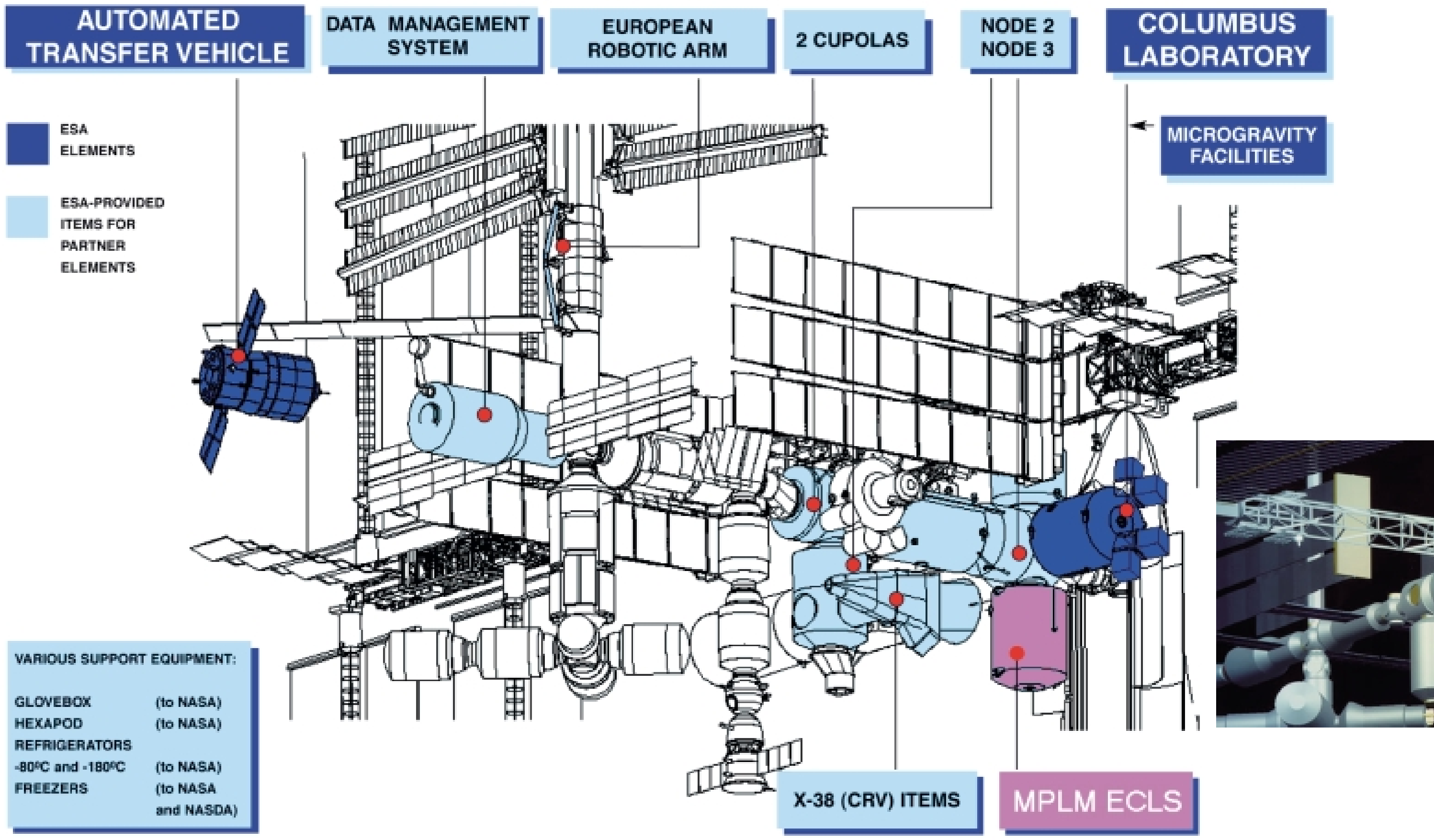
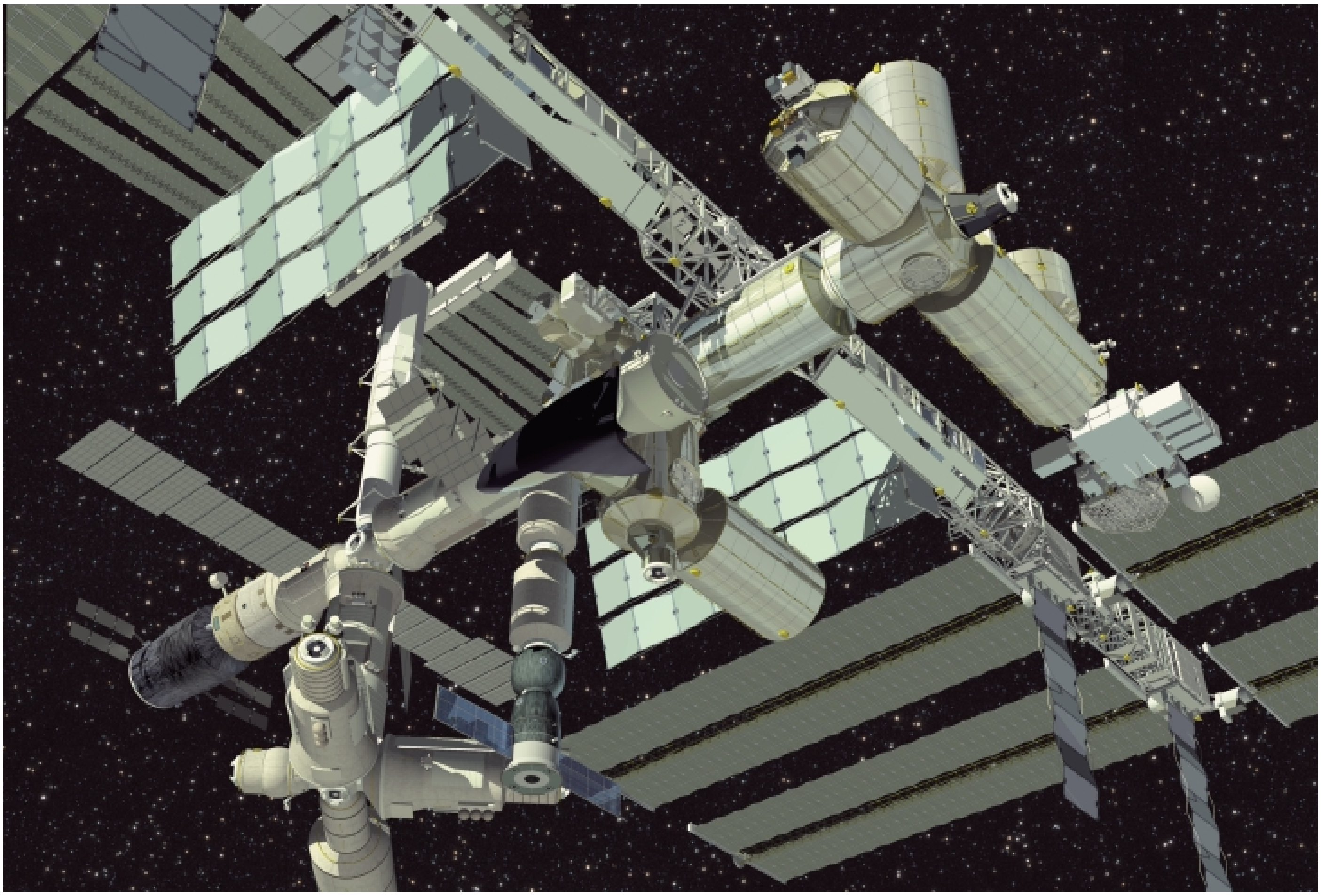


ESA's contributions to the ISS. MPLM is highlighted in pink; the other ESA-provided items for Partner elements are in light blue.
Right: MPLM remains berthed only while the Space Shuttle is docked to the Space Station – the spaceplane is omitted here for clarity.
(ESA/Alenia Aerospazio)



Environmental Control & Life Support for the Multi-Purpose Logistics Module

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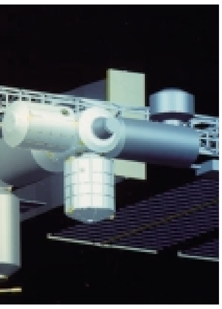


ESA has provided the Environmental Control and Life Support (ECLS) Subsystem for Italy's Multi-Purpose Logistics Module (MPLM) contribution to the International Space Station (ISS). In exchange, the Italian Space Agency (ASI) is providing a derivative of the MPLM primary structure for ESA's Columbus ISS laboratory module. Considerable savings have been achieved by the development and qualification of common hardware – more than 25 million Euros for each project. MPLM's ECLS Subsystem is described here, with emphasis on its similarity to the version used by Columbus.

Introduction

Assembly of the 470-tonne ISS began at the end of 1998 with the mating of the first two modules in orbit. Although assembly will not be completed until 2004, productive work aboard this outpost will begin in early 2000. This will require a regular flow of equipment, materials and consumables delivered by a range of vehicles. Other items, such as the results of experiments, will need to be returned to Earth.

Europe is providing two crucial elements of this ferry network. ESA's Automated Transfer Vehicle (ATV) and its mixed cargo will be launched on Europe's large Ariane-5 rocket. Italy is separately contributing the Multi-Purpose Logistics Module (MPLM) to be carried in the Space Shuttle's payload bay.

In late 1995, ESA's Council authorised the 'Arrangement Between the European Space Agency and the Italian Space Agency on the Exploitation of Common Features of the Pressurised Modules Developed by the Parties'. The goal was to avoid the duplication of development efforts by sharing common features on ESA's Columbus laboratory and ASI's MPLM. This led to ASI providing ESA and the Columbus prime contractor, DASA, with a derivative of the MPLM primary structure for Columbus. In exchange, ESA provided ASI and the MPLM prime contractor, Alenia Aerospazio, with the ECLS Subsystem for the three MPLM Flight Models. The estimated saving to each programme is more than 25 million Euros.

The ECLS Subsystem was designed to satisfy both MPLM and Columbus. The contract was awarded by ESA in early 1996 to Dornier Satellitensysteme of DASA, and the deliveries of all MPLM ECLS engineering models, associated Ground Support Equipment and the three Flight Model sets, with minor exceptions, were completed in 1998. The Columbus ECLS deliveries are planned for 1999.

MPLM ECLS Subsystem

MPLM is a unique part of the overall ISS logistics scenario: it is the only logistics module capable of transferring complete International Standard Payload Racks (ISPRs) to and from the ISS. The module will be berthed at Node-2 (Node-1 on its debut mission in mid-2000) using the Station or Shuttle robot arm.

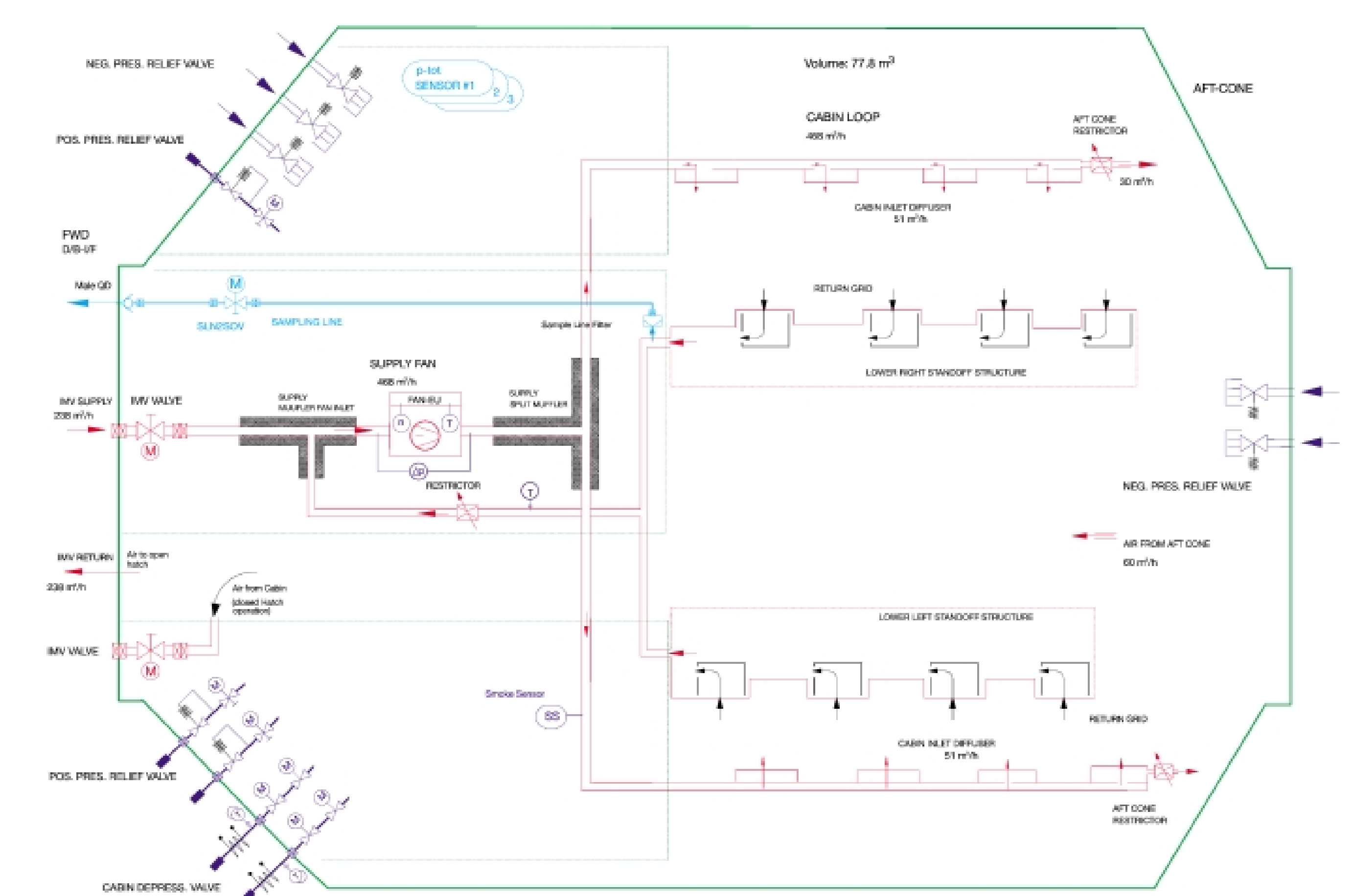
Equipment will be transferred by Station and/or Shuttle crew members, and this is where ESA's contribution to MPLM is critically important. The Agency-supplied ECLS Subsystem will maintain comfortable conditions for three astronauts to work in the module simultaneously for the projected MPLM mission length of two weeks. Drawing on Station resources, the ECLS controls the module's internal environment to provide a safe, sea-level 'shirtsleeve' environment.

In particular, it must provide: temperature and humidity control; atmosphere pressure control; fire detection and suppression; contamination monitoring and control.

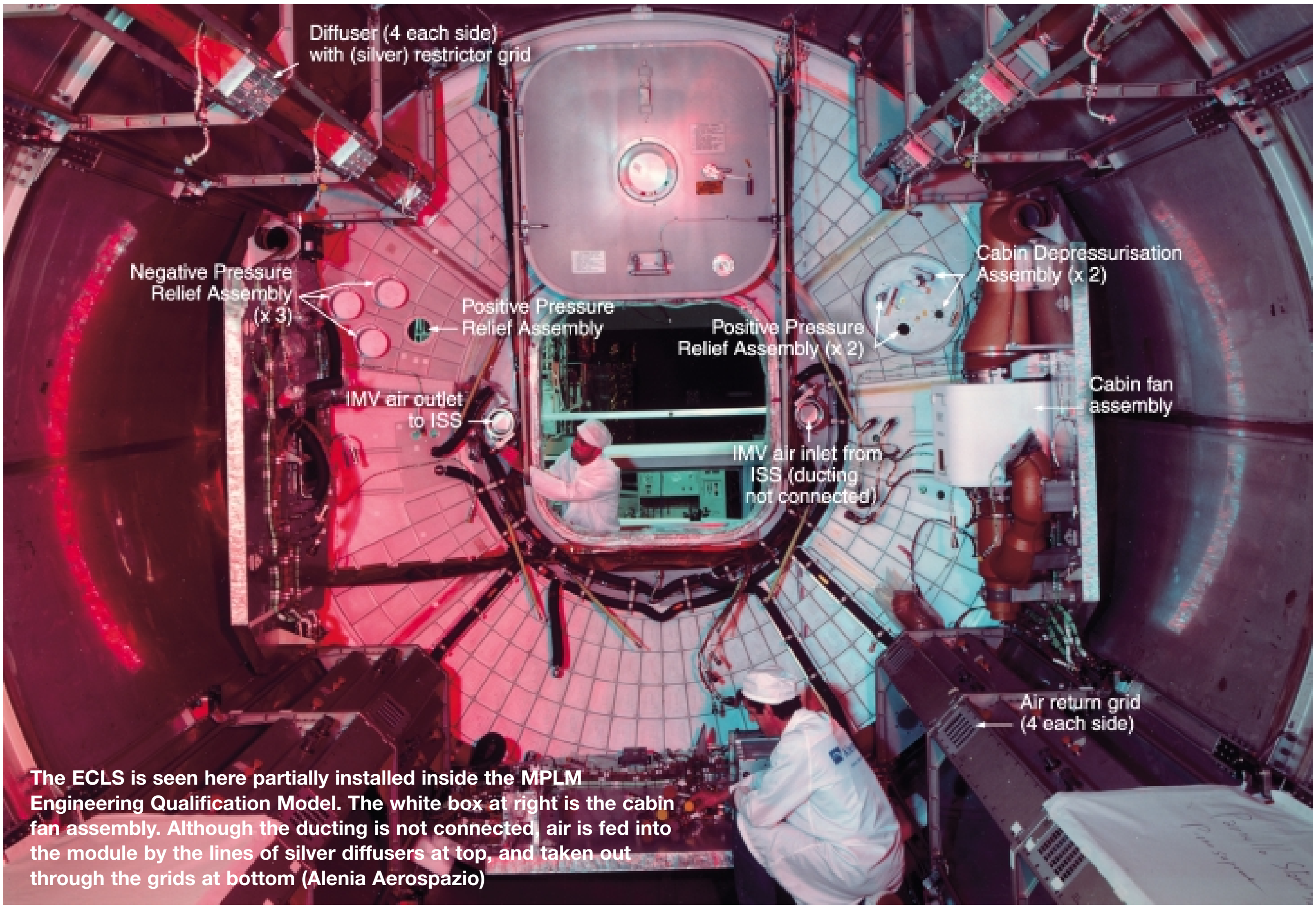
Temperature and Humidity Control

The ECLS Subsystem collects fresh air from

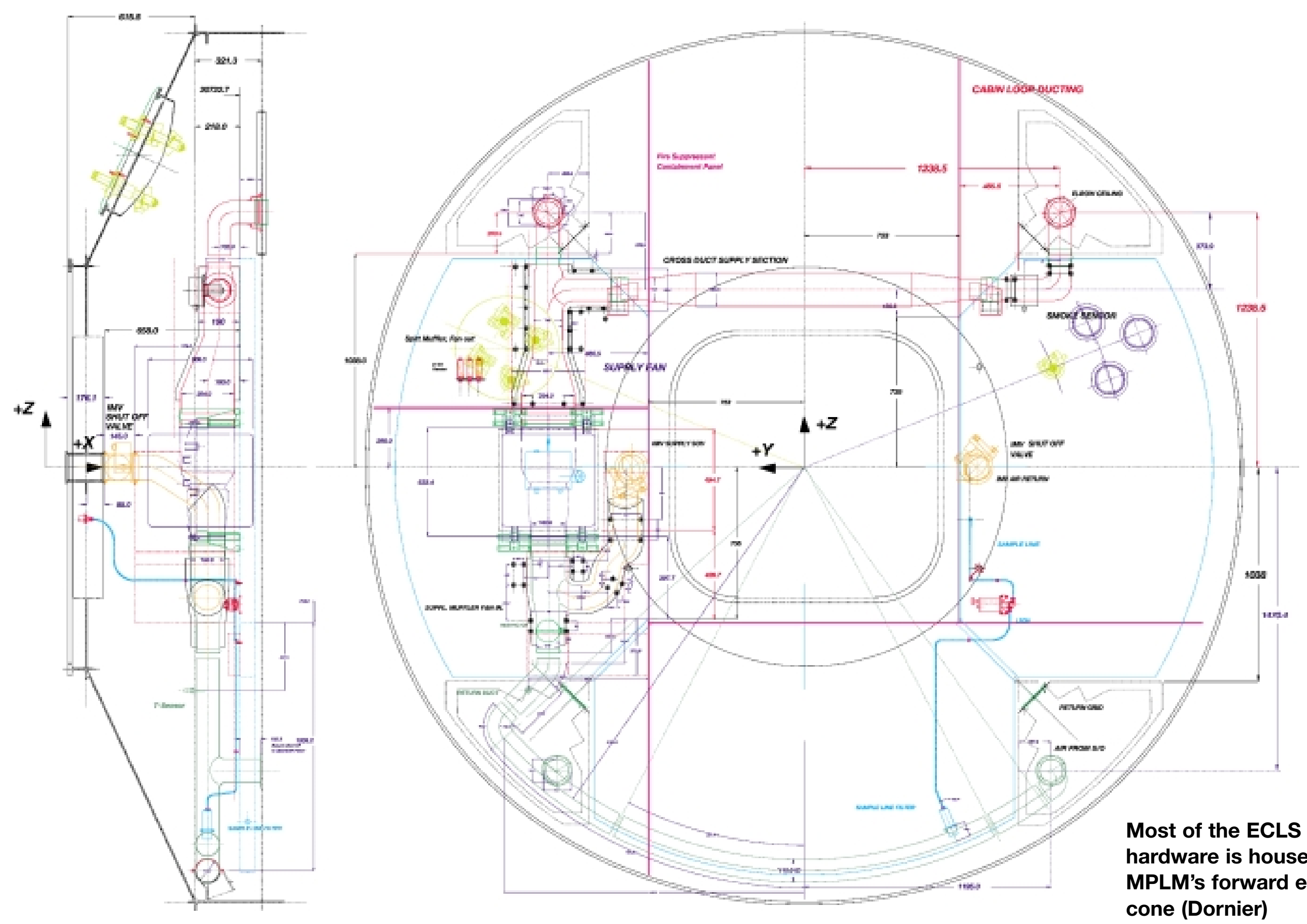
This article is abbreviated from the ESA brochure BR-143 'Supporting Life: Environmental Control and Life Support for the Multi-Purpose Logistics Module of the International Space Station'. An electronic version will be posted at http://esapub.esrin.esa.it/



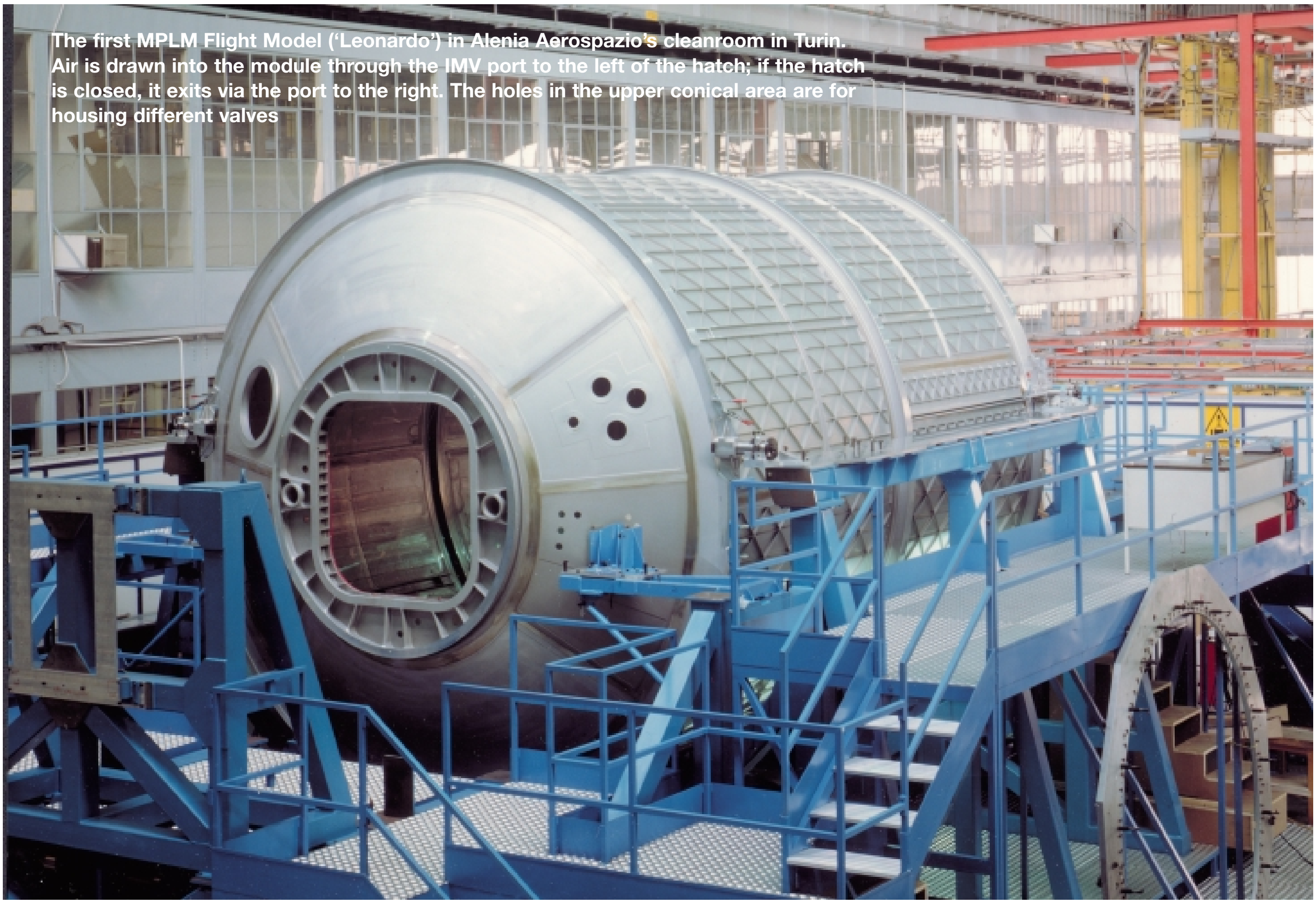
The layout of MPLM's environmental control and life support subsystem (Dornier)



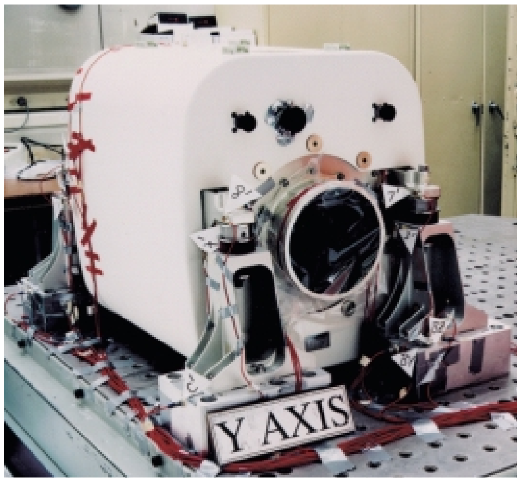
The ECLS is seen here partially installed inside the MPLM Engineering Qualification Model. The white box at right is the cabin fan assembly. Although the ducting is not connected, air is fed into the module by the lines of silver diffusers at top, and taken out through the grids at bottom (Alenia Aerospazio)



Most of the ECLS hardware is housed in MPLM's forward end cone (Dornier)



The first MPLM Flight Model ('Leonardo') in Alenia Aerospazio's cleanroom in Turin. Air is drawn into the module through the IMV port to the left of the hatch; if the hatch is closed, it exits via the port to the right. The holes in the upper conical area are for housing different valves



The cabin fan assembly undergoing a random vibration test during its qualification phase

the Station/MPLM Inter Module Ventilation (IMV) Interface, distributes it throughout the cabin and then returns it to the ISS for revitalisation. The air enters through a port to the right of the hatch in the forward end cone, and normally exits via the open hatch.

Ventilation is provided throughout the habitable volume to prevent dangerous pockets of stale air, and the temperature is monitored. The humidity and temperature are controlled from the Station Node.

The required airflow of 468 m^3/h is provided by a single fan assembly in the forward end cone. The air is distributed by ducting and diffusers in two branches along the upper cabin – four diffusers on each side. Each diffuser emits about 51 m^3/h to produce the required cabin air movement. A further 30 m^3/h is routed from each branch along the roof into the aft cone. Restrictor grids in the diffusers and restrictors in the outlets to the aft cone adjust the flows.

The air is sucked from the module via return grids in the lower stand-offs. The two branches are mixed in a junction duct and led back to the fan inlet, where the Station supply is added. A restrictor in the return duct ensures the pressure is lower than at the IMV supply interface, so air continues to be sucked from the Station.

Normally, air flows back to the Station through the open hatch. If the hatch is closed, the air travels through the separate dedicated IMV return duct. To isolate the module from the Station, a motorised valve in each of the IMV supply and return ducts closes off the airflow.

MPLM's cabin air is also monitored by a temperature sensor.

Cabin Ventilation Test

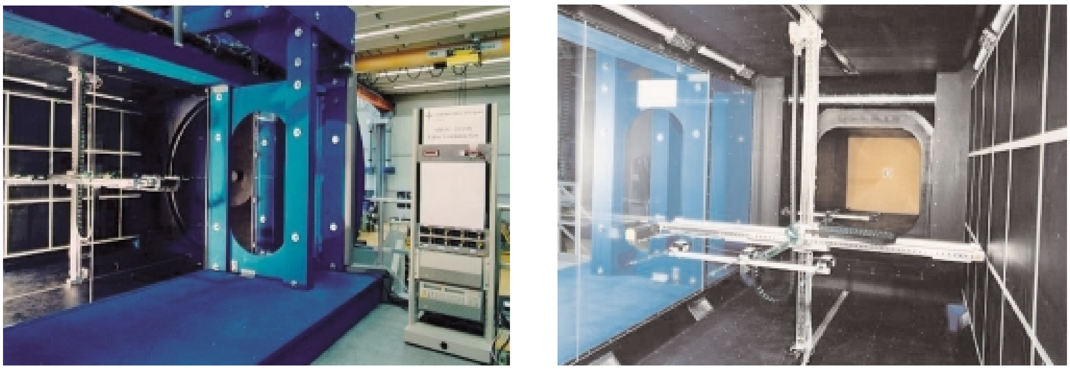
A cabin ventilation qualification test was performed using a full-scale cabin simulator/ mock-up. The two photographs show the test article with equipment installed for air speed and temperature measurements. The test verified that the cabin comfort requirements have been achieved: air speed is 0.076-0.203 m/s within at least 67% of the habitable volume, except near the diffuser outlets. The optimum airflow for injection through each of the eight cabin air inlet diffusers was found to be 51 m^3/h.

Atmosphere Pressure Control

The total atmospheric pressure is monitored, and MPLM's data management system transmits an emergency signal to the ISS if MPLM's air pressure strays beyond pre-set limits. Pressure valves protect the module's structural integrity and support fire suppression.

Positive Pressure Relief Assembly (PPRA)

MPLM's structure is designed to handle a pressure differential of 1.034 Earth-atmospheres (1048 hPa). To prevent it from reaching this level, the valve in the PPRA opens and vents air from the cabin when the pressure differential rises to 1.014 atm (1027 hPa). This 'crack pressure' can be reached when the MPLM is isolated, for example, inside the Shuttle during launch, when the internal temperature might increase because equipment is powered up without active cooling.



A cabin ventilation qualification test on a full-scale cabin mockup at Dornier showed that the required air speed of 0.076-0.203 m/s in at least 67% of the habitable volume had been achieved

The assembly provides 'two-failure tolerance' by using three valves in parallel, any one of which can do the job. Two are housed in a feed-through plate in the upper area of the forward cone; the third is mounted directly in the cone's lower area.

Each assembly comprises a power-independent pneumatic pressure relief valve and a butterfly shut-off valve, installed in series. The shut-off valve can be closed electrically by a brush-type 28 V DC motor or by manual override; this isolates the assembly in case the pneumatic relief valve or motor fail.

Ground controllers or Space Station crews can use the electric motors to deactivate the system when it is not required. For example, when MPLM is docked with its hatch open and the Station is providing overall pressure control.

Negative Pressure Relief Assembly (NPRA)
MPLM's internal pressure might fall below external pressure during ground operations, launch abort or nominal reentry. This negative differential is prevented from reaching the structure's design level of 0.0336 atm (34 hPa) by the NPRA.

This NPRA consists of a set of pneumatic, power-independent valves. As this capability is needed mainly during launch and reentry – when MPLM is unmanned – manual override is unnecessary. Three of these valves are mounted directly in the forward cone's lower area; two are positioned in the aft cone bulkhead.

The redundant cover on each is one-failure tolerant against leakage to space during nominal on-orbit mission phases, when the pneumatic portion of the valve is not needed. This phase can last up to 15 years for the Columbus module.

Cabin Depressurisation Assembly (CDA)
The CDA can vent the cabin air to space in less than 10 minutes as an integral element of the MPLM/ISS/Columbus fire suppression scheme. It consists of two separate units on the same feed-through plate as the two PPRAs in MPLM's forward cone upper area. Each is equipped with two butterfly shut-off valves, arranged in series so that the failure of one valve does not cause unexpected depressurisation or prevent closure after intentional venting. A 28 V DC brush motor operates each valve on command from the ISS data management system via MPLM's data management system. Manual override is unnecessary because they would be activated only when the module is unmanned.

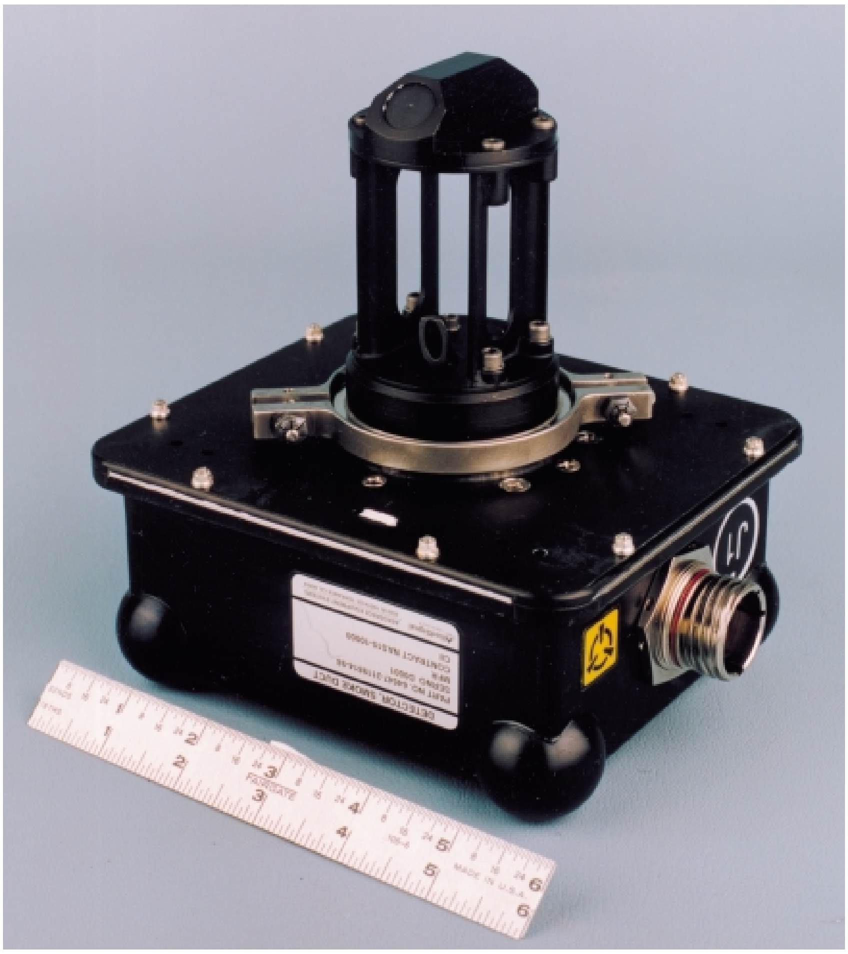
The Positive Pressure Relief Assembly bleeds off air if the pressure climbs too high. The unit mounted inside MPLM is at left. The valve can be closed manually by the handle at left or by the remotely-controlled electric motor at right. The unit mounted outside MPLM is at right

Total Pressure Monitor
MPLM is equipped with three redundant pressure sensors for monitoring the module's internal air pressure. They are designed for an absolute pressure measurement range of 0.0010–1.0856 atm (1–1100 hPa) with an accuracy of about 0.0158 atm (16 hPa).

The sensor uses a diaphragm that deflects in proportion to the applied pressure. This deflection is coupled to a resistive strain gauge bridge circuit, which sends a signal to the MPLM data management system for translation into a pressure reading.

Fire Detection and Suppression
The prospect of fire breaking out in the module is reduced by careful selection of non-flammable materials and by controlling potential ignition sources. The next level of protection and fire localisation is achieved by normal housekeeping monitoring of powered equipment to detect anomalies in temperatures, voltages and currents, for example, that could trigger a fire. If an anomaly is found, the affected equipment is switched off and redundant equipment is activated. Also, airflow in areas housing powered equipment would be halted by turning off the fan, specifically to avoid feeding any fire with oxygen. The fan can be switched on/off by the crew from any other ISS module or by ground controllers.

There is a portable extinguisher for the crew to fight fires in the forward end cone where most of MPLM's powered equipment is located. That area is divided into three compartments, so that



A single Duct Smoke Detector (DSD) on a cabin air duct alerts the MPLM data management system if it detects smoke

the carbon dioxide from a single extinguisher would reduce the oxygen concentration in any one below the minimum (10.5% by volume) necessary for sustaining a fire.

As a last resort, the hatch would be closed to isolate the module before the cabin air is dumped via the CDA.

Fire Suppression Tests

Full-scale mock-ups of the three forward cone compartments, where most MPLM powered equipment is located, were built to verify that a fire can be suppressed with a Station portable fire extinguisher. During early fire suppression development tests, the importance of leakage between the module shell and compartment close-out panels was identified. Great care was therefore taken in simulating those leakage areas.

The qualification tests were performed with the mock-ups in two orientations in order to eliminate the influence of gravity. It was shown that the fire could be suppressed in two side compartments, but leakage was too high in the third compartment, in the lower part of the forward cone, to achieve the low oxygen level. The sealing was improved and the qualification test for that compartment was successfully repeated.

Cabin Air Contamination Monitoring and Control

The cabin air's major constituents and trace gas contamination are measured by the Station's ECLS equipment. Samples of the cabin return air are periodically drawn into the Station via a dedicated tube.

The sampling line consists of a 1/4-inch (0.635 mm) diameter tube connected at one end to the cabin air return duct upstream of the cabin fan, and at the other end to the forward cone bulkhead. At the cabin end, a particle filter (mesh size 2 μm) screens out debris. A Line Shut-Off Valve (LSOV) isolates the line from the Station. It is normally operated electrically by a 28 V brush-type motor, but it is equipped with a manual override in case of motor failure.

Sharing with Columbus

ESA developed the common ECLS under its MPLM activities and procured the equipment needed for Columbus at recurring cost. The design drivers of both projects were combined: each MPLM is designed for 25 flights, and replaceable items on Columbus are designed for 10 years on-orbit.

Existing Space Station hardware – such as the Duct Smoke Detector – was incorporated where feasible. In other cases (CDA, NPRA, PPRA), designs used in NASA's Space Shuttle Orbiter and ESA's Spacelab were substantially improved to meet the more stringent requirements of the MPLM and Columbus programmes.

The Table summarises the hardware used in MPLM's ECLS Subsystem and its commonality with Columbus and the ISS. It is clear that common hardware has been used in most items.

Identical components used in both programmes are the cabin air diffuser, cabin air temperature sensor, IMV Shut-Off Valve, Line Shut-Off Valve, NPRA, CDA and PPRA.

The Duct Smoke Detector was developed for the ISS and is adopted by MPLM and Columbus not only to re-use existing hardware, but also to create similar alarm threshold conditions over the whole station complex. For MPLM, the detector was subjected to further qualification to cover the additional demands imposed by repeated launches on the 25 missions. All the others on the Station, including Columbus, are launched only once and checked periodically on-orbit using their inbuilt sensors. They can be replaced by the crew if necessary.

MPLM ECLS Hardware Commonality with Columbus and International Space Station					
Hardware Item	***MPLM/ Columbus Common***	***MPLM/ ISS Common***	***MPLM/ Columbus Similar***	***MPLM Dedicated***	***Remarks***
Cabin Fan Assembly/ Fan Damping System		X		X	FDS not needed on Columbus
Cabin Loop Ducting			X		
Cabin Air Diffuser	X				
Cabin Temperature Sensor	X				
IMV Shut-off Valve	X				
Negative Pressure Relief Valve	X				
Positive Pressure Relief Valve	X				
Cabin Depressurisation Assembly	X				
Total Pressure Sensor				X	Different Columbus and MPLM electrical interfaces
Sampling line			X		Line routing adapted to module; common sample filter
Line Shut-off Valve	X				
Duct Smoke Detector	X	X			ISS common item used on MPLM and Columbus

Identical cabin loop ducting is not feasible because the modules have different internal layouts. However, the material and construction of the single ducts and their incorporated features (such as mufflers) are similar and the experience from the MPLM development efforts is directly applicable to Columbus. Common parts such as the flexible bellows for duct connection are also incorporated.

A common fan was not adopted because of different schedule, mass, volume, noise and operational requirements. An existing ISS fan was used for MPLM, already qualified within the Station programme, but subjected to further testing to cover the 25 MPLM missions. In addition, since the MPLM fan launch vibration loads are higher than for the ISS, a fan damping system was developed. For Columbus, a new European fan is being developed.

Conclusion

The ECLS Subsystem for MPLM has been successfully developed, and the hardware for three module flight units delivered to ASI. This effort forms part of the cooperation between ESA and ASI aimed at improving the overall efficiency of industrial development for Europe's contribution to the International Space Station.

In exchange for the development of MPLM's ECLS Subsystem, the Columbus flight unit primary structure – directly derived from MPLM's design – is currently being manufactured under ASI's responsibility. As the requirements for the two modules are so similar, the Columbus structure needs no dedicated qualification testing.

Considerable savings for both projects have been achieved by single development and qualification of common hardware – a significant contribution to improving the affordability of manned space programmes.