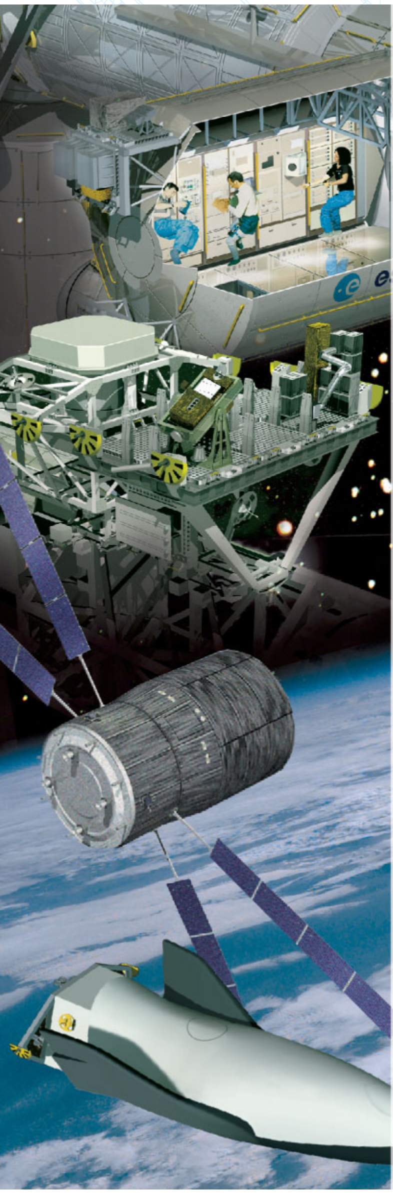
number 15, december 2003

on station

The Newsletter of the Directorate of Human Spaceflight http://www.esa.int/spaceflight



in this issue

European Space Agency
Agence spatiale européenne

Directorate of Human Spaceflight
Direction des Vols Habité

Time for Reflection

Jörg Feustel-Büechl
ESA Director of Human Spaceflight

The highly successful 'Cervantes' Spanish mission of Pedro Duque was flown in October, delivering the crew for ISS Expedition-8 (Michael Foale and Alexander Kaleri) and returning the Expedition-7 crew of Ed Lu and Yuri Malenchenko 10 days later. Pedro completed all of his 21 experiments flawlessly, which was particularly pleasing for the Spanish sponsors and also for the public visibility of human spaceflight in Spain. This was indeed an outstanding mission across all dimensions – the experiments, astronaut operations and public response.

We recently received some news that is disappointing for ESA. Our original information led us to believe that the Space Shuttle would return to flight by March 2004, but now we have learned that the target date has slipped to September/October 2004. It is expected that there will be nine Shuttle flights before our own Columbus module can be attached to the Station – a delay of as much as 2 years. That means a Columbus launch not in October 2004 but sometime around October 2006. This is much more than the 1-year delay envisaged soon after the Shuttle tragedy last February.

The ESA Council in October approved the proposal that we thoroughly review all the Human Spaceflight programmes in order to see how they could be rearranged in order to minimise the effects of the return-to-flight delay. Three major questions are guiding this review: what should we do with Columbus and the utilisation facilities during this delay; how do we keep our user community motivated as well as providing timely and concrete opportunities for them; and how do we proceed with the procurement of the Automated Transfer Vehicle (ATV)?

With respect to the first question, it is still open whether we store Columbus for 2 years after we complete it next Spring, or plan for something like upgrading or additional testing. As far as the user community is concerned, we are looking at adding interim utilisation opportunities such as Foton flights (two more were recently ordered), sounding rocket flights, drop-

André Kuipers (below left, with Mr Feustel-Büechl) will be the next ESA Astronaut to fly to the ISS, in April 2004. The mission name and logo were unveiled on 4 November at ESTEC: DELTA stands for 'Dutch Expedition for Life science, Technology and Atmospheric research'. It also refers to the Delta Works, the network of dykes and dams that protects the Netherlands province of Zeeland from flooding by the sea.

towers experiments, parabolic flights and the Russian segment of the ISS. It is clear that we have to do something to keep our users motivated and active with meaningful opportunities in the near future.

The third question is possibly the most difficult to answer because our obligation to the ISS Partners is to fly ATV only when Columbus is being prepared for launch or actually in orbit. We now have to decide whether we keep to our existing plan and fly the first one in the 2004-2005, followed by one or two more before Columbus reaches the Station, or do we put ATV follow-on flights on hold and wait until Columbus arrives? We are ready to fly ATV earlier than our obligation requires provided that NASA makes it clear they want to see it operational before Columbus. We are presently discussing the appropriate understanding with NASA.

We plan to answer these questions in time for the ESA Council Meeting of 17/18 December, which will decide on the financial participation of our Member States for all our Human Spaceflight programmes. We will then be able to see how we should reorganise our activities to cope with the delay.

ESA has not been passive while reviewing the 'Gehman report' on the *Columbia* accident. We are being pro-active in two directions. Firstly, we are checking whether we would pass the 'Gehman test': do we also have to change our *modus operandi* in human spaceflight in order to comply with the recommendations?

The second direction is more general for the Agency. The Director General has established a working group to look at the Gehman team recommendations with respect to ESA's overall activities. The 'better, faster, cheaper' approach is now being replaced by the 'smarter, stronger and safer' approach, so we need to consider if our approach is still valid under these new circumstances.

These working groups will report to the ESA Council and show if we have to adapt here and there or if we are in good shape with no changes necessary.

The planned Heads-of-Agency meeting in Moscow on 18 October did not take place because of illness. A major purpose of that meeting was to endorse the new schedule for the agreed Program Action Plan (PAP), so instead we expect to have a written consensus by the Heads very soon. I am confident that the PAP schedule will be extended to the end of 2004. This means we will have lost about a year in implementing it.

Pedro Duque completed a full series of experiments during his eight days aboard the ISS in October.

ISS Elements

As far as our ISS elements are concerned, Columbus is undergoing final integration so we have completed, more or less, its development. The Biolab, European Physiology Modules (EPM) and Fluid Science Laboratory (FSL) research facilities have all successfully undergone their Rack Level Test Facility (RLTF) checkout. The European Drawer Rack (EDR) will complete its RLTF test in December. Then these facilities can be integrated into Columbus for the full functional test of the overall system and its interaction with the European and US ground segments. In all probability, we will then store Columbus for some time before shipping it to the Kennedy Space Center for launch.

Although a highly complex vehicle, ATV is progressing well after passing its Critical Design Review in June. Nevertheless, we expect to have to do some additional work, particularly on the flight software, as well as accomodating a delay in delivering some equipment. As a consequence of the software delays, we expect a parallel slip in finishing the ground segment. We are assuming that the first ATV flight will slip beyond the original schedule.

Education

Some time ago, we established a Division to be responsible for education, and it has already produced excellent results. Important educational activities have been defined within the framework of ELIPS (European Programme for Life & Physical Sciences and Applications using the ISS). In August, we launched an educational fund where we are using some residual means left over from previous programmes. We are now looking towards industrial, institutional and individual contributions to this fund. Our goal is to enable us to comply with our promise of allocating 1% of European ISS resources to student and pupil experiments.

Furthermore, we are using our astronauts in promoting educational activities. For instance, Pedro Duque recently performed classroom-in-space experiments to demonstrate Newton's Laws to students and schoolchildren. André Kuipers on his Soyuz mission next April plans to add human physiology experiments. The idea is to build this classroom-in-space by each ESA astronaut contributing a different discipline, ultimately publishing them all on a CD-ROM for distribution to European schools. This should excite a general interest in space and help us to move towards the world's first knowledge-based society. This is a truly positive way of using our astronauts to revive the interest of young people in human spaceflight. ■

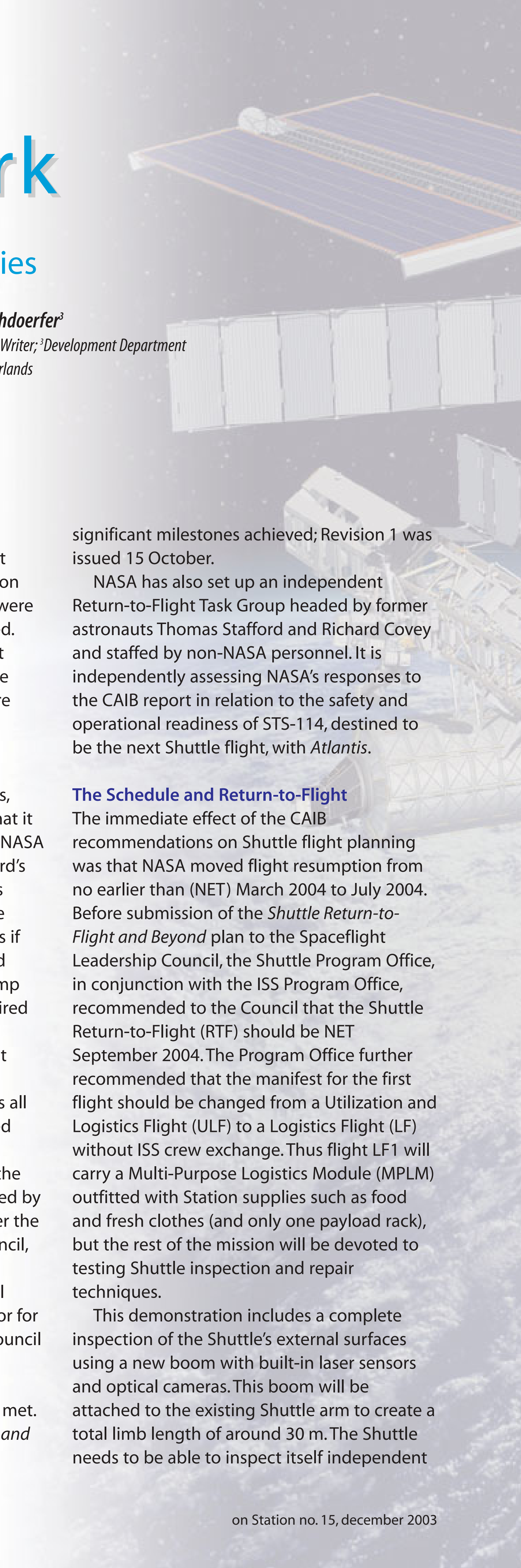
Two More Foton Missions

Mr. Feustel-Büechl (left) and Mr. V.I. Kozlov, Head of the Automatic Vehicle and Ground Control Department at Rosaviakosmos, conclude the signing of 'Mission Orders No. 6 and 7'.

The contract for two more Foton flights was signed at ESA's Moscow Office on 21 October. Following a year of extensive negotiations, the procurement is for 660 kg of ESA-supplied payloads aboard the Foton-M2 and -M3 missions in May 2005 and late 2006, respectively. This provides reflights of almost all the experiments lost in the Foton-M1 launch failure of 15 October 2002, and rescues a substantial part of the research lost in the *Columbia* tragedy.

The Foton-M2 payload will include experiments in fluid physics (FluidPac, Soret Coefficients in Crude Oil), exobiology (Biopan), material science experiments using Russia's Polizon DLR's Agat furnaces, a technology experiment (Favorite) and Autonomous experiments (Photo-II, Biofilter). Two experiments will be embedded in the capsule's heatshield: Keramik (reentry technology) and Stone (simulated meteorite). Foton-M3 will carry experiments in biology (Biobox, Kubik, Eristo/Osteo), exobiology (Biopan), fluid physics (SCCO, Gradflex), protein crystallisation, material science (Polizon), reentry technology (YES-2), plus other Autonomous experiments.

The ESA Payload Safety Review Panel, established in cooperation with NASA in 2002, met in September at ESTEC for a Training Workshop. October's 'Cervantes' mission was the first to carry ESA-certified payloads to the ISS.



Return to Work

The Path to Resuming Full ISS Activities

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Introduction

When the report of the Columbia Accident Investigation Board (CAIB) was published on 26 August 2003, its 29 recommendations were far more than expected. Fifteen have to be met before the next Shuttle flight, while the rest are longer term recommendations on the way that NASA works. Although the CAIB could only recommend and not set firm requirements, NASA nevertheless immediately agreed that it would implement everything. In addition, NASA declared that it would go beyond the Board's safety recommendations. For example, it is looking at how the Space Station could be used as a safe haven for Shuttle astronauts if on-orbit inspection of the Orbiter revealed serious damage. The astronauts would camp aboard the ISS while the Shuttle was repaired or a rescue Orbiter arrived.

The consequences for ESA and the ISS of Columbia's loss are now coming into clearer focus ...

On 8 September, NASA released the first version of its implementation plan *Shuttle Return-to-Flight and Beyond*. This addresses all the CAIB recommendations and elaborated who is responsible within the agency for satisfying each one, what is required and the schedule. The document has been endorsed by the NASA Administrator but remains under the control of the Spaceflight Leadership Council, chaired by William Readdy (Associate Administrator for Spaceflight) and Michael Greenfield (Associate Deputy Administrator for Technical Programs). This internal NASA council is tracking the implementation of all the recommendations, and has to provide a statement that the intent of each is being met.

Future issues of *Shuttle Return-to-Flight and Beyond* will document the progress and significant milestones achieved; Revision 1 was issued 15 October.

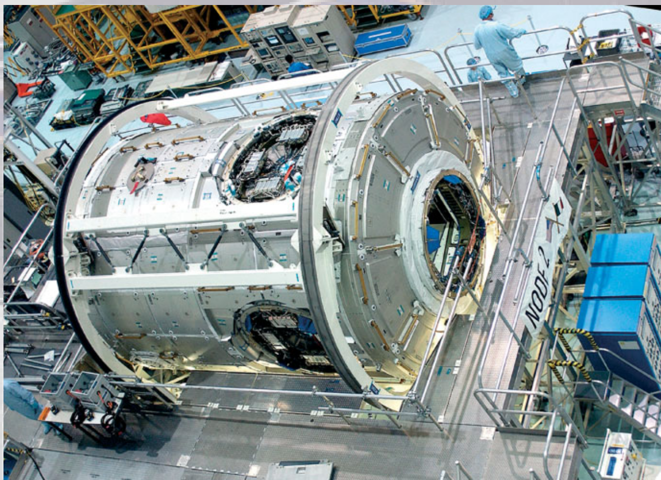
NASA has also set up an independent Return-to-Flight Task Group headed by former astronauts Thomas Stafford and Richard Covey and staffed by non-NASA personnel. It is independently assessing NASA's responses to the CAIB report in relation to the safety and operational readiness of STS-114, destined to be the next Shuttle flight, with *Atlantis*.

The Schedule and Return-to-Flight

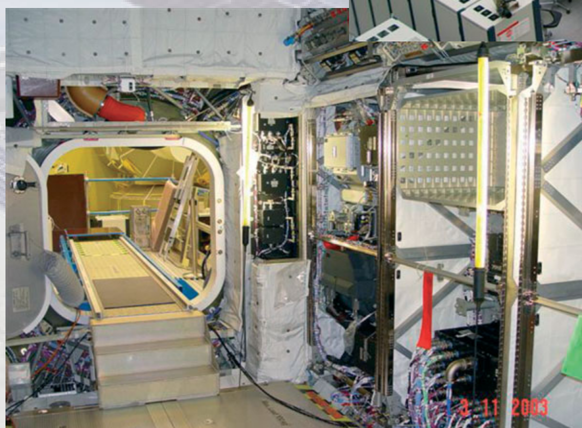
The immediate effect of the CAIB recommendations on Shuttle flight planning was that NASA moved flight resumption from no earlier than (NET) March 2004 to July 2004. Before submission of the *Shuttle Return-to-Flight and Beyond* plan to the Spaceflight Leadership Council, the Shuttle Program Office, in conjunction with the ISS Program Office, recommended to the Council that the Shuttle Return-to-Flight (RTF) should be NET September 2004. The Program Office further recommended that the manifest for the first flight should be changed from a Utilization and Logistics Flight (ULF) to a Logistics Flight (LF) without ISS crew exchange. Thus flight LF1 will carry a Multi-Purpose Logistics Module (MPLM) outfitted with Station supplies such as food and fresh clothes (and only one payload rack), but the rest of the mission will be devoted to testing Shuttle inspection and repair techniques.

This demonstration includes a complete inspection of the Shuttle's external surfaces using a new boom with built-in laser sensors and optical cameras. This boom will be attached to the existing Shuttle arm to create a total limb length of around 30 m. The Shuttle needs to be able to inspect itself independent

Most of ESA's hardware and software contributions to the ISS are progressing as planned before the loss of *Columbia*. The following pages highlight recent activities.



The European-built Node-2 in the Space Station Processing Facility at the Kennedy Space Center. (NASA)



André Kuipers training for his flight to the ISS in April 2004.

Columbus under integration and test at EADS in Bremen (D).

The Columbus trainer at the European Astronaut Centre, Cologne (D).

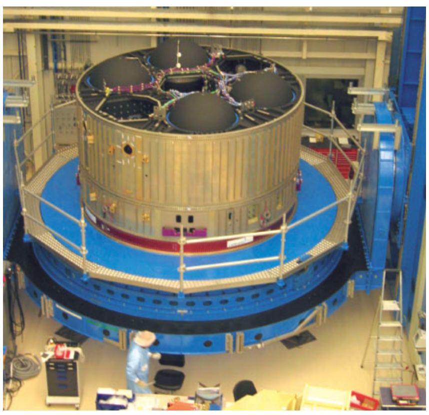
Pressure-testing the Cupola.

The Interconnected Ground System (IGS) node at NASA Marshall will relay the Columbus science data to Europe.

Pedro Duque working with the Microgravity Science Glovebox aboard the ISS.

The Protein Crystallisation Diagnostics Facility (PCDF), engineering model.

Materials Science Laboratory: the vacuum gas subsystem.

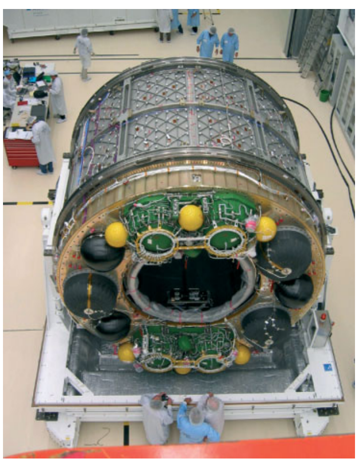


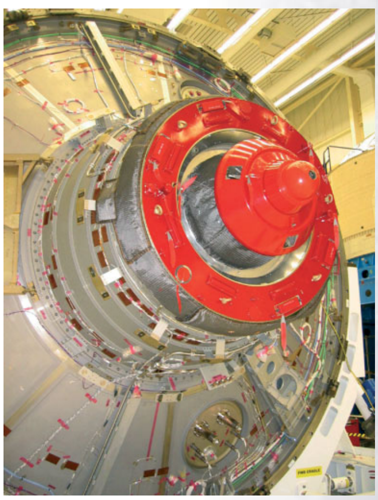
The ATV avionics section.

Simulation of astronaut monitoring of ATV docking with the ISS.

The ATV Control Centre, Toulouse (F).

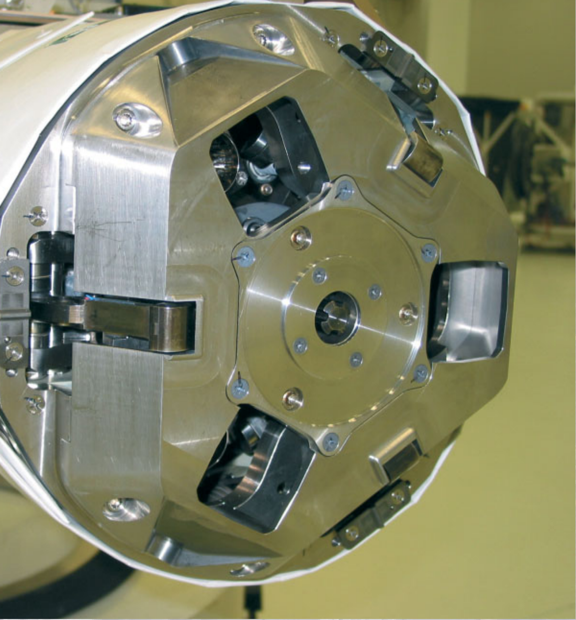
The ATV Integrated Cargo Carrier.





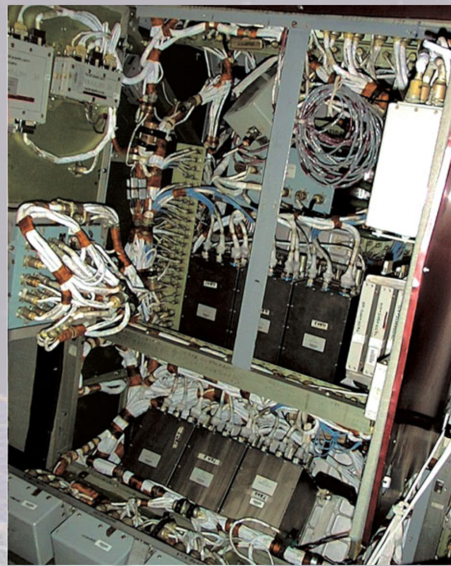
The ATV forward section, with the docking unit.

Installation of the ATV control room in Toulouse.

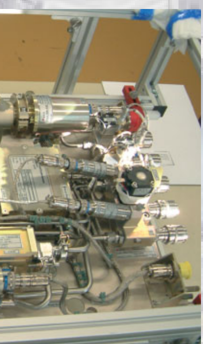


The business end of the European Robotic Arm.

MELFI (Minus Eighty-degree Laboratory Freezer for the ISS) is at the Kennedy Space Center ready for launch.

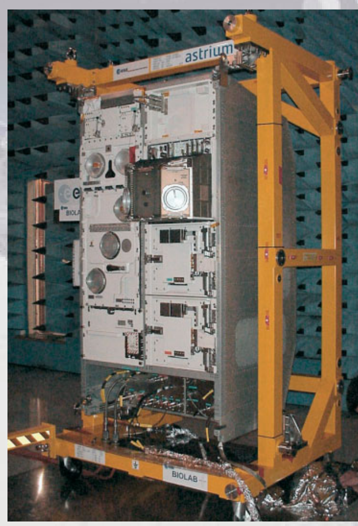


The DMS-R data management system has worked almost perfectly aboard Zvezda since launch in July 2000.

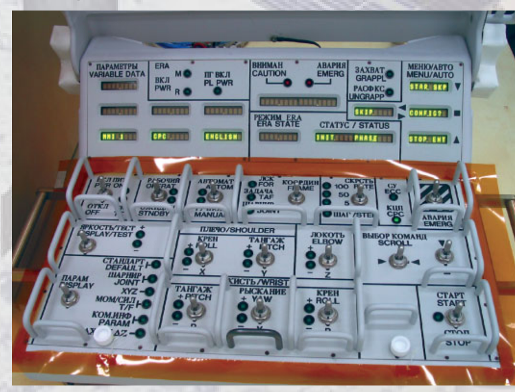


The European Drawer Rack (EDR).

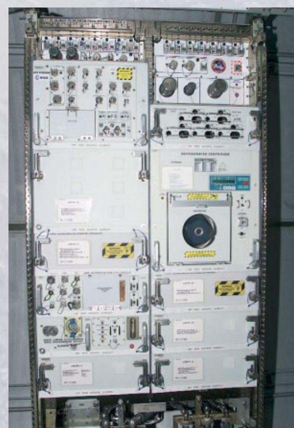
The European Physiology Modules (EPM) rack.



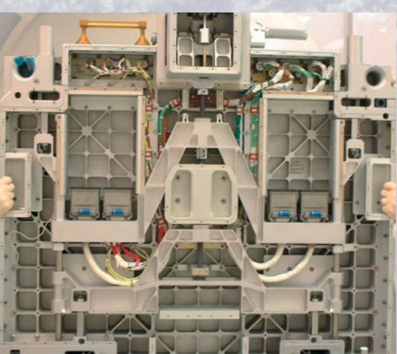
Biolab during electromagnetic testing at Intespace (F).



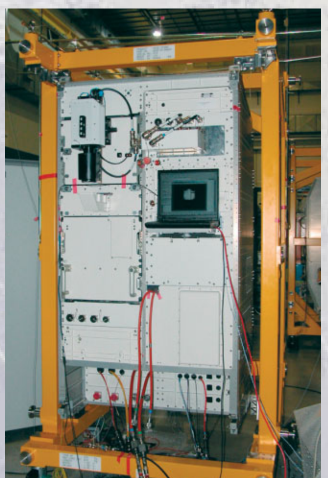
The spacewalker's control panel for ERA.



The HRF-2 Human Research Facility, with ESA's Pulmonary Function System (PFS) at top left.



The Columbus External Payload Adapter (CEPA).



The Fluid Science Laboratory (FSL).

The Matroshka life sciences phantom was delivered to Russia in November for launch to the ISS by a Progress unmanned ferry in January 2004.

of ISS help because there will still be occasional non-Station flights such as the Hubble Space Telescope servicing missions. On the first RTF mission, this demonstration is planned for flight day 2, before docking with the ISS. Upon arrival at the Station, the Orbiter will pirouette so that the Station's own arm can survey its exterior.

Although designing the boom is not considered to be a big problem, controlling it from the Shuttle mid-deck will be very difficult because it greatly extends the Shuttle arm that already has 7 degrees-of-freedom. Creating the software for controlling the boom is expected to be taxing.

After docking and unloading the supplies, two or three EVAs within the Shuttle payload bay will test the new repair methods devised for the Shuttle thermal tiles and, potentially, the wings' Reinforced Carbon-Carbon (RCC) leading edges. The RCC panels are long-lead items, so one might not be available for this demonstration. There are 22 unique panels in each wing and their repair is expected to be extremely difficult to achieve in space. Each has to remain not only aerodynamic but also provide thermal protection.

LF-1 will be followed by the new ULF1.1 mission to ferry further supplies and to restart ISS utilisation activities, using MELFI (Minus Eighty-degree Laboratory Freezer for the ISS), WORF (Window Observational Research Facility) and either HRF-2/PFS (Human Research Facility/Pulmonary Function System) or EMCS (European Modular Cultivation System; see article in this issue). On-orbit testing of thermal protection repairs will continue.

Return-to-Flight thus requires two qualification flights before the Shuttle can resume normal service. After them, the ISS Assembly sequence will pick up with mission 12A (NET February 2005) and then 12A.1 (NET April 2005). 12A will upload the Station's P3/P4 solar array truss assemblies and 12A.1 the P5 truss and more Station logistics.

The most obvious impact of the Shuttle fleet's grounding is the delay to the Columbus launch. This will be affected by the new ULF1.1 mission as well as the grounding period. Columbus may be delayed even more in the assembly sequence because new logistics missions might be necessary. Each Shuttle will lose about 1500 kg in cargo capacity in order to carry the arm/boom. The repair kits may cost a further 500 kg. Also, previous manifests included margins that would be allocated to payloads at a late stage in planning, but these margins will now be held in reserve in case additional repair or inspection hardware is required at short notice. ESA hopes to make an important contribution to solving this logistics problem with its Automated Transfer Vehicle (ATV).

A further restriction is that the reduced flexibility provided by a fleet of only three Shuttles will significantly affect the assembly sequence. For example, each Orbiter needs regular servicing and one is required for the Hubble Space Telescope servicing mission in 2005 before Columbus can fly.

So it looks as though Columbus can expect a 2-year delay unless – and ESA is pushing NASA hard on this – it is brought forward in the sequence. Columbus availability would boost utilisation not only in terms of new facilities (Biolab, FSL, EPM, EDR) but also cooperative science with NASA in the form of substantially extended accommodation resources for payloads and stowage.

ESA has set up a working group to look at the technical and financial aspects of a 2-year delay. Some internal replanning is now required for our Station elements and, just as importantly, what the delays means to the user community and how we can keep it active and interested in the ISS for two more years. Unfortunately, this is happening at the end of Columbus development, when ESA no longer has all the financial resources to sustain the industrial teams until the operational phase begins. We therefore have to find innovative ways of keeping the teams together and the user community interested. This exercise has only just started, and it will be some time before it shows the way to go.

The intention is to look at the amount of 'integrated' money that is already available in the Human Spaceflight programme for Exploitation, for ELIPS (European Programme for Life and Physical Sciences and Applications utilising the ISS), and left over from ISS development and so on, to see exactly what is available and how can it best be reallocated over the 2-year delay.

The largest amount of money available is currently planned for the Exploitation phase, which includes the procurement of ATVs and their Ariane-5s. There is now a tactical question as to whether it is wise to continue with these procurements or to redirect those resources to keep industry going.

An internal MSM group has been set up to decide by the end of November what to do in time for the December meeting of the ESA Council.

ESA Standards

The CAIB Report, although it is directed only towards NASA and the Shuttle programme, may contain recommendations that could and should be applied to our activities. There are two types of recommendations in the report: purely technical (related to making the Shuttle a safer piece of engineering), and the cultural and organisational (related to improving the way that NASA does business). These latter recommendations could be applicable to the way in which MSM in particular and ESA in general do business.

Two ESA internal working groups have been established by the Director-General: one is looking at human spaceflight programmes, and the second at all other ESA programmes. They must report back to the ESA Management Board with recommendations in early December. Within this framework, we also plan to assess whether our ESA standards and approaches pass what has become known as the 'Gehman test' (after CAIB Chairman, Harold Gehman): are we really operating according to the European Cooperation for Space Standardisation (ECSS) and the ESA management manuals, and do all these really satisfy the CAIB recommendations? This is clearly no simple task and requires significant effort to see if our way of doing business is appropriate and, if not, to show what needs to be done.

Program Action Plan

It should not be forgotten that there is as yet no real stability in the Return-to-Flight planning. The first flight is slipping faster than normal time. It is important for MSM to identify all the issues that need to be addressed so that, when some stability does return, ESA can move ahead with activities leading to a successful Columbus launch.

The Heads of Agency Program Action Plan (PAP), which defines the approach for achieving ISS crews 6-7 strong some 2 years after Columbus arrives, is clearly being affected. The PAP schedule is currently being agreed upon. Implementation of the Plan is delayed by about a year but that still requires a certain stability in the Station assembly sequence. An updated PAP with intermediate milestones is planned to be released in mid-2004. Then, in the following 6 months, negotiations and bartering will take place to see who-provides-what. So it will be at least the end of 2004 before an agreed PAP is available. This should embrace the CAIB recommendations and so provide some much-needed stability in our way forward.

The first joint Columbus Control Centre simulation with NASA, in September 2003.

The Aurora Programme

A Stepping-Stone Path for Humans to Mars

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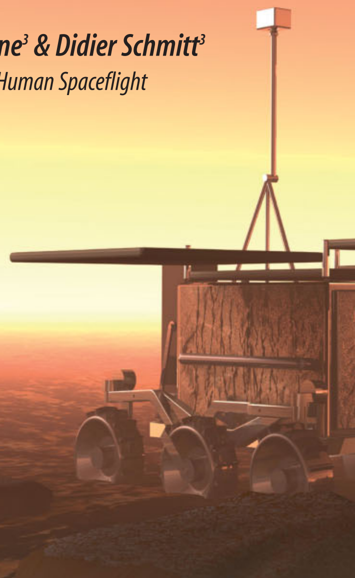


Introduction

The ambitious goal of ESA's Aurora programme is to prepare Europe for the next step in the human exploration of our Solar System: exploration beyond low Earth orbit. Created in early 2001 as a joint initiative of several ESA Directorates, Aurora was approved by all Member States and Canada as an Optional Programme at the Edinburgh Council at Ministerial Level in November 2001. At the same time, a 3-year preparatory period (2002-2004) was subscribed to by A, B, CDN, CH, E, F, I, NL, P & UK.

Aurora has identified a thrilling goal: Europeans on Mars by 2030 ...

With its vision of long-term human exploration and a coherent programme of missions to prepare the technology and support infrastructures, Aurora is of special interest to the Directorate of Human Spaceflight.

Programmatics

Aurora was approved as an envelope Optional Programme, with budgets extending over 5-year periods. The present preparatory period is focused on defining a long-term vision for human exploration (The European Framework for Exploration) and on preparing a new Programme Proposal to be submitted for approval at the next Ministerial Council, now expected to take place in early 2005. This Programme Proposal will cover activities over 2005-2009, defining in detail the technical content, the planning and the financial budgets for the first full period of Aurora.

A team was created in 2001 drawing on ESA's Directorates of Industrial Matters and Technology (D/IMT), Human Spaceflight (D/MSM), Science (D/SCI), Strategic & External Relations (D/SER) and Technical & Operational Support (D/TOS) under the responsibility of D/SER. The team's composition reflects Aurora's multidisciplinary aspects, with the ambition of combining human exploration with the build-up of the required knowledge and expertise via robotic missions. The programme consequently includes early developments in life support, understanding human physiology, ISS applications and other ambitious technologies dedicated to exploration.

Aurora's content has been defined over the last 2 years, built on a large foundation of scientific and technical expertise, with regular calls for ideas and continual consultation with a network of university and research institutes. In this sense, Aurora has established a solid and lasting synergy with the European Programme for Life & Physical Sciences (ELIPS) in human physiology and, particularly, in the development of the Pasteur payload of exobiology instruments.

The Executive is supported by the Exploration Programme Advisory Committee (EPAC), which includes equal proportions of science and technology experts from industry

and universities, plus there is a representative of ESA's Astronauts Corps. The EPAC activities are reinforced by regular Working Meetings involving large numbers of academic, scientific and technical experts from Europe and Canada. The Programme reports to the Aurora Board of Participants (ABP).

European Framework for Exploration

Fleshing out the European Framework for Exploration (EFE) is a major effort of this preparatory period. The EFE provides the vision and objectives, outlining a roadmap for exploring the Solar System. A major step is assessing the suitability of Mars for long-term human presence: habitability, resources and engineering constraints. In the longer term, and in line with the approaches of other Agencies, an international human mission to Mars may become a reality around 2030. Aurora would prepare for this mission and identify a strategic role for Europe. Following intensive consultation with EPAC, the European prime contractors and two Working Meetings, the objectives for this first mission to Mars were proposed as:

Primary objectives
- land a crew on Mars by 2030 and return them safely, ensuring planetary protection for both Earth and Mars;
- demonstrate human capabilities needed to support human presence on Mars;
- explore and expand scientific knowledge, taking maximum advantage of human presence, including sample selection.

Secondary objectives
- assess suitability of Mars for long-term human presence (habitability, resources, engineering constraints);
- motivate a new generation through outreach and educational activities.

The work so far has defined the knowledge required for such a mission. We have also identified the capabilities needed for the longer-term objectives.

Required Knowledge

The mission objectives and today's available knowledge lead us to concentrate on:

- existence of life forms on Mars;
- effects of radiation on humans;
- medical and physiological aspects;
- psychological reactions;
- on-orbit/surface radiation environment;
- martian soil properties;
- martian atmosphere properties.

The effects of long-term space travel on humans will be studied on the International Space Station (ISS) and in dedicated ground simulations. To acquire the necessary knowledge of Mars, we need a number of *in situ* experiments. These activities will be included in the Aurora Research Roadmap of EFE.

Required Capabilities

Some important capabilities for long-term human missions away from planet Earth are:

- assembly in orbit;
- advanced interplanetary propulsion;
- lightweight habitats;
- life-support systems;
- aerocapture/aerobraking;
- surface EVA suit;

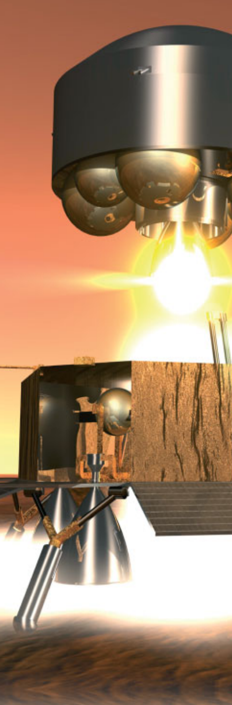
– surface mobility;
– nuclear power on Mars;
– *in situ* resource utilisation (ISRU);
– nuclear electric propulsion.

The activities to build up these capabilities will be included in the Aurora Technology Roadmap of the EFE.

The ExoMars spacecraft approaches the planet.

It is already clear from this short list that Europe cannot shoulder all this research and technology work alone. We believe, however, that it is important to understand the totality of what is needed before we can define priorities and enter into discussions on international cooperation.

Aurora missions are motivated either by the acquisition of knowledge and/or by the demonstration of capabilities. The research and technology roadmaps enable us to define an Aurora Mission Roadmap of robotic and human missions to prepare for the first human mission to Mars in 2030. This route is at one end determined by our present knowledge and capabilities, and at the other by the knowledge and capabilities needed for the first human mission. Although we are still working on the detailed definition of that mission and associated precursor missions, we have a fairly good understanding of our present capabilities and knowledge. So the major components of a near-term mission scenario have been identified with the EPAC and ABP. Preliminary priorities for work on technologies have also been defined and will be further discussed with industry. Finally, human mission studies will allow us to define more clearly how the present know-how and capabilities in the Space Station programme can be developed towards Aurora's goals.



Robotic Mission Studies

The mission scenario includes major (Flagship) missions plus small technology (Arrow) missions of lower cost and short development time, mostly in support of Flagship missions.

ExoMars Mission (Flagship)

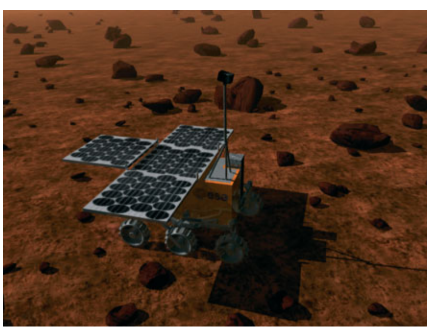
This first mission reflects the importance of resolving if there is life on Mars. The main objectives are:

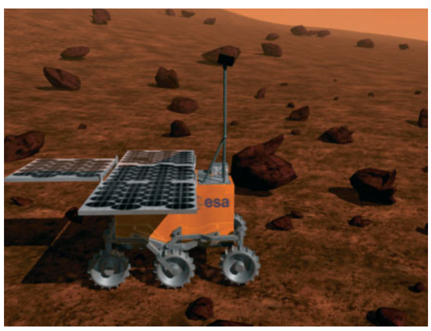
Knowledge objectives
– search for signs of past and present life;
– identification and characterisation of potential hazards to humans;
– improving knowledge of the martian environment.

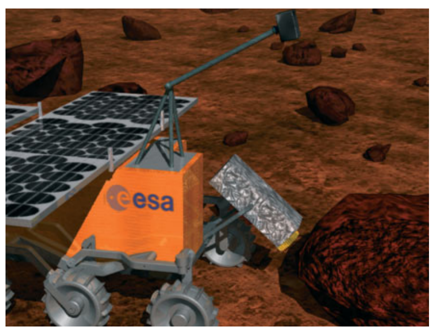
Capabilities objectives
– landing of large payloads on Mars;
– Mars surface mobility;
– rendezvous in Mars orbit;
– forward planetary protection;
– solar electric power on the surface of Mars.

ExoMars aims for launch in 2009. After releasing the descent module into a hyperbolic entry trajectory, the main craft will enter Mars orbit as a data relay satellite. Using an inflatable braking device or a parachute system, the descent module will deliver a large (200 kg)

The ExoMars rover in 2009 would pave the way for the sample return mission in 2011.







rover to the surface. The autonomous rover, powered by conventional solar arrays, will spend several months exploring the hostile terrain. The 40 kg payload (named Pasteur, after the French microbiologist) will include a drill and sampling/handling device to analyse soil from sites that may be hospitable to primitive life forms.

The rover navigation system (including optical sensors, onboard software and autonomous operations) and the life-detecting payload will be significant technological challenges for European and Canadian industries. Testing the rendezvous and docking techniques on ExoMars will prepare the way for the second mission, the Mars Sample Return.

The ascent stage of the Mars Sample Return Mission lifts off with its precious cargo.

A recent Call for Ideas for Pasteur experiments has attracted a very large response: more than 580 investigators from 30 countries want to participate in the mission.

Mars Sample Return Mission (Flagship)

This second mission follows essentially the same goals as the first:

Knowledge objectives
- search for signs of life;
- perform geological/mineralogical analyses on samples of martian soil;
- perform analyses of samples of martian atmosphere;
- identify and characterise potential hazards for humans.

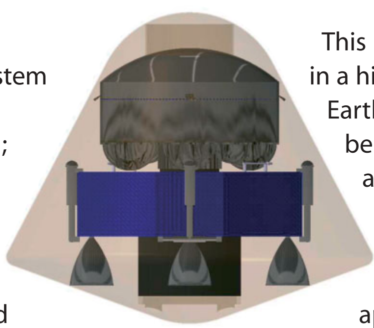
Capabilities objectives
- entry, descent and landing system validation;
- Mars ascent vehicle validation;
- sampling of atmosphere, top and deep soil;
- forward and backward planetary protection;
- operational aspects of a round trip to Mars.

Planned for launch in 2011, this mission will bring back the first sample of martian soil for analysis in laboratories on Earth. After braking into Mars orbit, a descent module will land. A robotic drill will collect a soil sample and place it inside a small canister on the ascent vehicle. This will then lift off and rendezvous with the parent craft in orbit. An Earth return vehicle will bring back the capsule straight into our atmosphere. Slowed by a parachute or inflatable device, it will make a fairly gentle touchdown before transfer into a planetary protection facility.

Entry Vehicle Demonstrator (Arrow)

A critical assessment of the capabilities needed for the sample return mission shows that Europe has never performed the 12.1 km/s reentry required for a vehicle returning from Mars. A dedicated Arrow mission must:

- validate the robust design of a reentry capsule;
- demonstrate high-speed reentry technology;
- demonstrate that planetary protection aspects can be fulfilled;
- validate operational aspects of sample retrieval.



The descent module of the Mars Sample Return Mission.

This mission will place a small craft in a highly elliptical orbit around the Earth. The reentry vehicle will then be accelerated into the atmosphere to test its heatshield and other technologies under Mars-return conditions. Since planetary protection rules apply in case of failure – such as the parachute not opening – we have to allow for a crash landing. The capsule must guarantee the structural integrity of the sample container even for the most serious failures.

Aurora: First Contracts

A milestone was reached on 29 September 2003 with the announcement of the winners of competitive contracts for ExoMars and the Entry Vehicle Demonstrator studies. Three industrial teams were selected to carry out Phase A full mission designs for ExoMars under 10-month €600k contracts:
- Alenia Spazio (I), with subcontractors OHB (D), GMV (E), SEA (UK), SSC (UK) and Laben (I);
- Alcatel Space (F), with subcontractors Deimos (E), ETCA (B), Fluid Gravity Engineering (UK), Kayser Threde (D), Laben (I), MD Robotics (CND), NGC Aerospatiale (CND), QinetiQ (UK) and Vorticity (UK).;
- EADS Astrium (F), with subcontractors Astrium Ltd (UK), EADS LV (F) and SAS (B).

Two teams were selected for the parallel EVD mission pre-Phase A 5-month €150k studies. The concept presented under the leadership of EADS Launch Vehicles (F), with OHB System (D) and Plansee (A) is solidly based on the experience of past projects. The team headed by SSTL (UK), with Fluid Gravity Engineering (UK), Kayser-Threde GmbH (D) and Vorticity Ltd (UK), has devised a highly innovative concept well adapted for a small technology mission.

Industrial proposals were submitted on 1 August for two €600k Phase A studies of the Mars Sample Return Mission. The winners were announced in October:
- Astrium Ltd (UK), with subcontractors EADS ST (F), Astrium SAS (F), Galileo Avionica (I), RAL (UK), SAS (B), SENER (E) and Utopia Consultancies (D);
- Alenia (I) with subcontractors Alcatel (F), ELV (I), MDR (CND), Dutch Space (NL) and SENER (E).

The Franco-Italian 'Concordia' Antarctic station is testing technologies such as life-support elements and performing scientific research to prepare the human aspects of future Mars missions. Further information can be found on the Aurora website.

Mars Aerocapture Demonstrator (Arrow)
Aerocapture slows a spacecraft through friction in a planet's atmosphere in order to establish a stable orbit. By avoiding onboard propulsion, the spacecraft can be considerably smaller and cheaper. Aerocapture has enormous potential for the large human missions – it may even be an enabling technology. Aurora therefore proposes this small mission to validate the technology at Mars before it is applied to larger, more ambitious Flagship missions and, eventually, to a manned expedition.

ESTEC's Concurrent Design Facility allows the rapid design of pre-Phase A missions.

Research and Technology

Technology activities within the first full period of 2005-2009 are divided into two groups. The mission-specific technology work will advance the technology needed for the first missions to a degree of maturity to allow the start of phases B/C/D. In the second group, we are looking for new promising approaches, which may offer advantages for later missions. These research activities will concentrate on the effects of long-term space travel on humans, because the missions already cover research into the Mars environment. Physiological studies in Earth orbit continue to provide direct experience with the effects of microgravity. However, because flight opportunities are still scarce and operational restrictions often influence the experiments, ground-based simulations (like bedrest research) will continue to play an important role, especially for evaluating new countermeasure. On a Mars mission, in-flight psychological support will be very limited, so crew selection and training in stress-management skills will be of major importance.

Human Mission Studies

Early human mission studies have been performed under ESA's General Studies Programme, with European companies making a series of parametric studies to identify the most critical areas of human missions to Mars. For example, using cryogenic propulsion for Earth-Mars injection and aerocapture at Mars could significantly reduce the mass to be lifted into Earth orbit.

In order to perform systematic architecture trade studies and preliminary human mission designs, the capabilities of ESTEC's Concurrent Design Facility have been extended with the help of D/MSM experts to deal with human missions. This capability is presently being used on a preliminary architecture for the conceptual design of Mars mission elements such as the Interplanetary Habitation Module. Progressively, other elements will be studied. Once the complete architecture is defined, trade studies will create a reference architecture. Later work will define the developments needed to advance today's Space Station expertise – such as Columbus and the Automated Transfer vehicle – towards the reference architecture.

Conclusions

The Aurora Programme is now in its second year, aiming to consolidate a long-term vision of human exploration while preparing for the robotic exploration missions, the technology and the required know-how in human physiology and life support. It is building on the experience acquired via the Space Station and prepares for the post-ISS era. ■

Further information on Aurora can be found at:
www.esa.int/aurora

ESA and the Human Research Facility

Studying Human Adaptation to Spaceflight

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Introduction

Since 1990, the International Space Life Sciences Working Group has coordinated international cooperation in space life sciences. The participating space agencies are NASA, ESA, CNES, DLR, CSA (Canada), JAXA (Japan) and NSAU (Ukraine). A guiding principle is to optimise the use of scarce resources by avoiding duplication of equipment and sharing hardware and flight opportunities. It is within this context that ESA is developing the European Physiology Modules (EPM) facility and contributing several elements to NASA's Human Research Facility.

ESA is making major contributions to life sciences research aboard the ISS ...

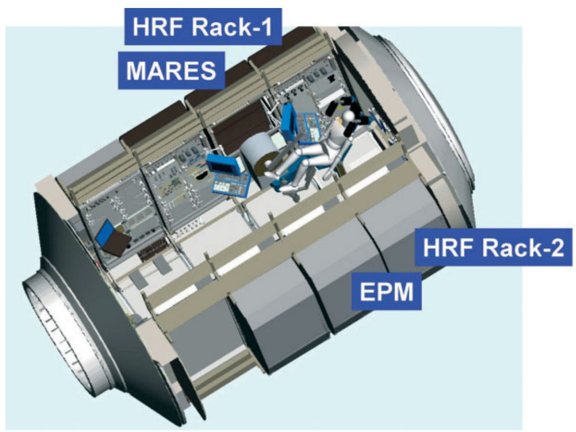
The Human Research Facility

The Human Research Facility (HRF) supports life sciences research aboard the ISS into the physiological and psychological changes in humans arising from spaceflight and the microgravity environment. Investigations are of two broad types:

- basic research that uses microgravity to address fundamental scientific questions of human physiology. The knowledge can help to solve medical problems on Earth.
- operational research aiming to solve problems of human adaptation to spaceflight. The results will help to improve countermeasures for astronauts during long flights.

HRF is a complete medical research platform, offering ultrasound imaging, pulmonary function analysis, body-mass measurement, advanced eye-tracking, a muscular atrophy research system, centrifuging of refrigerated bio-samples, etc.

Instruments are accommodated in three HRF racks, plus other equipment is stowed elsewhere. HRF-1 has been operating in NASA's Destiny module since March 2001 with exclusively US research equipment. HRF-2 will begin testing next February inside Columbus at the EADS site in Bremen (D) to ensure smooth installation in orbit. The racks will eventually be collocated in Columbus close to the EPM rack in order to optimise the life sciences research. Investigators will also have access to NASA's Crew Health Care System (CheCS). For example, the ergometer and treadmill were developed to counteract the long-term effects of weightlessness, but can also be used for HRF exercise experiments.



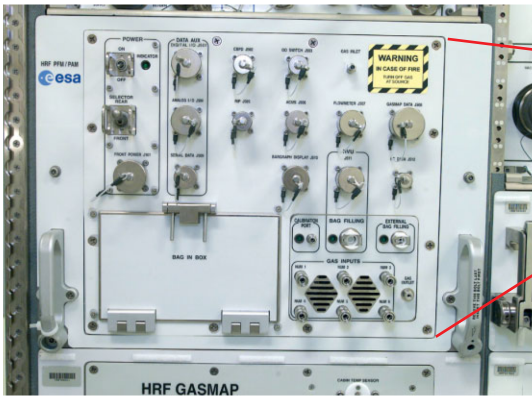
ESA is contributing four instruments to HRF:

- Pulmonary Function Module (PFM) and Photoacoustic Analyser Module (PAM), for the overall Pulmonary Function System (PFS);
- Handgrip and Pinch Force Dynamometers (HGD/PFD);
- Percutaneous Electrical Muscle Stimulator (PEMS);
- Muscle Atrophy Research and Exercise System (MARES).

Pulmonary Function System (PFS)

The overall PFS consists of several main modules:

- the Pulmonary Function Module (PFM);



PFS/PAM installed in HRF-2.

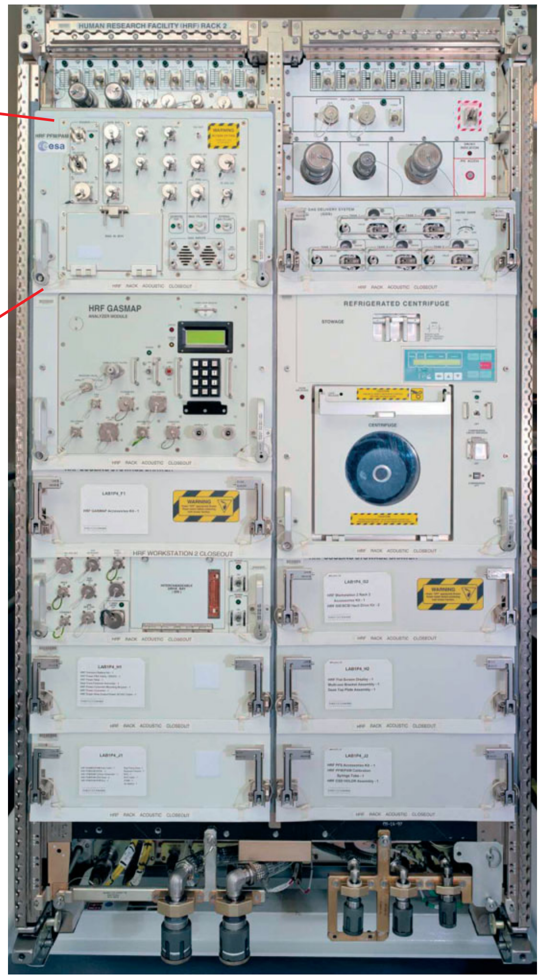
- the Photoacoustic Analyser Module (PAM);
- the Gas Analyser System for Metabolic Analysis Physiology (GASMAP), from NASA;
- the Gas Delivery System (GDS), from NASA.

By reconfiguring the interconnections between these building blocks, it is possible to use either GASMAP (a mass-spectrometer) or PAM for measuring gas composition.

PFM consists of the Respiratory Valve Unit and associated flow-meters, a rebreathing bag assembly and an electronics unit. Its flexibility allows a wide range of respiratory and cardiovascular measurements, including: breath-by-breath measurements, diffusing capacity of the lung, expiratory reserve volume, forced expired spirometry, functional residual capacity, cardiac output, alveolar ventilation, volume of pulmonary capillary blood, and other specialised tests of pulmonary function.

ESA Astronaut André Kuipers tests PFM during a parabolic flight.

PFM/PAM is capable of measuring the concentrations of O_2, CO_2, CO, Freon-22, SF_6 and CH_4 in an astronaut's exhaled breath. In a research environment, this task has been traditionally performed by a mass-spectrometer. ESA also used this technology in its first Respiratory Monitoring System, developed for the Spacelab-D2 mission (1993). PAM, however, is based on a novel gas analysis principle; photoacoustics offers many advantages in the clinical field and especially aboard the Space Station. It depends on the fact that different gases absorb infrared light at different and very precise wavelengths. The gas expands and contracts as narrowband infrared energy heats the samples in pulses. A microphone picks up the amplitude of these pressure pulses, yielding an accurate measure of the concentration of the gas specific to this infrared frequency.



HRF-2 in orbital configuration. It will shortly be tested inside Columbus at EADS in Bremen. (NASA)

PAM can be used, for example, to measure the O_2/CO_2 ratio in the exhaled air as the astronaut exercises. As exercise requires more oxygen intake than during rest this gives a good indication of metabolic status.

NASA plans to launch PFM/PAM as part of HRF-2 on the ULF-1 mission, possibly in 2004. Developed by SME Innovision A/S of Denmark, PFM/PAM was delivered to NASA in 2001. Innovision has been involved in respiratory instrumentation for space application since the mid-1980s, and have also produced successful commercial spin-offs in the medical field.

Handgrip and Pinch Force Dynamometers

HGD measures the force exerted by a hand gripping with four fingers against the palm (up to 1 kN). PFD measures the force exerted between the thumb

HGD back, PFD front, in the mission kit ready to fly.

and the opposing finger(s) (up to 270 N). Both dynamometers are handheld devices connected to the HRF data acquisition system to measure astronaut strength dynamically. In a typical experiment, they are used as a static exercise stimulus.

SME Kayser Italia developed HGD/PFD and delivered them to ESA in 1999; the three flight units were delivered to NASA Johnson in February 2000. NASA will probably launch these devices on the Columbus 1E mission. An HGD/PFD derivative was used by ESA Astronaut Roberto Vittori during his ISS visit in April 2002.

Percutaneous Electrical Muscle Stimulator

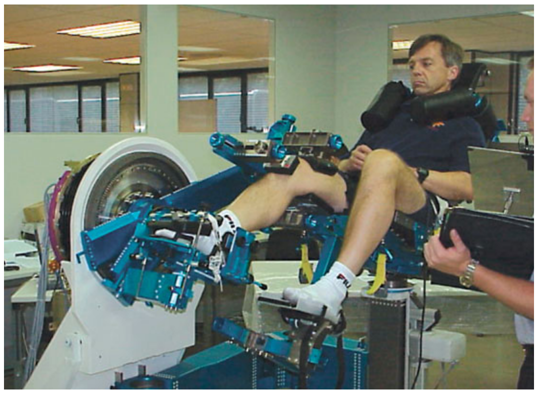
PEMS stimulates muscle groups on the limbs (ankle, knee, thumb, elbow and wrist) with electrical pulses applied via skin electrodes. The pulse duration and current amplitude are programmable to either 50 µs for up to 0.8 A or 250 µs up to 0.16 A. It provides either single pulses or fully programmable pulse trains, and can be triggered either manually or remotely, typically by MARES (see below). A typical application is to study muscle strength independently of the subject's voluntary neural drive.

The PEMS flight model.

PEMS is a self-contained item, stowed in a locker. It was developed by Alcatel Space Switzerland (CH), formerly CIR, and delivered in 2002. The plan is to launch PEMS and MARES together on the UF-3 mission, in around 2006.

Muscle Atrophy Research and Exercise System

The 250 kg MARES is ESA's heaviest contribution to HRF. It measures how well muscle groups perform by accurately measuring an astronaut's reaction to programmed loads during exercise. It is a contest of physical strength in which the MARES motor can be programmed to win or lose.



MARES will monitor muscle strength during long flights.

Typical usage is to obtain the 'torque-velocity curve' for a muscle group, measuring its strength as a function of the angular speed. It can also be used in motor-control experiments and as an exercise machine to experiment with different training protocols.

MARES can operate in single joint (angular) movements (ankle, knee, hip, trunk, wrist, elbow, shoulder) and in multi-joint (linear) movements (arm/s-press and leg/s-press). The programmed load can range from being as simple as maintaining a constant speed or torque irrespective of what the user does (isokinetic, isotonic), to imitating combinations of springs, masses and frictions. An astronaut could, for example, replicate what a rower feels: high resistance in flexion, low in extension.

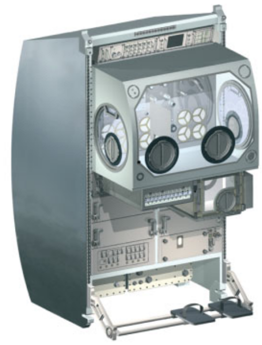
MARES covers torque ranges of up to 900 Nm and rates up to 9 rad/s. At the same time, it allows fine motor-control experiments, with torques set at resolutions of 1 Nm. This large dynamic range requires a very specialised motor design.

MARES will be operated in the aisle of Columbus, attached to the seat tracks of an HRF rack. It physically consists of the Main Box (containing the motor and electronics), the Chair and a large number of Human Adapters for accommodating a wide range of astronauts. When not in use, all of its elements will be stored inside the HRF rack.

MARES was developed by NTE (E), Etel (CH) and Origin (NL), and it will be launched in the UF-3 mission in around 2006.

MSG: A Station Success

Microgravity Science Glovebox 18 Months in Space



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Introduction

The Microgravity Science Glovebox (MSG) – Europe's first research facility for the International Space Station (ISS) – was launched in June 2002 on Shuttle STS-111/UF-2. This glovebox can house investigations into combustion, fluids and biotechnology and handle a wide range of materials. After the astronauts installed it in NASA's Destiny research module, it underwent an extensive checkout to verify that it was still working properly following the rigours of launch. The crew was supported in this crucial step by a NASA team at the Telescience Support Center (TSC) of the Marshall Space Flight Center in Huntsville, Alabama, supplemented by the ESA and industry experts who had performed the ground test campaign. Special attention was paid to the air circulation system of the core facility, the different operating modes and the video system.

MSG is proving to be a valuable research facility aboard the ISS ...

Pedro Duque working with MSG.

As part of this commissioning phase, the first two materials science experiments were conducted: 'Solidification Using a Baffle in Sealed Ampoules' and 'Toward Understanding Pore Formation and Mobility Investigation'. Over the next 3 months, the experiments were run repeatedly and the facility was operated extensively and flawlessly. At the end of this phase, MSG was fully accepted and formally handed over to NASA.

European Experiments

In December 2001, the first design proposals for four European MSG experiments were discussed as part of the ESA-Belgian Soyuz taxi mission, flown by Frank De Winne in October 2002: COSMIC (Combustion Synthesis under Micro-gravity Conditions), DCCO (Diffusion Coefficients in Crude Oil), Nanoslab (aggregation mechanisms and kinetics of zeolite particles) and PromISS (protein crystal growth monitoring by digital holographic microscope). PromISS required direct commands from the experiment to the Video Drawer, a feature that was not originally planned for MSG. This new capability was quickly developed and the updated MSG application software was installed on the MSG engineering model and verified, both standalone and together with the PromISS flight unit.

Frank's MSG activities during his 8 days aboard the Station were closely coordinated between the Erasmus Payload Operations Control Centre(EPOC) at ESTEC and the TSC, where ESA and European industry experts, as well as a Russian representative, supported the NASA Marshall team. This close cooperation proved to be valuable during the experiments because some problems appeared that required prompt real-time solutions from everyone involved. PromISS initially failed to activate because of a 'safety inhibit' problem, which was solved by changing the procedure and repeating the set-up sequence. The experiment then went as planned. A component failure in Nanoslab's own electronic unit caused the loss of that experiment. The real-time adjustment by the crew of the time window for COSMIC's ignition ensured live video coverage on the ground.

MSG Problems Appear

The ESA-Belgian mission enjoyed flawless behaviour by MSG itself. However, on 20 November 2002, 2 weeks after Frank's departure, an electrical fault developed in MSG's power system: a 12 V circuit breaker tripped several times in the Power Distribution & Conversion box (PDC) and communications with the sensor board were lost. The TSC immediately alerted the ESA team, who defined and triggered a long series of troubleshooting activities in space. Unfortunately, their efforts showed that there was no way to solve the problem on-orbit and that the affected hardware – designed anyway as an Orbital Replacement Unit – had to be returned to the ground for more detailed investigations. Shuttle STS-113 was still docked to the Station at the time, so the two suspect units (PDC and the RPDA-ESEM3 main power supply card of the Remote Power Distribution Assembly) could be retrieved quickly.

The troubleshooting, led by ESA and EADS, was mostly done at the premises of subcontractor Bradford Engineering (NL). One cause was promptly identified: the 5 V DC/DC converter in the PDC powering the sensor board had a design weakness that led to progressive degradation of its components. This was easily corrected and the PDC was reverified on the MSG engineering model at NASA Marshall. However, the source of the 12 V problem could not be found or reproduced. The RPDA-ESEM3 card was blameless in both cases.

ESA was again fortunate with scheduling: the ESA-Spanish mission in October 2003 had booked capacity on several Progress supply ferries, so the repaired items could be launched aboard Progress 10P on 2 February 2003. As soon as they arrived, the units were reinstalled in MSG ... and the 12 V circuit tripped again. A long period of detailed troubleshooting began, activating the E-Box circuits progressively, each step requiring the MSG rack to be partially tilted to gain rear access and to run through the entire activation procedure. This took until 19 March. The 12 V problem was not triggered again and MSG has worked flawlessly since.

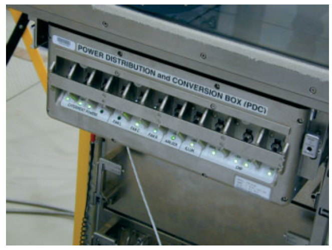
Since the main failure and some events leading up to it could not be precisely identified, an independent Failure Inquiry Board worked from January to April 2003. Although the root of the 12 V problem was not pinpointed, the final report made recommendations for MSG operations and extended electrical testing of subsequent European ISS payloads, as well as for the design of future power systems (all other current ESA payloads have different circuits).

Normal Operations

MSG has worked without problems ever since its repair. Another NASA experiment (In-Space) was performed successfully during the summer, but the *Columbia* accident in February 2003 prevented additional utilisation. Then, in October, the Spanish Soyuz mission brought two experiments: the reflight of Nanoslab, and the improved PromISS2. They went perfectly. In addition, two new technology experiments are being developed for plasma bulbs (ARGES) and advanced heat pipes (HEAT), to be performed in April 2004 by André Kuipers during his ESA-Dutch mission. Beyond that, ESA has begun studies for further European investigations within MSG, such as magnetic fluids, aqueous foams and crystallisation from gas phase.

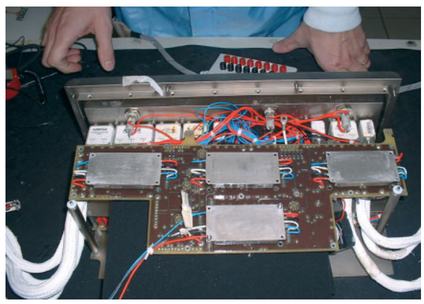
Conclusions

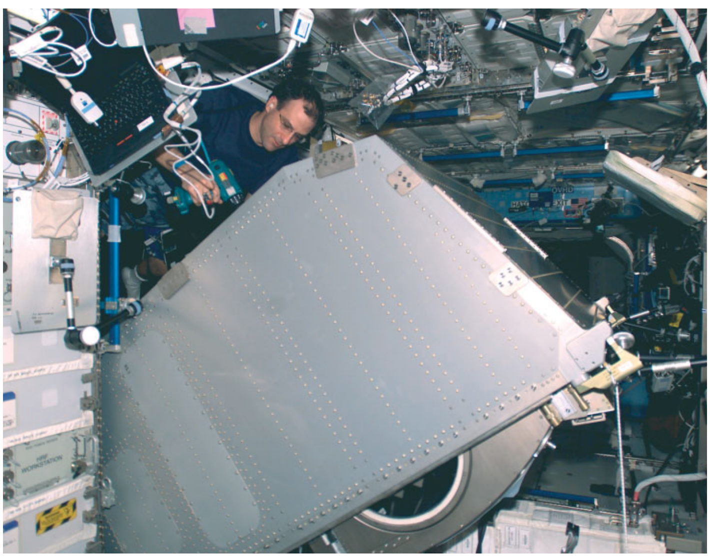
The first 18 months of MSG's life aboard the Station have proved to be quite intensive in terms of experiments performed and the maintenance required. Indeed, the delay in delivering other ISS facilities means that MSG is being used much more than expected. Thanks to its flexibility, the excellent spirit of cooperation between the Industry, ESA and NASA teams and the availability of the European Soyuz missions, sponsored by national agencies, important science is being performed aboard the ISS even during this difficult time. ■



PDC troubleshooting on the ground.


The repaired PDC ready to be loaded into Progress 10P.


PDC is tested on the ground.


Don Petit removes the suspect units. (NASA)

Growing Plants in Space

The European Modular Cultivation System

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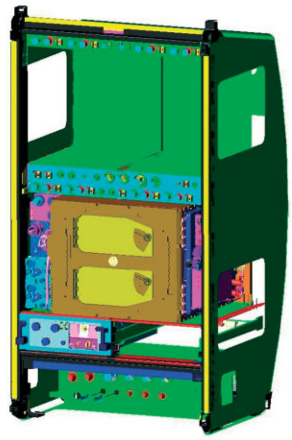
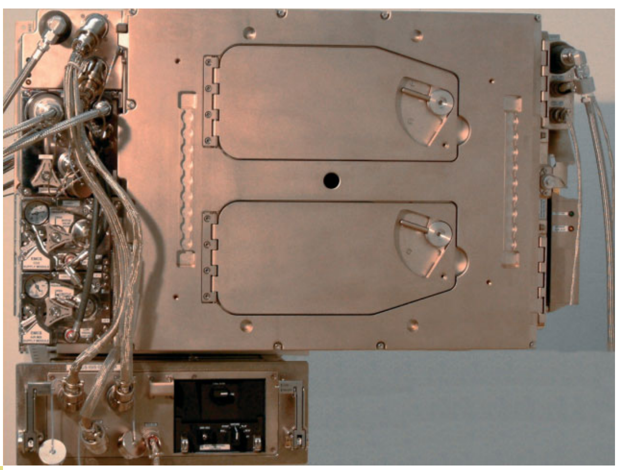


ESA's new facility for studying the biological effects of gravity is nearing completion ...

Introduction

The European Modular Cultivation System (EMCS) is a new ESA gravitational biology research facility dedicated to experiments on plants, focusing on multi-generation experiments and the periods of early growth. Research using insects, amphibia, invertebrates, and cell and tissue cultures are also planned. EMCS will be housed in NASA's Destiny research module aboard the International Space Station (ISS), and will be operated in cooperation with NASA via a Memorandum of Understanding for at least 2 years of continuous operation. Access to ISS resources such as stowage, cooler/freezer and gloveboxes for sample storage, transportation and handling is also provided.

EMCS consists of an incubator (the Holding Structure) hosting two large centrifuges, each capable of carrying four Experiment Containers (ECs). The incubator's Thermal Control System provides temperatures selectable within +8°C to +40°C. EMCS will be accommodated within a NASA Express Rack occupying a volume of four Shuttle Middeck Lockers, with the associated control electronics contained in an International Subrack Interface Standard (ISIS) drawer. Video, data and command signals will allow experiment control from the ground.



The EMCS Holding Structure (Flight Model) with ISIS Drawer (lower panel). The doors provide access to the Experiment Containers.

Control experiments will be performed on Earth for comparison with the space results using EMCS Ground Reference Models, one at the University of Trondheim (N) and the other at the NASA Ames Research Center (USA).

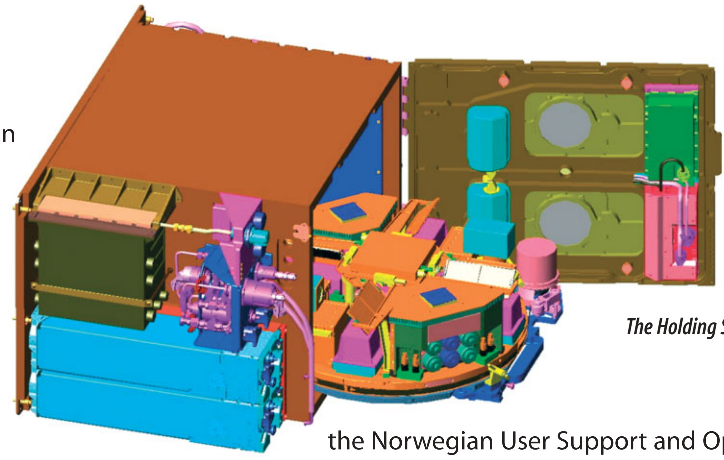
Centrifuges

Both of the 60 cm-diameter centrifuges rotate around the rack's vertical axis. Normally, one centrifuge is either held fast as the microgravity platform or it provides variable *g*-levels (10^{-3}-2 *g*). The second centrifuge rotates at 1.8 rpm to provide the 1*g*-reference environment for the experiments in space.

Together, the centrifuges offer: eight EC positions (interfaces), the life-support system for air humidification/dehumidification, four movable video cameras and tilting mirrors for observation of the container interiors, the electronics boxes for power, data and video processing, two fresh-water (250 ml) and liquid waste (250 ml) reservoirs, and eight LED arrays with up to 75 W/m^2 light output for photosynthesis.

Atmospheric Control System

The entire air volume inside the incubator is conditioned by an Atmospheric Control System (ACS) – a gas supply unit, an ethylene removal unit and a sensor module. The humidity is controlled individually at the EC level: air from the incubator is filtered through the EC and conditioned by individual humidifier/ dehumidifier units connected to each EC. This system also retrieves the water evaporated by



The Holding Structure, with one rotor shown.

the plants for re-use, avoiding condensation problems.

Experiment Container

In addition to power and data lines and inlet/outlet gas connectors, the EC baseplate also has quick-disconnects for water supply from the fresh-water reservoir and removal to the waste-water reservoir on the rotor. Nutrients for plant growth are added within the EC to prevent contamination of the water reservoir. Any particulates in the air stream going into the EC from the incubator air volume will be trapped in membrane filters (0.2 µm pores) at the EC inlet. Each EC also has sensors for monitoring temperature and pressure. The internal volume (0.58 litres) is available for experiment hardware and plant specimens of up to 60 x 60 x 160 mm. The EC's large size allows the installation of highly automated hardware to support, for example, the growth of plant cultures without the need for astronaut access to the EC.

Early Operations

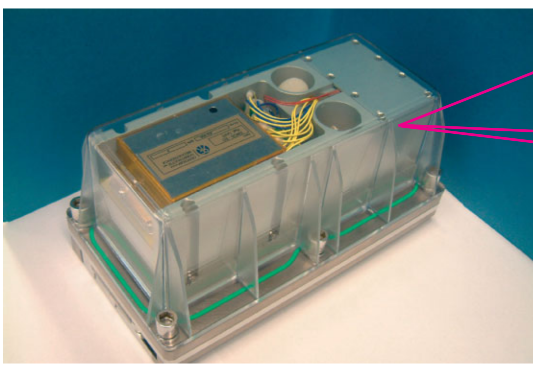
The EMCS will pass its Flight Acceptance Review before the end of 2003, and flight-standard ECs will arrive in batches throughout 2004. Following launch (default on Shuttle flight ULF-2, but possibly on ULF-1.1 or ATV-1), EMCS will be installed and checked out in Express Rack #6 in Destiny. The facility operations and a first NASA experiment run during on-orbit commissioning will be remotely controlled by a joint NASA/ESA team from the Marshall Space Flight Center (MSFC) in Huntsville, Alabama. Subsequently, control of European experiment runs will be delegated to the Norwegian User Support and Operations Centre (N-USOC) at the University of Trondheim.

Project Team

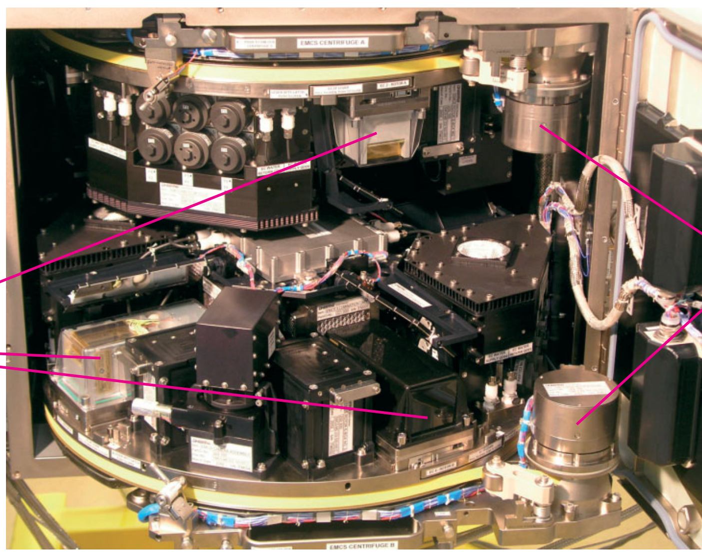
An industrial consortium involving EADS-ST (formerly Astrium, D) and OHB (D), Verhaert (B), Carlo Gavazzi Space (I), Ferrari/DTM (I), EADS-Astrium (F), EREMS (F) and NTE (E) built the EMCS Flight Model. Rovsing (DK), Dutch Space (NL) and CCM (NL) produced the ground reference hardware and software. The NASA experiments for EMCS are being designed and built by NASA Ames. The responsibility for designing the first batch of ESA-selected experiments was recently contracted to EADS-ST (Phase-A/B), to provide flight-qualified experiments by early 2005.

Conclusion

EMCS provides a promising next step in the development of advanced facilities dedicated to biological research in space. It builds upon the long experience gained by ESA in flying similar facilities over the last two decades, and offers scientific investigators new capabilities for scientific research aboard the ISS.



An EMCS Experiment Container.



Drive motors.

The two plant rotors installed.

Creating Microgravity

Europe's Drop-Tower for Microgravity Research

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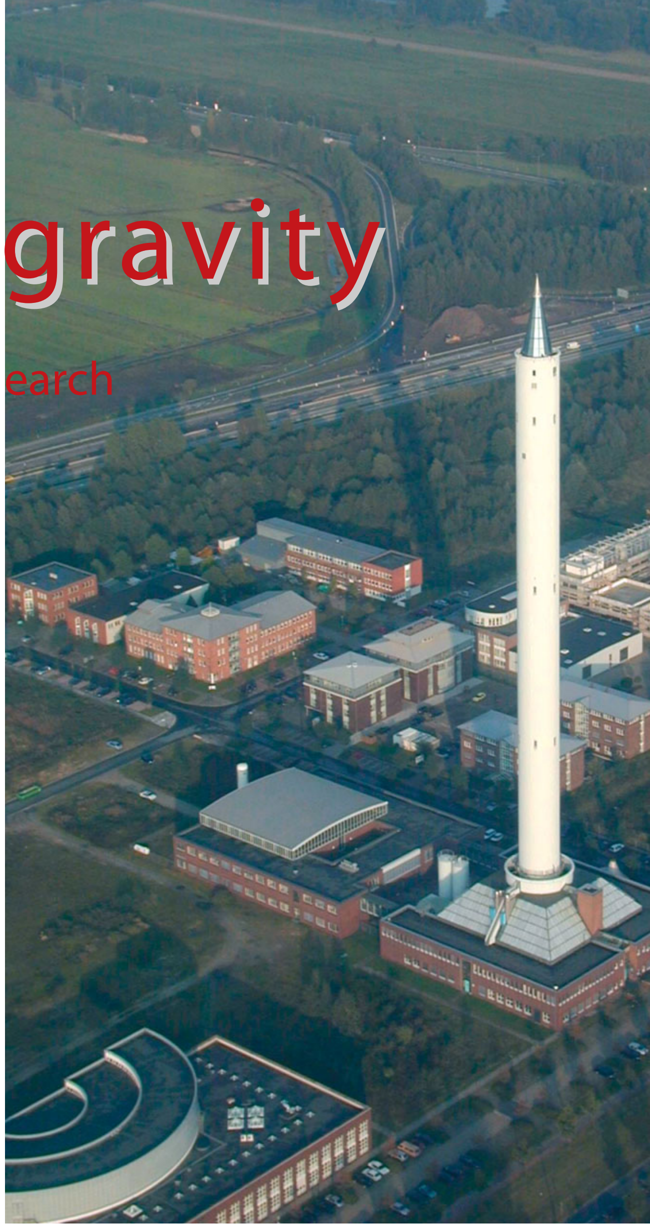
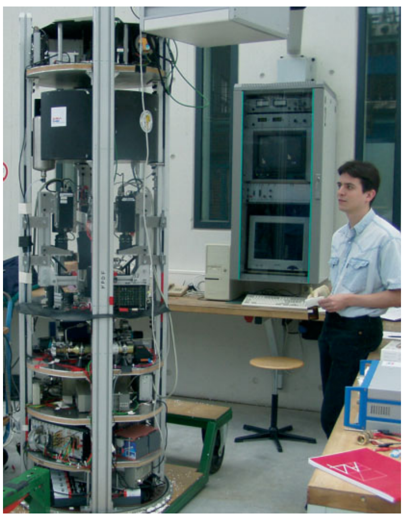


The ZARM drop tower.

Introduction

The drop-tower at the 'Centre for Applied Space Technology and Microgravity' (Zentrum für Angewandte Raumfahrt Microgravitation, ZARM) in Bremen (D) is unique in Europe and provides up to 4.75 s of microgravity for experiments. ESA is currently supporting four European teams using this facility for research into soot formation, droplet evaporation, material combustion, thermophoresis and diffusiophoresis. Gravity affects such physical phenomena on time scales from seconds to weeks. In particular, gravity-driven instabilities set in within a matter of seconds during experiments involving steep density gradients. So drop towers and their free-fall periods lasting a few seconds are powerful research tools.

The 146 m ZARM tower in Bremen provides scientists with brief periods of microgravity ...



Preparing the experiment 'Soot Particle Growth of a Diffusion Flame' using laser-induced incandescence.

Microgravity durations offered by drop towers are inescapably limited by the height of the free-fall being proportional to the time squared. About 2 s are achieved in 20 m-high facilities, typically using drops through air at ambient pressure using a drag shield to protect the experiment from air friction and drag. For 10 s of microgravity, a 500 m-tall vertical facility is required. In order to reach the terminal speed of about 100 m/s without air drag affecting the quality of microgravity, the experiment is carried in an evacuated capsule that is propelled by gas thrusters as it speeds downwards. Braking the capsule requires another few hundred metres. Typically, old mine shafts are exploited for such facilities: a 10 s shaft was operated in Hokkaido, Japan, until last March and a new facility is being built in Saskatchewan, Canada.

The best microgravity quality ($10^{-5}g$) is achieved by dropping capsules in vacuum to exclude aerodynamic influences, with the experiment hardware rigidly installed inside. ZARM, with Europe's largest drop facility, has such an evacuated shaft.

The set-up for studying how materials burn in space. The windtunnel (arrowed) simulates typical airflow aboard the Space Station.

The Drop-Tower at ZARM

In building the drop-tower, ZARM focused on reducing the residual accelerations during the fall. The team designed a free-standing 110 m-high, 6 m-

diameter vacuum chamber as the drop shaft, protected from weather perturbations by a 146 m-tall concrete tower. Eighteen pumps create a vacuum level of 10^{-5} Earth-atmosphere in about 1.5 h so that the residual drag on the capsule is less than $10^{-5}g$ by the end of the fall. The capsule is braked in an 8 m-deep tank of polystyrene pellets. Equipment is mounted on platforms specifically designed to minimise oscillations at release and to hold steady during the short braking time. The whole shaft is then repressurised to recover the capsule. Up to three drops can be carried out in a day.

When the capsule is at the top of the tower hanging over the shaft, all of its functions can still be checked and its parameters re-set. Release is triggered either by the operator or the experiment itself. All of the experiment and housekeeping data are stored onboard.

A unique excimer laser shining down from the top of the tower can illuminate experiments as they hurtle down the shaft. The capsule's automatic alignment system maintains the position of the experiment zone relative to the laser. This is particularly valuable for combustion experiments because it allows the quantitative measurement of the concentration of various gaseous species and solid particles. Such measurements are crucial to understanding combustion processes.

By the end of this year, a catapult will become operational to fire capsules up from the bottom of the shaft, thereby doubling the free-fall time. This will make the tower even more interesting to the scientific community.

ESA-Funded Experiments

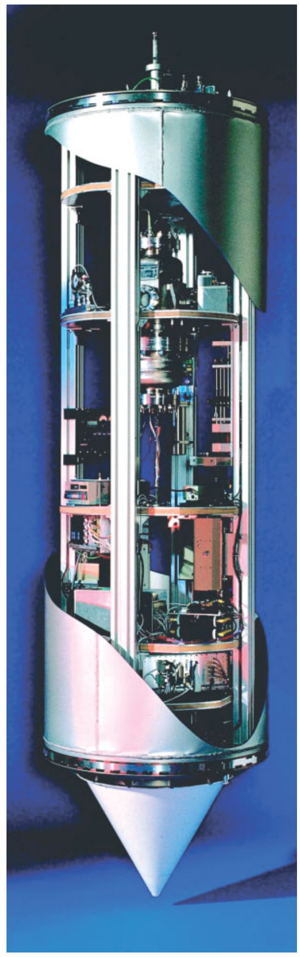
ESA continues to promote use of the Bremen tower Bremen among European scientists. It has enabled scientists to complete self-standing projects as well as complementing larger programmes employing aircraft parabolic flights, sounding rockets and the Space Station. The tower is so important to ESA and Europe that, on 2 October, a contract was signed with the ZARM FAB operating company to designate it as an ESA External Facility.

Preparing research programmes for the ISS is now in full swing at the tower; four teams are being supported by ESA at the moment. One teams is investigating the soot concentration and primary particle sizes in flames by laser-induced incandescence. Related experiments aim at understanding the production of soot during combustion in order to help develop cleaner diesel engines and to improve the production of carbon black. A second programme is looking at the combustion properties of partially premixed fuel sprays, including fuel droplets, droplet arrays and spray vaporisation. The results are of interest to companies producing turbine engines such as aircraft engines and power plant turbines.

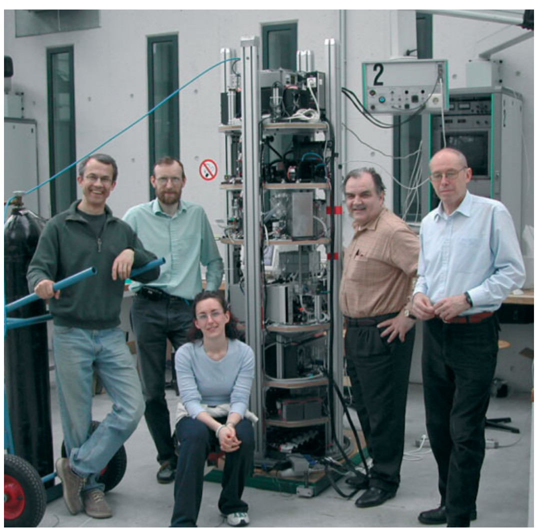
A third team is studying the combustion properties of materials intended for space applications, as well as laminar flames representing fires in space. The scientists are developing methods to qualify space materials and to fight fires on microgravity platforms. Finally, a fundamental-physics programme is studying thermophoretic and diffusiophoretic effects by using digital holography, with the long-term goal of understanding how planets form.

Conclusion

The ZARM drop-tower is an indispensable tool for Europe to perform microgravity investigations on the ground. It is used to develop experiment hardware for other microgravity platforms such as sounding rockets and the Space Station, and its excellent microgravity quality provides highly interesting scientific data. By that, it complements ground studies, contributes to the development of numerical modelling tools, helps to define key parameters for long-duration space experiments and helps to evaluates results from other microgravity platforms. ■



The capsule is dropped down the shaft.



The research team for 'Phoretic Experiments using Digital Holography', which looks at the motions of paraffin and sodium chloride particles in nitrogen.

What is MSM-E?

The Operations Department of MSM

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Bob Chesson, Head of the Operations Department.

Introduction

The main responsibility of MSM-E is the operation and maintenance of ESA's Space Station elements. These are mainly the Columbus module, the Microgravity Facilities for Columbus (MFCs), the Laboratory Support Equipment (Microgravity Science Glove-box, MELFI and Hexapod) and the Automated Transfer Vehicle (ATV). The Department was formed in 2000 as the Exploitation Preparation Department and now has 34 staff and 43 on-site support contractors split between ESTEC and the ATV Control Centre in CNES Toulouse. MSM-E comprises four divisions:

MSM's Operations Department operates ESA's ISS contributions and handles ATV production ...

Operations Management Division

MSM-EO, managed by Hiltrud Pieterek, is the main interface with NASA's ISS Program Office for operations management and integration. It provides the ESA flight directors for Columbus assembly and integration, the ATV operations managers and the managers who control ESA's involvement in each ISS increment. The division is also responsible for developing the ESA ground segment: the ATV and Columbus control centres at CNES Toulouse and DLR Oberfaffenhofen, respectively; the ATV Crew Trainer and Ground Simulator, already delivered to the European Astronaut Centre (EAC) and CNES Toulouse, respectively; the Columbus crew trainers that are now in use in EAC and Houston; the ATV Test Facilities being used in the qualification and acceptance programme for ATV-1 'Jules Verne'; and the ground communications network that interconnects the entire ground segment and provides the communications interfaces to NASA's Johnson and Marshall centres, as well as to Mission Control in Moscow. The integration and testing of both control centres is now under way and to be operational by mid-2004. Preparations for the ATV Jules Verne mission is gathering speed, with the development of the operations procedures, databases and documentation well advanced. The same is true for the Columbus assembly mission although the pace has relaxed somewhat owing to the delays stemming from the *Columbia* Shuttle accident. To gain operational experience for ATV and Columbus, the Division provides the ground segment, planning staff and flight and ground controllers for the European Soyuz missions.

Payload Integration and Operations Division

MSM-EP, headed by Aldo Petrivelli, is responsible for the engineering and operations integration of payloads. This includes integrating the initial Columbus payloads, including those from NASA. This work is progressing well, with testing of the Biolab, European Physiology Modules (EPM) and Fluid Science Laboratory (FSL) on the Rack Level Test Facility at EADS Space Transportation in Bremen (D) already completed. The European Drawer Rack (EDR) tests will be completed by the end of the year and those for the external payloads in 2004. The MFC and EDR racks will be physically integrated into the Columbus flight model in Bremen in the first quarter of 2004 for interface testing, followed by a System Validation Test (SVT) in March with the ground segment. To gain confidence in the compatibility of the NASA payloads with Columbus, NASA's second Human Research Facility will be integrated into Columbus and tested after the SVT.

MSM-EP is also responsible for setting up and operating the User Support and Operations Centres (USOCs). Ten are planned as interfaces to the users for engineering and operations integration of their experiments into the Station. The major USOCs (Facility Responsible Centres, FRCs) are charged with operating ESA's research facilities as part of the decentralised scheme coordinated by the Columbus Control Centre. These centres are now being outfitted with standardised communications and data processing equipment and their operations personnel are ready to support the SVT with Columbus and the MFC payloads in March.

The Division is also charged with the Columbus Control Centre operations during payload commissioning and the actual experiments. It will provide the ESA flight directors to manage this work during the early Columbus increments. To prepare for Columbus, MSM-EP is responsible for managing the European Soyuz missions. Twenty-two experiments were performed during the Belgian mission, 21 during the Spanish flight and 23 are being prepared for the Dutch mission of April 2004.

ATV Production and Product Support Division

MSM-EA is presently managed by Bob Chesson, the Department Head, until a separate division manager is appointed. Its main responsibility is to manage production of the ATV craft following development and the first flight. Another six ATV missions are planned between 2006 and 2013 to deliver supplies to the Station and periodically raise its orbit to combat atmospheric drag. A considerable amount of hardware for the ATV production phase has already been procured, either to avoid obsolescence or to support ATV development by providing spare units for integration and closed-loop testing of the guidance and navigation system. It is planned to sign the contract for full-scale production of ATVs by the end of the year. In addition, MSM-EA is responsible for procuring the Ariane-5s from Arianespace for launching the ATVs.

This Division has the space hardware expertise of the Department and is therefore also charged with logistics support, maintenance and sustaining engineering of all the ESA elements of the ISS. The sustaining engineering is particularly daunting, bearing in mind that many hundreds of companies have been involved in developing the flight elements and only a small fraction can be retained to support the operational phase. MSM-EA and Industry are analysing how best to transfer and centralise expertise, equipment, maintenance and troubleshooting capabilities to provide an affordable yet effective sustaining engineering service for the lifetime of the ISS. Meeting this challenge is a key to the overall success of ESA's ISS Exploitation Programme.

Commercialisation Division

The three divisions above require substantial funding to carry out their activities, while the fourth is charged with *generating* revenue. This is MSM-EC, managed by Maurizio Belingheri. A proviso attached by the ministers to their approval in 1999 of the ISS Exploitation Programme was that the Agency should exploit the commercial possibilities offered by a large orbiting infrastructure. Since then, MSM-EC has been working hard to attract customers from different market segments to buy Station resources and accommodation. It became apparent early on that one of the biggest obstacles was the lack of public knowledge of the ISS and ESA's part in it. An image-promotion drive was launched, accompanied by an 'ISS branding' campaign together with the ISS Partners. In parallel, a number of small-scale 'Pathfinder Projects' have been launched with varying degrees of success to learn how to manage and exploit commercial ventures aboard the ISS. Despite some encouraging early signs, ISS commercialisation is proving to be very difficult to achieve and it is apparent that, without penetration by specialists into the various market segments, it will be impossible to locate potential customers. To this end, MSM-EC is in the process of selecting dedicated 'commercial agents' in specific market segments, starting with biotechnology, to root out prospective customers.

From left: Hiltrud Pieterek, Aldo Petrivelli and Bob Chesson.

The Division is also working hard to implement the modern commercial business practices that are essential for attracting commercial customers but are alien to any space agency more used to strict, formal engineering disciplines. It has yet to be seen whether we will succeed in generating a steady stream of revenue to enhance the Station's institutional funding but it will not be for want of trying!

Exercising Control

European Control of Columbus and ATV Operations

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Europe's two principal ISS control centres will be ready for operations in 2004 ...

Introduction

As the ISS is a truly international programme, each ISS Partner controls its own elements, vehicles and payloads from its own facilities. NASA coordinates the activities of the Partner centres and looks after safety-critical operations. For Europe, control is exercised via the Columbus Control Centre (Col-CC, DLR/Oberpfaffenhofen, D), the Automated Transfer Vehicle Control Centre (ATV-CC, CNES/Toulouse, F) and the Ground Communications infrastructure. ESA payload operations will be conducted from a number of User Support and Operations Centres (USOCs) located in different countries. The ESA Operations Management Team will reside at ESTEC and the control centres, while multiple industrial centres across Europe will support the operations.

Col-CC is housed at DLR Oberpfaffenhofen.

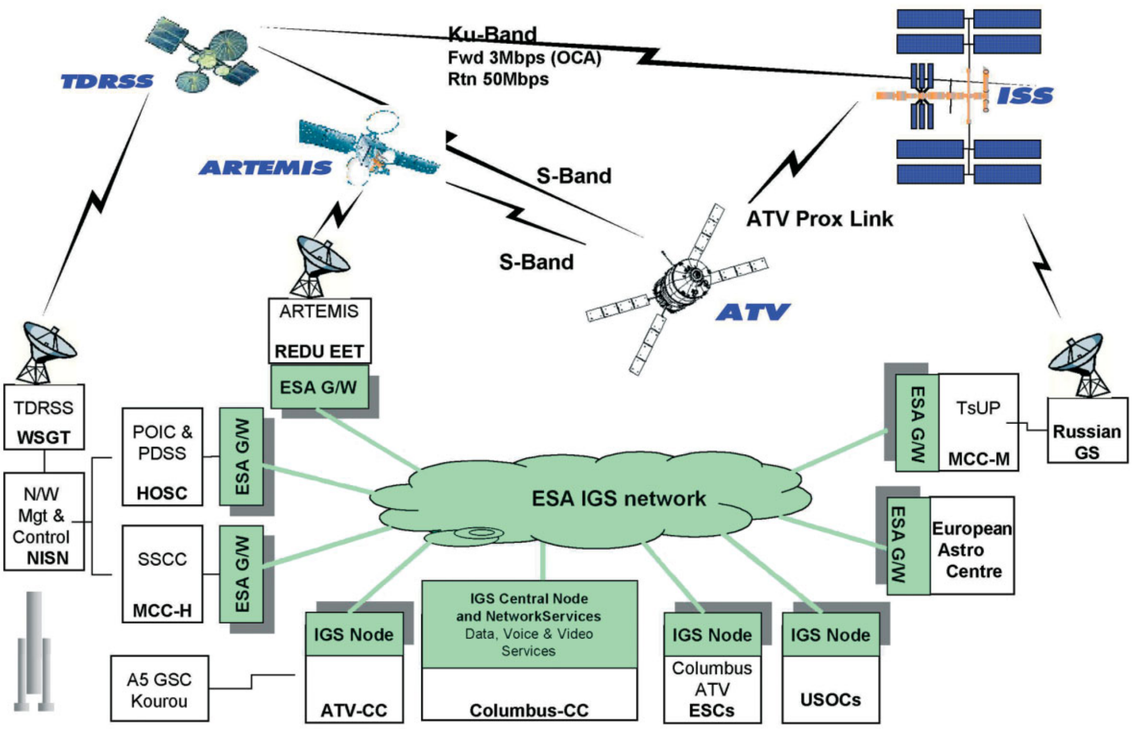
Columbus Operations

DLR's mission control building already has experience with the Spacelab-D2 and Euromir missions and has now been furnished with new systems as the Columbus Control Centre. ESA signed the €37.7 million development contract with DLR on 31 March 2003 (Astrium is lead contractor); a further contract will cover operations. Col-CC will operate the Columbus laboratory in close cooperation with the Space Station Mission Control Center (MCC-H) at the NASA Johnson Space Center in Houston and the Payload Operations and Integration Center (POIC) at the NASA Marshall Space Flight Center in Huntsville. The Col-CC and the communications infrastructure support payload operations, including routing of telecommands from the USOCs to Columbus, distribution of data, audio and video to the USOCs, and archiving of low- (S-band) and medium-rate (Ku-band) telemetry, audio and video. Col-CC can also accommodate users in local payload operations rooms.

Columbus system and payload commands are uplinked to Columbus via MCC-H. Columbus telemetry is downlinked via S- and Ku-band to MCC-H and POIC, respectively, for processing and collection by the communications networks. Other ISS data are received from MCC-H, POIC and the Russian MCC-M control centre in Moscow.

Col-CC flight controllers will operate the Columbus module systems. Because Columbus will carry a mixture of European and US experiment facilities requiring a wide range of operating periods and degrees of interaction, it is impossible to predict when Col-CC will be required to change the system configuration. Consequently, it is planned to operate continuously, in three shifts per day, once Columbus is fully outfitted with experiments.

For attaching and commissioning Columbus – a phase with a tight timeline and many critical operations – an integrated team of flight controllers will monitor and control the Columbus activities. This team consists of flight control personnel from DLR/German Space Operations Centre, Astrium and ESA. Under the ESA lead flight director (a member of the Operations Management Team), the team is already preparing for flight, including the development of flight rules, joint integrated



A5: Ariane-5
EET: ESA Earth Terminal
ESC: Engineering Support Centre
GSC: Guiana Space Centre
HOSC: Huntsville Operations Support Center
IGS: Interconnected Ground System
NISN: NASA Integrated Services Network
N/W: network
PDSS: Payload Data Services System
POIC:Payload Operations Integration Center
SSCC: Space Station Control Center
TsUP: Russian Flight Control centre
(Other acronyms are explained in the text).

procedures between the Partners' control centres, console handbooks, and ground procedures and displays.

ATV Operations

ATV-CC uses a new building at CNES/Toulouse, with primary and back-up control rooms. ESA signed the €16.1 million development contract with CNES in April 2003; a further contract will cover operations.

Although ATV is a highly automated spacecraft, some of its onboard functions need to be monitored and controlled by the ground. In particular, the flight dynamics will be shared between the onboard software and the ground. A sophisticated set of flight guidance and navigation functions will be implemented in the ATV-CC, in addition to the conventional monitoring and control functions.

Telecommands and telemetry between ATV and its Control Centre will be routed through the US TDRS satellite network via MCC-H and the White Sands Ground Terminal (WSGT) in New Mexico, and the Artemis satellite via ESA's Redu tracking station in Belgium. For communication with the Russian Zvezda module, additional routes are used: the radio link during approach and docking, and a Bus connection while docked. Zvezda also provides video images to ATV-CC of the docking.

ATV-CC hosts the major teams for preparing and executing an ATV mission: the Flight Control Team, the ATV Operations Management Team (which oversees the mission and ensures the allocation of resources) and part of the ATV Engineering Support Team (EST). The Flight Control Team will work closely with MCC-M during the final stages of rendezvous.

ATV operations will follow the ATV Flight Operations Plan and the ISS Operations Detailed Daily Plan. ATV-CC will operate continuously during free flight and docking, and then support the scheduling during the attached phase. Decisions for real-time actions in case of off-nominal situations will be coordinated with MCC-M, MCC-H and the ATV Operations Management Team.

The Engineering Support Team consists of ESA and Industry staff who were directly involved in developing ATV. They will assess ATV's behaviour and advise the Flight Control Team and the Operations Management Team in case of off-nominal situations. ■

The new ATV-CC building in Toulouse.

On Station

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Revised English edition available now!

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International Space Station

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- Stimulate curiosity and creativity through active participation;
- Highlight the important contributions being made by space technology and science to the well-being of society;
- Focus on future, possible areas of space research and technology, as well as the importance of international cooperation and cross-cultural interaction.

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