre*). The operation of the robotic arm system can be performed either by the crew and/or from ground control, with ground control operations taking somewhat longer time than crew operation.

The external payload can obtain power from the SSRMS if this requested during the design of the payload. Otherwise there are periods during the transfer operations when the payload will be unpowered.

An example of how payloads launched with HTV can be installed on the ISS can be found in the JAXA HTV-1 and HTV-2 presskits;

JAXA HTV-1 Presskit, installation of SMILES and HICO-RAIDS on the JEM-EF from an Exposed Pallet launched on HTV-1;
http://www.nasa.gov/pdf/384523main_htv_press_kit.pdf

JAXA HTV-2 Presskit, delivery of Exposed Pallet with ISS system replacements units;
http://iss.jaxa.jp/en/htv/mission/htv-2/library/presskit/htv2_presskit_en.pdf

A typical timeline of payload transfer from HTV to installation on ISS is given below

Table 5: Typical timeline for robotic deployment of payloads delivered by HTV (Assumes payload is FRAM based, including CEPA payloads)

Phase	Tasks	Operator	Step Time	Payload Unpowered Time
A	SSRMS retrieves payload and temporarily stows on MBS attachment point (POA)	Crew	7.6h (13.25h if performed by ground control	3.1h (4.3h if performed by ground control)
B	Translation of MBS/SSRMS to payload deployment site (eg. ELC's on US Truss, Generally not required for Columbus CEPF payloads)	Ground Control	2h	1.25h
C – option #1	Direct Deployment of Payload to final location on ISS	Ground Control	10h	5.6h
C – option #2	Part 1: Transfer payload to temporary stowage location on SDPM (EOTP) Part 2: Transfer from EOTP to final location on ISS	Ground Control	5.3h 5.8h	1.5h 2.5h

A preliminary timeline for payload transfer from SpaceX Dragon unpressurised trunk to ISS. Note, that for this operation the SPDM (Dextre) is required

Table 6: Preliminary timeline for transfer of for robotic deployment of payloads delivered by SpaceX Dragon(Assumes payload is FRAM based, including CEPA payloads)

Phase	Tasks	Operator	Step Time	Payload Unpowered Time
A	SSRMS retrieves SPDM for transfer operation (preparation activity)	Ground Control	7.6h	N/A
B – option #1	Direct transfer of Payload to final location on ISS (Columbus CEPF)	Ground Control	7h	5.1h
B-option #2	Part 1: Transfer payload to temporary stowage location on SDPM (EOTP) Part 2: Transfer from EOTP to final location on ISS (Columbus CEPF or ELC on US Truss)	Ground Control	3.5h 5.6h	1.7h 2h

Figure 34: The SSRMS grappling the External Pallet (EP) from HTV-2

Figure 35: Schematic showing extraction of HTV External Pallet (EP) from HTV by the ISS SSRMS (Canadarm-2)

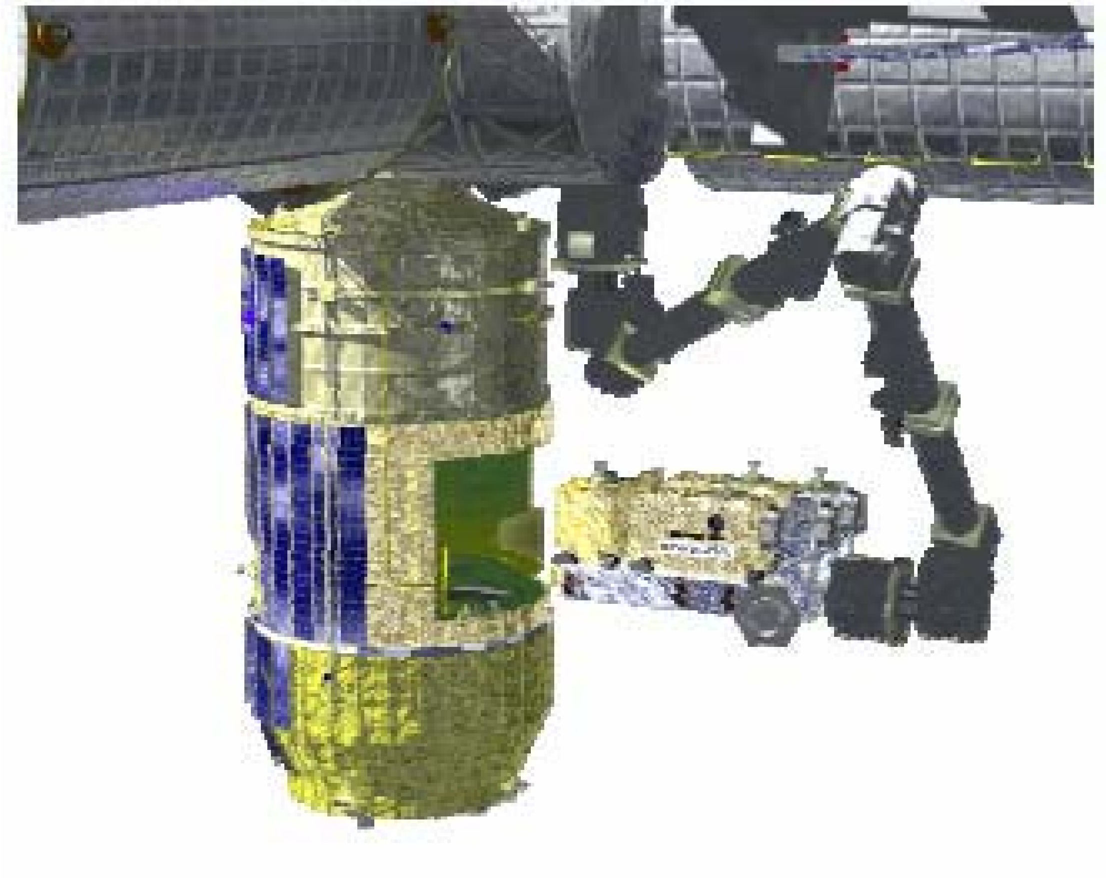
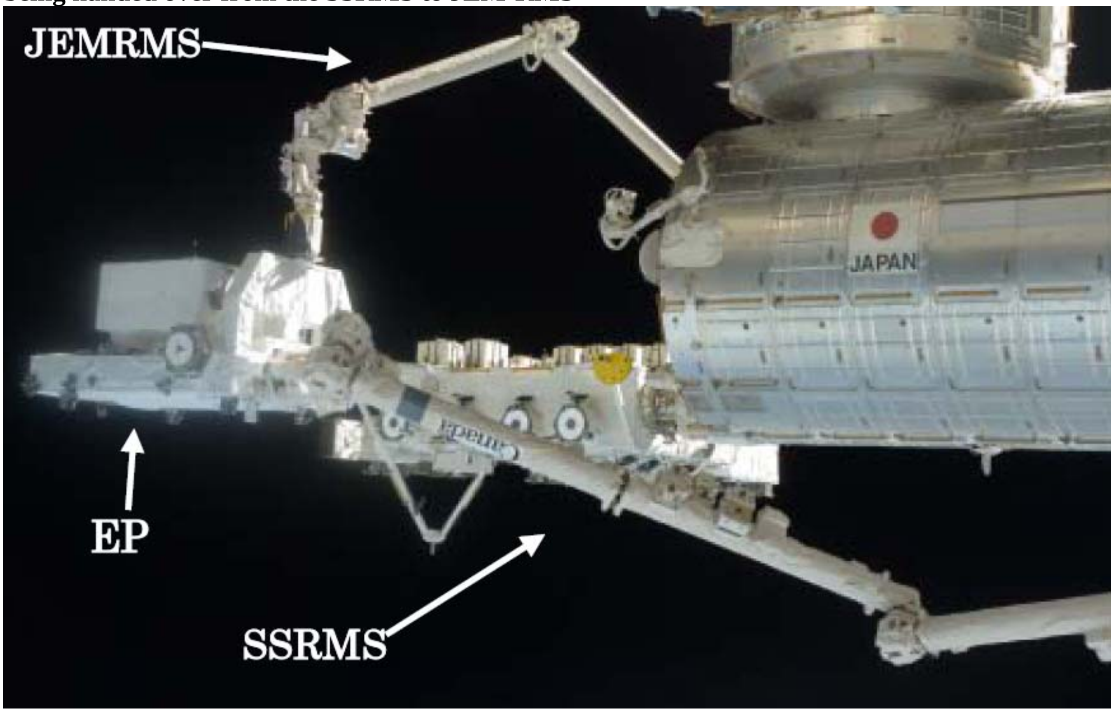


Figure 36 HTV-1 External Pallet (EP) carrying the SMILES and HICO/RAIDS instruments being handed over from the SSRMS to JEM-RMS



3.6 Internal instrument accommodation locations

General overview:

The ISS has a number of window viewing ports that can be potentially used for Earth observation instruments. These include a large nadir pointing window in the U.S. Destiny module, the Cupola with multiple windows (to be added to ISS in 2010) and several windows in the Russian segment. Compared to externally instruments, internally mounted instruments offer a number of advantages as well as disadvantages. These include;

<u>Advantages</u>;

- Instruments accommodated in shirt-sleeve environment of ISS, subjecting the instrument to less severe conditions than external instruments.
- Direct interaction of crew with instrument possible
- Relatively simple development step from breadboard laboratory type instruments to a flight instrument.
- Potentially short lead time for development and implementation (~2-3 years)
- Instrument operation and data transfer through station laptop computers & data management system
- Simple interface with station (e.g. window mounting rails)

<u>Disadvantages</u>:

- Observation through window:
    - Limited wavelength range available (typically visible, but UV and near infrared through some windows).
    - Possibility of internal reflections

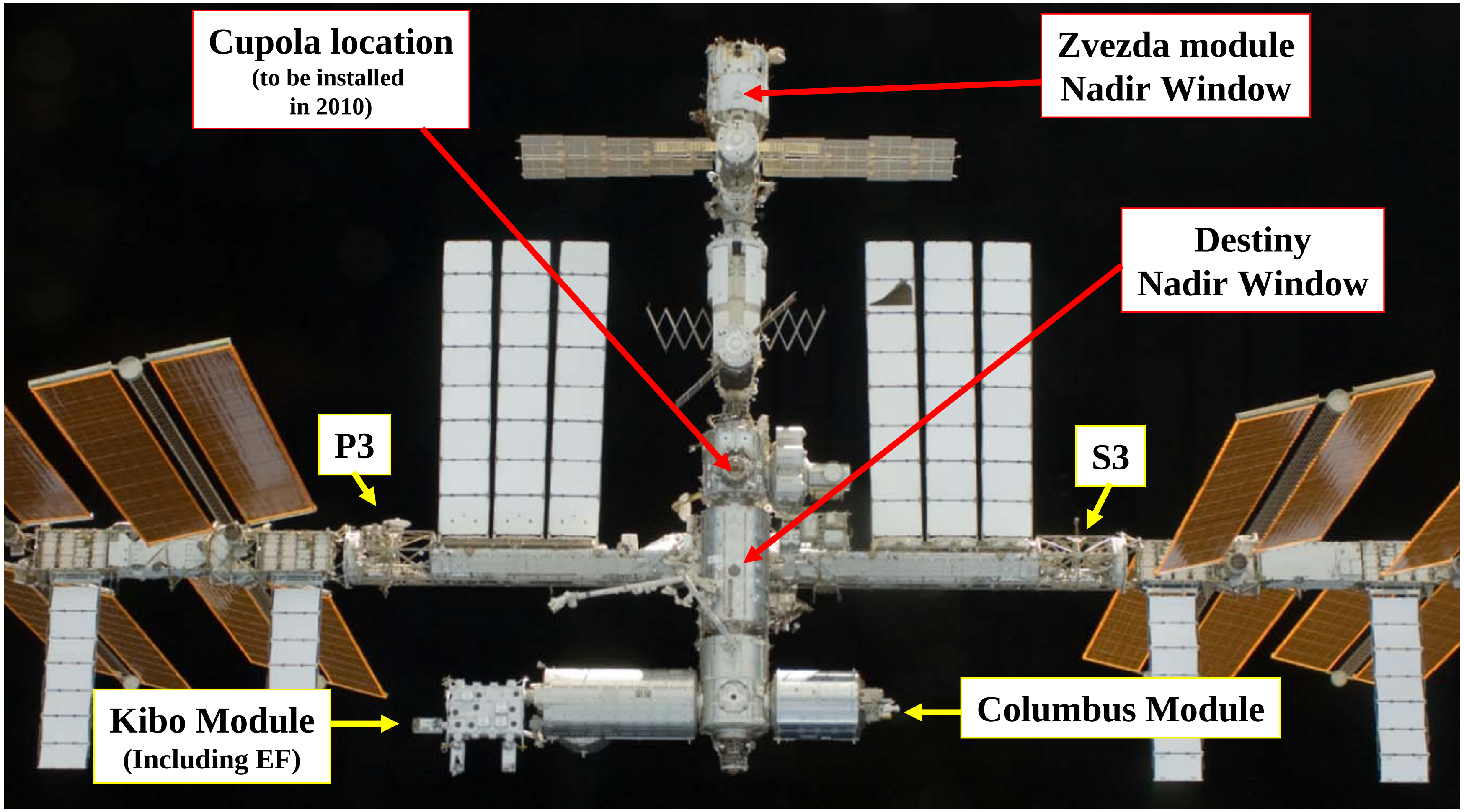
    - o Window shutter not continuously open, so instrument operation may be only performed during defined period (e.g. campaign operating mode)
- Instrument may only be set up for a defined period (e.g. campaign operating mode), due to restrictions on available space / operating area in cabin

The concept of operating internally mounted instruments on ISS is similar to that of using small instruments in observation campaigns onboard aircraft (Figure 37). A typical instrument would be expected to be approx 10kg upload mass or less, with the instrument optics mounted to a window frame attachment point and electronics in a dedicated data processing unit (DPU) or driven by a laptop. Operation of the instrument can be either by directly by the crew and / or via the space station data management system.

Figure 37
Example of a small optical instrument, viewing through aircraft window (right) deployed on the NASA DC-8 aircraft during the Stardust SRC reentry campaign (NASA Ames Research Center)

The locations of observation windows onboard the ISS are shown in red in Figure 38 (Columbus, Kibo and P3/S3 Truss locations also shown for reference) The characteristics of the observation windows and associated facilities are described below

Figure 38
Underside view of the ISS showing observation window locations (in red). External locations suitable for Earth observation payloads are indicated in yellow for reference



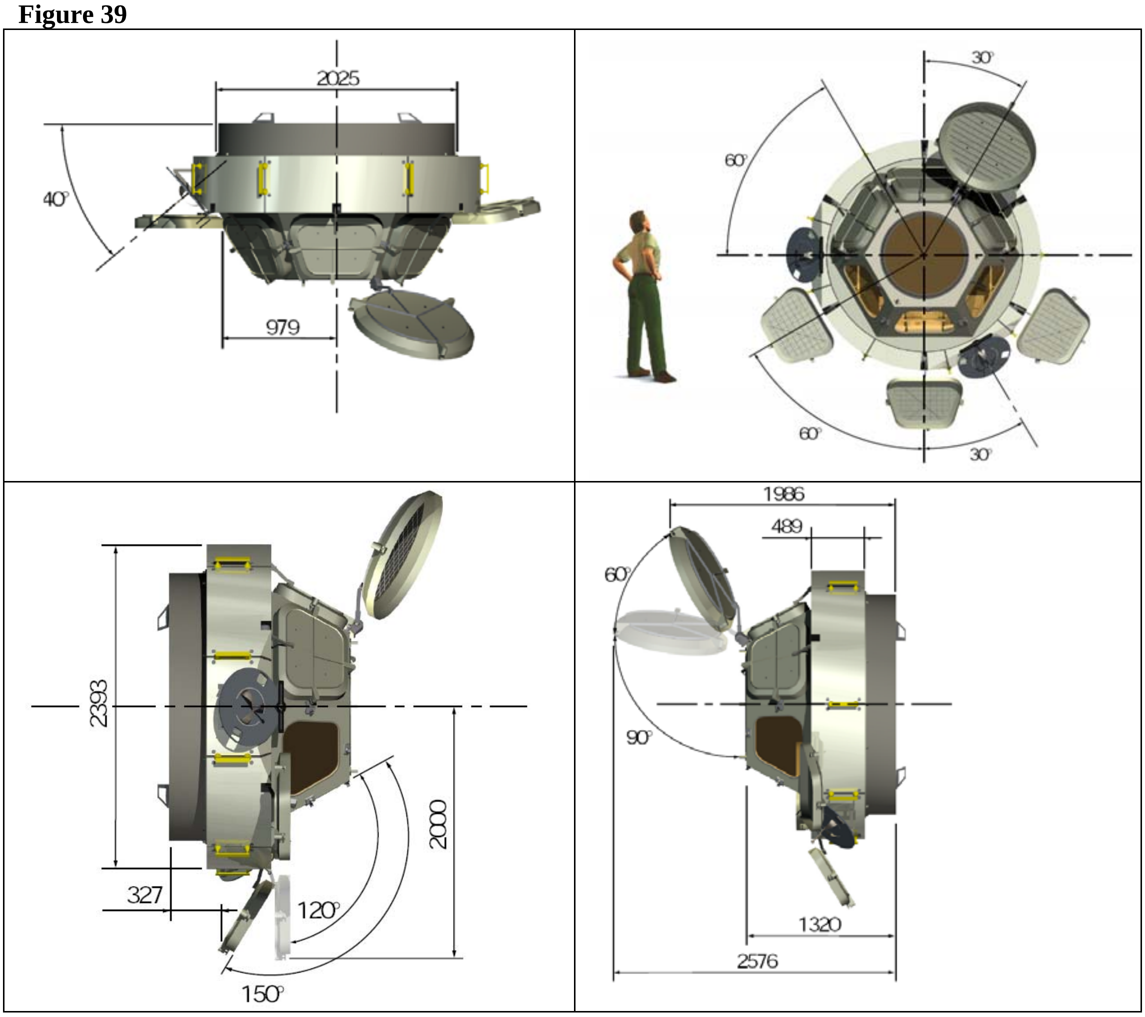
3.6.1 Cupola

The Cupola is a dedicated module for observation of the Earth, the exterior of the ISS and visiting vehicles that was attached with Node 3 to the ISS in February 2010. It consists of an module attached to a port on Node 3 (Harmony) with seven large windows, permitting Nadir and limb observations.

A circular window, 71 cm in diameter, is in the nadir pointing position. Additionally, there are 6 trapezoidal windows arranged around the circumference of the Cupola permitting near nadir and limb pointing.

When not in use the windows are covered by shutters to protect the optical quality of the glass. Each window consists of three panes of high quality borosilicate glass, plus an protective inner pane. The inner pane can be removed to permit high quality observations through the windows. The windows transmit primarily in the visible and short wave Infrared wavelength range

Figure 39



Instruments can be mounted next to the windows using standard adaptors to window track rails and power can be provided to operate the instruments. Data connection between an experiment and the space station data management system can be provided via the wireless network in Node 3. The general configuration of Cupola is shown below in Error! Reference source not found. and Error! Reference source not found.. Further technical information on the window structure, internal layout and operation of Cupola is given in the following sections and Figures

Figure 40 General External View of Cupola on orbit

Figure 41
General configuration of Cupola

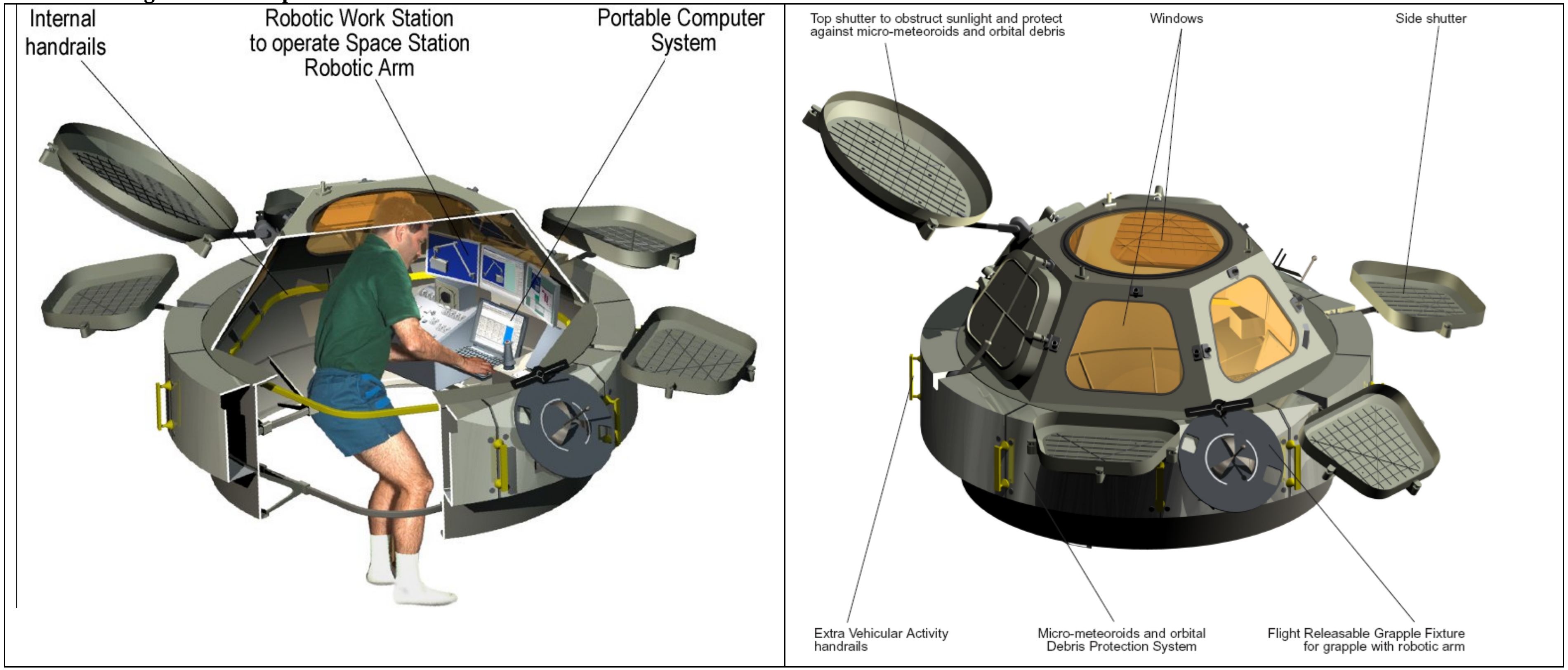


Figure 42 Cupola Interior Nadir View

Figure 43 Cupola Interior View showing general arrangement and external visibility

Figure 44 Nightime view of the Nile Delta and northern Africa taken from the Cupola with a digital SLR camera. Artificial lighting shows clearly the distribution of the human population in this desert region, in particular following the course of the River Nile and Nile Delta. Moonlight provides illumination of the Earth's surface and clouds. On the limb the airglow layer can be seen as a yellow-green band at approximately 90km altitude

ISS025E009858

3.6.1.1 Cupola Window Physical Characteristics:

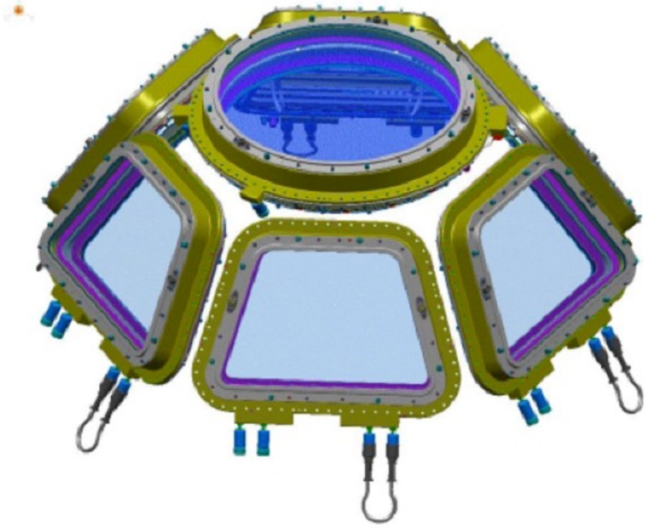
Circular Top window (1x)

- Diameter (transparent area): 27.8 in. (70.6 cm)
- Overall thickness 8.18 in. (20.8 cm)

Trapezoidal Side windows (6x)

- Height (transparent area): 15.94 in. (40.5 cm)
- Short side length (transparent area): 15.75 in. (40.0 cm)
- Long side length (transparent area): 24.96 in. (64.4 cm)
- Overall thickness 7.28 in. (18.50 cm)
- Corner radius: 1.28 in. (3.24 cm)

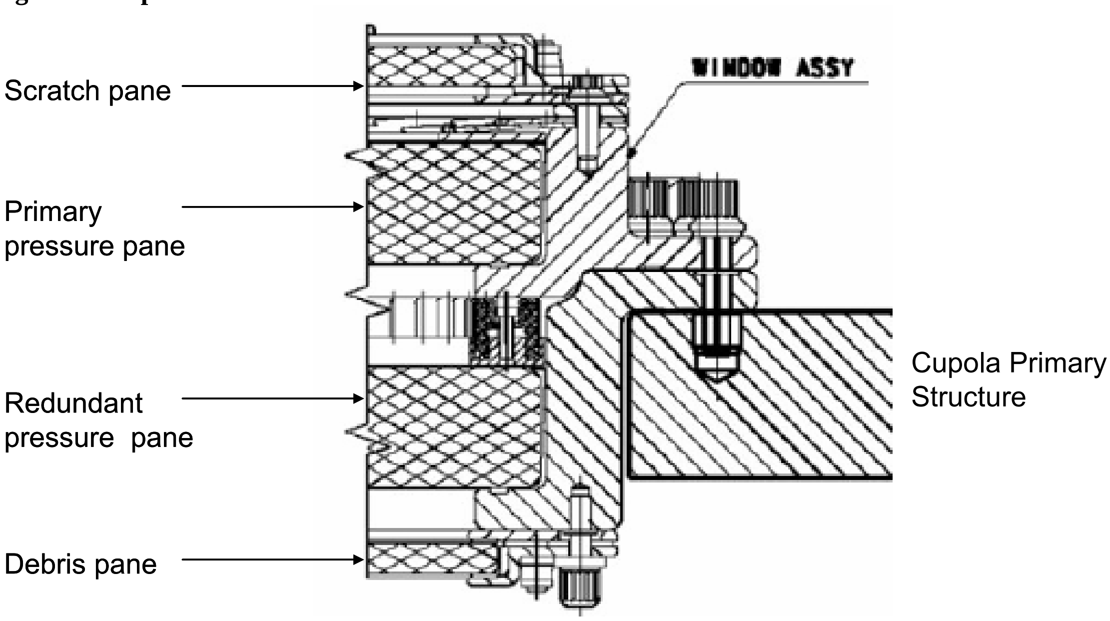
Figure 45 Cupola Window Arrangment



Glass pane material & thickness

- Pressure panes (Primary & Redundant) :
  - anti-reflection coated fused silica glass
  - 1.45 in. (3.68 cm) thick for the top window, 1.0 in. (2.54 cm) thick for the side windows
- Scratch panes:
  - borosilicate glass (SCHOTT BK7)
  - 0.44 in. (1.12 cm) thick for both top and side windows
  - Anti-spall film on the cabin side of the glass, treated with scratch resistant anti reflection coating
  - Conductive anti-reflection coating (ITO) acting as heater on space-oriented glass surface
  - The removal of this pane can be considered in exceptional cases to improve window optical performance
- Debris panes :
  - anti-reflection coated fused silica glass
  - 0.37 in. (0.94 cm) thick for both top and side windows

Figure 46 Cupola window cross section



Surface Reflections

- A. Anti–Reflection Coatings SHALL not cause resolution degradation exceeding 0.007 mr (1.5 arc sec).
- B. Window panes SHALL be designed such that specular reflectance from each anti–reflection coated surface, disregarding red–reflector coated surfaces, for 450 to 700 nanometers normally incident light SHALL not exceed 2.0 percent absolute

Optical Characteristics

- Deviation at any point on the non–tempered window panes SHALL not exceed 1.45 mr (5 arc min). Deviation at any point on the window panes SHALL not exceed 2.9 mr (10 arc min) for tempered panes.
- Distortion of all type window materials SHALL not exceed a plane slope of 1:24.
- Haze of uncoated window panes for all thicknesses SHALL not be greater than 2 percent.
- All glass window panes SHALL not exhibit warp and bow greater than 0.030 inch per linear foot of glass.
- Parallelness – The innermost surface of the inner pane and the outermost surface of the outer pane of the window system SHALL not be more than 3.0 degrees from parallel. Adjacent panes of a multipane window SHALL be between 0.1 to 0.3 degrees from parallel;

Optical Transmittance requirements

The window assembly will meet the following:

- Infrared – The transmittance SHALL be less than 10.0 percent for wavelengths between 1000 and 850 nanometers.
- Visible – The transmittance SHALL be not less than 60.0 percent for wave lengths between 800 and 450 nanometers. The transmissivity

SHALL not vary more than 25 percent for incident angles ranging from 30 to 45 degrees as measured from a normal to the surface.

- Ultraviolet – The transmittance SHALL be less than 0.1 percent for wavelengths between 320 and 280 nanometers. The transmittance SHALL be less than 0.01 percent for wavelengths between 280 and 220 nanometers.

Figure 47 Cupola Scratch Pane Transmission

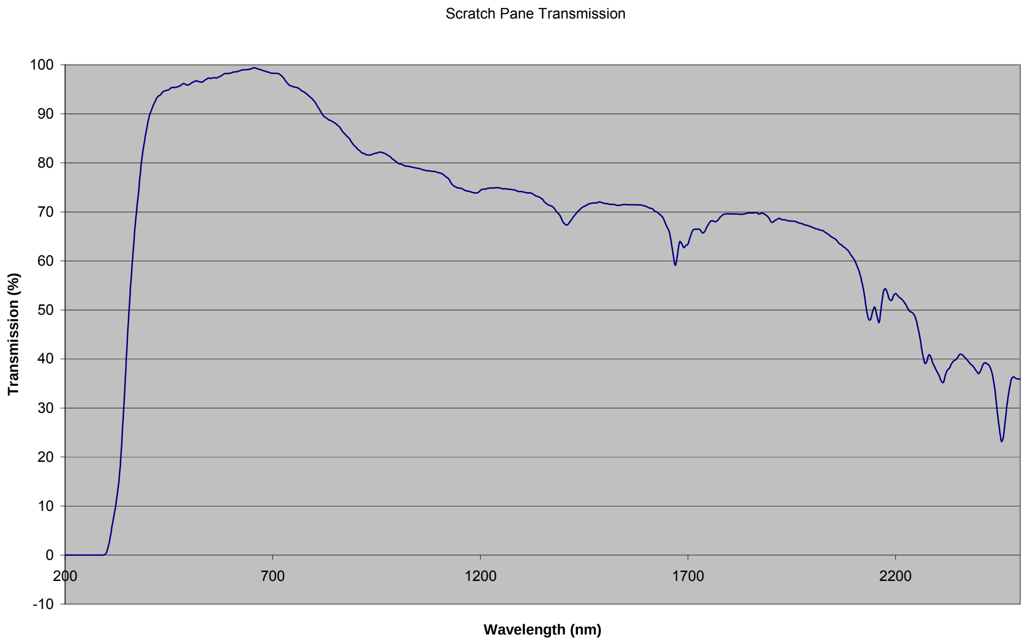


Figure 48 Cupola Debris Pane Transmission

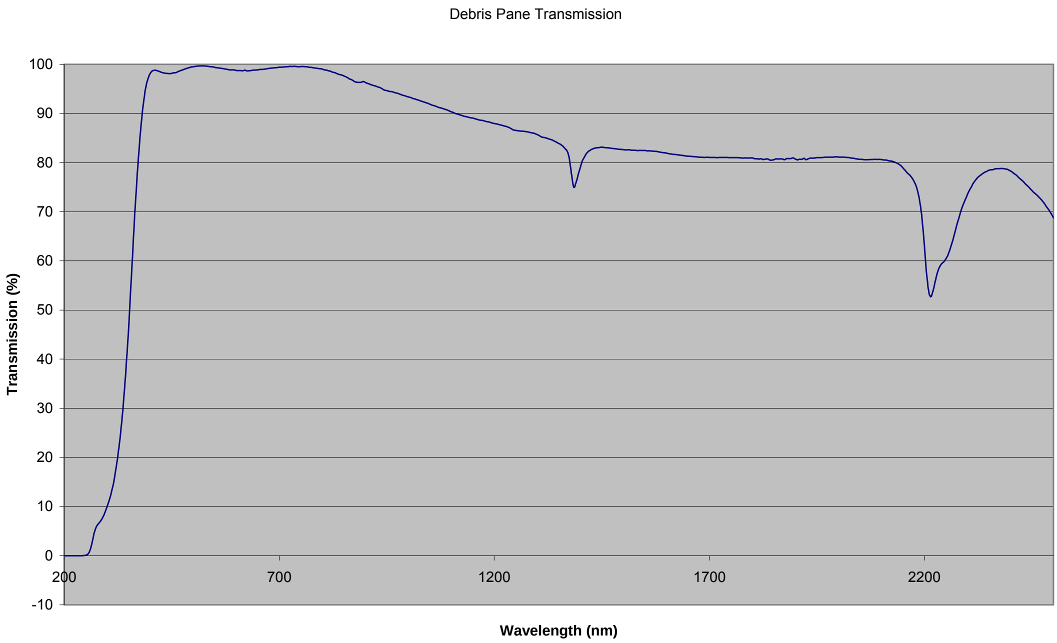
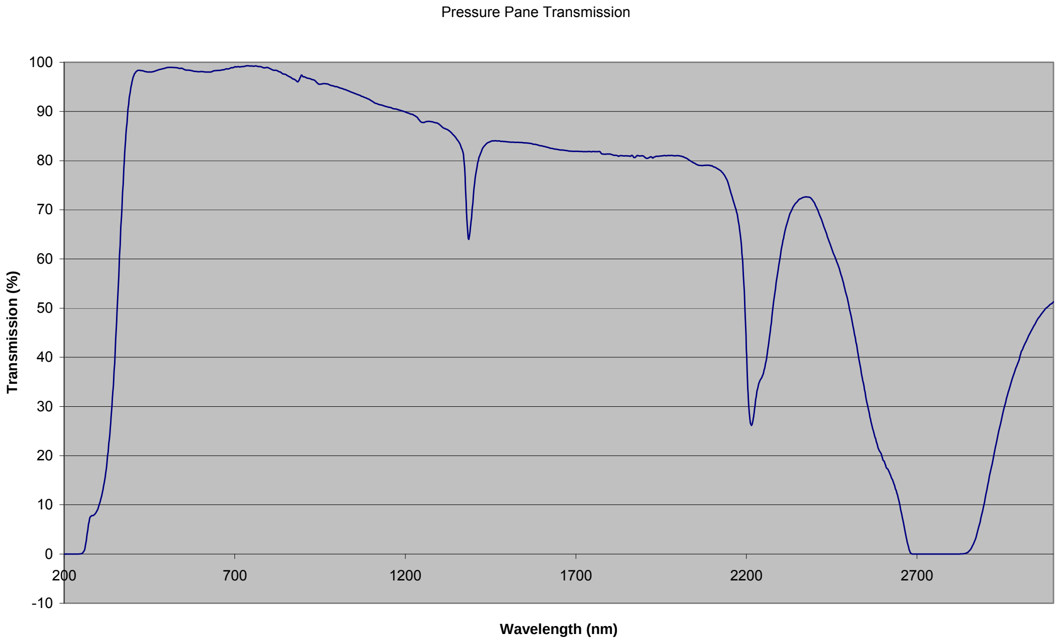


Figure 49 Cupola Pressure Pane Transmission



3.6.1.2 Cupola Mechanical Attachment points

- 2 standard ISS seat tracks on each of the 6 mullions (structure between 2 side windows) for a total of 12.
- Continuous handrail at the bottom of the side windows over the complete element circumference (upper handrail)

Figure 50 Cupola Mechanical Attachment Points

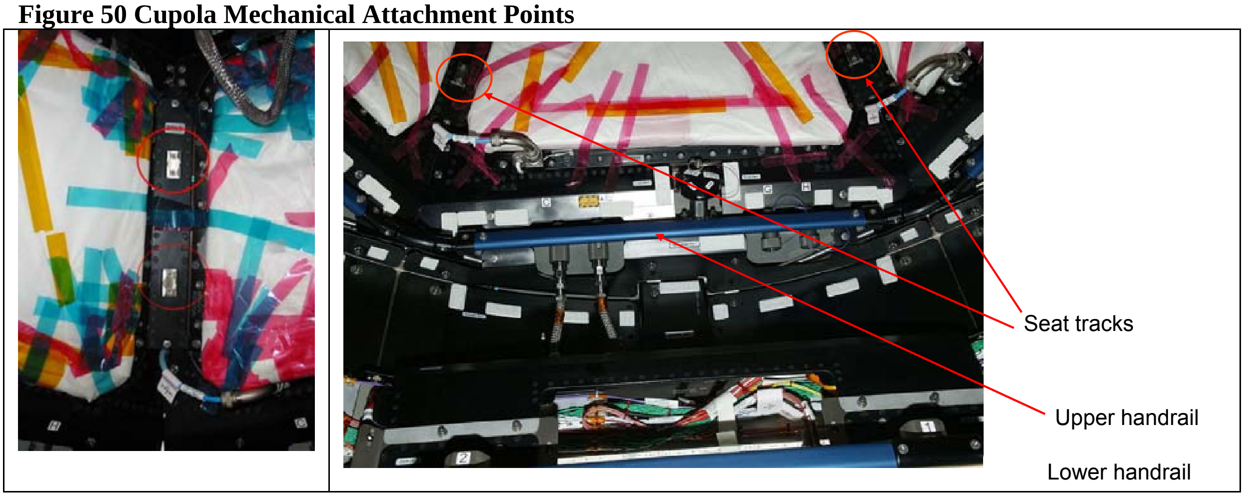


Figure 51 Seat Track Interface

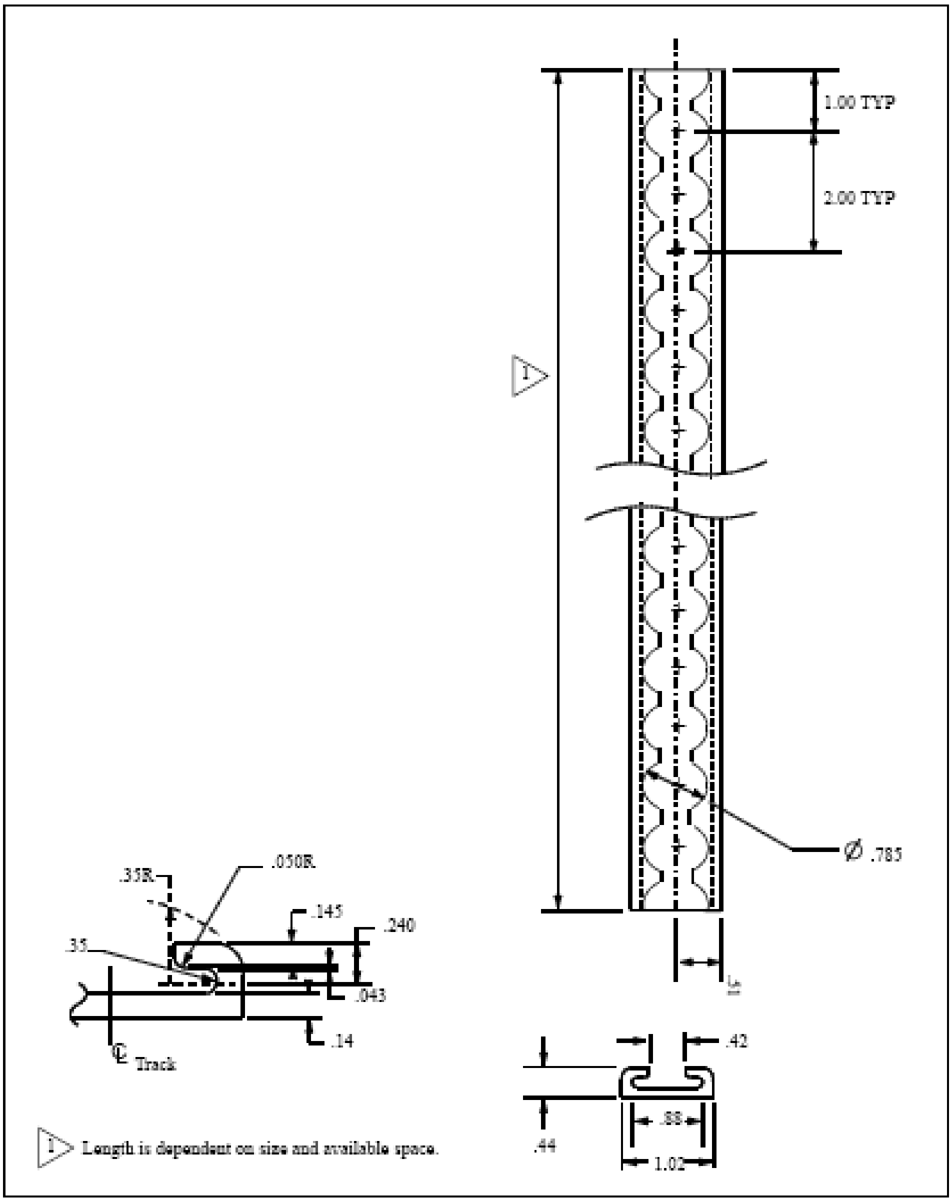


Figure 52 Cupola Hand Rail

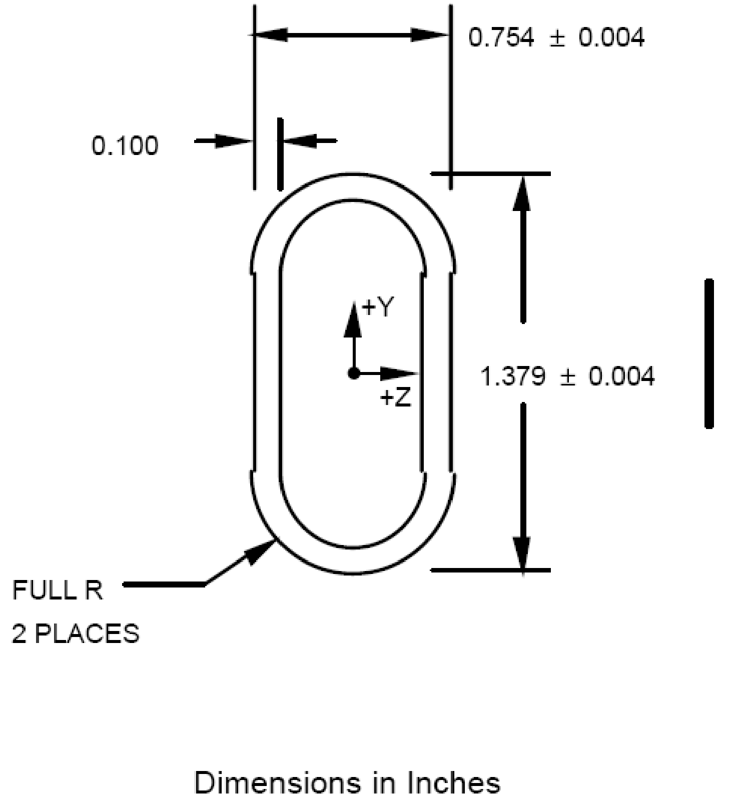


FIGURE 4.2.1.2–1 CUPOLA UPPER AND LOWER HANDRAIL CROSS SECTION

3.6.1.3 Cupola Power and Data Connections

- The Cupola offers 2 ISS Utility Outlet Power (UOP). Each unit has two outlets providing 120 VDC and access to station 1553 bus
- Internet wireless signal from Node 1 is expected to be available in Cupola (see section 3.6 ISS Data storage, recording and transmission constraints for data transfer capabilities)
- Wired Internet access port(s) will likely be implemented by NASA when Cupola is on-orbit.
- The Cupola incorporates an Audo Terminal Unit (ATU) allowing communication with the rest of the Station or the ground
- The Cupola incorporates two sets of Quick Disconnect (QD) interfaces to the Node 3 Moderate Temperature loop.
- One set is used by the ATU cold plate. The other set is available to provide cooling, if necessary (TBD flow rate/kW).
- Sun visor
    - Aluminium plate to shade from sun light when shutters are open.
    - Attaches to Cupola to seat tracks via a lockline bracket
    - Lockline bracket connects to visor plate via a camera shoe interface.

Figure 53 Cupola UOP and ATU arrangement

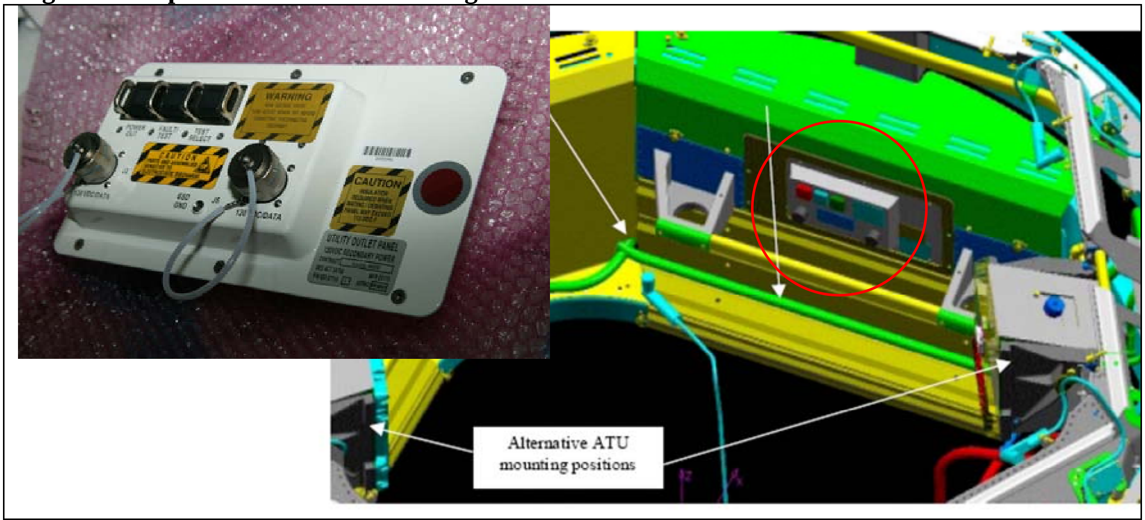
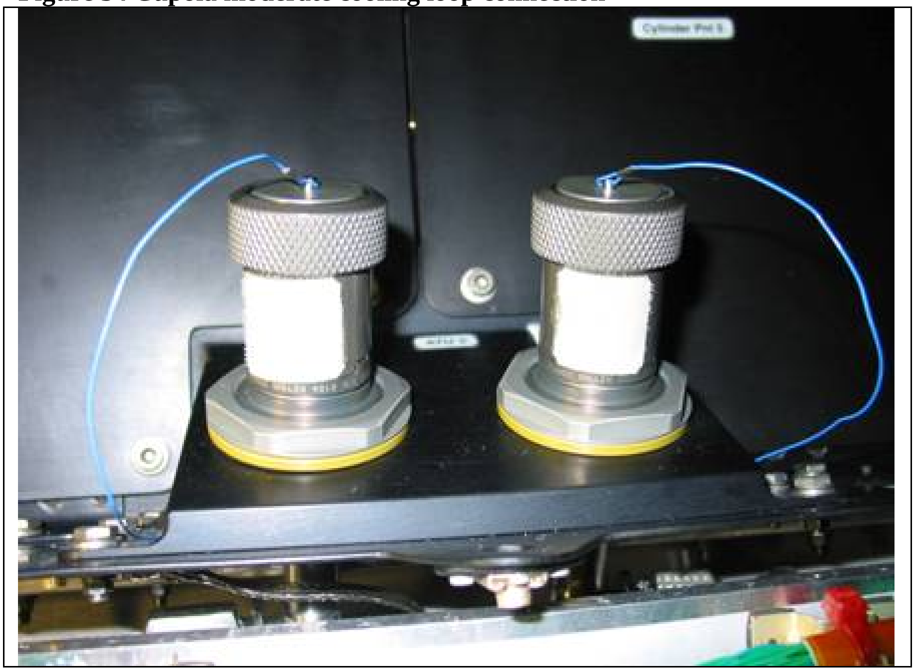


Figure 54 Cupola moderate cooling loop connection



3.6.2 Destiny Window and Observation Research Facility (WORF)

The U.S. laboratory module Destiny contains a dedicated Earth observation optical quality window, 51cm in diameter nadir pointing with a +/-30° cone of visibility. The window is transparent from the near UV (300nm) to approximately 2μm in the near infrared. The NASA EarthKAM project, a digital camera used for education activities associated with Earth observation currently uses the Destiny Window. In April 2010 an internal rack, known as the Window Observation Research Facility (WORF) was installed in the Destiny module , enhancing the capabilities for Earth observation through the Destiny window (RD-13). The WORF provides dedicated mechanical, electrical and data interfaces for instruments. The key characteristics of the Destiny window are illustrated below. Further information on WORF can be found at the Facility website (http://worf.msfc.nasa.gov/)

Figure 55
Destiny Window (NASA RD-8)

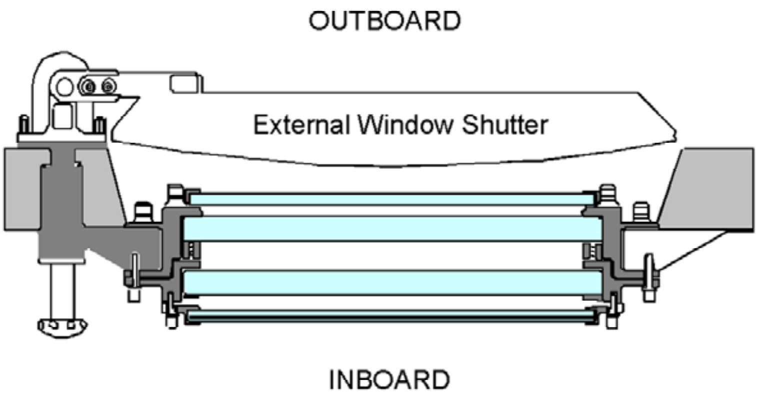


Figure 56
WORF General Arrangement (Source: NASA RD-8)

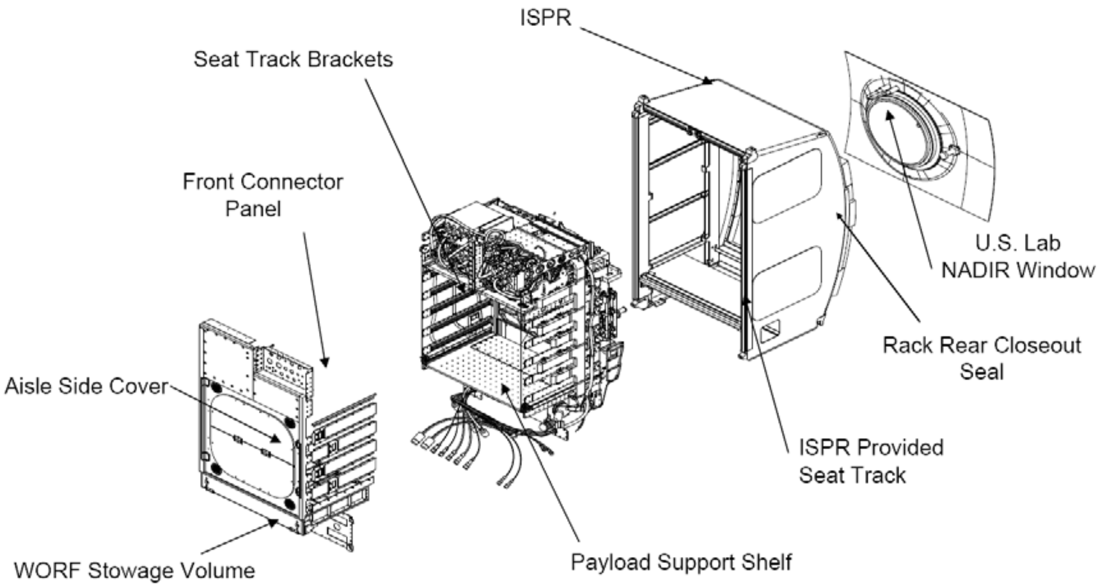


Figure 57
Destiny Nadir Window Port Transmittance (Source: NASA RD-8)

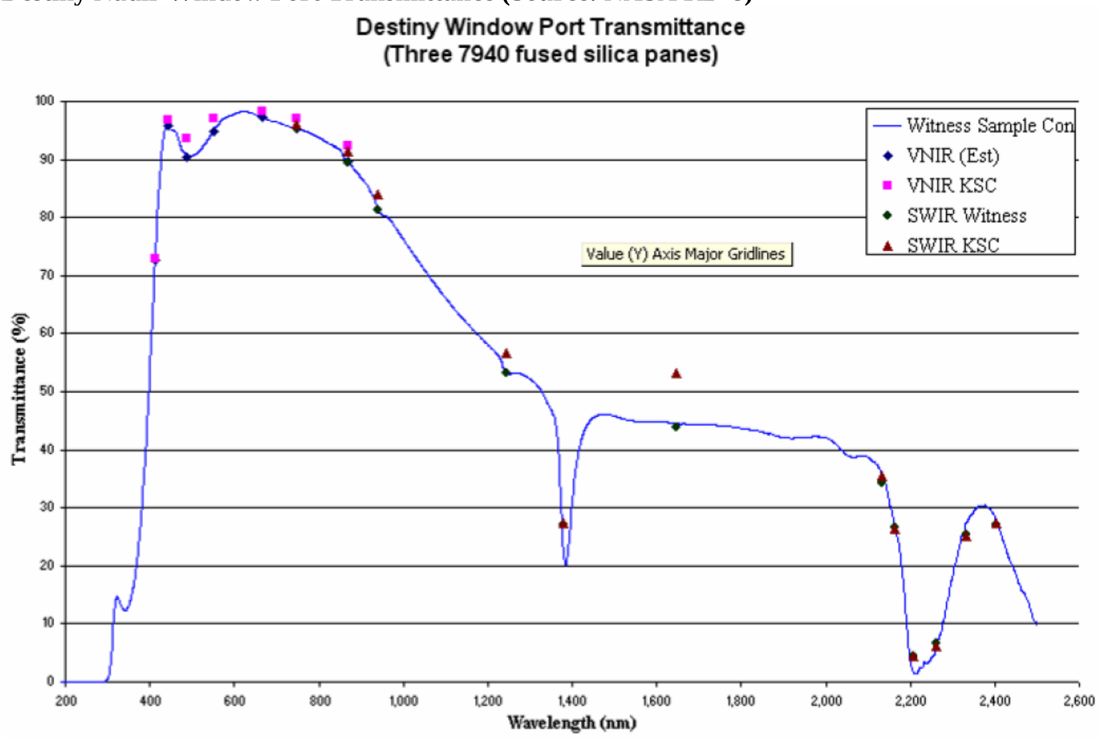
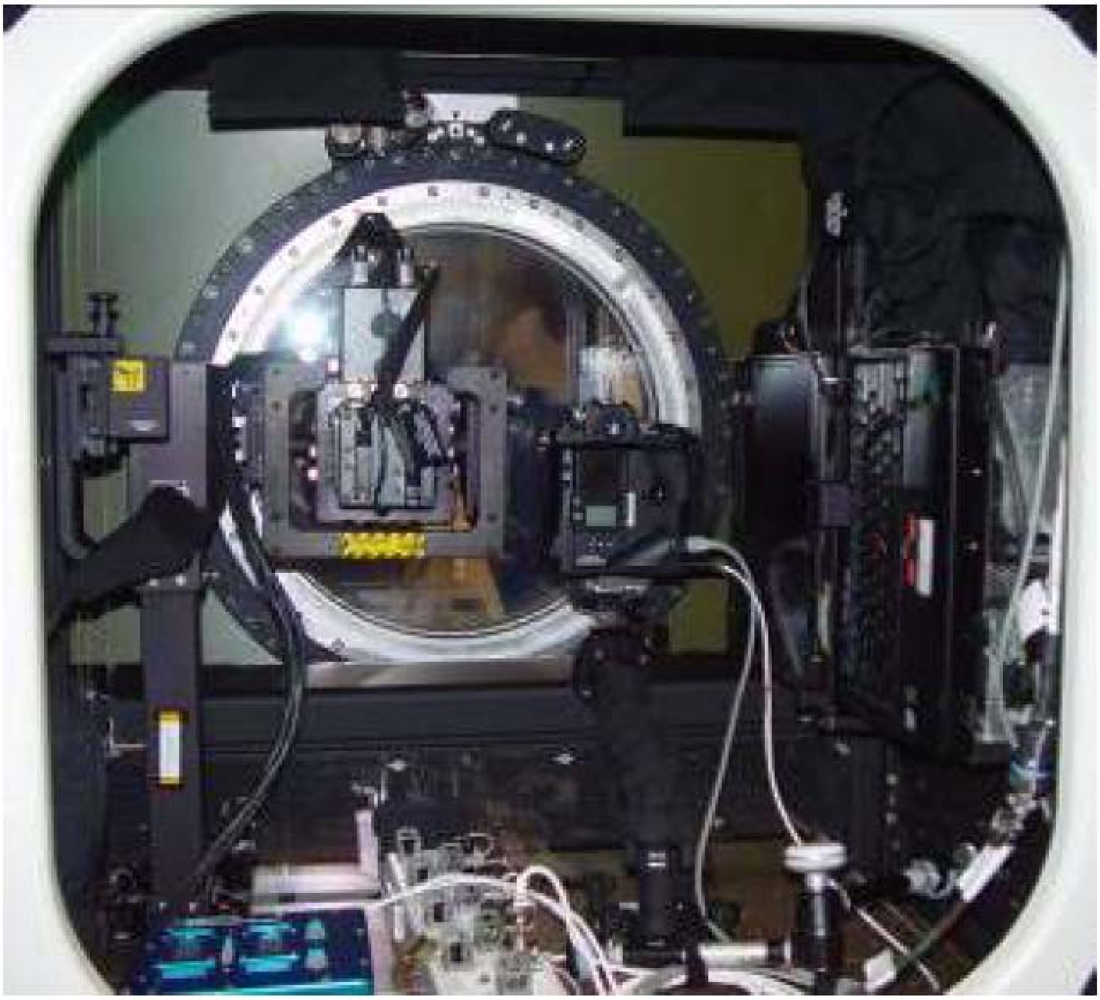


Figure 58
Example of instrument installation in WORF (Source: NASA RD-8)

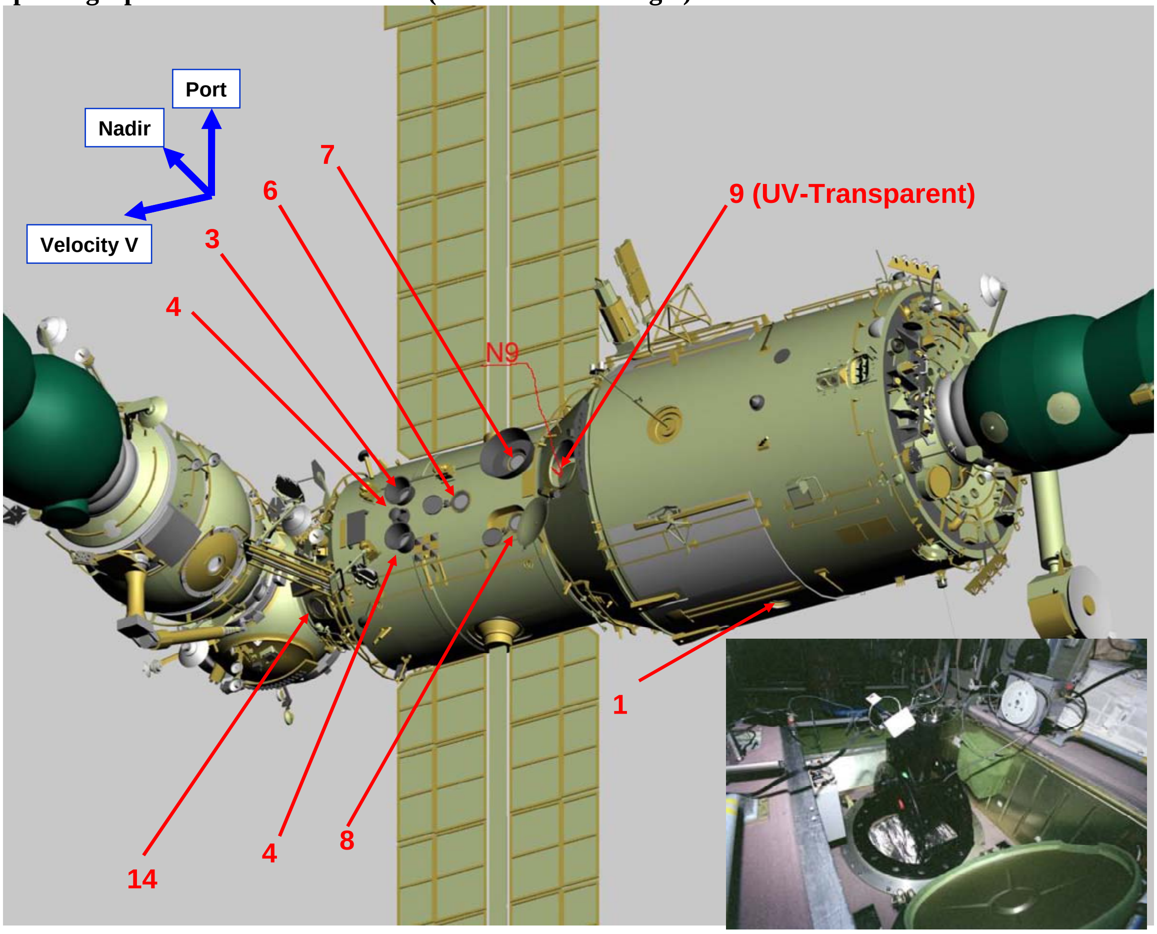


3.6.3 Russian Segment Windows

The Russian segment service module has a total of 14 windows with different characteristics. These include nadir, limb and zenith pointing windows. Some windows also have UV and near infrared transmission, in addition to transmission in the visible wavelength range. Window #9 is the nadir and is transparent to UV. The layout of windows on the Russian segment are illustrated in Figure 59

.

Figure 59
Location of selected windows on Zvezda module (Russian Service Module). Window #9 is Nadir facing and is transparent in the near ultraviolet. Inset shows the Fialka UV camera and spectrograph installed on window #9 (Source: RSC-Energia)



3.7 ISS Data storage, recording and transmission constraints

3.7.1 ISS and Columbus Data storage capabilities

There is no dedicated data storage facility on board of Columbus or in the ISS. Therefore, if on-board data storage is required this must be implemented within the instrument payload.

3.7.2 ISS and Columbus Data transmission capabilities

The instruments and payloads on ISS are command and data downlinked via NASA's Tracking and Data Relay Satellite System (TDRSS) using S-band and Ku-band datalinks. The S-Band datalinks are typically used for command up and downlink. The Ku-band is used primary for video and data downlink, with all data being combined via a high rate multiplexer.

The data downlink bandwidth is shared between all users. Furthermore, data downlink is considered as an ISS resource to which ESA has rights to use 8.3% of total capacity. During each orbit Ku-band coverage is not continuous, since there is a small gap between coverage by individual TDRSS satellites (known as loss of signal periods – LOS). Furthermore, there the view of the satellite by the Ku-band antenna may be blocked by elements of the ISS structure, although some S-band coverage may be possible during these blockage periods. As a result the S band and Ku-band coverage varies between 30% and 70%. Data can also be potentially transmitted via a Ka-band antenna on the Japanese Kibo module to the ESA ARTEMIS and JAXA DRTS satellites. To simplify scheduling of data transmission the ISS data management system incorporates a buffer (HCOR) which holds all data transmitted from payloads during LOS, until transmission can be restarted after acquisition of signal (AOS). Hence the gaps in TDRSS coverage are transparent to the transmission of data by the instruments. The overall data transmission capacity of the ISS (for all users) is summarised below in Table 7

Table 7
Summary of overall ISS data transmission capabilities (ESA has rights to 8.3% of overall data)

Data Transmission System	Data Rates
Command uplink rate (S-band)	High Data Rate: 72kb/s Low Data Rate: 6kb/s Columbus module allocation: 10-36kbps
Command downlink rate (S-band)	High Data Rate: 192kb/s Low Data Rate: 12kb/s Columbus module allocation: 15-60kb/s
Data/Video Downlink (Ku-band)	Up to 100Mb/s available for utilisation (rates may vary from 2.8 to 95Mb/s) Columbus module: up to 43Mb/s (actual allocation determined in planning, can vary from 0-43Mb/s)

For Payloads attached to the Columbus External Payloads Facility (CEPF), data can be transmitted from the instrument / payload via a variety of different connections. These include the following;

- Payload 1553B interface Bus: low data rate and housekeeping telemetry (all payloads must use this interface) via analogue, discrete and serial connections to the payload control unit
- Medium data rate: Standard Ethernet LAN, limited to 10Mb/s (currently restricted 3Mbps). Future evolution may permit data rates up 100Mb/s
- High data rate: Fibre optic line Up to 32Mb/s/channel to be expanded to 120Mb/s/channel

Data can be transmitted from instruments/payloads to the Columbus Video/Data Processing Unit (VDPU) at up to 100Mb/s (limited by total bandwidth available to instrument, shared with other users). The Columbus VDPU then transmits data to the ISS multiplexer for downlink.

The scheduling of data downlink needs to be scheduled in advance and will only be available in defined blocks. Therefore, all instrument payloads need to have autonomous capacity for storage of data and potentially employ data compression. Typically, preliminary planning is started 12-18 months prior to the initial operation of the instrument / payload, with definition of requirements (i.e. desired data rates, frequency of transmission, and total volume of data to be transmitted). This is updated during the detailed operational planning of the instrument / payload implementation.

Recent experience with ESA Columbus payloads, including those mounted on the CEPF, gives an indication of the actual data rates that may be expected to be achieved for individual payloads. Some actual data rates / frequencies used since Columbus commissioning in February 2008 include the following;

- ESA EDR Facility: ~2Mb/s near continuously for an operating run of 120 days total duration (During LOS data dumped to HCOR)
- ESA EVC experiment externally attached to CEPF: ~2Mb/s for 6-8h once per week, supplemented with ~2Mb/s for 1h each day.
- ESA FSL facility: 8Mb/s for 6-8h period once per week

Often these experiments were transmitting data in parallel, so that transient data transmission rates could peak at 12-14Mb/s. Potentially transient data transmission rates for all ESA payload could be allowed up to ~30Mb/s. Additionally, the JAXA MAXI instrument on Kibo-External facility transmits 0.6Mb/s nearly continuously using TDRSS and DTRS links.

3.8 Instrument and payload development cycle, integration and operation

A detailed description of the requirements, documentation, integration planning and operation of ESA payloads can be found in the “European Users Guide to Low Gravity Platforms”, chapter 7: International Space Station – ISS (RD-1) This can be downloaded from the following link;
http://www.spaceflight.esa.int/users/index.cfm?act=default.page&level=1c&page=adv-ug

3.9 Examples of Earth Science and External Payloads on ISS

Details of example Earth science and external payloads can be found at the following links

3.9.1 ESA Air Space Interactions Monitor (ASIM)

The ASIM instrument will be attached to the Columbus CEPF in 2013. The objective of the instrument will be to study high altitude optical (TLEs; Red Sprites, Blue jets and Elves) and gamma ray emissions (TGF's; Transient Gamma Flashes) from the mesosphere and stratosphere associated with Thunderstorms

ESA ASIM Webpage;
http://www.esa.int/SPECIALS/HSF_Research/SEMTTK0YDUF_0.html

ASIM Science Team Website
http://web.ift.uib.no/Romfysikk/RESEARCH/PROJECTS/ASIM/

3.9.2 JAXA Superconducting Submillimeter-Wave Limb Emission Sounder) SMILES

The JAXA SMILES instrument is limb sounding instrument that will measure trace gases in the stratosphere using submillimeter emissions. SMILES was recently deployed on the Kibo-EF

JAXA SMILES website;
http://smiles.tksc.jaxa.jp/

3.9.3 NASA HREP (HICO and RAIDS Experimental Payload)

The NASA HREP payload consists of two instruments – HICO and RAIDS. The Hyperspectral Imager for the Coastal Ocean (HICO) is a visible and near-infrared maritime imaging system. The Remote Atmospheric and Ionospheric Detection System (RAIDS) will measure the major constituents of the thermosphere and ionosphere via ultraviolet and visible range emissions.

NASA HICO website;
http://www.nasa.gov/mission_pages/station/science/experiments/HREP-HICO.html

NASA RAIDS website;
http://www.nasa.gov/mission_pages/station/science/experiments/HREP-RAIDS.html

3.9.4 NASA ISS EarthKAM

The NASA ISS EarthKAM is an education instrument which takes digital still images of the Earth via the Destiny module nadir window.

NASA ISS EarthKAM webpage;
http://www.earthkam.ucsd.edu/public/about/index.shtml

3.9.5 ESA Atomic Clock Ensemble in Space (ACES; Example external payload)

The ESA ACES is an atomic clock experiment that will be used as an ultra precise time base for comparison with ground based atomic clocks. ACES will be mounted to the Columbus CEPF

ESA ACES webpage;
http://www.spaceflight.esa.int/projects/index.cfm?act=default.page&level=12&page=829
ESA ACES Factsheet (PDF);
http://www.spaceflight.esa.int/users/downloads/factsheets/fs031_10_aces.pdf

3.9.6 ESA European Technology Exposure Facility (EUTEF; Example external payload, which has flown on ISS on CEPF Feb 2008 – Aug 2009)

THE ESA EUTEF is a multiuser facility which carried 9 external exposure experiments. EUTEF was attached to the Columbus CEPF from Feb2008 until retrieved by the STS-128 Shuttle mission in August 2009.

ESA EUTEF webpage;
http://www.spaceflight.esa.int/projects/index.cfm?act=default.page&level=12&page=832
ESA EUTEF Factsheet (PDF);
http://www.spaceflight.esa.int/users/downloads/factsheets/fs030_10_eutef.pdf

3.9.7 ESA SOLAR Instrument

The SOLAR instrument sits on the zenith port of the Columbus External Payloads Facility (CEPF) and has been performing solar irradiance measurements, using three science instruments, since early 2008.

ESA SOLAR Factsheet (PDF);
http://www.spaceflight.esa.int/users/downloads/factsheets/fs021_10_solar.pdf