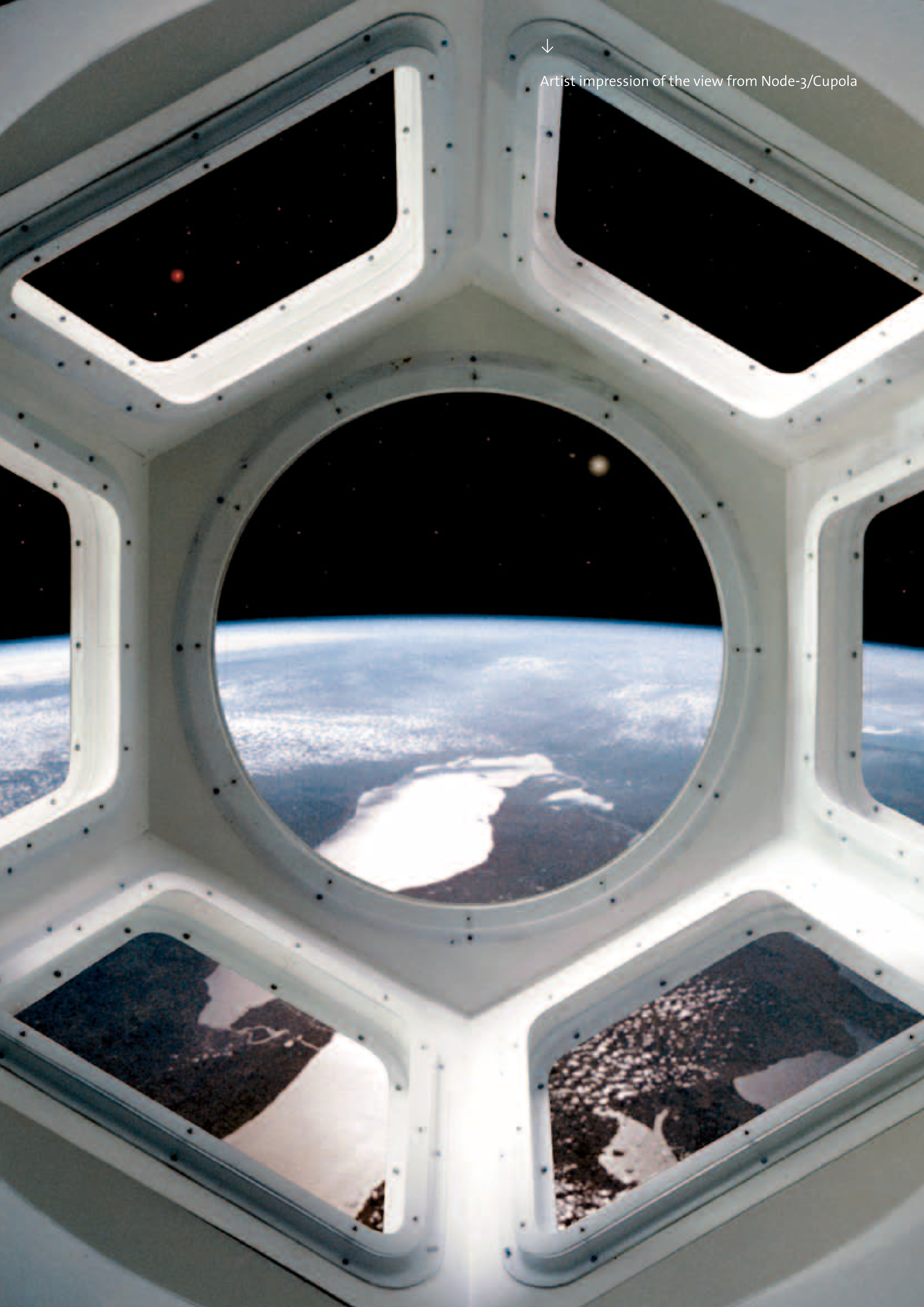

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Artist impression of the view from Node-3/Cupola

→ ESA'S ROOM WITH A VIEW

Node-3 and Cupola ready for launch

Philippe Deloo & Sara Pastor
Directorate of Human Spaceflight, ESTEC,
Noordwijk, The Netherlands

Marking the completion of the development of ESA's permanent pressurised elements for the International Space Station, the Node-3/Cupola assembly will be fully ready this summer for a launch next year.

After almost 12 years of design, development and storage, Node-3 will finally be shipped to NASA's Kennedy Space Center in Florida in spring 2009 to complete the ultimate preparations for launch, currently scheduled for early 2010. At the end of a challenging and successful endeavour, the ownership of Node-3 and the Cupola will be transferred to NASA. The Cupola, already at Kennedy Space Centre, will be mated with Node-3 as part of the launch preparations and will benefit from a free ride to the ISS.

Today's Node-3 is significantly different to the Node-3 that Europe initially agreed to develop back in 1997. It has evolved over the years from a connecting module into a very complex element, able to accommodate sophisticated crew and life support equipment. It is now a much more complex element with many more capabilities than originally foreseen. Cupola will provide an unprecedented capability for the ISS, and both modules will help in the efficient exploitation of ISS operations and provide the accommodation for facilities intended to improve the well-being of the crew.

We are looking forward to seeing both these elements in orbit, operating flawlessly like Node-2, Node-3's big brother. We are confident this will be to the satisfaction of NASA and the ISS crew for many years to come, an achievement which ESA and the European industry involved can be proud of.

Troubled development

Only as far back as 2003, not many people would have bet on the sentence 'Node 3 and Cupola ready for launch' becoming a reality today. Indeed, Node-3 was having severe programmatic difficulties to the point that its development was stopped, and Cupola, whose development was nearly completed at the time, had its Shuttle flight to the ISS cancelled as a result of a cost-reduction exercise.

In spite of this unfavourable environment, the project continued to work with the confidence that these difficulties would be overcome. Thanks to the efforts, dedication and commitment of ESA, ASI, NASA and Alenia Spazio (now Thales Alenia Space Italy), a solution was found to pursue the Node-3 development. Generally recognised by the ISS community as the most complex pressurised element of the ISS, this masterpiece of space engineering could be brought to completion.

With Node-3 back on track, the only solution to fly Cupola to the ISS was obvious: launch Cupola directly attached to Node-3. Following some analyses demonstrating the feasibility of the idea, the launch of Cupola together with Node-3 became a real proposition, saving the Cupola from a life in a museum.

Origins of Node-3 and Cupola

Originally, at the time of the 'Space Station Alpha' plan, Boeing was in charge of the design and development of both elements under contract to NASA. The mid-1990, descoping of the Space Station Alpha concept led to the cancellation of

> **"Node-3 will contain one of the most advanced life-support systems ever flown into space."**

the Cupola and forced NASA to find solutions to optimise the costs of essential elements such as the Nodes.

In 1997, NASA and ESA signed a barter agreement, known as the 'Columbus Launch Offset Agreement', or 'Nodes Barter', in which ESA would build Node-2 and Node-3 in exchange for the Shuttle launch of Columbus. This was a 'win-win' situation, as the money for the Columbus launch would be spent in Europe thus enhancing European industry's know-how in human spaceflight engineering while NASA would acquire two modules without having to pay their development costs.

A couple of years later, another barter agreement with NASA was signed in which ESA agreed to provide Cupola in exchange for the launch and return with the Shuttle of five European payloads for Columbus.

One peculiarity of the Nodes Barter agreement was related to the management of the project on the European side. While ESA would retain the overall responsibility of the development of the Nodes, the day-to-day management of the project would be delegated to the Italian space agency ASI. ESA and ASI operated under this scheme until 2004, when it was decided to transfer all management

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The complexity of Node-3: view inside the 'starboard' port

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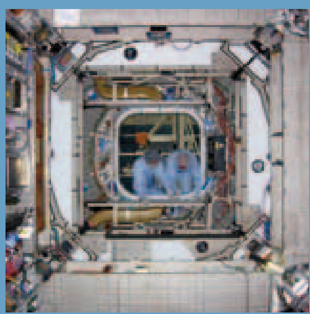
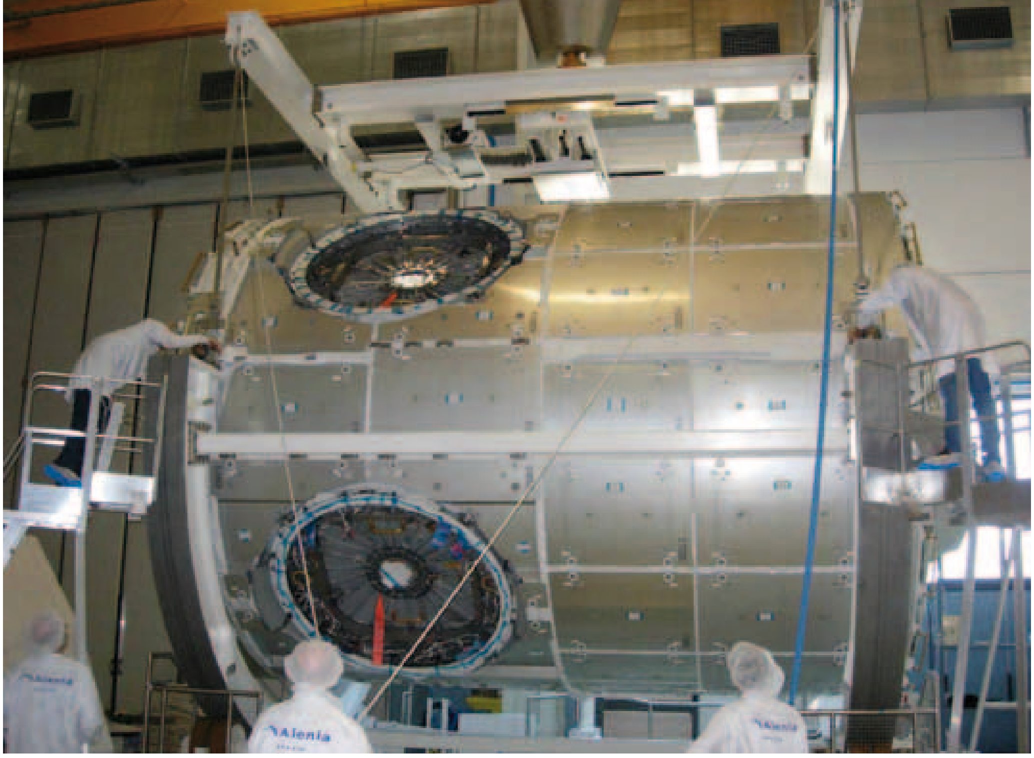
Fitting out Node-3, developments over time, looking towards 'port' port





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Node-3 during preparation for a leak test in 2007, showing the outer cylindrical shell and two of the radial ports with hatches closed

responsibilities to ESA for the completion of the project, consisting of the NASA support to Node-2 ground operations, launch and on-orbit activation and the complete Node-3 phase D.

Node-2 was delivered to Kennedy Space Centre and the ownership transferred to NASA in June 2003. It has been operating in orbit for over a year following its launch with STS-120 on 23 October 2007. The Cupola was delivered to NASA in September 2004 and the ownership transferred to NASA in July 2005. It was stowed in the Space Station Processing Facility at Kennedy until spring 2008, when the final ground operation preparations for launch were started to be ready for the mating with Node-3 in spring 2009.

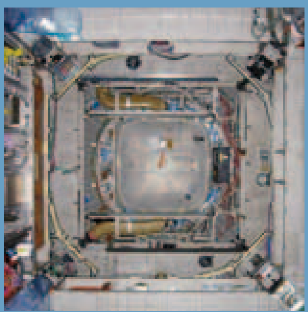
Node-3 development and Assembly, Integration and Testing (AIT) activities officially ended with a successful Preliminary Acceptance Review held on 25 July 2007. From that moment on, it was supposed to be in storage until it was needed at Kennedy for launch processing, however that plan did not really work because changes to the baseline continued to be introduced by NASA. The shipment of Node-3 to Florida is now planned for mid-April 2009.

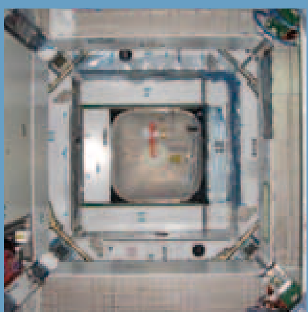
Node-3 functions and layout

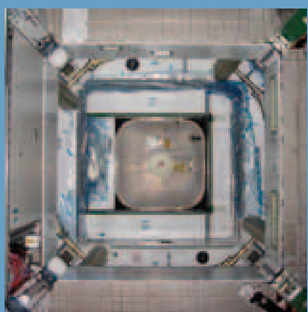
Node-3 is a pressurised cylinder with a diameter of 4.5 m and length almost 7 m. It can house up to eight ISS equipment racks and provides a pressurised passageway between berthed habitable volumes. It also accommodates the items necessary for the distribution of commands and data, audio, video, electrical power, atmosphere, water and thermal energy to adjacent elements. In addition, dedicated utilities are foreseen, to interface with special racks supporting crew habitability functions at station level.

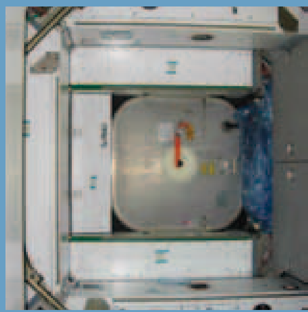
Major functions of Node-3

- Form the interconnecting node between the US segment of the ISS and other attached elements for distribution of power, audio and video, thermal conditioning, ventilation and sampling;
- Support a crew of six members on ISS by accommodating specific hardware and related functions;
- Support ISS air pressure control and composition with the Pressure Control Assembly – an item able to vent atmosphere to vacuum and introduce air inside the ISS;
- Support Node-3 cabin crew operations.









The core of the primary structure is a shell made of two cylindrical sections, two cones at the ends of the cylinder, reinforcement rings and bulkheads. Internal and external secondary structures are used to support the installation of equipment, piping and electrical harnesses.

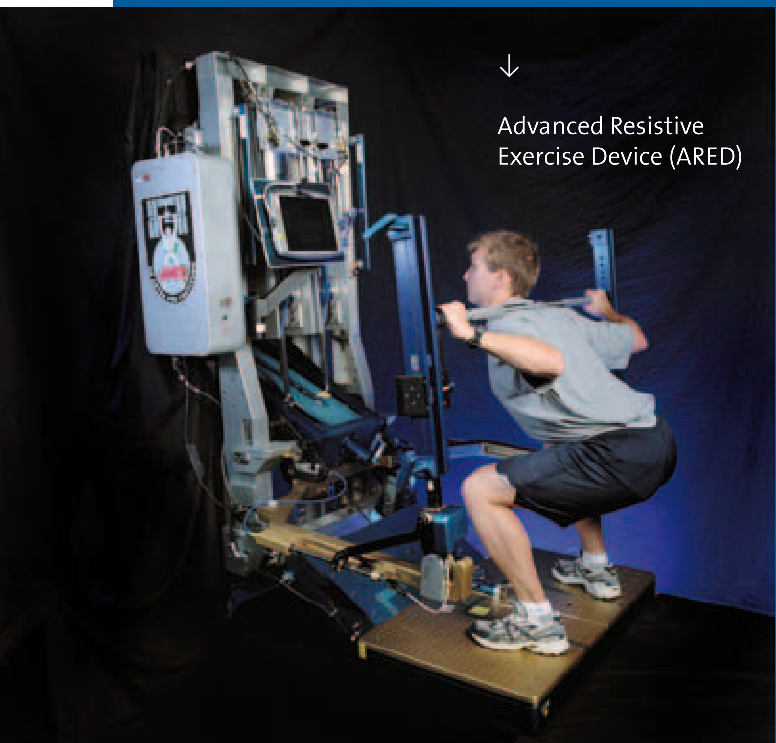
The Node-3 architecture includes six ports with hatches, four radial and two axial. Three of the four radial ports and the nadir axial port are provided with Active Common Berthing Mechanisms for the berthing of attached elements, whereas the zenith port presents a Passive Common Berthing Mechanism.

Originally, the Habitation module, the Crew Return Vehicle and the Pressurised Mating Adaptor 3 (PMA-3) were also attached to Node-3 but the first two elements were deleted from the station configuration and the PMA-3 moved to Node-1 nadir port following the Node-3 relocation.

→ Inside Node-3

Some of the hardware included for the support of six-person crew is:

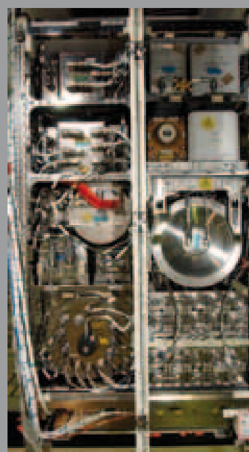
- **a second Air Revitalisation System rack for on-orbit air composition monitoring, including carbon dioxide removal;**
- **an Oxygen Generation System rack for oxygen and water;**
- **a Water Recovery System Racks (WRS-1 and WRS-2) for urine and water processing;**
- **a Waste and Hygiene Compartment Rack (WHC) for crew waste and hygiene processing (this rack features an extendable cubicle to grant more space while in use by the crew);**
- **a second treadmill and Advanced Resistive Exercise Device (ARED) for crew on-orbit physical exercise.**



↓ Advanced Resistive Exercise Device (ARED)

The treadmill for crew excercise

Water Recovery System 1



Water Recovery System 2

Waste and Hygene Compartment (WHC) ...or toilet!

Extendable cubicle and privacy curtain on the WHC

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NASA astronauts Terry Virts and Charles Hobaugh familiarise themselves with the interior of ESA's Cupola (NASA)

The atmosphere of Node-3's internal pressurised volume is controlled in terms of air pressure, temperature, humidity, velocity, particulate and microbial concentrations.

Node-3 provides a piping network for the distribution of water (for fuel cells, drinking, waste and processes) between Node-1 and Node-3 and within Node-3. It also provides the line for the transfer of pretreated urine from WHC to WRS racks inside Node-3. Special lines and sectioning devices are adopted to distribute oxygen and nitrogen.

Fire detection is supported by two cabin smoke sensors and monitoring of electrical equipment. Other smoke sensors are used in particular racks. Fire suppression within predefined internal enclosures is by portable fire extinguisher.

Two avionics racks accommodate almost all the electronic units for the command and data handling, audio and video functions, and for the conversion and distribution of the electrical power from the ISS solar arrays to the internal and attached elements. Command and control functions, as well as fault detection isolation and recovery algorithms, are supported by processing capabilities implemented in Node-3 computers.

Two water loops (respectively low-temperature and moderate-temperature loops) allow the rejection of the heat generated inside the element to the ISS ammonia buses by means of two heat exchangers mounted on the external side of one end cone.

Multilayer insulation blankets and heaters are used to prevent the effects of internal condensation or risk of water freezing on the external lines. A meteoroid and debris shielding system is used to reduce the probability of shell penetration.

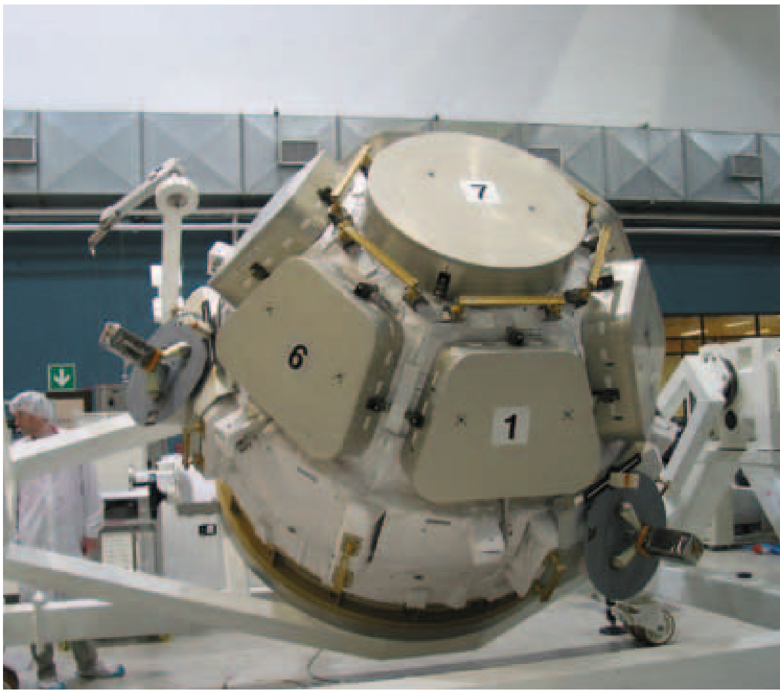
Cupola functions and layout

The Cupola is a 'shirt-sleeve' environment module, with six trapezoidal side windows and a circular top window of 80 cm in diameter, making it the largest window ever built for space. The window glass is protected against the external environment by special external shutters that can be opened by the crew inside the Cupola.

The Cupola's internal layout is dominated by upper and lower handrails supporting most of its equipment, and by closeout panels that cover the harness and the water lines attached to Cupola. These panels also provide air distribution to the outer structure and internal cabin. These panels are removable for inspection of the lower subsystems.

In its final location, the Cupola will be attached to the Node-3 nadir port i.e. facing Earth, and will provide the crew with a 360° panoramic view of the external surfaces of the ISS with exception of the zenith area.

The main functions of the Cupola are: panoramic control of ISS robotics and extravehicular activity operations (or 'spacewalks') by accommodation of the Robotic Work Station and other items like sun visors; crew psychological and scientific observation of Earth; support of habitability by two crew members, i.e. air ventilation system, alarm annunciation and crew/ground communications through an Audio Terminal Unit, thermal control (provided by window



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Cupola seen with window shutters closed

heaters and water lines) and power and data distribution to portable items by implementing two Utility Outlet Panels.

Dynamic design/development environment

While the Cupola baseline did not evolve much throughout its design and development phase, the Node-3 baseline has been in continuous evolution. In the original Nodes Barter agreement, Node-3 was a straight replica of Node-2 and its development should have been purely a production job. However, it did not stay that way for very long.

Six months after the signing of the Barter, NASA requested to accommodate the Environment Control Life Support (ECLS) racks in Node-3. This was the beginning of an impressive series of changes that was still ongoing over a year after the completion of AIT activities. In addition to the ECLS racks already mentioned, the most significant changes to impact the Node-3 development were after the Design Review 2 (Node-3 Critical Design Review) in September 2002, and after the Preliminary Acceptance Review in July 2007.

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One of Cupola's windows

These included:
- generation of flight operation input and support to NASA;
- performance of non-destructive testing of all the welds of the primary structure shell after the proof pressure test;
- implementation of the NASA close-out for flight process;
- modification of the close-out panels in the hatch areas to correct the design for an interface requirement error
- transfer to Turin of some ground operation activities planned at Kennedy Space Center;
- storage and maintenance at TAS-I and performance of the remaining ground operations at KSC under Thales Alenia Space responsibility;
- implementation of the Cupola launch on Node-3;
- demanifesting of the Air Revitalisation System rack from the launch configuration;
- Node-3 relocation on Node-1 port;
- accommodation of Treadmill 2 and ARED exercise equipment, new Waste and Hygiene Compartment and Total Organic Carbon Analyzer (TOCA);
- implementation of secondary structures to accommodate up to 2000lbs cargo for launch;
- accommodation of a Power and Video Grapple Fixture on the zenith port the Special Dextrous Manipulator (SPDM) parking.

←

The ISS currently features a 50 cm diameter optical research window, giving the crew a view of Earth's surface, seen here with STS-124 astronaut Karen Nyberg. The high-tech 12 cm thick glass is actually a composite of four laminated panes consisting of a thin exterior 'debris' pane that protects it from micrometeorites, two internal pressure panes, and an interior 'scratch' pane to absorb accidental marking from inside (NASA)

These changes were only the tip of the iceberg. In reality over 300 Contract Change Notices (CCNs) were signed in the frame of the Nodes contract, nearly all originating from NASA. To give an idea of the magnitude of the changes requested by NASA, the related CCNs affecting the Nodes contract (Node-2 and 3) amounted to €69 million. This amount was settled in three ways: first, the Amendment 2 of the barter agreement (€17 million), second, a new barter for the cryogenic freezer cancellation (€10 million) and finally, with direct payments (€42 million). For the latter, a contract between agencies was signed and a specific financial process put in place to allow the execution of the payments to Thales Alenia Space.

The amount of changes that affected Node-3 might be surprising, and could give the idea that the project was kicked-off with an immature baseline plan. Actually the baseline has been very well defined throughout the project, but the evolution of the ISS over the years, whether for political, financial or operational reasons, has pushed NASA to revise it several times. It is also believed that the European efficiency to accommodate the NASA changes was another contributing factor to the quantity of new work requested by NASA.

This is taken as a sign of the trust that NASA put in the ESA Nodes project and European industry for delivering top-quality products, on schedule and at an affordable cost even under the most demanding conditions. The Thales Alenia Space Italy project team are to be commended for this outstanding performance, shown by the low number of issues that were on the table at the Pre-shipment Acceptance Review: only 30 open Review Item Discrepancies (RIDs) and 19 requirements open out of 559 in such a dynamic baseline environment.

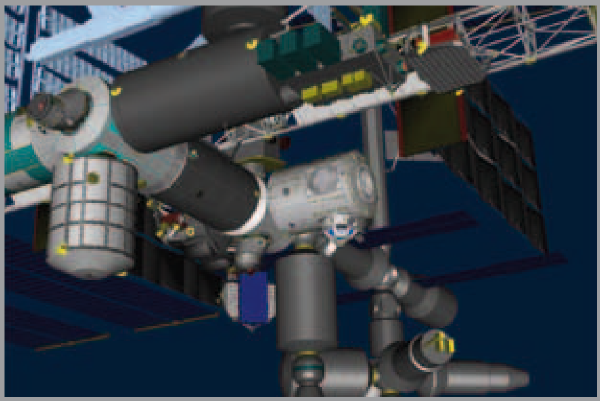
Remaining steps before launch

The Cupola is at Kennedy Space Center waiting for final integration on the Node-3 axial hatch and closeout for flight. Node-3 will be shipped to Kennedy in April 2009. At the launch site, the Node-3 will undergo completion of mechanical tasks, then horizontal mating with the Cupola and a leak test, a second set of functional tests with final flight software and then the final closeout for flight. This process ends with the Acceptance Review when the Node-3/Cupola assembly will be declared ready for launch and transferred to NASA for the 20A Shuttle flight launch processing. With the launch date set by NASA for February 2010, Node-3/Cupola should be integrated in the Shuttle cargo bay by the end of 2009.

Node-3 and Cupola on-orbit activation

Following launch and opening of the Shuttle's cargo bay doors, the Node-3 heaters will be powered up to provide temperature control of the shell. During launch, Cupola is protected by a multi-layer insulation shroud covering the whole structure.

When the Shuttle berths to the PMA-2 docking port, the Shuttle crew will conduct a spacewalk to remove the cover of the Passive Common Berthing Mechanism and disconnect



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Artist impression showing the final location of the Node-3/Cupola assembly on the ISS (Thales Alenia Space)

the power line used by Node-3 inside the Shuttle. The whole Node-3/Cupola assembly will be transferred by the ISS robotic arm to dock with the Node-1 port. The astronauts will then complete the first spacewalk by restoring power to the Node-3 heaters. Inside the ISS, the crew will then pressurise the area between Node-1 and Node-3, to open the Node-1 hatch, and perform utilities connections and fit out the area between the Nodes.

A second spacewalk will be performed to connect external power lines from the ISS truss to Node-3 and the ammonia lines for the thermal loop activation, plus other external outfitting tasks, such as the installation of handrails and Worksite Interfaces. Following this second spacewalk, the Node-3 system will be fully activated and the Node-3 hatch opened to allow the crew to enter the Node-3 cabin.

Node-3 will be ready for the installation and activation of all crew support racks and equipment already on the ISS, awaiting the arrival of Node-3 to reach their nominal location.

During the last part of the 20A flight, the crew will perform all the tasks required to prepare for moving Cupola to its final location, and then will perform the unberthing of Cupola. The ISS robotic arm will transfer and reberth the unpressurised Cupola to the Node-3 nadir port. The Cupola internal area will be pressurised and the Node-3 nadir hatch opened to allow the connection of electrical and water lines, the activation of window heaters, the assembly of the Audio Terminal Unit and the two Utility Outlet Panels.

Other tasks, such as the filling of the water lines and the relocation of panels will be performed during this period. Once the heaters are activated, a spacewalk will be needed to remove and jettison the Cupola thermal shroud. From then on, the robotic workstation can be installed and the Cupola used by the crew to drive the robotic arm, monitor ATV and HTV berthing, make observations, or just relax and enjoy the view of Earth and the stars. ■