The European Multi-User Facilities for the Columbus Laboratory

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In 1995, ESA Member States confirmed their participation in the International Space Station (ISS) Programme. This participation consists of infrastructure elements (e.g. Columbus, Automated Transfer Vehicle, European Robotic Arm) and utilisation elements (e.g. Microgravity Facilities for Columbus, European Drawer Rack, Laboratory Support Equipment).

Once in orbit, Columbus will be outfitted with several multi-user facilities. The experiments will provide a much-needed boost to the European scientific and industrial community. Equally important, they will greatly increase the competitiveness of European Industry by fostering innovative research – a major priority for ESA and the European Union. They will also facilitate the start of the commercial utilisation of the Space Station.

Introduction

The Columbus laboratory, planned for launch in 2004, will accommodate the following multi-user facilities:

- Biolab
- Fluid Science Laboratory (FSL)
- European Physiology Modules (EPM)
- European Drawer Rack (EDR)
- European Stowage Rack (ESR)
- Materials Science Laboratory (MSL).

Biolab, FSL, EPM and MSL are being developed within the Microgravity Facilities for Columbus (MFC) Programme, while EDR and ESR come within the Utilisation Programme. Columbus will be launched with all the facilities installed (Figure 1) except for MSL, the launch of which is still to be defined. There will also be an allocated stowage volume (e.g. one-quarter of ESR for each facility) to upload a minimum set of maintenance spares and the required experiment hardware (containers, cartridges, etc). Once in orbit, Columbus will accommodate 10 active racks. In the framework of the Space Station Agreements with the USA, ESA is allocated 51% usage of Columbus, the other five racks being allocated to NASA.

Physical and Life Sciences research under microgravity conditions covers a wide range of activities such as fundamental physics, solidification physics (e.g. crystal growth, metallurgy), physical chemistry, fluid science, biology, biotechnology, human physiology and medicine. These areas cover the largest group of European users of the Space Station. The objective of the ESA Microgravity and Life Sciences Programme is to have materials and fluid sciences, biology and human physiology continuously aboard the Station in order to maximise the return to European scientists. Until 1996, the microgravity effort was funded only via the European Microgravity Research Programmes EMIR-1 and -2. In January 1997, the MFC Programme was initiated, complementing EMIR-2; it covers the development of a set of multi-user microgravity facilities in Columbus and, via Co-operative Agreements with NASA, in the US Laboratory (e.g. MSL).

EDR is a multi-purpose carrier able to support experiments in disciplines such as technology, biology and physical science. ESR is a passive multi-user facility for modular and standardised stowage of Columbus payload support equipment, samples, experiment containers, etc.

Each active multi-user facility has a specific Science Team, of well-known European scientists, that advises the Agency about the scientific requirements. The Team also reviews the facility design to ensure the science requirements are satisfied. The highly demanding scientific and engineering requirements of the facilities, coupled with the low mass budget (e.g. 500 kg for each ESA facility, whereas NASA's is around 800 kg) and reduced financial resources, have necessitated the development of new design solutions, including new technologies that could find application in the commercial market. The strong synergy with ESA technology programmes such as the Technology Research Programme (TRP) and General Support Technology Programme (GSTP) has also played an important role in containing the facilities' development costs.

In order to select experiments for the facilities, International Life Sciences and ESA Physical Science Announcements of Opportunity (AOs) were released in 1998 and in 1999. Following the relevant peer recommendations and endorsement from the Microgravity Programme Board, the first batch of experiments was selected for each facility. New AOs are planned to be issued every 1-2 years.

The development schedule for each facility is shown in Figure 2, and the principal features in Table 1. All facilities will make use of the Japanese International Standard Payload Racks (ISPRs) and the Standard Payload Outfitting Equipment (SPOE, including standard payload computer, smoke sensor and remote power distribution assembly), developed through the Utilisation Programme. A laptop will serve as the primary interface between the flight crew and each facility. It allows full monitoring and control of the facility and the experiment modules. Crew members can view scientific images (digital video and analogue NTSC) from the experiment processes, as well as information on the health and operational status of the facility. Table 1 indicates the technical features common to all facilities. The main features are available on <http://www.estec.esa.int/spaceflight/inmfc.htm> to increase awareness of the possibilities offered to the scientific and industrial community.

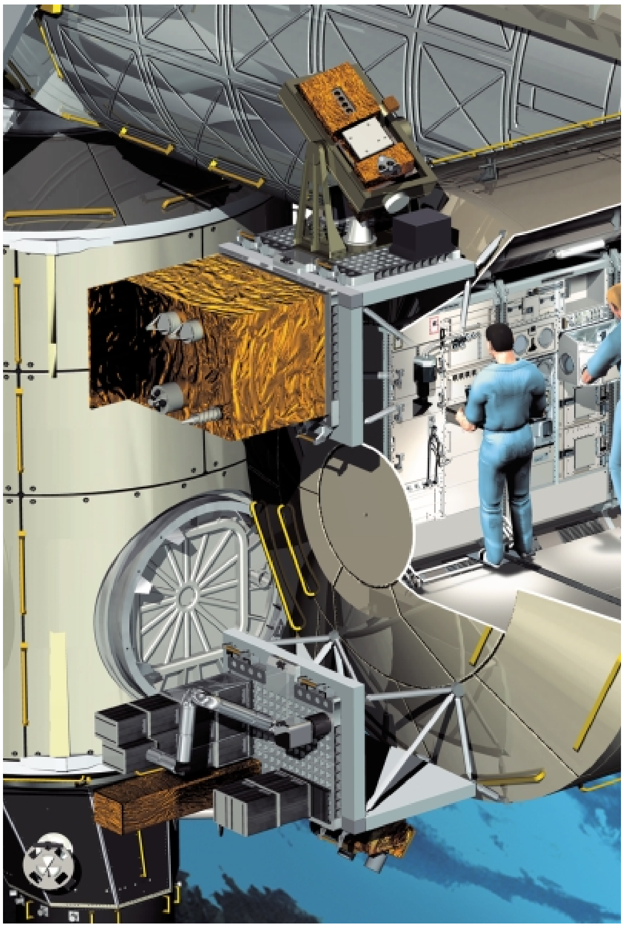
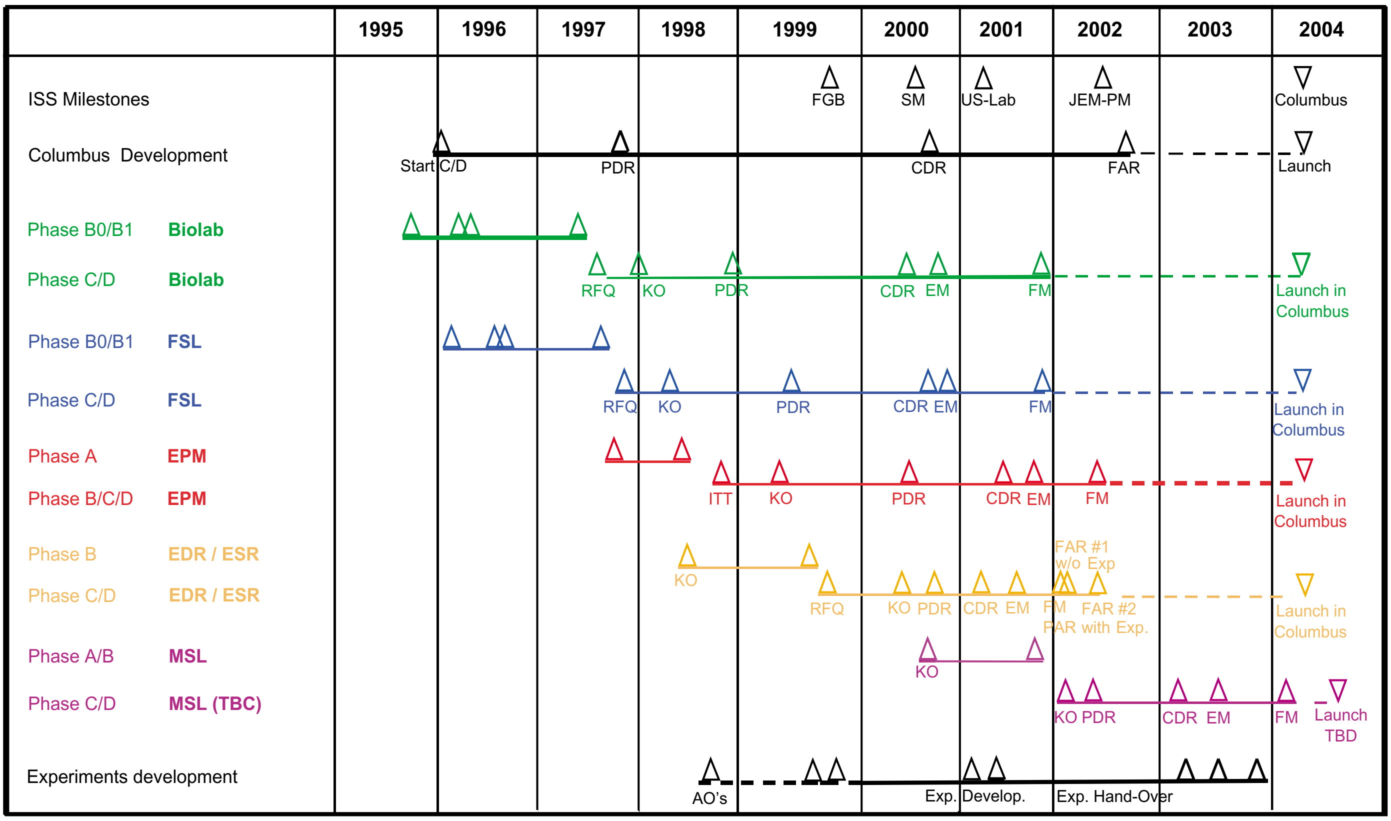
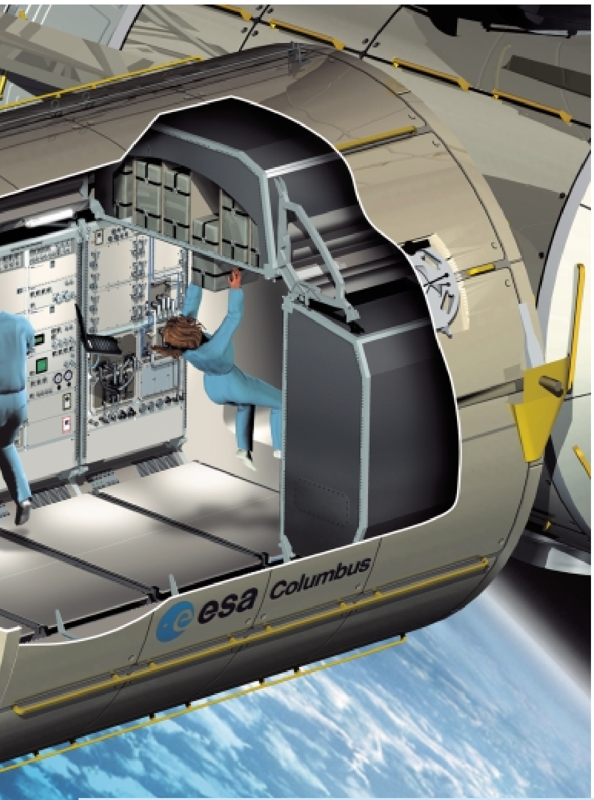


Figure 1. The multi-user facilities inside the Columbus laboratory. (ESA/D. Ducros)

Figure 2. Development schedule of the Columbus multi-user facilities





Biolab

Scientific objectives

Life Sciences experiments in space aim to identify the role that microgravity plays at all levels of life, from the organisation of a single cell to the nature of gravity-resisting and -detecting mechanisms in the more highly developed organisms, including humans. While the effects of microgravity on humans will also be investigated by other facilities (e.g. EPM), it is important to begin the investigation with the smaller elements of the biological structure. At the science community's behest, ESA has always been strongly involved in the investigation of biological samples, e.g. with Biorack and Biobox. The scientific results from these flights can certainly influence our everyday lives, particularly in the areas of immunology, bone demineralisation, cellular signal transduction and cellular repair capabilities. Such results could eventually have a strong bearing on critical products in the medical, pharmacological and biotechnological fields.

[1]ISIS = International Subrack Interface Specification,
[2]SED = Standard European Drawer (8-PU size),
[3]MDL = Middeck Locker,
[4]MPLM = Multi-Purpose Logistics Module,
[5]ATCS = Automatic Temperature Controlled Stowage,
[6]ASS = Automatic Ambient Stowage
[7]PU = Panel Unit

Table 1. Principal features of the Columbus multi-user facilities

	Biolab	FSL	EPM	EDR
Research Field	– Cell culture – Microorganisms – Small plants – Small invertebrates	– Bubble formation/growth – Condensation phenomena – Thermophysical parameters – Directional solidification	– Metabolic Functions – Cardiovascular – Muscular/Skeleton system – Neuroscience	– Platform for up to 8 experiment modules – PCDF is part of first experiment module set
Automation	Complete experiment execution including analysis by using handing mechanism	Experiment execution including analysis	When feasible to shorten experiment set-up and teardown times	– All experiments can be executed in parallel – Each experiment module will be fully autonomous
Telescience	All automatic features can be altered from ground	All automatic features can be altered from ground	All automatic features can be altered from ground	All automatic features can be altered from ground and be replaced by manual crew commands or from ground
Advanced Diagnostics	– Microscope – Spectrophotometer	– Particle image velocimetry – Thermographic mapping – Interferometric observation	– Science Modules	– N/A – Experiment modules may contain their own diagnostics
Modularity/ Serviceability	– Modular design of the facility – Experiments in standard container box – Experiments carried out in 0-*g* and 1-*g* simultaneously	– Modular design of the facility – Experiments in standard container box	– Modular design of the facility – Science Modules can be exchanged and operated in other Space Station locations	– Each of the 8 experiment modules can be accommodated in ISIS[1] SEDs[2] or standard ISS MDLs[3] – SEDs and MDLs can be frequently up/downloaded in MPLM[4]
Facility Configurability	Experiment Containers, ATCS[5] inserts, AAS[6] inserts and analysis instruments can be exchanged in orbit	Experiment Containers, reference targets and front-mounted cameras can be exchanged in orbit	All Science Modules can be exchanged in orbit	– Experiment Modules can be exchanged in orbit – Control software can be reconfigured from ground
Experiments Container Box/Cartridge size/Science Module (WxHxL)	– 60x60x100 mm – 170x120x140 mm	400x270x280 mm	Internal usable volume for Science Modules: 4 PU[7] = 400x143x580 mm 8 PU = 400x321x580 mm	Internal usable volume for Science Modules: – SED: 387x327x573 mm – MDL: 440x253x566 mm

The current Biolab concept is that of a multi-user facility for conducting biological experiments on cells, microorganisms, small plants and small invertebrates, as well as research in biotechnology (Figure 3). The design respects the science recommendations, the outcome of the scientific and feasibility studies (e.g. Phase-A/B), the experience gained from facilities flown previously, and the requirements and possibilities offered by the Space Station.

Facility description and operation

Biolab is divided physically and functionally into two sections: the automated section in the left side of the rack, and the manual section, including the BioGlovebox, in the right side. In the automated section, also known as the Core Unit, all activities are performed automatically by the facility after manual sample loading by the crew. By implementing such a high level of automation, the demand on crew time is drastically reduced. The manual section, in which all activities are performed by the crew themselves, is mainly used for sample storage and specific crew activities. The biological samples are contained in standard Experiment Containers (ECs), which offer standard external interfaces with Biolab, an approach that has been well-proved with Biorack. The internal volume available to experimenters is 60x60x100 mm for the standard container, but the larger Advanced Experiment Container (170x120x140 mm) is also available. Biolab's main features are indicated in Table 1.

The biological samples, with their ancillary items, will be transported from the ground to Biolab either already in the ECs or in small vials if they require temperatures as low as –80°C, taking advantage of the ESA-developed MELFI freezer. Once in orbit, samples already in ECs will be manually inserted into Biolab for processing, while frozen samples need to be thawed in the Experiment Preparation Unit (EPU) installed in the facility's Bioglovebox.

Once the manual loading is completed, the automatic processing of the experiments can start. These experiments will be run in parallel on the two centrifuges, one at 0 g and the other at 1 *g* for reference. During the experiment, the handling mechanism

Figure 3. The Biolab multi-user facility. (ESA/D. Ducros)

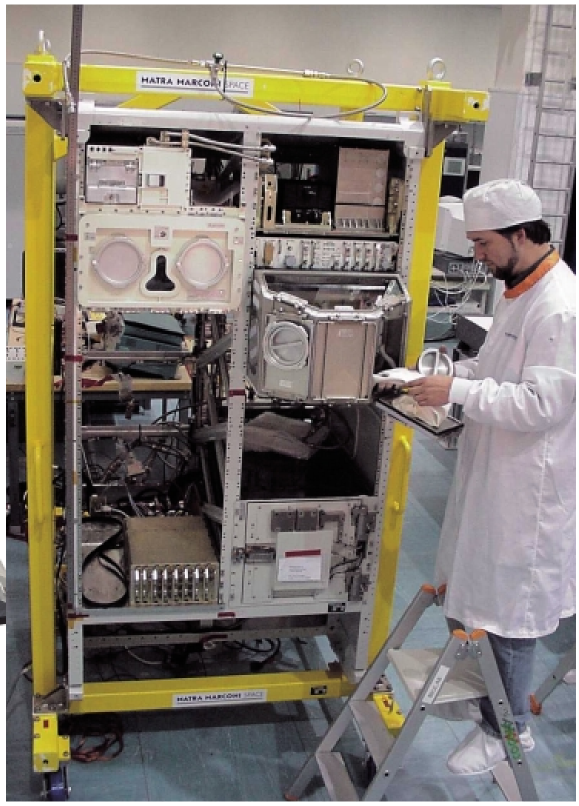


Figure 5. The Biolab Engineering Model under integration. (ESA/MMS-F)

will transport the samples to Biolab's diagnostic instruments. With the aid of teleoperations, the scientists on the ground can participate in this preliminary analysis process. Typical experiment durations can be between a few days and a few months.

Industrial organisation and development status

Biolab's Phase-C/D was initiated in December 1997 with Matra Marconi Space of Toulouse (F) as prime contractor. The consortium is shown in Figure 4. The manufacturing of all Engineering Model (EM) subsystems has been completed and the EM is under integration (Figure 5). Completion of the functional and performance test campaign is planned for the second half of 2000. The Flight Model will be delivered by the end of 2001.

Among the subsystems, one of the first elements to be manufactured was a set of ECs. Great care was taken to ensure that their construction materials are bio-compatible with the widest range of biological samples. In this respect, the industrial consortium benefited from the results of the Experiment Container Standardisation (ECS) study, a GSTP study that identified a set of standard items for use in ECs.

The Centrifuges (Figure 6) were manufactured early in the Biolab development plan, to ensure smooth integration inside the complex Incubator. Each centrifuge is equipped with a central gas slip-ring to supply its six ECs with a controlled atmosphere. Biolab's slip-ring had to fulfil stringent requirements in terms of reduced torque, reduced leakage and material bio-compatibility, combined with a low-pressure

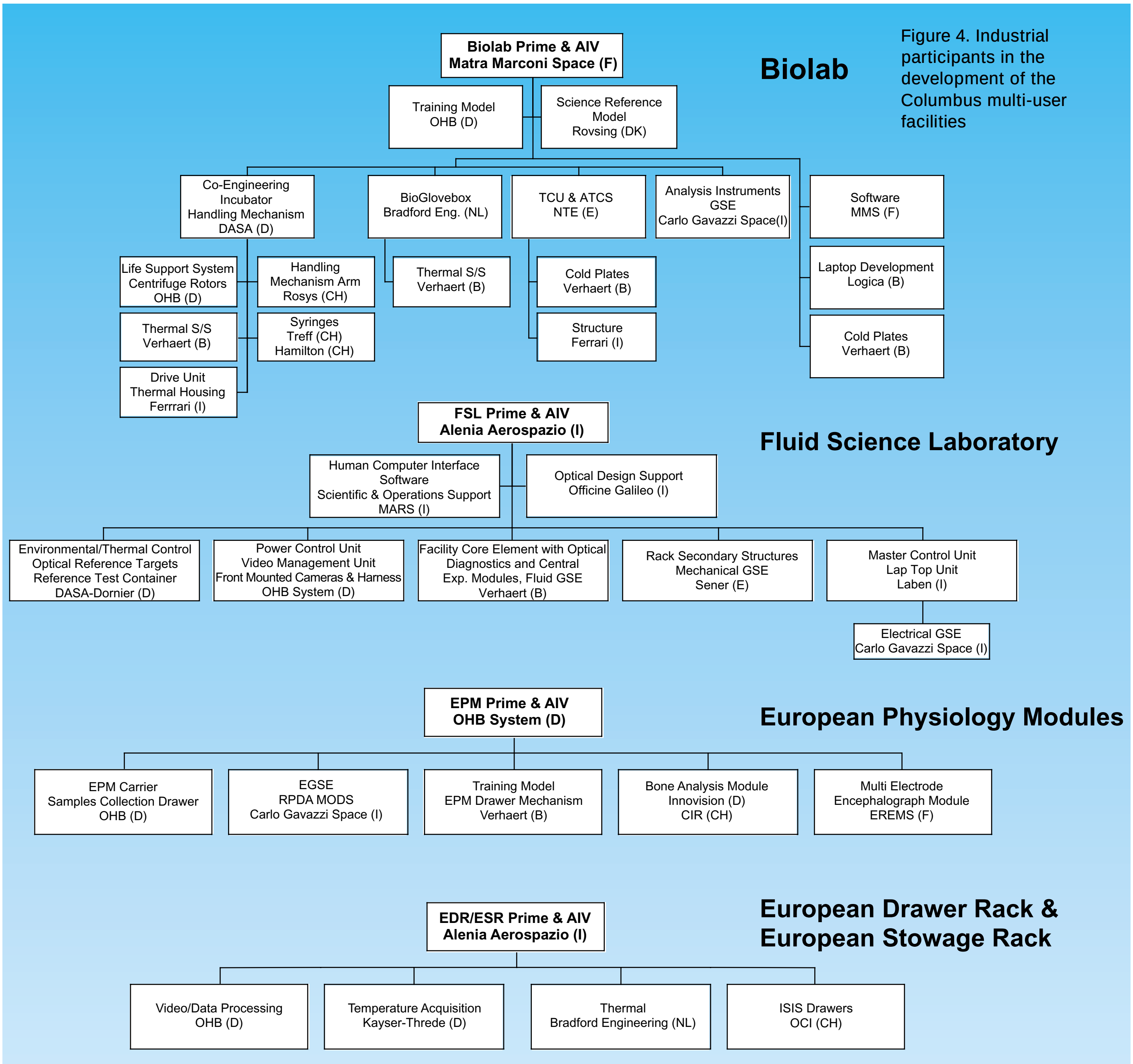


Figure 4. Industrial participants in the development of the Columbus multi-user facilities

supply gas. Since no suitable commercial slip-rings were available on the market, the critical development was supported in Phase-B by a dedicated breadboard, which proved the design's acceptable performance. Biolab's Science Team supported the Industrial Consortium by performing dedicated bio-compatibility tests.

Owing to the nature of Biolab's experiments, the BioGlovebox includes an ozone generator to clean and sterilise some of Biolab's subsystems. The ozone is created by a high-voltage alternating electrical discharge through the air, breaking down molecular oxygen into atomic oxygen. The generator will be used to:

– sterilise Biolab before starting experiments, to avoid contamination from the Station infecting the experiment;
– clean and sterilise a sample spillage, to avoid biological contamination growing uncontrol-lably within Biolab.

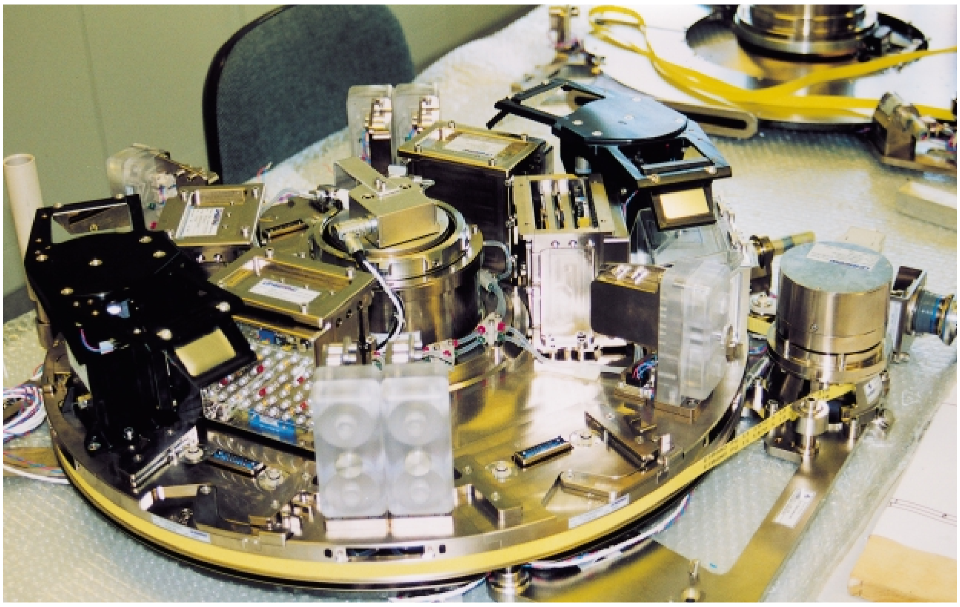


Figure 6. One of the two centrifuges for Biolab. (ESA/OHB)

Developed specifically for Biolab, this ozone generator may find a large commercial market on the ground, where it can quickly and easily sterilise medical tools.

User-support activities and selected experiments

In the frame of the user-support activities, the EPU's Phase-B/C/D began early in 2000 with the prime contract awarded to Verhaert (B). The breadboarding tests will be completed by the second half of 2000.

Following the 1998 International Life Sciences Research Announcement (LSRA), two experiments are in the definition phase, with Biolab as one of the selected possible facilities. The first experiment will provide insight into the repair processes in mammalian cells in microgravity, after these cells are damaged by known doses of radiation. The results will be important in assessing the risks of spaceflight, since there is a synergistic link between space radiation and microgravity. One set of damaged cells will be studied in space by fluorescence microscopy using telescience, while the second set will be deep-frozen for analysis on the ground.

The second candidate experiment will study the effect of spaceflight on the virulence potential of bacteria that are infectious to humans. This will also be an important contribution to risk-assessment for space travellers, since the space environment may alter the pathogenic potential of the bacteria. This is of particular importance because microgravity negatively affects the human immune system.

Fluid Science Laboratory (FSL)

Scientific objectives

Fluid science experiments in space are designed to study dynamic phenomena in the absence of gravitational forces. Under microgravity conditions, such forces are almost eliminated, including their effects in fluid media such as gravity-driven convection, sedimentation and stratification, and fluid static pressure. This allows the study of fluid dynamic effects that are normally masked by gravity, such as the diffusion-controlled heat and mass transfer in crystallisation processes – the absence of the normally dominant convective flow processes results in reduced defect density.

The absence of gravity-driven convection eliminates the negative effects of density gradients (inhomogeneous mass distribution) that always arise on Earth in processes involving heat treatment, phase transitions, diffusive transport or chemical reactions. Convection in terrestrial processes is a strong perturbing factor, the effects of which are seldom predictable with great accuracy and which dominate heat and mass transfer in fluids.

The ability to control such processes is still limited. Their full understanding requires further fundamental research by conducting well-defined model experiments for the testing and development of related theories under micro-gravity. This will allow the optimisation of manufacturing processes on Earth and improvement in the quality of high-value products such as semiconductors.

ESA has already been involved in studying fluid science phenomena under microgravity conditions for several years, notably with the Bubble, Drop and Particle Unit (BDPU) facility that produced important results from several Spacelab missions.

Facility description and operation
FSL is illustrated in Figure 7. The kernel of the facility consists of the Optical Diagnostics Module (ODM) and the Central Experiment Modules (CEM), into which the Experiment Containers (ECs) (Figure 8) are sequentially inserted and operated. Together, these modules represent the Facility Core Element (FCE), which is complemented by the functional subsystems for system and experiment control, power distribution, environmental conditioning, and data processing and management.

In order to cope with the experiment observation requirements, a set of optical diagnostics is integrated in FSL, including:

– visual observation in two axes (y, z) with direct registration via electronic imaging and photographic back-up via Front Mounted Cameras (FMCs) providing high speed, high resolution and colour recording;
– background, sheet and volume illumination with white light and monochromatic (laser) light sources;
– particle image velocimetry, including liquid crystal tracers for simultaneous velocimetry and thermometry;
– thermographic (infrared) mapping of free liquid surfaces (also via FMC);
– interferometric observation in two axes (y, z) by convertible interferometers with active alignment:
  - holographic interferometer;
  - Wollaston/shearing interferometer;
  - Schlieren mode combined with shearing mode;
  - Electronic Speckle Pattern Interferometer (ESPI).

In addition to the integrated system, Flight Support Equipment (FSE) will be available onboard: spare parts, special tools and consumables such as cleaning agents, the

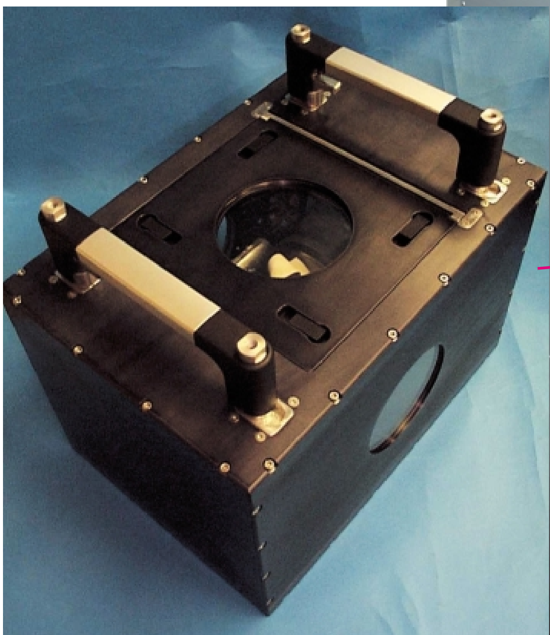


Figure 7. The Fluid Science Laboratory multi-user facility (right). (ESA/D. Ducros)

Figure 8. The Engineering Model of the FSL Experiment Container (above). (ESA/DASA)

FMCs and the Optical Reference Targets (ORT) for calibration of the experiment and diagnostic equipment before an experiment run.

For each experiment or experiment category, an individually developed EC will be used. Stored in the ESR during non-operational phases, each EC will be inserted by the crew into the CEM drawer, where it will undergo an experiment and diagnostics calibration cycle before any process activation. Each EC, with a typical mass of 30-40 kg and standard dimensions of 400x270x280 mm, provides ample volume for accommodating the fluid cell assembly, including the process stimuli and control electronics. It may also be equipped with dedicated experiment diagnostics to complement the standard diagnostics provided by FSL itself.

The control concept for system and experiment operation provides for alternative modes comprising fully automatic experiment processing, even during certain communication outage phases such as regular Loss Of Signal, semi-automatic processing of defined experiment subroutines, and fully interactive step-by-step command keying. All operating modes can be triggered either by the flight crew or from the ground, thus ensuring the possibility of quasi-real-time tele-operation (telescience).

Industrial organisation and development status

FSL's Phase-C/D contract was signed in April 1998. The industrial consortium, shown in Figure 4, is led by Alenia Aerospazio (I) as prime contractor. The Engineering Models for most of the subsystems have been completed. The system EM programme will be completed by the end of 2000. The Flight Model will be completed by the end of 2001.

There are particular technical challenges in designing the diagnostics and the scientific data management system. The combination of four different convertible and state-of-the-art interferometers offers very high flexibility for experiment observation and diagnostics but, on the other hand, inevitably increases complexity. It requires not only a very dense and compact layout but also a high end-to-end optimisation effort, in view of the manifold technical and scientific performances required.

Potential upgrades, partly resulting from new technology developments, are under investigation for a decision in the near future on their implementation:

- the active Microgravity Vibration Isolation Subsystem (MVIS, Figure 9), using magnetic levitation. Each Principle Investigator (PI) can activate the subsystem to isolate his experiment from the *g*-jitter perturbation induced by Space Station dynamics. MVIS is being developed by the Canadian Space Agency;
- diagnostics, replacing the bulky and heavy thermoplastic film camera with the now-mature technology of photorefractive crystals in combination with digital holographic interferometry.

Figure 9. The breadboard of the FSL Microgravity Vibration Isolation Subsystem (MVIS) with the Facility Core Element being tested during a parabolic flight. (CSA)

Experiments selected

Based upon the 1998 Physical Science AO, about 15 peer-recommended experiment proposals, from various scientific and industrial research organisations all over Europe, require FSL. Even in the USA, a growing interest was found in running experiments on FSL. Definition studies of experiment containers will be initiated for the following experiments in view of their maturity:

- *Development of Advanced Foams and Hydrodynamics of Wet Foams*
  These experiments will provide knowledge to European industry on the development and production of advanced foams by overcoming the limits imposed by various instabilities experienced in normal gravity.

Several industries including the oil industry are participating.

– *Fundamental and Applied Studies of Emulsion Stability*
These experiments will investigate the physio-chemical aspect of surfaces in support of emulsion science technology of special interest for the food, cosmetic and pharmaceutical industries.

– *Convection and Interfacial Mass Exchange*
These experiments are devoted to the study of mass-transfer processes through interfaces. These phenomena are of the utmost importance for chemical engineering processes. Thirteen European and two US groups are involved. Industrial applications are expected for thermal-control equipment in space industries.

– *Simulation of Geophysical Flows under Microgravity*
These experiments will investigate, on a small scale, large-scale motions in the outer layer of the Earth and in the atmospheres of giant planets. The results will be used to improve models predicting thermal convection in those situations.

All of the other experiment proposals will undergo further definition work.

European Physiology Modules (EPM)

Scientific objectives

Human physiology experiments in microgravity not only increase knowledge of how the human body reacts to long exposure weightlessness, but also contributes to a better understanding of Earth-related problems such as ageing processes, osteoporosis, balance disorders, biomedical research, cancer research and muscle wasting in limb immobilisation (casts) and bed-rest. Investigations have been conducted for many years and ESA has successfully flown facilities, such as Sled and Anthrorack on several Spacelab missions.

In order to evaluate the data collected onboard, it is essential that reference (or baseline) data be collected both before the mission and after the crew returns to Earth. For this purpose, EPM will provide a Baseline Data Collection (BDC) system that includes functional copies of the onboard instruments. The BDC will be easily transportable to ensure that the equipment is available at the crew location shortly before launch and immediately after landing.

NASA's Human Research Facility (HRF) will be similar to EPM. The first of two ISPRs will be launched early in the Space Station assembly sequence and the second somewhat later, although still well before Columbus. ESA and NASA plan to collocate EPM and HRF in Columbus, thereby allowing experiments using scientific instruments from both.

Facility description and operation

The multi-user EPM (Figure 10) consists of a complement of Science Modules (SMs) plus the Carrier infrastructure to support their coordinated operation. The Carrier provides data handling, thermal control and mechanical accommodation for the SMs. A maximum of nine active Science Modules can be accommodated at any one time, allowing for different Module sizes.

Figure 10. The European Physiology Modules multi-user facility. (ESA/D. Ducros)

The SMs are accommodated in standard drawers of sizes of 4 PU and 8 PU (1 PU = 4.45 cm). They interface with the rack via a standardised guide system that simplifies the on-orbit exchange and installation of new SMs. All rack-mounted SMs are cooled via a ducted air system provided as part of the Carrier.

EPM's modularity allows a very flexible configuration of SMs. Based on inputs from the Facility Science Team, it has been decided to include the following instruments in the initial configuration:

– *Multi-Electrode EEG Measurement Module (MEEMM)*
  MEEMM will be used for different types of non-invasive brain function investigations. During experiments, the test subject wears a cap equipped with up to 128 electrodes (Figure 11) connected to sensitive, low-noise electronics to measure the very small signals at very high sampling rates. In order to generate appropriate stimuli, different stressors can be used that are available onboard. Examples are the Virtual Environment Generator and muscle stimulators (associated with NASA's Human Research Facility). Together with EPM's ELITE-S2 module (see below), it will be possible to perform experiments that simultaneously measures brain activity and body movements. MEEMM also contains an ambulatory unit that will allow measurements to be made while the test subject is performing other activities or asleep. The data are recorded on a removable hard disk and later transferred to the EPM Data Management System to be sent to ground.

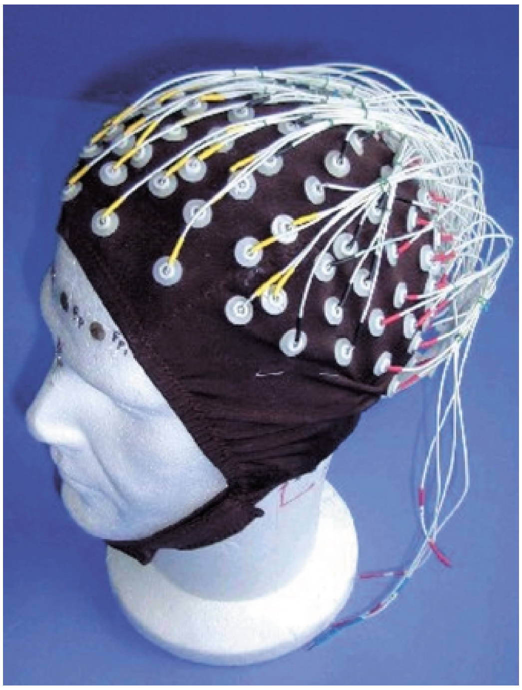


Figure 11. The EPM Multi-Electrode EEG Measurement Module cap. (ESA/EREMS)

– *Bone Analysis Module (BAM)*
  Bone loss is a severe problem in long-duration space flights. Understanding the related dynamics and developing effective countermeasures are important requirements for flying long missions. BAM will study the efficacy of various countermeasures by evaluating changes in the ultrasound transmission properties of the heel bone (Figure 12). BAM is based on a commercial system, where the foot is placed in an open water tank. This approach is unsuitable for space, so instead water-filled latex bags are placed on each side of the foot. A test campaign using the prototype and other bone densitometers on a large number of subjects will verify the new design.

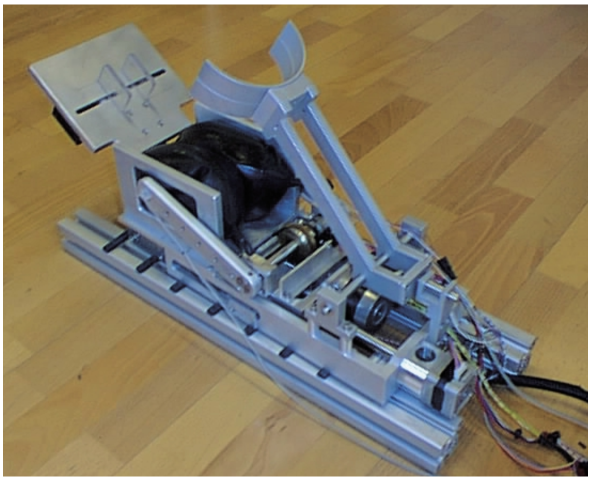


Figure 12. The breadboard model of EPM's Bone Analysis Module. (ESA/Innovision)

– *Sample Kit Drawer*
  This drawer will help the crew to take blood and urine samples. Most samples must be stored onboard in a controlled environment for later download to the ground for analysis. Limited analysis can also be performed onboard.

Apart from the above hardware being developed as part of the EPM contract, National Agencies will contribute the following instruments:

– *Cardiolab*
  Cardiolab (CNES and DLR) comprises different equipment supporting cardio-vascular research, e.g. electro-cardiogram and blood pressure holter, portable Doppler, air plethysmograph, cardiopres;

– *ELITE-S2*
  The 'Elaboratore Immagini Televisive–Space 2nd generation' ELITE-S2 (ASI and CNES) is a facility for the quantitative analysis of human kinematics in weightlessness. Four cameras mounted around the test subject record the movements. Special software detects sensor positions mounted on the

subject and from this recreates a 3D model that can be used to analyse the movement patterns in detail.

– *XSMI/PPMI*
The Xenon Skin Blood Flow Measurement Instrument (XSMI) and the Physiological Pressure Measurement Instrument (PPMI) (Danish space agency) are two small ambulatory instruments to measure skin blood flow and physiological pressures such as central venous and oesophageal pressures.

The EPM contribution to NASA's Human Research Facility
ESA is developing a number of instruments for contribution to NASA's HRF, thereby allowing their earlier in-orbit deployment than possible aboard Columbus. One is a collaboration with NASA to develop a Pulmonary Function System (PFS). This will consist of four building blocks, two provided by NASA (Gas Analyser System for Metabolic Analysis Physiology; Gas Distribution System) and two by ESA (Photoacoustic Analyser Module, PAM; Pulmonary Function Module). Together, these blocks will make up a highly flexible and sophisticated pulmonary and cardio-vascular research tool. PAM is based on a European niche technology and it will be reduced in volume compared with the earlier version (Figure 13). This development has helped the commercial application of this technology in hospitals.

Industrial organisation and development status
OHB (D) was awarded the prime contract in May 1999 for Phase-B/C/D; the industrial consortium is shown in Figure 4. For the EPM Contribution to the HRF-2, the prime contractor is Innovision (DK). EPM's Preliminary Design Review is planned by mid-2000. Breadboardings of MEEMI and BAM are underway. Delivery of the Flight Model is expected by mid-2002.

Experiments selected
One experiment selected for Definition from the 1998 International LSRA requests the use of PFS. Its objective is to evaluate cardiac fluid volume regulation. The 1999 LSRA is the first to include EPM's capabilities. Of the 43 proposals involving human research, there are 13 that could make use of the EPM and/or PFS instrumentation.

European Drawer Rack (EDR)
EDR is a multi-user facility (Figure 14) providing the infrastructure for accommodating and servicing experiment modules housed within Standard European Drawers (SEDs) and standard Shuttle-type Middeck Lockers (MDLs). It is a flexible experiment carrier since it is not dedicated to a specific discipline. EDR's main design drivers are modularity and standardisation. The use of standard drawers and lockers assure quick turnaround and thereby increased flight opportunities for the microgravity user community. Mission preparation activities are estimated to take 6 months. In particular, SEDs and MDLs can be exchanged in orbit.

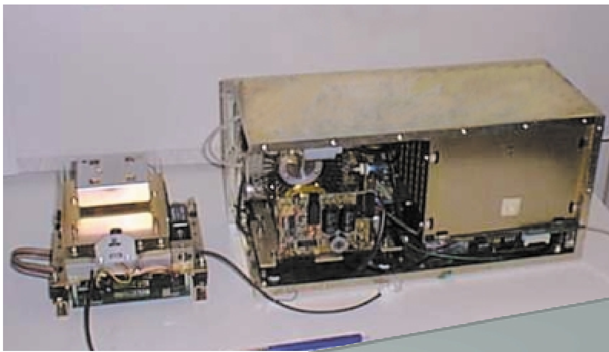


Figure 13. The Photoacoustic Analyser Module (PAM, left) for EPM. The earlier version is at right. (ESA/Innovision)

Figure 14. The European Drawer Rack multi-user facility, including the FAST and PCDF experiment modules. (ESA/D. Ducros)

Facility description and operation
EDR provides small and modular experiments in SEDs and MDLs with access to Columbus services. Its main features are shown in Table 1. A fundamental EDR goal is to support the development of smaller sub-rack payloads (Class-II) by providing accommodation resources and rapid-turnaround flight opportunities. EDR's design is oriented to maximise user-friendliness and flexibility of experiment accommodation and operation.

EDR's SED and MDL concept allows experiment module access to the EDR centralised services, ranging from the distribution of system resources (e.g. power, data, venting and cooling) to dynamic resource management (e.g. simultaneous access to system resources by more than one experiment module). EDR includes all the capabilities for monitoring and controlling the facility, its operations and resource usage envelopes, as well as the capability for operating the experiments. Its main subsystem functions are implemented in five units: Power; Thermal; Processing Control and Command; Video Management Units; Laptop. It supports simultaneous control of up to eight different experiments, i.e. one for each drawer and locker within the allowed resource budgets. EDR is reconfigurable in flight to allow the exchange of SED/MDL experiments on-orbit. It is designed to need only minimal crew intervention.

The SEDs are compatible with the International Subrack Interface Standard (ISIS). This ensures mechanical compatibility between the NASA Express Transport Rack (ETR) and EDR and, as such, allows rapid EDR payload turnaround by using ETR for EDR SED up/download. The Standard ISS Lockers (MDLs) are mechanically compatible with the ISS Shuttle Middeck interfaces and ETR. This allows rapid EDR experiment locker turnaround by using either the Shuttle or ETR for EDR MDL up/download.

Industrial organisation and development status
EDR completed Phase-B in July 1999 and Phase-C/D will begin in 2000. Some bread-boarding activities were completed during Phase-B. The industrial consortium is led by prime contractor Alenia Aerospazio (I); the industrial consortium is shown in Figure 4.

Experiments
A set of potential experiment modules for EDR accommodation has been identified:

- FAST (Facility for Adsorption and Surface Tension Studies) is an ESA multi-user facility that has already flown on the STS-95/Spacehab mission (October 1998). It is now undergoing refurbishment for flight on STS-107/Spacehab in March 2001 and is a candidate for reflight in EDR for long-duration experiments in Columbus. FAST is accommodated in two MDLs (Figure 14).

- PCDF (Protein Crystallisation Diagnostics Facility) is an ESA multi-user facility under development to provide in-depth knowledge and understanding of the protein crystal growth process under microgravity. PCDF crystal growth processing may use either batch or dialysis crystallisation. Protein crystal growth takes place in four reactors with the temperatures and temperature gradients of the protein solutions individually controlled. The built-in advanced diagnostics system allows the scientists to operate the experiments in a fully automatic mode (time-line and parameter controlled) or in a semi-automatic mode (telescience from ground).

The PCDF consists of two elements to be accommodated in EDR (Figure 14): the Process Unit (PU) and the Electronic Unit (EU). The PU accommodates the process chamber in which the four reactors are contained. The reactors contain the protein and salt solutions. The PU incorporates two temperature control layers. The EU accommodates the control circuitry for experiment execution and the PCDF diagnostics system, which incorporates a monochrome digital video camera with a wide field of view and microscope optics, the Dynamic Light Scattering (DLS) system and a Mach-Zehnder interferometer. For future applications, the PCDF can be expanded to support osmometry and pH measurement. The PU will be accommodated in the new ISS MDL, and the EU in a SED. For harvesting the protein crystals and reloading the protein and salt solutions on the ground, the complete PU has to be transported from/to Columbus within the Space Shuttle's middeck. This allows power provision to guarantee temperature control during transport, early access to the PU for protein crystal retrieval and late access for the PU installation in the middeck for uploading. This is mandatory, as proteins are sensitive and fast-deteriorating macromolecules.

PCDF is being developed under ESA's Microgravity Programme EMIR-2. The completed breadboarding has confirmed the design. The prime contractor is DASA/Dornier (D) with subcontractors Aerospatiale Matra Lanceurs (AML, F), Laben (I), Chevalier Photonics (B) and ALV (D).

European Stowage Rack (ESR)
ESR is a passive multi-user facility to allow

modular and standardised stowage of European payload support equipment and experiment samples within Columbus (Figure 15). It is based upon an enhanced ISPR structure with a number of inserts (shelves and dividers) that can be adjusted according to specific configuration requirements. These inserts enable optimal accommodation of standardised ISS Cargo Transport Bags (CTBs). During on-orbit operations, the CTBs may be removed from ESR and temporarily attached near to the payload racks where their contents are required. As a standardised ISS capability, CTBs are compatible with the NASA transport capabilities such as the Multi-Purpose Logistics Module (MPLM) Re-Supply Rack (RSR) and the Shuttle middeck provisions.

ESR's industrial organisation and its development status are the same as for EDR.

Materials Science Laboratory (MSL)

MSL is a follow-up to the version intended for the US Laboratory, allowing extensive reuse of hardware. The scientific objective is the study of thermodynamics and kinetics that control the delayed solidification of molten materials, as well as the measurement of physical properties in under-cooled melts.

Figure 15. The European Stowage Rack multi-user facility. (ESA/D. Ducros)

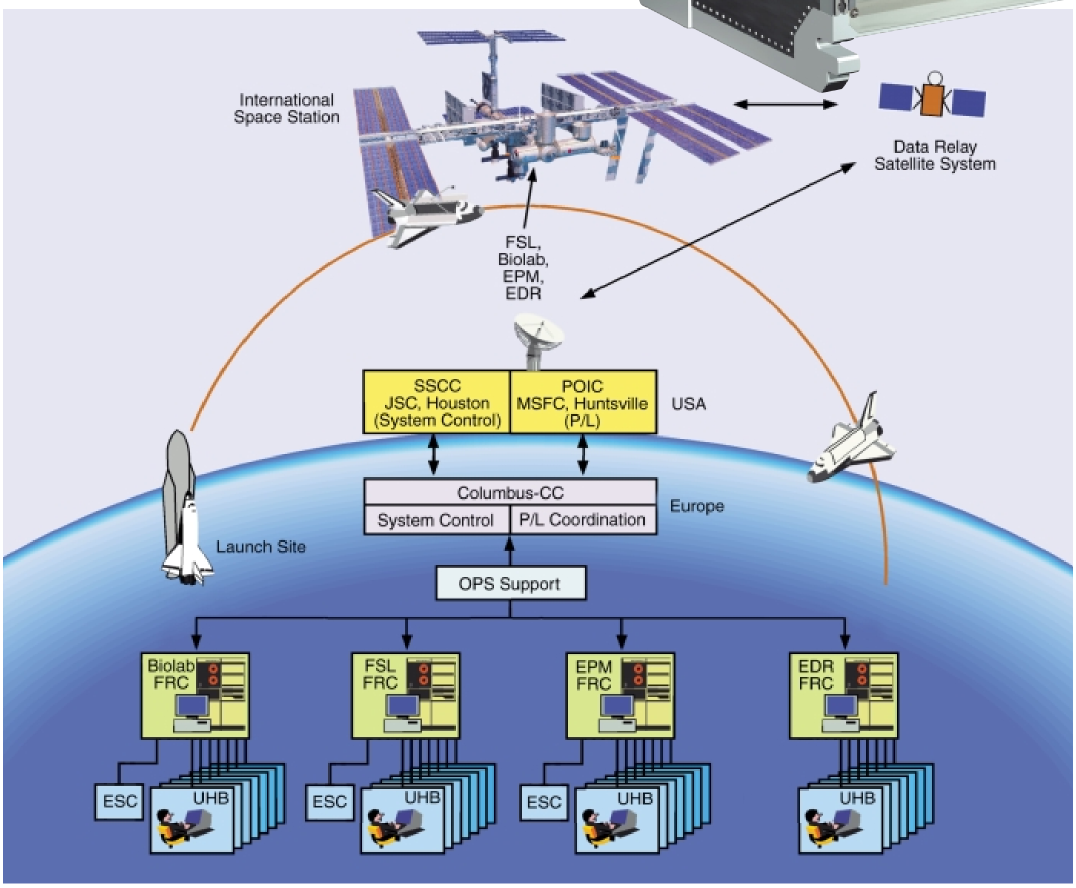


Figure 16. Operation of the Columbus multi-user facilities. CC: control centre. JSC: Johnson Space Center. MSFC: Marshall Space Flight Center. OPS: operations. P/L: payload. POIC: Payload Operation Integration Center. SSCC: Space Station Control Centre. Other acronyms are explained in the text

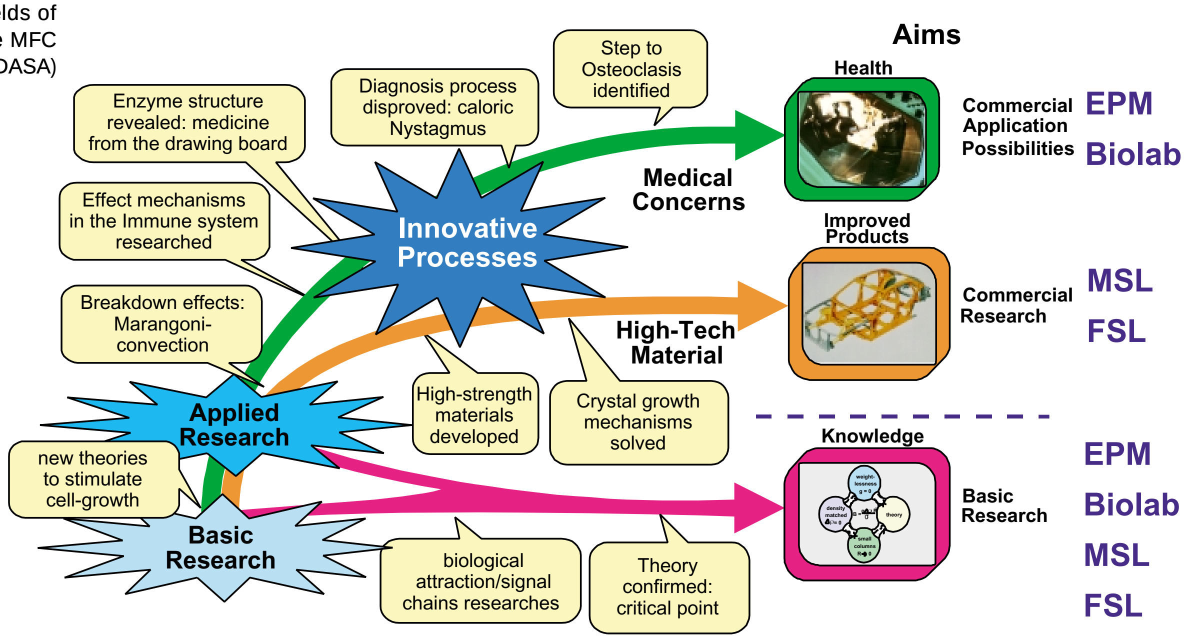


Figure 17. Possible fields of utilisation for the MFC facilities (ESA/DASA)

An industrial definition Phase-A/B is expected to begin in the second half of 2000. The start of Phase-C/D will be decided at the end of the definition phase.

Operation of the facilities

During development of the facilities, the science teams, user representatives (e.g. Facility Responsible Centres and User Operation Support Centres) and astronauts are helping to optimise the designs. At the end of the FSL, Biolab, EPM and EDR development phases, their final acceptance will take place using the Rack Level Test Facility (RLTF) to simulate the Columbus interfaces. Once Columbus is in orbit, this will be the only means of accepting payloads before uploading them to the Space Station.

Figure 16 shows a scenario for the scientific operation of the multi-user facilities aboard Columbus. Each laboratory will make use of a dedicated Facility Responsible Centre (FRC) that serves as the interface between all of the scientific users and the appropriate payload control centre. These FRCs will also prepare the timelining for the experiments and perform the first level of troubleshooting during operations. The prime contractor for each facility will support a second level of trouble-shooting and provide sustaining engineering support.

The following FRCs have been selected: MUSC (D) for Biolab, MARS (I) for FSL, CADMOS (F) for EPM and ESTEC (NL) for EDR. For some complex experiments, Experiment Support Centres (ESCs) will provide specific expertise in defined scientific fields. Some have already been identified: ETH (CH) for Biolab, DARIVA (E) for FSL and DAMEC (DK) for EPM.

Experiments may be executed from the User Home Bases (UHBs, primarily universities and research centres), with overall coordination by the FRC and, when required, by the ESCs. This decentralised payload processing is seen as the most efficient approach for implementation of Columbus utilisation.

Each mission increment will last 3-6 months and the selection of successive experiment complements will follow a similar schedule. The equipment required to conduct the experiments will be uploaded by the MPLM aboard the Space Shuttle.

Commercial use of the facilities

In view of the request by the ESA Council at Ministerial Level in 1999 to propose a scheme for commercialising the Space Station, the MFC Programme has completed a preliminary study with a consortium of MMS (F; Biolab), Alenia (I; FSL), DASA-RI/Dornier (D; MSL) and OHB (D; EPM) on defining a strategic plan for attracting commercial users. The goal of the study will be to generate income for ESA from conventional fields (such as R&D centres) and from 'unconventional' fields such as education. Possible fields of utilisation for the facilities are indicated in Figure 17. A follow-up phase will concentrate on some pathfinder projects to prove the effectiveness of the proposed plan with the identification of specific commercial customers.

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