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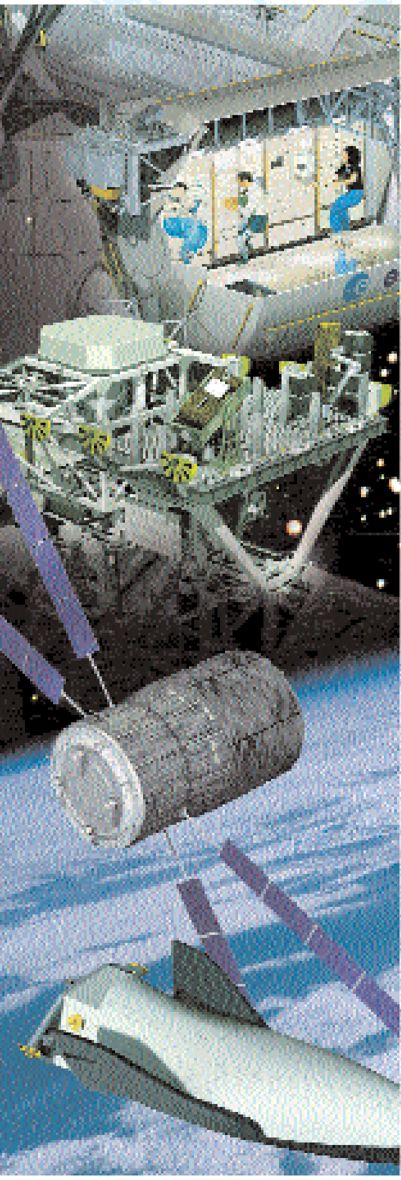
number 1, december 1999

on station

The Newsletter of the Directorate of Manned Spaceflight and Microgravity



in this issue

Welcome Onboard!

Jörg Feustel-Büechl
ESA Director of Manned Spaceflight and Microgravity

Welcome to the first issue of the *On Station* newsletter of ESA's Directorate of Manned Spaceflight and Microgravity. *On Station* combines and replaces the former *Microgravity News* and *Columbus Logbook* newsletters. Its name reflects the potential readership: *On Station* is a metaphor for 'being ready' or 'being on post'. This approach is not limited to the International Space Station, but also covers the on-going microgravity projects, whether they make use of the International Space Station, the US Space Shuttle, Russian Foton capsules, European sounding rockets, parabolic flights or drop towers and tubes.

Today, the Directorate of Manned Spaceflight and Microgravity is responsible for the management of several major programmes with more than 20 individual projects, ranging from the Columbus laboratory, through the Automated Transfer Vehicle and the European share in the Crew Return Vehicle, to International Space Station Utilisation, Microgravity Facilities for Columbus and the EMIR programmes. Altogether, they represent an average annual budget of almost EUR500 million, of which 85% is placed as contracts with European industry. Some 3600 highly skilled jobs in Europe are directly related to these programmes and projects.

The large majority of our projects were approved at the ESA Council meeting at ministerial level in Toulouse in October 1995 and formally started on 1 January 1996. Since then, 40% of the allocated budget has been spent and many hardware elements are nearing completion – a good reason to keep you informed with more up-to-date information than is possible through the classical channel of the *ESA Bulletin*.

Information tools have profoundly changed over the past few years and, like many others, the Directorate of Manned Spaceflight and Microgravity is making use of the Internet (http://www.estec.esa.int/spaceflight). ESA has also started its own daily television service over a Eutelsat direct TV satellite (for more information see: http://television.esa.int). But even in the era of e-mail and the paperless office, we feel that there is still a need and a real added-value for a paper newsletter.

European Space Agency
Agence spatiale européenne

Directorate of Manned Spaceflight and Microgravity
Direction des Vols Habité et la Microgravité

With the launch in 1998 of its first two elements, Zarya and Unity, the International Space Station, considered by many people for a long time as an abstract idea of a remote future, has become reality. It is even regularly visible to the naked eye as one of the brightest stars over Europe (for overflight schedules and maps visit <http://www.estec.esa.int/spaceflight/msmnews.htm> and follow the link to 'Visibility of the International Space Station'). Other key elements are soon to be launched and the Station is expected to be permanently inhabited and used for scientific and technological experiments beginning in 2000. Even if Europe's own laboratory on the Station, Columbus, is not scheduled for launch before 2004, Europe will not be absent from the early Station: the next element to launch, the 'Zvezda' (star) Russian Service Module is outfitted with a computer system made in Europe, the Data Management System for the Russian Service Module (DMS-R), built by a European industrial consortium under ESA contract. The same module will also carry the Station's first externally mounted experiment, the European Global Transmission System (GTS). More reasons for us to be 'on station'!

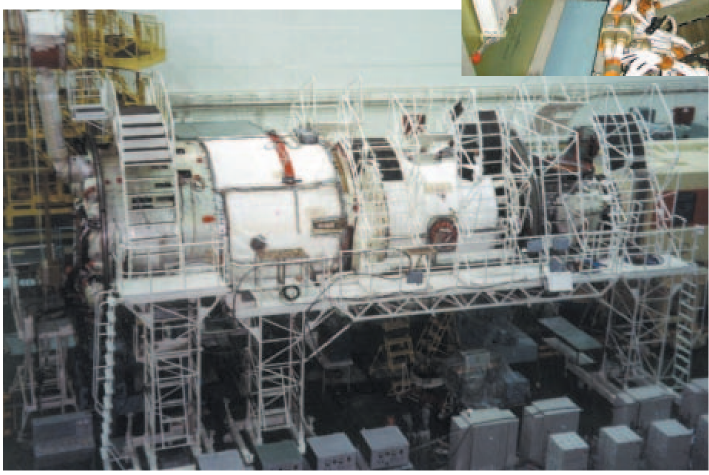
This newsletter is produced for the space community at large. We are writing for readers from industry who are involved in the development of our many programme elements, as well as the scientists from research institutes who are interested in the utilisation of the European experiment facilities, ranging from the Station to the European Airbus A300 zero-g aircraft. The representatives of partner space agencies and governmental delegates from ESA member states will also find useful information. But *On Station* will also be valuable for the media and the general public interested in spaceflight topics.

Where Do We Stand?

For this first issue it might be of help, especially for those of you who have not so closely followed our activities in the past, to summarise where we stand today, 4 years after the Ministerial Council of Toulouse, with 5 years ahead of us until the completion of the development programme for the European participation in the International Space Station.

For the Columbus laboratory, the fixed-price industrial contract for development and manufacture was placed in March 1996. It was ESA's largest single-ever contract. Since then, Columbus has successfully passed the Preliminary Design Review (PDR), and the Critical Design Review (CDR) is approaching. The structure for the flight unit is already under assembly in Turin. The laboratory's utilisation potential has been significantly enhanced by the addition of external payload facilities.

The European experiment facilities for accommodation inside Columbus (and, as far as the Material Science Laboratory is concerned, in the US Laboratory) are covered by separate projects. They comprise the four elements (Biolab, Fluid Science Laboratory, Material Science Laboratory, and the European Physiology Modules) of the Microgravity Facilities for Columbus (MFC), the European Drawer Rack and the European Storage Rack. For Biolab, the Fluid Science Laboratory and the Material Science Laboratory, the PDRs at system level were successfully completed in 1999 and the CDRs are planned for 2000. For the European Physiology Modules, the development contract was signed in May 1999. A Request for Quotation for Phase-C/D of the European Drawer Rack was issued to industry recently. The European Storage Rack, the development of which is less time-critical, is under definition.



The Zvezda Russian Service Module carries ESA's DMS-R.

On the Automated Transfer Vehicle (ATV), for which the Phase-C/D contract was awarded to industry in November 1998, there has been major progress in the operational scenario and the technical definition of the vehicle, despite the highly complex nature of its interfaces with the Russian Segment of the Station, for which an agreement has been reached with our Russian partners from both industry and the Russian Space Agency (now called Rossaviakosmos). The ATV's PDR is scheduled for February/March 2000.

In the field of reentry technologies, with the successful flight of the Atmospheric Reentry Demonstrator on the third Ariane-5 mission, in October 1998, Europe has entered the very exclusive club of space-faring nations who are able to conduct a space mission from beginning to end: launching a payload into space and returning it to the ground. Building upon this concrete experience, and the expertise previously acquired through the Hermes programme, Europe is participating in NASA's X-38 project, which is the prototype and unmanned demonstrator vehicle for the Crew Return Vehicle (CRV), the future lifeboat for the Station crew. The X-38 project is well advanced and the assembly of the V201 orbital test vehicle is nearing completion.

At the Ministerial Council Meeting of Brussels in May 1999, the ESA Member States participating in the International Space Station Programme decided on the

The International Space Station is the largest international civil engineering project ever undertaken. (ESA/D. Ducros)

initiation of the Exploitation Programme and complemented it by a specific programme covering the participation of Europe in the Crew Return Vehicle, thus ensuring continuity in European reentry technology activities, and at the same time offering a possibility for the participating states to pay their share in the variable cost of Station operations through an investment in technology. The CRV is an illuminating example of a new quality and depth of cooperation between ESA and NASA. At the same time, it is an unprecedented model for a highly adaptive approach of global cooperation uniting in a strategic alliance the interests of international and national space agencies, industries and even regional governmental entities. In addition to the industrial teams in 22 companies in eight European countries, a team of European engineers from space agencies and industry is presently working on the X-38 programme, together with their American colleagues, in a joint team based at the NASA Johnson Space Centre in Houston.

Using the Space Station

The ultimate goal of European participation in the Station is to take advantage of the large utilisation potential it offers. Europe's preparation for Station utilisation is well advanced. Several announcements of opportunity have already been issued, inviting scientists, engineers and the application-oriented user community to submit experiment proposals. These announcements received overwhelming responses, not only from the 'classical' user community of life sciences and physical sciences, who are interested in the Station's microgravity environment, but also from new user groups in the field of application-oriented experiments and services. It is worth pointing out that the Station's first European utilisation payload will be an application-oriented externally mounted experiment, called GTS (Global Transmission System), which will distribute synchronisation signals to radio-controlled watches. From the Station orbit, the system is able to reach 95% of the Earth's population. GTS will also be used to test and demonstrate a new worldwide service capable of blocking stolen cars directly from space.

For the preparation of the first experiment facilities and the support to experiments that have been proposed or already selected for the early utilisation phase, ESA has placed a significant number of contracts with European research institutes, industry and national agencies. Two European symposia on Station utilisation were held in 1996 and 1998; the first global utilisation conference, called Forum 2000 and jointly organised by all five International Partners (USA, Russia, Europe, Japan and Canada) is planned for Berlin in summer 2000.

All experiment proposals submitted in response to the Announcements of Opportunity are not only analysed by specialists from ESA and industry to investigate their technical feasibility, compatibility with operational procedures and compliance with safety rules, but also assessed for their scientific relevance and the soundness of the proposed experimental approach by Peer Reviews. The Peers are selected according to their scientific renown and expertise in the proposed research disciplines. The Peer Reviews assure that the International Space Station will become and remain a research institute for world-class science. ESA is presently formulating, in cooperation with all interested partners in Europe, an overall strategy, as well as the associated practical administrative and technical procedures, for extending the access to the Station to commercial users. The issues at stake touch not only financial aspects, but also questions of legal responsibility, selection criteria and the protection of intellectual property and confidential business data.

In order to make potential users aware of the Station's utilisation possibilities for their own business or research, and to help interested users in getting access to the station, ESA has built up the International Space Station Erasmus User Centre at Noordwijk. The centre's function can best be described as a combination of a marketing centre with a customer care service. It has the task of providing information and practical advice and guidance to Station users and supporting and coordinating the information activities of the various national User Support and Operations Centres (USOCs) in Europe. It will also contribute to increasing the awareness of the Station with decision makers, media and the European public at large. An important aspect of the centre's mandate will be to make the results of the experimental work performed onboard the Station better known and to bring together scientific teams working in similar fields of research.

According to the agreements governing the cooperation of the five International Partners, the right to make use of the Station's research potential begins only with the arrival of the Partner's own 'real estate' on the Station. The Columbus laboratory formally constitutes the European entry ticket to the Station. It is presently scheduled for launch in 2004. In order to give European users earlier access to the Station, ESA has negotiated with NASA and the Russian space agency Rosaviakosmos the possibility of using part of their payload accommodation capabilities. In this way, European users have access to the US 'Destiny' laboratory and to external payload-carrying structures on the US Truss and the 'Zvezda' Russian Service Module.

Barter Arrangements

In exchange for the utilisation rights on the US elements, ESA is providing laboratory equipment made in Europe to NASA. ESA has also negotiated for European experiments to fly on NASA's STS-107 Space Shuttle mission in early 2001, in exchange for a Super Guppy aircraft that had previously been used to transport Airbus elements between the various European Airbus manufacturing sites.

Further utilisation rights on the US Space Shuttle will be obtained in exchange for the delivery by Europe of the Cupola. The function of the Cupola for the International Space Station can be compared to that of a control tower for aircraft operations around an airport. It is a multi-window dome, sitting on one of the Station's three connecting nodes, from where the astronauts monitor and control the external operations performed by their fellow astronauts and the station robots, as well as the proximity operations of arriving or departing space vehicles.

The US Space Shuttle will carry Columbus to the Station. Instead of paying

cash to NASA for this launch service, ESA will pay in kind, with products developed and manufactured by European industry: two of the Station's three connecting nodes, together with other hardware and engineering services, will be provided by ESA.

The various barter agreements, as we call the cooperation scheme whereby ESA delivers European hardware against the provision by other Partners of hardware, services or utilisation rights, have resulted in a closer cooperation with all of the four International Partners. They avoided unnecessary duplication of effort and made the cooperation more efficient. At the same time, they allowed the Station's utilisation possibilities by European users to be expanded. They have also resulted in the non-negligible benefit that ESA has placed additional development and manufacture contracts, in highly interesting technological areas, worth EUR280 million, with European industry, instead of paying European money to hardware or service providers outside of the European economic system.

European Astronauts

Even in such a highly-automated and robotic environment like the International Space Station, where many functions are remotely operated and monitored from the ground, astronauts have an important role to play. As onboard engineers, their intelligence, mobility, dexterity and tactility, which are unmatched by any robot to date, are an important factor in the mission success of this first permanently occupied international off-shore platform above the Earth's atmosphere. 1999 saw the creation of the single European Astronaut Corps, under ESA responsibility, based at the European Astronaut Centre in Cologne, which, from an organisational point of view, constitutes one of the four departments of the ESA Directorate of Manned Spaceflight and Microgravity. The transfer of national astronauts to the single European Astronaut Corps, and the dismantling of the national astronaut corps, was not only the visible sign that Europe wants to speak with one voice in astronaut matters, but also further proof that the Station is a powerful driver for the reinforcement of existing, and the creation of new, international cooperation structures. At the end of 1999, with 15 astronauts in the European Astronauts Corps, and one more expected to join in 2000, the build-up of the corps and the transfer of the national astronauts have been almost completed.

In the recent past and the near future, several Europeans have been or will be flying to space. Pedro Duque was a crew member on STS-95 in October/November 1998; Michel Tognini on STS-93/Chandra in July 1999; Jean-Pierre Haigneré worked for 6 months on the Mir station, from February to August 1999, thus setting a new world duration record for non-Russian astronauts; Claude Nicollier and Jean-François Clervoy are scheduled for launch with the third Hubble Servicing Mission on STS-103 in December 1999; and Gerhard Thiele will be onboard STS-99/SRTM in January 2000. If all goes to plan, the first European astronaut to fly to the International Space Station will be Umberto Guidoni, who is scheduled for the first Space Shuttle mission in the second half of 2000.

Microgravity Programmes

Experimentation in space is not limited to the International Space Station. In particular for physical and life sciences experiments in weightlessness, ESA also makes use of European sounding rockets, Russian retrievable capsules and the US Space Shuttle. Space itself is not a prerequisite for microgravity experiments, since parabolic flights or drop towers and tubes provide at least several seconds of weightlessness conditions of Earth. These carriers and facilities can usefully complement or help in preparing and validating experiments in space. Their activities are covered by the microgravity programmes EMIR-1, EMIR-2 and EMIR-2 Extension.

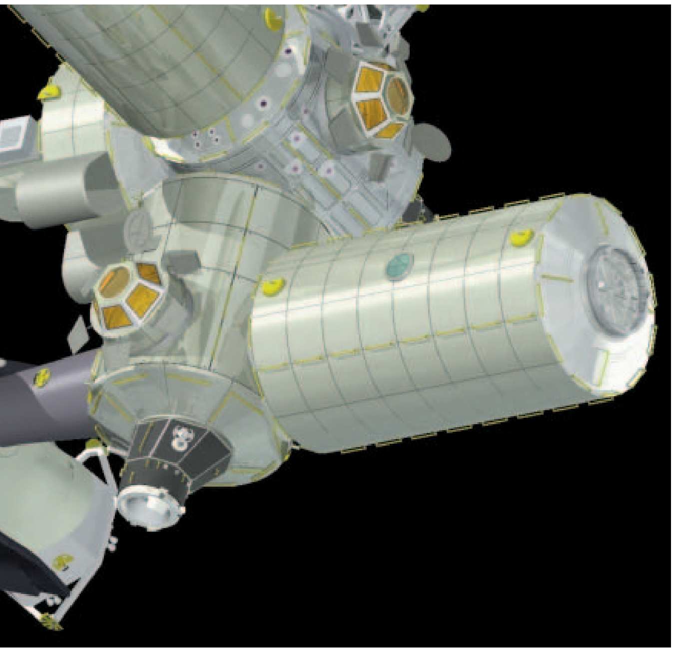
Sounding rockets offer short turnaround times of 1-2 years between experiment approval and flight, since there are a large number of reusable experiment modules available for a broad spectrum of investigations. At the ESRANGE sounding rocket launch site in Kiruna, Sweden, ESA and the Swedish Space Corporation have set up over the past 15 years an excellent infrastructure for the launch of three types of sounding rockets providing 3-13 minutes of microgravity, and with well-equipped laboratories for experiment preparation. During the last 2 years, the Maser 8 mission, the Maxus 3 mission and two MiniTexus missions (MT5 and MT6), all of which were 100% funded by ESA, have flown successfully. The most recent mission was Maser-8, launched on 14 May 1999 from Kiruna. The payload was safely brought back to the launch site by helicopter about 1.5 hours after lift-off. Despite significant technical difficulties that had to be overcome during the development of the flight hardware, and despite a number of problems that had to be solved during the launch campaign, all five onboard experiments were executed successfully and interesting scientific results have been achieved. Also, the new Maser Service Module performed according to expectations.

Preparing for the launch of MiniTexus 6 from Kiruna.

Based on the high scientific return, the use of sounding rockets has always received the unanimous support of the ESA Advisory Groups. The EMIR-2 Extension Programme will therefore continue to cover sounding rocket activities over the coming years. This, together with Germany's national sounding rocket campaigns, will maintain a viable sounding rocket programme for Europe. The next missions in preparation are Texus-37 and -38 in March 2000, Maxus-4 in April 2001 and Maser-9 in November 2001.

On 9 September 1999, the Russian Foton-12 capsule with 11 ESA experiments onboard was launched from the Plesetsk cosmodrome and returned 15 days later to Earth, landing near Orenburg, Russia. The experiment hardware was in excellent condition. Besides ESA, the German space agency DLR, the French space agency CNES and the Russian space agency Rosaviakosmos also provided the mission's scientific payload.

On Foton-12, ESA's new FluidPac facility made its maiden flight, marking the introduction of ESA fluid physics experiments on Foton. For Biopan it was the



ESA is a major partner in the Crew Return Vehicle and is providing the multi-window cupola. (ESA/Ducros)

third operational flight. Out of Foton's 11 ESA-sponsored experiments, only one fluid physics experiment could not be activated in space because of a hardware malfunction. FluidPac with its TeleSupport Unit, Biopan and the autonomous experiments (Algae, Symbio I and Symbio II, Stone) were all returned, and the evaluation of the experiment data is in progress. The Agat furnace, provided by DLR and utilised 50% by ESA-selected experiments, also performed nominally. Negotiations are underway with our Russian partners on a further Foton mission.

Future Flight Opportunities

EMIR-2 also provides for the use of the US Space Shuttle for flying ESA experiment facilities. The next will be the reflight of the Morphological Transitions in a Model Substance (MOMO) and the flight of the Granada small and passive protein diffusion and crystallisation package, on STS-101/Spacehab. This is a logistics flight to the International Space Station scheduled for 2000, after the launch of the Russian Service Module.

The STS-107/Spacehab mission in early 2001 will see an important European payload. In the framework of the ESA/NASA arrangement on the delivery of a Supper Guppy aircraft for the transport of Space Station elements to NASA, ESA will have the right to fly Biobox-5, the Facility for Adsorption and Surface Tension (FAST-2), the Advanced Protein Crystallisation Facility (APCF-6) and Biopack. In addition, ESA has procured on a commercial basis from the Spacehab company the necessary additional resources for flight of the Advanced Respiratory Monitoring System (ARMS).

Although no further Spacehab flights after STS-107 have yet been firmly manifested by NASA, we expect they will materialise. As an alternate option for microgravity payloads, it can be assumed there will be flight opportunities on Space Shuttle Station assembly flights. Although their typical durations of 8-10 days are shorter than the normal 16-day Spacehab flights, we believe that most of the ESA-sponsored experiments selected for flight could be carried out using these assembly flight opportunities. We are therefore exploring the possibility of flying Biopack experiments on assembly flights with the Space Shuttle.

One of the assembly flights is already envisaged for use by ESA: mission STS-105/ISS 7A1, scheduled for end-2000. The Advanced Protein Crystallisation Facility (APCF) is scheduled for this mission. It will be accommodated in an Express rack in the US 'Destiny' laboratory for 10 weeks and returned to Earth with the Shuttle flight STS-106/UF-1.

ESA also continues to use the Airbus A300 zero-g aircraft of CNES/Novespace for experiments under microgravity conditions. The 27th ESA parabolic flight campaign, the fourth with the A300, took place last October in Bordeaux. Eleven experiments were part of the campaign, four in physical sciences and seven in life sciences. They involved investigators from 18 research institutes from Belgium, Denmark, France, Germany, Italy, Sweden and the USA. It was the first use in microgravity of ARMS.

The use of carriers such as sounding rockets, Spacelab (until its last mission, Neurolab, in April 1998), Spacehab, the Mir station and the Foton capsules over the last decade has provided the foundation for a strong intensification of microgravity research and applications activities in Europe. This has contributed significantly to improving basic scientific knowledge and has led to practical applications that have helped to improve products and services with considerable impact.

Last year, the European Academy of Sciences and Art published the report *European Interest in the Scientific Utilisation of Space Station – Fluid Physics, Material Sciences and Combustion* which clearly identified the expressed and published interest of scientists for conducting experiments, among others, in combustion, crystal growth, foam research, magnetic fluids, solidification, thermophysical properties and the use of magnetic fields in crystal growth. Furthermore, the results of a statistical analysis show that many hundreds of European scientists have participated in space life sciences research. The results also indicate that this research community is increasingly integrated with ground-based biomedical research and that spaceflight is seen as a real research tool for addressing not only specific questions related to microgravity but also fundamental questions of general interest.

A Network of Users

The ESA Programme for the European Participation in the International Space Station includes a strong utilisation promotion element. The strategy is to bring researchers from academia with experience in microgravity experimentation into contact with researchers of industrial research and development laboratories. The contact is established by setting up 'Topical Teams' addressing topics with high application potential. The first Announcement of Opportunity in Physical Sciences and Microgravity Applications had a very positive response from teams made up by members from both industry and academia. The high interest of industry in microgravity applications is reflected by the significant financial participation of industry in the proposed joint projects.

The increasing interest in microgravity experimentation is the result of a strong internationally recognised community in science and industry that has been built up in the last 15 years. During that period, although there were many individual flight opportunities, only limited numbers of experiments in each topic could be carried out with little continuity or possibility for extensive iterations. This situation will radically change with the start of International Space Station utilisation which, thanks to continuous availability over at least a decade, will allow microgravity research and applications programmes to be carried out in a more systematic and iterative manner.

You can see from this tour d'horizon that we have interesting times behind us and we are heading for even more interesting times!

I am confident, therefore, that *On Station* will become your faithful companion on our journey into the future, and I hope that it will be an esteemed in-flight magazine for the whole International Space Station and Microgravity communities within and beyond Europe. ■

ESA and the Crew Return Vehicle (CRV)

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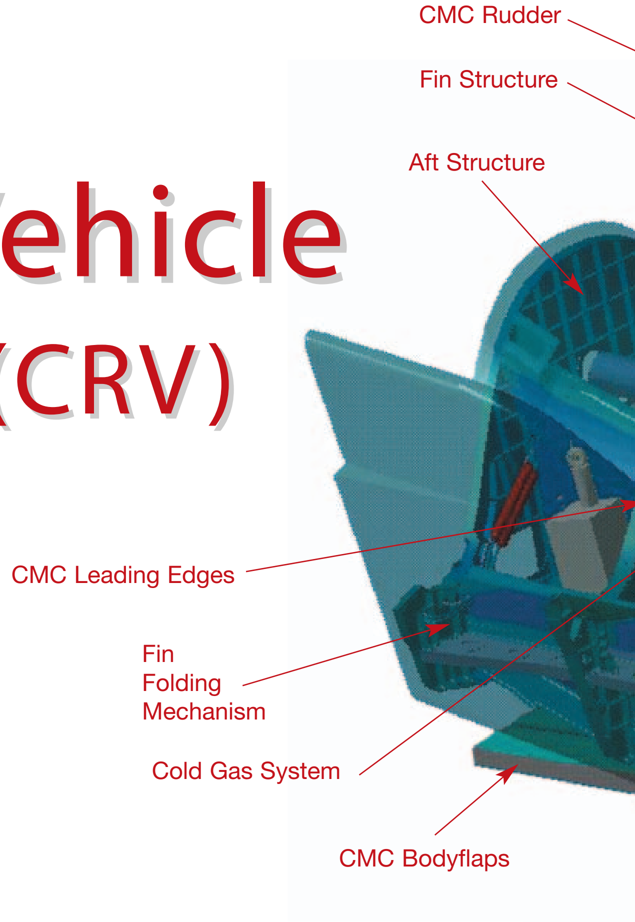


The CRV will be used from about mid-2005 as 'ambulance', 'lifeboat' or as alternate return vehicle for the crew of the International Space Station (ISS). ESA's participation in developing this next manned spacecraft will be significant, building on the Agency's responsibility for 15 subsystems and major elements of the current X-38 prototype.

Building upon the highly successful partnership with NASA for the prototype X-38 spacecraft, ESA will play a significant role in the development and production of the operational CRV

ESA is issuing the Statement of Work for the CRV Phase 1 by the end of 1999, appropriately phased with NASA's Request for Proposals, and is synchronising the detailed design activities performed by ESA contractors with the overall vehicle design activities performed by US industry during Phase 1.

ESA and NASA agreed in 1997 that it would be mutually beneficial to extend the X-38 partnership to the CRV. These early agreements at programme management level were followed up by a NASA/ESA Protocol on X-38/CRV Cooperation, signed in November 1998.

At the May 1999 ESA Ministerial conference in Brussels, it was decided to link a European contribution to the CRV programme with ESA's ISS exploitation phase commitments. Following ESA's detailed programme proposal to the Manned Space Programme Board, confirmed and expected contributions by Belgium, France Germany, Netherlands, Italy, Spain, Sweden and Switzerland are substantial.

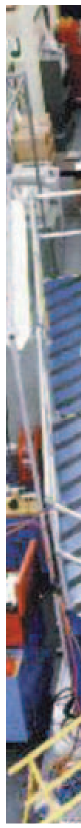
The scope of the participation will be beyond the X-38 partnership and will include additional major subsystems or elements, like the novel international berthing/docking system, fin folding and trunnion retraction mechanisms, cold plates, crew seats and the cold gas attitude and orbit control subsystem.

ESA will also be responsible for system engineering analyses, interface management for ESA elements, assemblies or subassemblies and integration or pre-integration of vehicle assemblies.

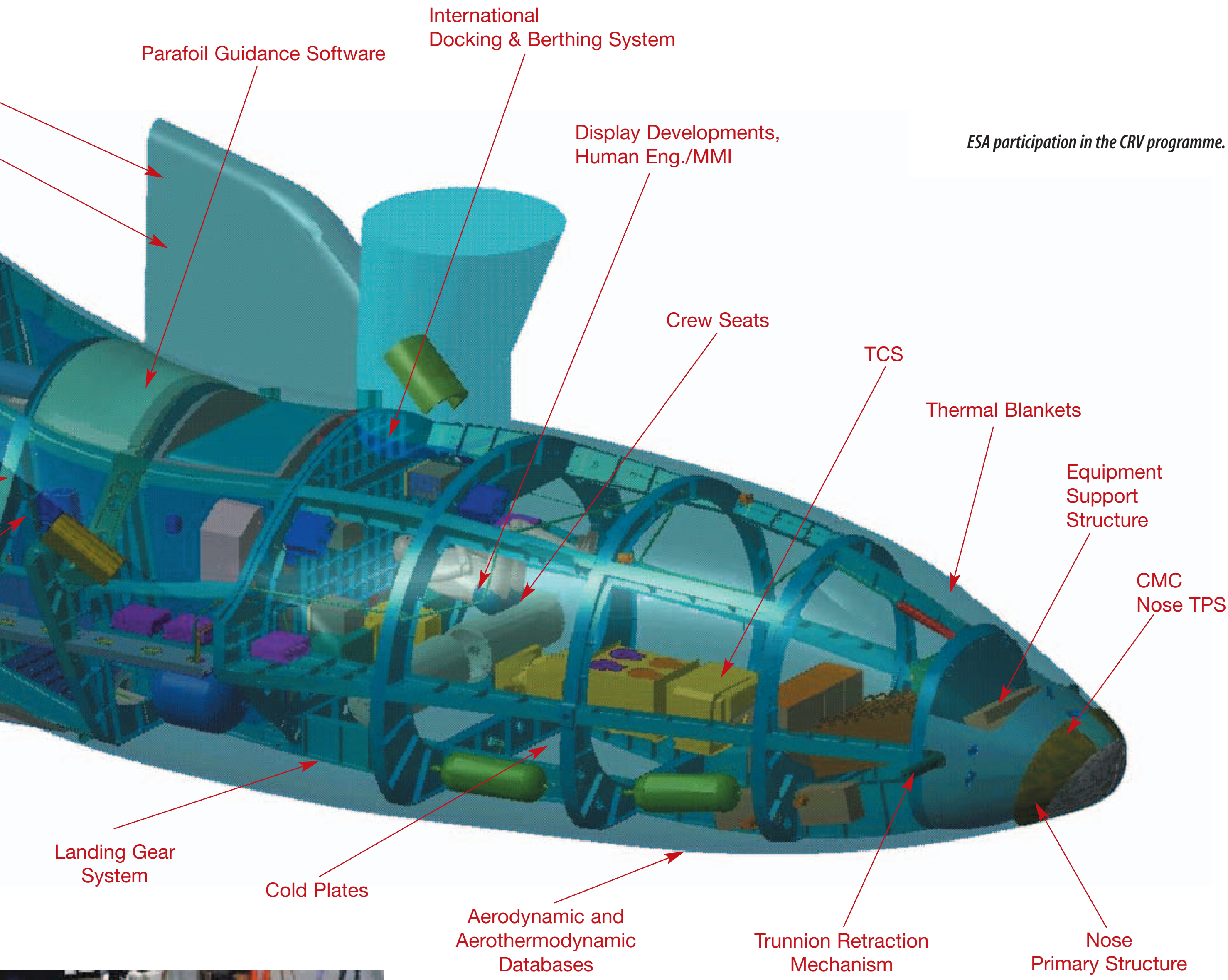
Early activities of the first phase of the CRV Phase C/D are starting end-1999/early 2000. Phase 1 will be completed shortly after the Critical Design Review, scheduled for August 2002. Phase 2 will start in October 2002 and will cover production of the four vehicles, ending in 2006.

Building on the considerable knowledge and experience of the X-38 industrial team, ESA will transition from the present X-38 Phase C/D into the CRV Phase C/D, with the programmes overlapping by about 2 years.

ESA's major participation in the CRV programme will ensure that technologies and systems expertise needed for future space transportation systems will already be validated in an operational programme. The envisaged CRV production flight test in 2005 will precede any European demonstration programme resulting from Future Launcher Technology Programme (FLTP) studies. This flight test would be an autonomous, zero crew, early return of the first CRV flight unit when it is replaced by the second vehicle. ■



An article on the X-38 and CRV programmes will appear in the February 2000 issue of ESA's Bulletin.



ESA participation in the CRV programme.

The V201 space-test X-38 prototype is under assembly at NASA's Johnson Space Center.

X-38: a First for ESA

The development of essential systems and technologies for a reusable reentry vehicle is a first for Europe, and sharing the development of an advanced reentry spacecraft with foreign partners is a first for NASA.

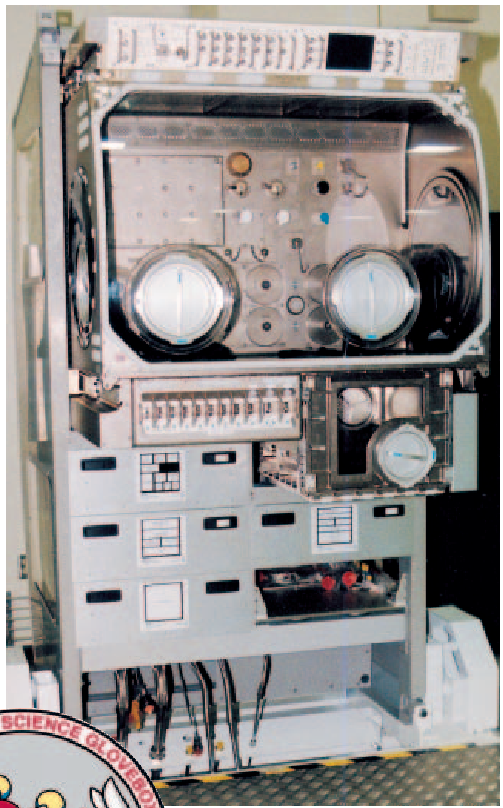
The X-38 programme is using four prototypes: three atmospheric drop-test vehicles (V131, V132 and V133) and a spaceflight test vehicle (V201). V131 has the primary goal of demonstrating the transition from lifting body to parafoil flight. The control surfaces are fixed. It flew successfully on 12 March 1998 and 6 February 1999. V132 is demonstrating the flight control systems using Electro Mechanical Actuators and advanced control software technology. It was successfully flight-tested on 5 March 1999 and 9 July 1999. V133 will have the ESA-modified shape scaled to a 9.1 m length, with the primary objective of verifying the aerodynamic shape modifications as well as the control laws. Construction will begin next year.

Following its two flights, V131 has been refurbished to reflect the modified CRV shape, including the berthing/docking mechanism on the top of the fuselage. This V131R will resume flight testing early next year.

The space test vehicle, V201, will be deployed from Space Shuttle Columbia in February 2002 for a full-up entry test. It is now in assembly at NASA's Johnson Space Center – the primary structure is almost complete, the cabin has been successfully pressure-tested and cabin equipment pallets have been installed. During the last 21 months, 22 Preliminary Design Reviews and Critical Design Reviews for the ESA contributions have been successfully held. The last two CDRs (nose structure and V201 crew seat) were completed in July. The rudders were delivered in November, and all other hardware and software elements are in manufacture, to be integrated into V201 during 2000.

Recent & Relevant

ESA Delivers Glovebox Ground Unit



The MSG Ground Unit at DASA, Bremen (D), ready for shipping to NASA.

ESA made its first rack-level hardware delivery to NASA for the International Space Station in late August when it handed over the Ground Unit of the Microgravity Science Glovebox to NASA at the Marshall Space Flight Center in Huntsville, Alabama. The unit was complemented in October by the Rack Controller (including the Application Software). The MSG Ground Unit will be used to verify experiment interfaces and protocols as well as on-orbit operations.

MSG is a double-rack facility for initial accommodation in the Station's US Lab module. It provides a 255-litre sealed environment with a 100 000 cleanliness level achieved by continuously circulating and filtering the air inside the glovebox. There are two containment levels: one realised by the sealed work volume, the second by maintaining the work volume's pressure below ambient. The glovebox is thus particularly suited for handling hazardous materials and repair and maintenance tasks in a manned vehicle. MSG experiments will be supplied with ISS resources such as data links, water and air cooling, vacuum/venting, gaseous nitrogen, and 120 Vdc as well as several converted power levels.

The delivery of the Training Unit and the Flight Unit are planned for February and August 2000, respectively. Launch is expected on Utilization Flight UF-1 in January 2001. MSG's ownership will be transferred to NASA after the on-orbit commissioning phase.

MSG is an element of ESA's Laboratory Support Equipment programme, as defined by the ESA/NASA Memorandum of Understanding enabling Early Utilisation Opportunities on the International Space Station ISS. Its development and qualification activities are contracted to an Industrial Consortium led by DaimlerChrysler Aerospace (D) with the participation of Bradford Engineering (NL) and Verhaert (B). ■

Success for SUCCESS

ESA's competition for student space experiments came to a climax in October with the awards ceremony in Amsterdam. The teams for all 15 final proposals were invited to a special event during the International Astronautical Federation congress to hear the three winners announced. The team of the best proposal will now spend time at ESTEC developing their experiment for testing on a microgravity parabolic-aircraft flight campaign. In time, some of the experiments may even be adopted to fly on the International Space Station (ISS).

Presenting the awards on 8 October 1999 at the Amsterdam RAI conference complex was ESA's Director of Manned Spaceflight & Microgravity, Mr Jörg Feustel-Büechl, supported by Karl Knott (Head of Microgravity & Space Station Utilisation Department), Ulf Merbold (Head, ISS Utilisation and Microgravity Promotion Division) and ESA astronaut André Kuipers.

The *Space Station Utilisation Contest Calls for European Students' Initiatives* (SUCCESS) competition kicked off in November 1998 after ESA decided to involve the future generation of space users in the ISS as soon as possible. Almost 1000 universities in Member States were notified and a website was activated, resulting in more than 500 registrations of interest. By the deadline of 12 March 1999, 126 students had provided 103 preliminary brief essays. These were evaluated by the independent Space Station User Panel (SSUP), a group of European scientists responsible for selecting the Agency's ISS experiments. The SSUP chose 50 proposals, involving 65 students. From these, 26 full proposals were received by the 27 August deadline for consideration by ESA's own expert panel. Ulf Merbold, ESA's SUCCESS manager following the retirement of Alain Gonfalone, commented, "We were very impressed with all the proposals – we even received detailed engineering drawings and funding projections."

ESA then forwarded 15 to the SSUP for detailed analysis: 8 Technology, 4 Physics/Material Science, 2 Life Sciences and 1 Earth Observation.

As in all good competitions, the winners were announced in reverse order, with Mr Feustel-Büechl wrily noting, "The life of an ESA Director is often a difficult one, but from time to time there comes a moment of pleasure – and SUCCESS is one such moment!"

The third prize of a trip to see the launch of an Ariane (Kourou) or Space Shuttle (Cape Canaveral) was awarded to Anna Glenmar and Alexander Roger for their "ATTISTA" proposal of a gyro-stabilised pointing unit for attaching to cameras, torches and so on to allow astronauts to work hands-free.

The second prize of a laptop was won by Paolo Ariaudo for his plan to mount an Earth-viewing video camera on the Space Station truss for broadcasting to schools and the public via the Web.

The winning entry came from the 4-man team of Jose Mariano, Fernando Mancebo, Daniel Meizoso and Pablo Vals. Their Orbital Liquid Experiment (OLE) would study the behaviour of liquid droplets in microgravity. As their prize, each team member will spend 3 months at ESTEC preparing their experiment for a flight campaign on the Novespace A300 Airbus based at Bordeaux. ■

The SUCCESS winners receive their certificates from Mr Jörg Feustel-Büechl.

Orbital Liquid Experiment (OLE)

J. Mariano, F. Mancebo, D. Melzoso & P. Vals (Polytechnic University of Madrid)

OLE is a compact but versatile fluid physics mini-laboratory housed in the European Drawer Rack to study the gravity-dependence of certain fluid phenomena, particularly fluid drop impacts and thermocapillary non-coalescence. A rotating platform simulates different gravity levels, with a set of syringe needles generating droplets of different sizes. The behaviour of drops impacting on the flat surface of the same fluid in a container are recorded by a CCD camera. Depending on the conditions, drops can bounce off the surface, coalesce or coalesce briefly before a different drop emerges. In thermocapillary non-coalescence, spontaneous coalescence between drops of the same liquid can be permanently inhibited by imposing a temperature difference to drive thermocapillary surface flows. These draw air into the layer between the drops, preventing merger. This is a new and promising field of study; an envisaged application is the production of perfectly smooth self-centring and almost frictionless bearings.

SEE-US (Space Earth Observation Experiment for Universities and Schools)

P. Ariaudo, Microgravity Advanced Research & Support Centre, Italy

SEE-US uses a simple CCD camera with a 300-500 mm focal length lens and autonomous transmitter to broadcast 30x30 km Earth views from the ISS to low-cost ground stations in schools and universities. As a secondary payload, it shares volume and power with an existing ESA payload on a nadir-pointing External Pallet. The whole of the Earth would be imaged in 2-3 years, relaying one or two images on every pass at 64-256 kbit/s. A 1024x1024-pixel CCD image requires about 1 Mbyte and up to 1 min to transmit.

ATTISTA: An Attitude Stabilisation Device for Free Floating Tools

A. Glennmar, The Royal Institute of Technology, Sweden

A. Roger, University of Glasgow, UK

ATTISTA is a 3.4 kg clip-on attachment for holding free-floating equipment such as cameras and lights in a fixed orientation for astronauts working aboard the Space Station. It uses 4 cm-diameter reaction wheels in a closed control loop and either three rate gyros or a CCD vision system to control and sense body rates. The CCD is preferable because the pointing is fixed within the Station frame of reference, whereas the gyro's inertial pointing drifts with the Station's own motion. ATTISTA's pointing accuracy is at least 1-degree. Depending on the battery and motors selected, the running time could be about 5 hours.

Recent & Relevant

ESA astronaut André Kuipers (centre) works with the Advanced Respiratory Monitoring System (ARMS) during the 27th ESA parabolic flight campaign of 26-29 October aboard Novespace's Airbus A-300 aircraft in France. The campaign focused on medical (emphasising respiratory physiology) and physical science experiments. Two employed ARMS, planned to make its space debut aboard Space Shuttle STS-107 in 2001. ARMS produces electrocardiograms and respiratory gas concentration/flow and blood pressure measurements of human test subjects.

ESA will run two parabolic campaigns annually over the next 4 years. Scientists are regularly invited to submit experiment proposals for review and selection by peers. ESA is including student experiments to encourage the scientists of tomorrow to learn about experimentation in weightlessness and the extensive research opportunities offered by the International Space Station. Further information on ESA parabolic flights can be found at: http://www.estec.esa.int/spaceflight/parabolic ■

STAFF NEWS

New Head of Programme Integration

Manuel Valls took over as MSM's Head of the Manned Spaceflight Programme Integration Department on 1 September. *On Station* asked him about the position and his experience in the space field:

Manuel Valls.

"My job has two equally important facets. One is programme control, which takes account of planning and monitoring of costs, schedules and geographical returns for all the various programmes and projects within the Directorate, such as Columbus and ATV. The other is the development of programme policy, which essentially encompasses the negotiations of agreements with the other International Partners, such as implementation of memoranda of understanding and barter agreements, agreements with Member States and inter-directorate agreements.

"For the last 28 years I have devoted myself to the aerospace sector. First, in aircraft design, then in several space programmes, including Spacelab – so I am an early member of the community of manned spaceflight. After a number of years involved in aeroengines, I came back to pure space activities, to which I have devoted my time as a director in my previous company, SENER." ■

New Head of ISS Utilisation and Microgravity Promotion

Marc Heppener recently became Head of Division for ISS Utilisation and Microgravity Promotion. He told *On Station*:

Marc Heppener.

"My job title is quite a mouthful but it means this Division interfaces with all Space Station users. So all first contacts, be they with scientists or industries who want to use Space Station, and in whatever application field, microgravity research, technology, Earth observation or space sciences, all initial contacts will be here, and we see to the evaluation and selection of new projects. Of course, we also actively promote all types of utilisation on Space Station. In the microgravity area it is a little broader: we also solicit experiments for Spacehab flights, sounding rockets and parabolic flights. When the projects are selected, they are transferred to the Divisions responsible for the development, integration and operation of hardware, but we remain in the loop for the scientific aspects.

"I trained as a chemist and also in bio-chemistry, so I know a little bit about biology. In addition, my PhD dealt with spectroscopy, which later helped me enormously in understanding problems in Earth observation and astrophysics. I have been working at the Space Research Organization of the Netherlands (SRON), where I was initially responsible for X-ray detector development for space science and later then became responsible for 10 years for the Dutch scientific programmes in microgravity and Earth observation. So I hope that I bring expertise in at least three different disciplines that will make use of Space Station: microgravity, Earth observation and space science. And I also developed many contacts with government and industry. For the last 10 years, I was Dutch delegate to many ESA programme boards, and for the last 3 years I was chairman of the microgravity programme board." ■

Recent & Relevant

New Head of EAC

Ernst Messerschmid will take over as Head of the European Astronauts Centre on 1 January 2000. Dr Messerschmid flew as a Payload Specialist on the Spacelab-D1 mission in 1985.

Jean-Pierre Haigneré became Head of the Astronauts Division in ESA's Directorate of Manned Spaceflight and Microgravity and Deputy to the Head of the European Astronauts Centre on 1 November 1999. Mr Haigneré returned safely to Earth on 28 August after his 189-day flight as part of the Soyuz-TM29 expedition to the Mir space station. He was the fourth ESA astronaut to board Mir, although he had already visited Mir in 1993 as a CNES astronaut. These missions make him the Western European space duration record-holder.

SNIPPETS

EXPOSE: the kick-off for Phase-C/D with the prime contractor Kayser-Threde (D) for the space exposure facility for exobiology took place on 4 October 1999. The Engineering Model and hardware for the scientific ground preparation programme will be ready in mid-2001; the Flight Model is expected to be available in early 2002.

TEXUS: the next sounding rocket flights, the TEXUS 37/38 double campaign from ESRANGE, are planned for March 2000.

APCF: the two Advanced Protein Crystallisation Facility flight units are being refurbished at Dornier (D) for new missions on Space Shuttle STS-107 in January 2001 (see below) and aboard the International Space Station in late 2000.

STS-107: ESA's payloads for the 2001 Shuttle/Spacehab mission are expected to be Biobox-5, FAST-2, APCF (see above), Biopack and ARMS.

Biolab: the system CDR is expected in early 2000 for the Columbus facility that will support biological experiments on microorganisms, animal cells, tissue cultures, small plants and small invertebrates.

FSL: the subsystem CDRs for the Fluid Science Laboratory are planned for early 2000, with the system CDR by mid-2000.

EPM: the end of Phase-B for the European Physiology Modules is expected in early 2000, with the goal of beginning Phase-C/D by mid-2000. The Phase-B mid-term presentation with prime contractor OHB (D) was successfully held in October 1999.

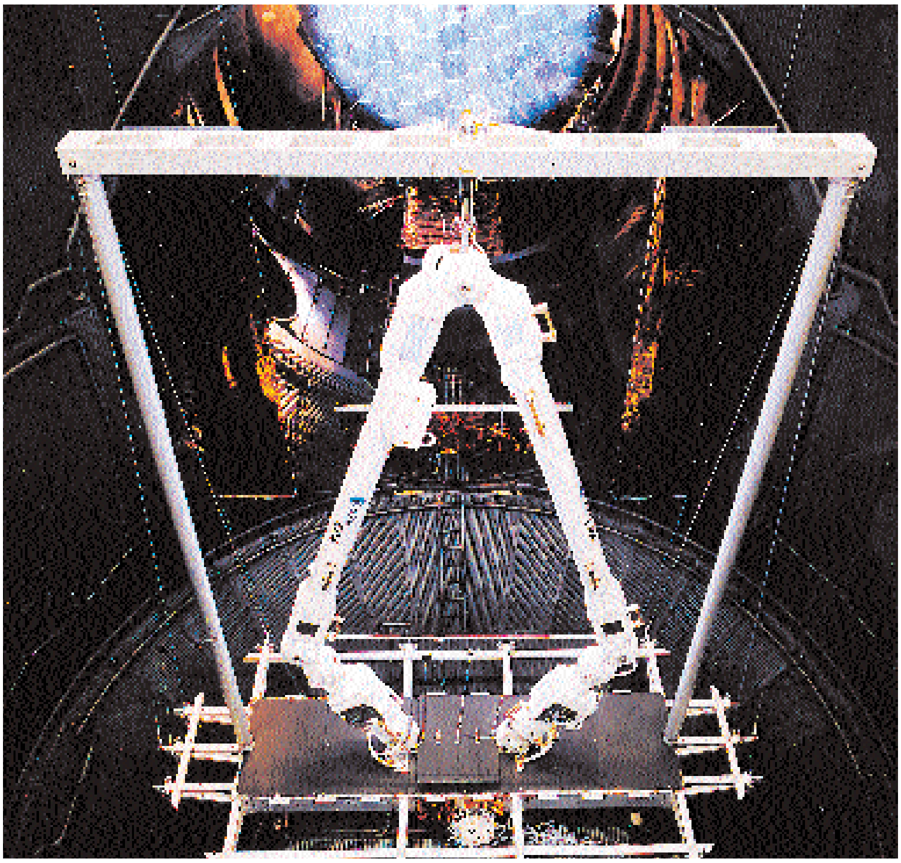
PCDF: delivery of the Protein Crystallisation Facility flight unit by prime contractor Dornier is planned for May 2002. Phase-C/D began 22 June 1999. PCDF will be accommodated in a European Drawer Rack aboard Columbus.

PEMS: the Critical Design Review of the Percutaneous Electrical Muscle Stimulator is expected in January 2000. PEMS is being supplied by ESA as part of NASA's Human Research Facility on the US Lab; it stimulates specific human muscle groups to study muscle atrophy in weightlessness. Launch will be about March 2002.

Russian Confinement Study: ESA is participating in the study at the Moscow Institute of Biomedical Problems of four test subjects confined in the Mir Simulator for 240 days (until 20 February 2000) and four in the Mars Spaceship Simulator (110 days, concluded in November 1999).

EMCS: Phase-C/D for the European Modular Cultivation System began formally at prime contractor Dornier at the end of November 1999. EMCS will fly aboard the US Laboratory of the Space Station.

NEW PUBLICATIONS: two new volumes have recently been issued. The 188pp *Exobiology in the Solar System and The Search for Life on Mars* (SP-1231) is available at a cost of 70 Dutch Guilders or EUR32 from ESA Publications Division, ESTEC, Postbus 299, 2200 AG Noordwijk, The Netherlands (fax: +31 71 565-5433). The 41pp *Columbus: Europe's Laboratory on the International Space Station* (BR-144) costs 20 Dutch Guilders or EUR9. It can also be viewed at <http://esapub.esrin.esa.it/br/br.htm>.



ERA Testing at ESTEC

The Engineering/Qualification Model (EQM) of the European Robotic Arm (ERA) underwent a week of thermal balance tests during November 1999 in the Large Space Simulator at ESTEC. Assembly of the Flight Model at Fokker Space <http://www.fokkerspace.nl/products/era/era.htm> is expected to be completed in May 2000, with delivery to Moscow targeted for end-2000. Launch is planned for November 2001 aboard the Space Shuttle as part of Russia's Science & Power Platform cargo.

Three ESA Astronauts Flying on

This is the second Hubble servicing mission for Claude Nicollier. (NASA)

Picture below: Jean-Francois Clervoy is the robot arm (top right) lead operator for the latest Hubble servicing mission. (NASA)

Nicollier & Clervoy: STS-103 Hubble Servicing Mission

For only the second time, two ESA astronauts will fly together on the Space Shuttle, aboard the STS-103 servicing mission to the Hubble Space Telescope. With launch planned for December as *On Station* went to press, Claude Nicollier and Jean-François Clervoy are part of the 7-man crew that will visit Hubble earlier than previously planned because of problems with the telescope's pointing gyroscopes.

The Third Servicing Mission (SM3) was originally scheduled for June 2000, with Nicollier participating, but it became clear in March that Hubble's pointing system might not survive that long. Science operations require at least three gyros but redundancy was lost when the third of the six failed early this year. SM3 was thus divided into two flights, so that SM3A can replace all six gyros, a guidance sensor and the main computer. The astronauts will also fit Hubble with a new transmitter and solid-state recorder, and add new thermal blankets.

SM3B will complete the remaining upgrades in late 2000, including the replacement of ESA's pioneering Faint Object Camera with a new Advanced Camera. The FOC will be returned to Earth but its eventual resting place has yet to be decided. ESA contributed a 15% share to Hubble's

development and European astronomers receive in return a guaranteed 15% share of observing time, although it averages 20% in practice.

Nicollier, an ESA astronaut since 1978 and making his fourth flight, is part of the team that will perform at least four EVAs. An astronomer by education, he took part in the first Hubble servicing mission (STS-61) in 1993, controlling the Shuttle's robotic arm while astronauts on the work end performed the delicate repairs to the telescope. He also served on STS-46 in 1992, using the arm to deploy ESA's Eureca retrievable spacecraft from the Shuttle, and on STS-75 with the Italian Tethered Satellite System in 1996. Nicollier is currently the chief of the robotics branch in NASA's astronaut office and ESA's lead astronaut in Houston.

Clervoy, a member of ESA's astronaut corps since 1992 and making his third flight, is the lead operator of the robotic arm for this mission. He previously served on STS-66 in 1994 using the arm to deploy and later retrieve the German SPAS atmospheric research satellite, and on STS-84 in 1997, a Shuttle mission to the Russian Mir space station.

Details of ESA's astronauts and their activities can be found at <http://www.estec.esa.nl/spaceflight/astronaut/>. The high orbital inclination of STS-99 (57˚) means that it is visible from most of Europe, while the lower-inclination STS-103 (28.5˚) limits its visibility to southern Europe. Check the site at <http://spaceflight.nasa.gov/realdata/sightings/index.html> for sighting from your own location.

Space Shuttle missions involving ESA astronauts are covered in detail at <http://www.ksc.nasa.gov/shuttle/missions/missions.html>.
Photographs can be found at <http://www.ksc.nasa.gov/shuttle/photos/>.
For STS-99, <http://www.jpl.nasa.gov/srtm/>, <http://www.dlr.de> and <http://www.asi.it> provide further information.

Two Space Shuttle Missions

As this issue of On Station went to press, ESA astronaut Gerhard Thiele was expecting to be launched on his first space mission in January, aboard Space Shuttle STS-99. The goal of this 11-day Shuttle Radar Topography Mission (SRTM) is to generate 30 m-resolution digital topographic and radar maps of 80% of the Earth's land surface.

The SRTM radars have already flown aboard the Space Shuttle: the 5.3 GHz US Shuttle Imaging Radar-C in April 1994 and the 9.6 GHz German/ Italian X-band Synthetic Aperture Radar in October 1994. SRTM's major innovation is to fly additional

Gerhard Thiele: STS-99 Radar Mapping Mission

antennas on a 60 m-long mast – the longest rigid structure ever used in space. Simultaneous reception with antennas in the Shuttle cargo bay offers slightly different views of the same locations. Combining them generates 3D topographic maps and dramatic visualisations of the Earth's surface. Processing the 9.8 Tbytes of raw data – the equivalent of 15 000 CDs – will take 18 months.

Thiele and his five international colleagues will spend much of their time monitoring the radars and keeping a close check on the recorders. As well as tweaking the Shuttle's position to make sure the radar systems remain perfectly aligned, the crew also has the tricky task of deploying the 60 m mast within 12 h of reaching orbit. Thiele is teamed with mission commander Kevin Kregel and mission specialist Janet Kavandi on one of the two 12 h work shifts. Thiele and Kavandi are the two crew members trained for emergency spacewalks, so preparing for contingencies were key elements of their training, especially as any one of a number of scenarios could involve a tricky manoeuvre to extend the mast manually.

"If the latches fail to open automatically on command then it should be possible for us to release them manually during a spacewalk," said Thiele. "Even if all goes to plan, the crew will still be very busy. This mission will create a huge amount of digital data at a staggering 270 Mbit every second and it all has to be stored on special tapes using high-rate recorders. Three will be running at any one time and one of our tasks is to ensure there are no problems." Fresh tapes have to be mounted and if any data recorder suffers a problem, there are three backups.

At mission's end, the mast will be folded and stowed but, should it prove stubborn, a small explosive charge can separate it from the Shuttle.

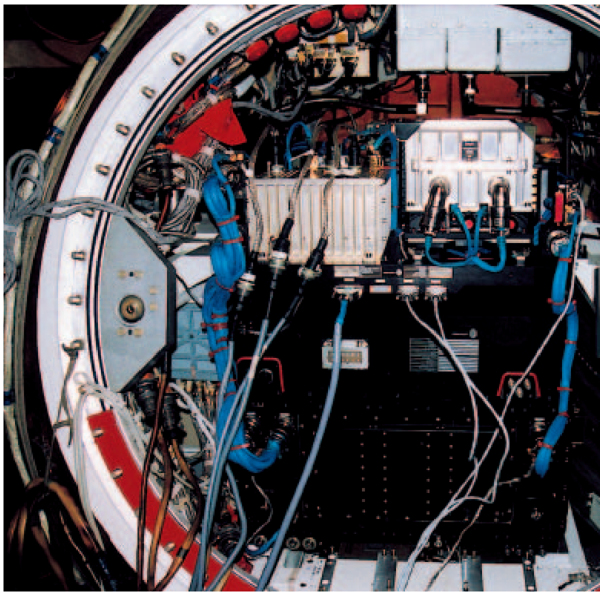
Thiele has been a member of ESA's astronaut corps since August 1998. Born in 1953 in Heidenheim-Brenz, Germany, he always wanted to be an astronaut. After completing his doctorate in physics at Heidelberg University in 1985, he spent 2 years at Princeton University researching into large-scale ocean circulation. In 1988, Thiele began basic astronaut training at the German Aerospace Research Establishment (DLR) and then served as Alternate Payload Specialist for the Spacelab-D2 mission in 1993. He was selected by DARA (German Space Agency) and DLR (German Aerospace Research Establishment) to attend NASA's Astronaut Candidate Training in July 1996, and qualified 2 years later for flight assignment as a Mission Specialist.

"It is important to understand as much as possible about our environment and this is what I think exploration is all about. We are what we are because we have never accepted our boundaries," says Thiele. "For me, going into space is also a very personal challenge. It was just a dream in the early 1960s but dreams can often come true and I am very fortunate to get this opportunity." ■

Gerhard Thiele prepares for underwater EVA training at NASA Johnson Space Center. (NASA)

ESA Success with *Foton-12*

Antonio Verga, Pietro Baglioni & René Demets
Microgravity and Space Station Utilisation Department, D/MSM, ESTEC, Postbus 299, 2200 AG Noordwijk, The Netherlands



ESA's latest mission was flown and completed successfully in September. Here are the preliminary results.

The international Foton-12 mission was launched from the Plesetsk Cosmodrome on 9 September 1999 carrying a large ESA payload. After 14.6 days in orbit, its descent capsule landed safely in SW Russia close to the Kazakh border; the ESA payload was retrieved within hours and carried back to Europe.

Russia's recoverable Foton free-flyers have been used by ESA's Microgravity Programme five times since 1991, but Foton-12 marked a new milestone in terms of payload mass, complexity and scientific diversity. The Agency's contribution amounted to an unprecedented 240 kg – almost half of the total load that Foton is designed to carry. Included was a new facility (FluidPac) with its associated Telesupport unit, which, for the first time, provided scientists with online monitoring of their experiments. Foton's 11 ESA experiments covered fluid physics, biology, radiation dosimetry, material science and meteoritics – another first.

The FluidPac/Telesupport combination enabled the scientists to perform interactive experiments from the ground station at ESRANGE, Kiruna (S) or their home laboratories. Two fluid physics experiments (MAGIA and TRAMP) were successfully performed, while BAMBI suffered a technical failure and had to be aborted.

FluidPac is the first automatic fluid physics instrument flown on Foton. Its multi-diagnostics include two Electronic Speckle Pattern Interferometers, a Wollaston interferometer, three CCD cameras for visual observation and velocimetry, an IR camera and a variety of temperature, pressure and microgravity sensors. Three complex independent experiment containers, sharing a central cooling loop for thermal regulation, were accommodated on a rotating carrousel and positioned under the selected diagnostic during experiment execution. Images and data were processed and stored on a digital tape recorder, as well as being sent to the ground along with housekeeping data via Telesupport. In parallel, Telesupport relayed uplinked commands to FluidPac.

ESA's Biopan exposure facility, completing its fourth flight, performed as hoped. The unit's

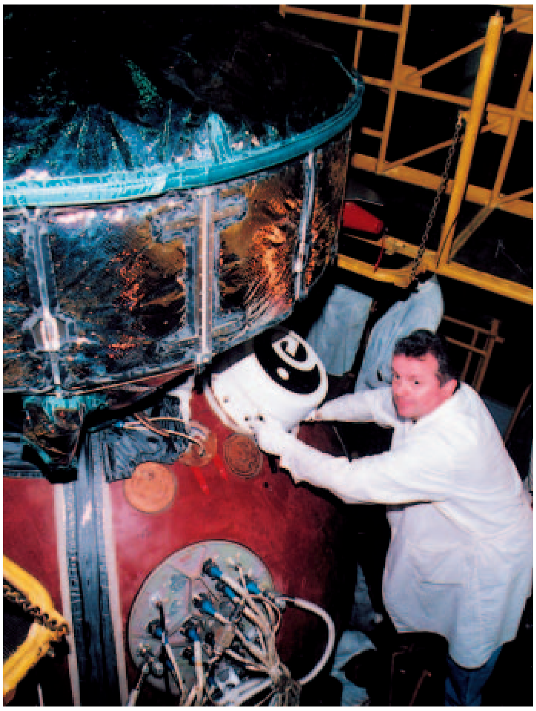


Fig. 2. Biopan integrated on the Foton descent capsule.

Table 1. ESA Experiments on Foton-12

Experiment	*Principal investigator*	*Science field*	*Multi-user facility*
MAGIA	Prof. D. Schwabe (D)	Fluid physics	FluidPac/Telesupport
BAMBI	Prof. J-C. Legros (B)	Fluid physics	FluidPac/Telesupport
TRAMP	Prof. F.S. Gaeta (I)	Fluid physics	FluidPac/Telesupport
VITAMIN	Dr. N. Dousset (F)	Radiation biology	Biopan
YEAST	Prof. J. Kiefer (D)	Radiation biology	Biopan
DOSIMAP	Dr. G. Reitz (D)	Radiation dosimetry	Biopan
SURVIVAL	Dr. G. Horneck (D)	Exobiology	Biopan
SYMBIO	Dr. G. Briarty (UK)	Botany	–
ALGAE	Prof. H. van den Ende (NL)	Cell biology	–
STONE	Dr. A. Brack (F)	Meteoritics	–
Te, In in GaSb	Dr. J.P. Praizey (F)	Material science	Agat

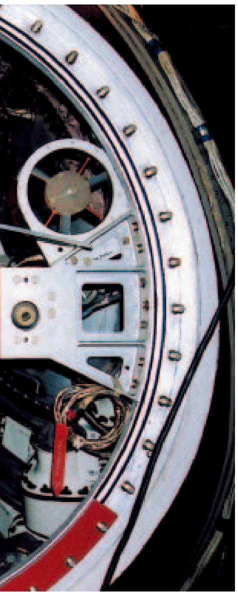


Fig. 1. The FluidPac and Telesupport unit.

motor-driven hinge allows its lid to be opened and closed under ground command to expose its experiments directly to the space environment, and a variety of sensors (radiometer, UV, pressure and temperature) monitor the conditions during flight. The lid was opened on 10 September, 20 hours after launch by telecommand from the Moscow control centre and closed after 303 hours' exposure. The data analysed after flight indicate that the experiments' temperature-control (always difficult for experiments exposed directly to space) worked better than ever.

Biopan's own ablative heatshield successfully protected it during reentry, emerging with remarkably little damage. The unit was returned to ESTEC and the experiments extracted during 28 September.

Like Biopan's four experiments (Table 1), the standalone ALGAE and SYMBIO went as planned and were safely recovered after landing. The novel reentry study, STONE, with simulated-meteorite rock samples embedded in the capsule's heatshield, went well, although one of the three samples was lost during descent.

Another ESA experiment processed three samples in the Agat furnace to investigate the diffusion coefficients of tellurium (Te) and indium (In) in gallium antimonide (GaSb). Other payloads, from France, Germany and Russia, also flew on the mission.

Throughout the mission, Foton-12's status could be closely followed on the Web, where a special homepage was updated daily. Further information can still be found at:

http://www.estec.esa.nl/spaceflight/foton/

From a technical point of view, the mission was undoubtedly a success. The scientific outcome of ESA's experiments looks promising, but it is still too early to provide a definitive view. We plan to be back in the next issue of *On Station* with more comprehensive information! ■

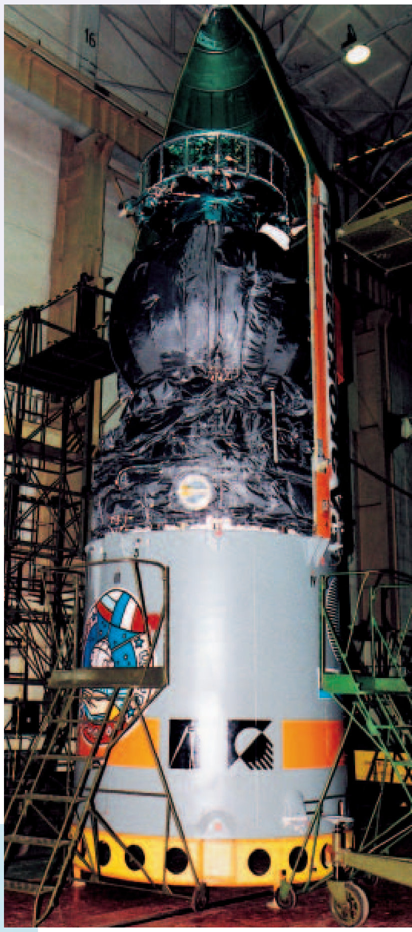


Fig. 3. Foton-12 during integration with its Soyuz-U launcher at Plesetsk. The white Biopan can be seen at top right.

Fig. 4. The 2.2 m- diameter Foton-12 reentry capsule with Biopan, soon after landing.

Focus on ESA's Moscow Office

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ESA's Permanent Mission in the Russian Federation has been stationed in Moscow since 1993 as the outpost of ESA projects in cooperation with Russia. Here, On Station takes a look at its activities.

What Do We Do?

From the very beginning of ESA's activities in Russia, everything possible has been done to establish friendly long-term relations with what is now known as the Russian Aviation & Space Agency (RASA) and Russian partner organisations, and to obtain all possible support from the Russian authorities. Two high-level agreements have been signed between ESA and Russia. That of 1995 granted diplomatic status to the Mission, while 1997's gave ESA the right of tax-free importation of equipment and materials into Russia.

As a small and highly mobile team of dedicated people, we feel privileged to be a focus point of cooperation between Russian and European space industries and government bodies. ESA's Moscow Office now totals nine employees: one Frenchman, one Austrian and seven Russians. Our day-to-day work includes following-up and supporting ESA projects in Russia, developing advanced programmes with Russian participation, issuing a weekly bulletin News from Moscow (for ESA staff, found via the ESTEC TIDC website) covering political, technical and space news in Russia, and logistical support of ESA delegations to Russia.

The office also provides assistance for the customs clearance of equipment and materials imported via Moscow for the needs of various projects. We also organise various public relations events aimed at promoting ESA-Russia cooperation. We are involved in a broad range of activities stretching out from Moscow to TsUP Mission Control Centre in Korolyov, the Plesetsk and Baikonur launch sites, the cities of Novosibirsk and Krasnoyarsk in Siberia and other places all over Russia.

We cooperate closely with ESA's Department of Manned Spaceflight & Microgravity (D/MSM), supporting Permanent Staff located in our office, astronauts under training and, of course, all those actually involved in our contracts with Russia.

Of course, the International Space Station now occupies much of our time. In cooperation with Russia, ESA is supplying the European Robotic Arm (ERA) and the Data Management System (DMS-R) for the Zvezda module. Zvezda, due for launch in November from Baikonur, also carries the European Global Time System (GTS), and the Matroshka biomedical experiment will be added later.

ESA's Automated Transfer Vehicle (ATV) will use Zvezda for docking with the ISS, so there have been large-scale preparatory activities underway for many months. In September, at RSC Energia in the city of Korolyov north of Moscow, the first ATV Management Meeting took place in the framework of the ATV Integration Contract recently established with RSC Energia/RASA. The ESA team was led by Jochen Graf and Patrice Amadieu, and its Russian counterpart by Valeri Ryumin, Energia's

veteran cosmonaut, and Mikhail Sinelschikov of RASA.

Space Station ESA/RASA meetings regularly take place at different levels: I. Directors; II. Department Heads; III. Project Managers. For example, September's ATV meeting was at Level II, under Mr. Sinelschikov and Frank Longhurst, Head of ESA's Manned Spaceflight Programme Department.

Supporting Launch Activities

Russia has a long history of space launches and, despite its current economic, financial and political difficulties, its launchers and launch services continue to demonstrate a strong export capability. Several contracts have been signed to launch ESA payloads on Russian launchers from Plesetsk and Baikonur. ESA microgravity payloads have flown on the Foton and Bion spacecraft since 1992, and Foton-12 in September made a successful flight carrying 240 kg of ESA-sponsored hardware A joint ESA/industry team spent more than 2 weeks working hard at the Plesetsk cosmodrome in northern Russia getting the experiments ready. ESA's Moscow Office, of course, supported the team in its activities in Russia, including logistics, interpretation and – perhaps the most important – helping to create understanding with the team's Russian counterparts and making things happen in a most efficient and European-like way.

There will be more launches of ESA payloads on Russian launchers: two Cluster flights on Soyuz in summer 2000, Integral on Proton in 2001 and Mars Express on Soyuz in 2003. We hope there will be a Foton-13 in 2 years.

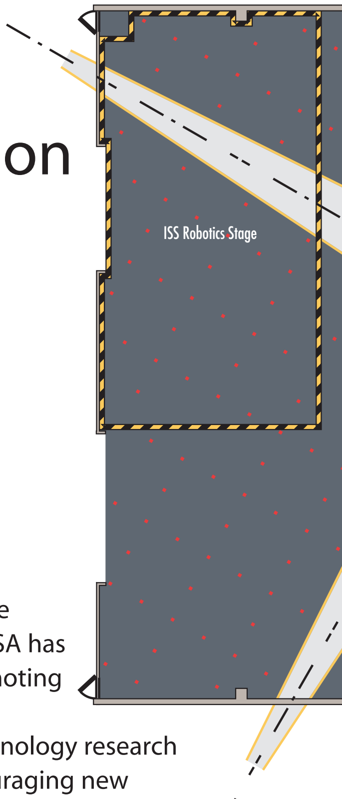
Elsewhere, the Moscow Office facilitates cooperation with Russia on technology and expertise of space interest for European industry. For example, reentry technologies and thermal protection has been a traditionally strong area of research in Russia. ESA is now engaged in the Inflatable Reentry Demonstration Technology (IRDT) Project financed via the International Scientific & Technical Center (ISTC), together with the specialists of NPO Lavochkin. ■

Alain Fournier-Sicre heads the Moscow Office

ESA's Moscow Office supported the Foton-12 team in Russia. Biopan is seen here being installed on the return capsule.

The Erasmus User Centre

Preparing for a New Era in Space Exploitation



Jean-Claude Degavre
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The Erasmus User Centre began operations at ESTEC this summer to promote the International Space Station's utilisation by research communities and to encourage new applications. The Project Manager describes what the Centre offers, and the plans for the future

Introduction

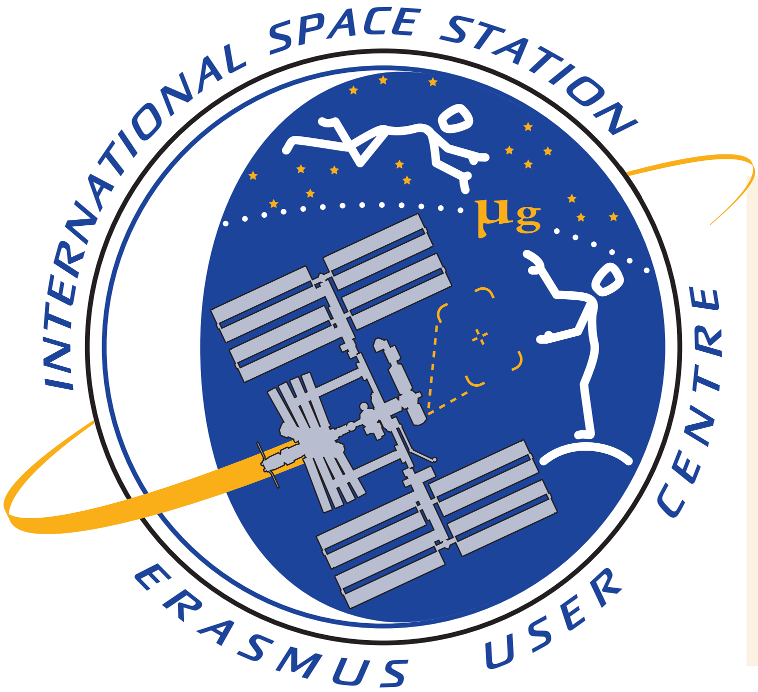
On 28 June 1999, Monique de Vries, State Secretary for Transport, Public Works and Water Management of the Netherlands, and Antonio Rodotà, Director General of ESA, inaugurated the Erasmus User Centre (EUC) at ESTEC, Noordwijk. The Centre is already promoting utilisation of the International Space Station (ISS) by European science and technology research communities, and encouraging new applications.

Why do we Need Erasmus?

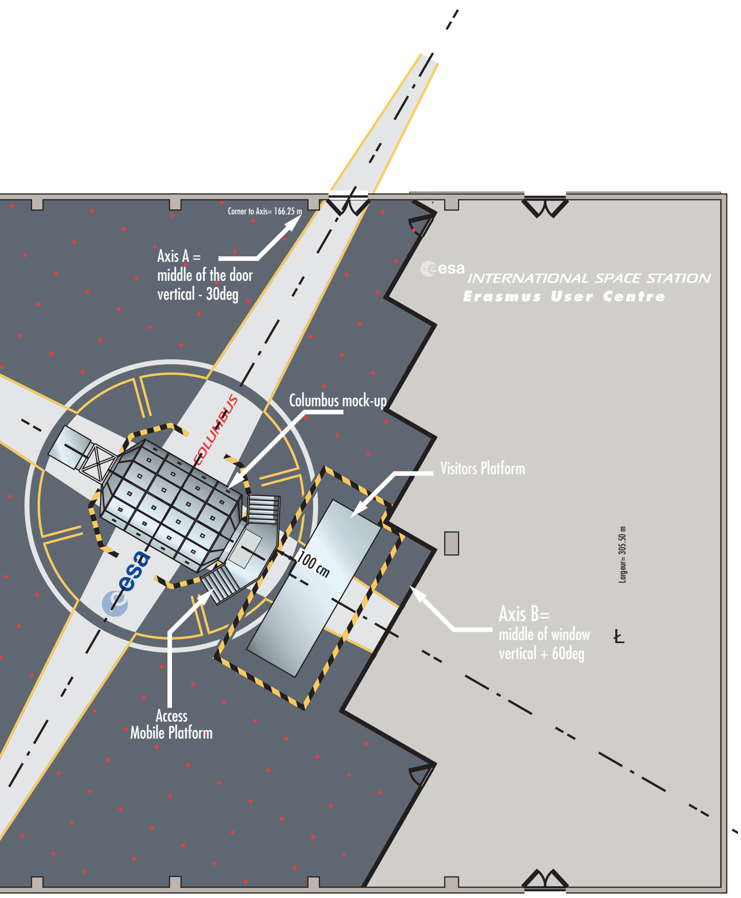
The USA, Europe, Japan, Russia and Canada began assembling the ISS at the end of 1998 and experiments aboard the Station will begin in 2000. In addition to developing major hardware elements for the Station, ESA has the important task of promoting the Station's utilisation by European science and technology research communities, and of encouraging new applications. It must also bring the Station into the public eye and create a focal point in Europe for the media and opinion leaders.

Serving Candidate Users

Experimenters, payload developers and their support organisations need access to an official and centrally controlled source of information on the Space Station. In view of the ISS element development responsibility entrusted to ESA and the established formal links between ESA and NASA, the Erasmus User Centre is best placed to take over this task. The Centre is the *depot legal* for any new information and updates. The information encompasses the entire library of user accommodation documentation jointly established among the



This ambitious centre requires an emblem easily recognised by potential European scientific users, ISS Partners and the general public. This new motif, designed by Maxime Lavie, highlights the name using the official font for ESA's programmes. Its creator wanted to '…symbolise the strong link the Centre will maintain between astronaut-scientists and the on-ground European research teams.' He adds, '…drawing two figures that represent all men and women, of any culture or country, was the most difficult task. I took inspiration from cave paintings, the most universal graphical representation of Mankind.'



The EUC High Bay floor features the futuristic design created by the French designer Maxime Lavie. He explains that he '...tried to emphasise the importance of the Columbus module, installing it in the Centre of a star-shaped geometrical pattern of coloured stripes'. This pattern, covering 800 m², is a symbolic evocation of Europe's goals in its ISS participation. 'It can be seen as a giant shining star, a high-tech spacecraft landing pad, as well as a target for on-orbit rendezvous manoeuvres.'

Space Station Partners. It comprises technical data describing what the user can expect from the Station and what the Station expects from the user. It includes links to the Announcements of Opportunity Web sites and to other utilisation-related programmatics. The information constitutes a 'utilisation database' accessible as much as possible electronically, on the World Wide Web, via the Centre's intranet and via national support Organisations.

The goal is to help candidate users to submit acceptable and innovative experiment proposals.

Familiarising Selected Users

The EUC High Bay houses replicas of all the accommodation hardware available to European users for ISS experiments. The masterpiece is a full-scale mock-up of ESA's Columbus module, including models of its pressurised multiuser facilities and its External Payload Facility for external exposure facilities.

The models show how an experiment can be accommodated mechanically and, later, electrically, and what resources can be provided.

One rack position in the Columbus mock-up includes the Utility Interface Panel (UIP), which provides power, water cooling, data buses, video, nitrogen and vacuum/venting for experiments.

Mechanically high-fidelity models of an International Standard Payload Rack (ISPR, with its transportation frame rack), the European Drawer Rack (EDR, with mid-deck locker and standard drawer rack accommodation) and the European Stowage Rack (ESR) are displayed to demonstrate the logistics and stowage factors affecting the experimenters.

EUC Facilities

High Bay
- 900 m²
- Cleanroom class 100 000
- Mock-up of Columbus module; 1/10th-scale Station model
- ESA-developed multi-user and microgravity facilities (mock-ups, engineering models)
- Standard Payload Outfitting Equipment (engineering models)
- Columbus Laboratory Support Equipment (engineering models)
- ISS Robotics Workshop
- Simulation Workshop
- Visitors gallery

Multimedia Library
- 120 m²
- Visualisation of on-line or recorded Space Station data and video; International Space Station voice loops; access to Internet, Intranet sites and Data Bases; ISDN interfaces
- Multi-purpose video wall screen (2.2x3 m)
- Exhibits, tutorials

Virtual Reality Theatre
- Immerse stereo wall or 3-D effect (10-25 visitors sitting)
- Single 2.5x3 m screen
- Sound and voice facilities

TV Broadcasting Studio
- Studio floor (12x12x8.5 m high), with lights
- Non-linear video editing and play-out
- Extendable video mixer (16 inputs)
- Chromakey Blue Limbo (6x8x5 m)
- Video interface to graphics station (virtual studio)
- Audio facilities
- Transmit/Receive Ku-band terminal

Columbus is the centrepiece of the High Bay.

For external payloads, models of the Express Pallet Adaptor (ExPA), European Technology Exposure Facility (EuTEF) and Coarse Pointing Device (CPD) are also displayed in the High Bay.

The goal is to show candidate users what global accommodation possibilities are offered by the Space Station and, particularly, by the European elements, and to explain what resources are available taking into account the allocations between Partners, logistics constraints and human factors such as man-machine interface and safety constraints.

Serving the Public

The Centre is linked to the US and Russian launch sites and to the User Support and Operation Centres (USOC), so that live video and voice communications – even with the astronauts aboard the Station – can be organised.

Live and recorded television programmes can be broadcast by the Centre's TV Studio via relay satellites, leased line, ISDN and Internet. The Studio supports interviews and press conferences with call-in from remote sites, including the Station itself. ESA also uses the facilities to edit and play-out ESA video products.

The Press have access to ESA technical experts and managers to organise interviews and thematic events in the Studio. The Centre library will have a Press section with access to PR materials.

The goal is to attract public attention during the space missions of the Station's 5-year assembly, and to maintain a repeated and familiar ESA image to the public during the exploitation phase.

Visiting the Erasmus User Centre

The Centre is designed to receive groups of about 25 visitors without disturbing on-going activities. Visitors are welcomed in a pre-show area that introduces the Station and its utilisation. Then, they are taken to a 1/10th-scale model of the Station where the assembly sequence can be explained. On their way, they can watch activities in the High Bay and contemplate the Columbus module. Then, the Virtual Reality Theatre allows them to 'visit' the Station. On their way, they can see the multimedia library and its video wall with multiple displays of documentation and operational data from space.

The Centre's TV Studio facilities will be increasingly used as the Space Station is assembled. Here, the launch of Zarya is being covered.

Behind the Columbus module in the High Bay are the centre's other facilities, such as the Multimedia Library, TV Studio and Virtual Reality Theatre. In the foreground is the robotics area.

The Future

Building up a Utilisation Database

Building up the utilisation database has started with the creation of the Microgravity Database, covering the data acquired so far from spaceflights. An inventory of all the utilisation-related data and documentation on the future Space Station is being performed by Vitrociset (I). It will be followed by the creation of the database itself and of the navigation tools to make it user-friendly.

As an extension to this database and as a complement to the hardware already available in the Centre, the development of 'digital models' of payload subsystems is envisaged, easily portable on users' own computers to complete their familiarisation and to prepare their experiment accomodation by virtual reality techniques.

Demonstrating Standard Payload Outfitting Equipment

In the framework of the Utilisation Preparatory Programme, ESA is qualifying Standard Payload Outfitting Equipment (SPOE). It includes a water/air heat exchanger, a Remote Power Distribution Assembly and a Standard Payload Computer (SPLC).

Each SPOE item is represented in the High Bay in its working environment with sufficient fidelity for users to appreciate its advantages.

Installation of Test and Operation Facilities

The selected users of a given payload facility will be assisted in the planning, development, integration and operation of their experiments by a dedicated Facility Responsible Centre (FRC). The Erasmus User Centre is responsible for the European Drawer Rack inside Columbus and will host the dedicated user support facilities. The Centre will become a User Support and Operation Centre (USOC) and will be integrated in the decentralised payload operation scheme baselined for exploitating the Station in Europe.

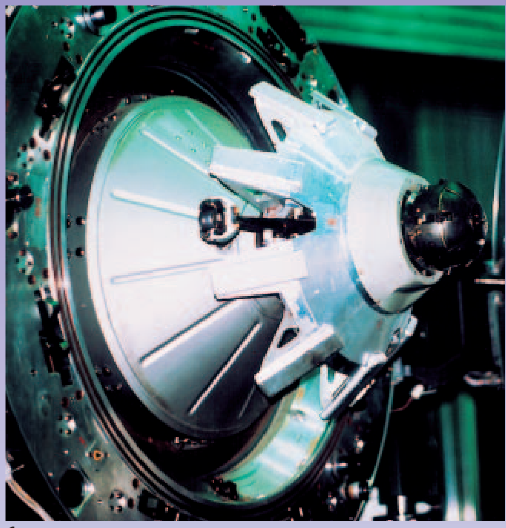
The responsibilities of the EDR FRC located in Noordwijk are under definition but will include:

- planning and integration of the EDR operations;
- acceptance of the drawers in the EDR flight model;
- validation of the experiment operation procedures;
- monitoring of the rack's in-flight performance in comparison with its ground engineering model.

The EDR is a multi-disciplinary payload facility. It will be supported by Experiment Support Centres (ESCs), specialising in particular applications and which could take over specific science operations, such as performing telescience

Visit the Erasmus User Centre web site at:
http://www.estec.esa.int/spaceflight/usercentre

Mrs de Vries, State Secretary for Transport, Public Works and Water Management of the Netherlands (centre), greets four ESA astronauts following the Columbus unveiling, assisted by Antonio Rodotà, ESA Director General (right). From left: Ulf Merbold, Andre Kuipers, Pedro Duque and Wubbo Ockels.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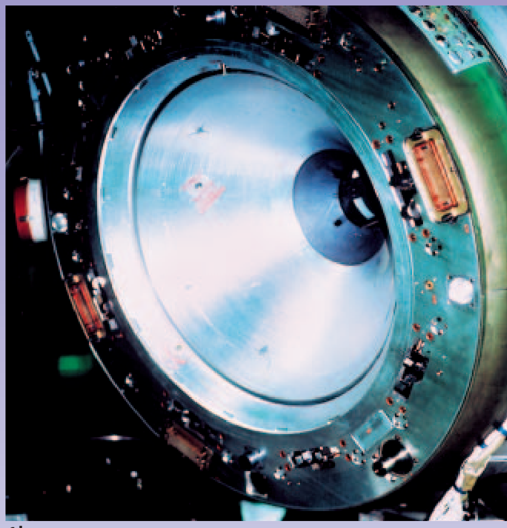
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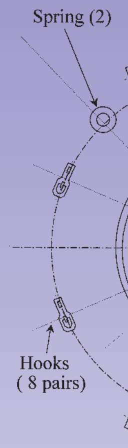

2

Connecting with the *International Space Station*

ATV's Russian Docking System

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6

Introduction

In order to avoid the cost of developing a European docking system and to be compatible with the Russian Segment of the International Space Station (ISS), ESA's Automated Transfer Vehicle (ATV) is adopting a slightly modified Russian Docking System (RDS) of the type used on Soyuz-TM and Progress-M vehicles. The barter agreement was signed in March 1996, under which ESA has provided the Data Management System (DMS-R) for Russia's Zvezda service module and the Agency will receive two flight sets of the docking system's active portion.

Objective

The goal is to allow a harmless contact between the 20 t ATV and the 450 t ISS, dampen their relative motions, align them, and create a rigid mechanical connection capable of transmitting the ATV's reboost and attitude control thrust loads to the Station. The connection is pressurised for access to the ATV Pressurised Module to unload the pressurised cargo, water and gasses. After loading the ATV with Station waste, the RDS allows undocking before destructive reentry into the atmosphere.

Description

The RDS consists of the ATV's 'active' part and the 'passive' section installed on the Zvezda service module.

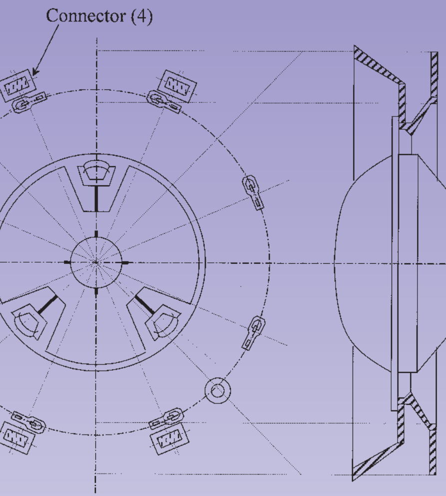
The Active Docking Assembly (ADA) consists of a housing with hooks and connectors, the 80 cm-diameter hatch, an alignment mechanism with three levers and their rollers, an extendible boom, and a probe head with four latches (Figs. 1-3).

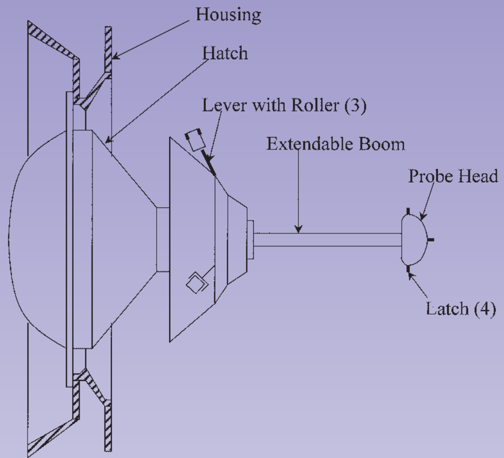
The Passive Docking Assembly (PDA) consists of a housing with hooks and connectors, and the hatch with probe head latch receptacle (Fig. 4).

Operation

Shortly after ATV launch, the ADA boom is extended from its launch position to its docking position, which also extends the three interconnected levers and their rollers. The Latch arm keeps the probe head latches extended.

When the probe head contacts the inner surface of the PDA's cone, the head's four linked petals are compressed (Fig. 5). Below the petals, contact switches transmit the 'contact' signal to the ATV (Fig. 6), which accordingly





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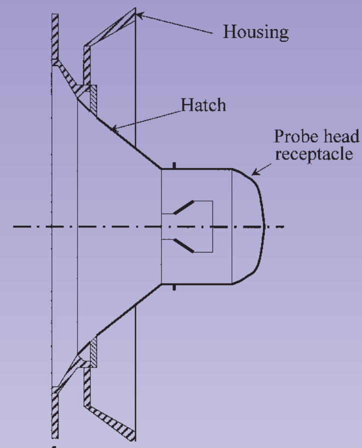

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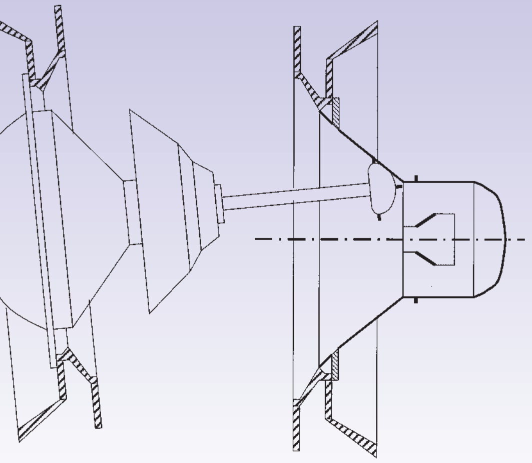

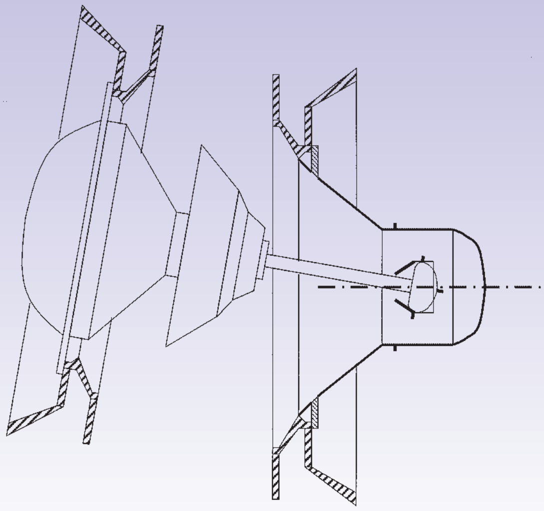

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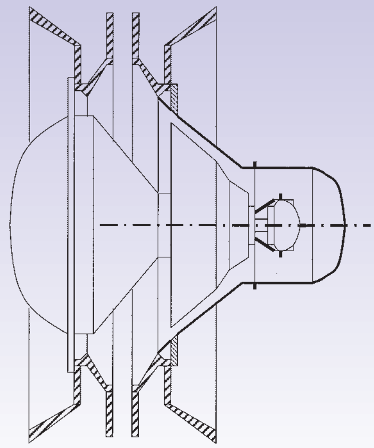

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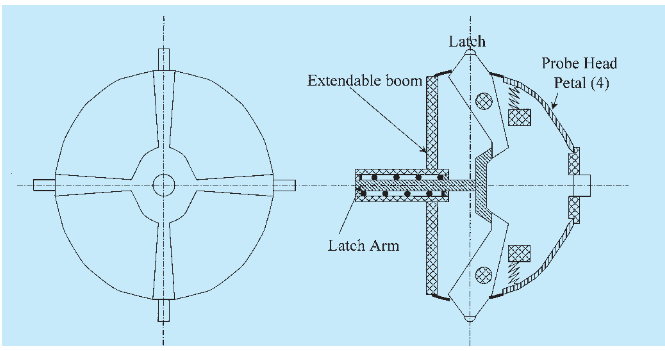


executes a forward thrust pulse. As a result, the probe head slides centrewards over the cone's surface and enters the latch receptacle. A second contact switch on the top of the probe head makes contact with the bottom of the receptacle. The ADA latches engage in the latch cavities. This completes 'capture' or 'soft docking' (Fig. 7). During this action, a system of springs and dampers constrain the boom's axial and angular movements and so damp out the ATV's kinetic energy.

As the boom is retracted, the gradual compression of the rollers and levers of the alignment mechanism force the ADA and PDA to align. Retraction continues until the ADA/PDA seals touch, closing the hydraulic and electrical connectors, and compressing the push-back springs and the contact microswitches, all located on the 1.3 m-diameter housing (Fig. 8).

From this position, eight 'active' hooks on the ADA's circumference are retracted. These are actuated by a cable pulling a cam at the base of each hook. The cable itself is tensioned by an electric motor. The ADA hooks connect with eight spring-mounted passive hooks on the PDA's circumference. This retraction compresses the seals, the push-back springs and mates all connectors to their final positions (Fig. 9).

The PDA's own eight active hooks are now retracted to increase rigidity. This completes the docking *per se,* or 'hard docking'.

Next, the extendable probe is extended slightly to allow retraction of the probe head's latches so the head can disengage from the receptacle.

Before opening the hatches, the inter-hatch volume is first filled from the Station side. The two pressure equalisation valves in series are then opened on the ATV. As a back-up, a

Fig. 1. The active (1a) and passive (1b) docking assemblies.

Fig. 2. Active Docking Assembly: launch position.

Fig. 3. Active Docking Assembly: docking position.

Fig. 4. Passive Docking Assembly.

Fig. 5. Probe head.

Fig. 6. Contact!

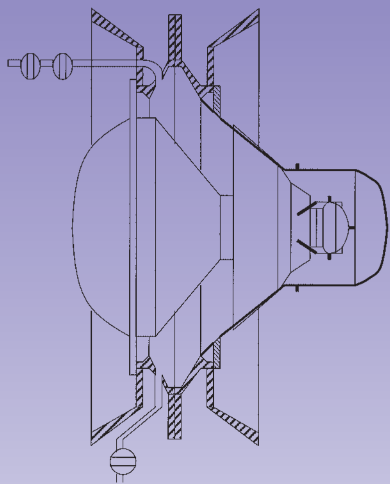
Fig. 7. Capture.

Fig. 8. Boom retraction.

Fig. 9. Hook closure.

Fig. 10. Valves.

Fig. 11. Hatches open.



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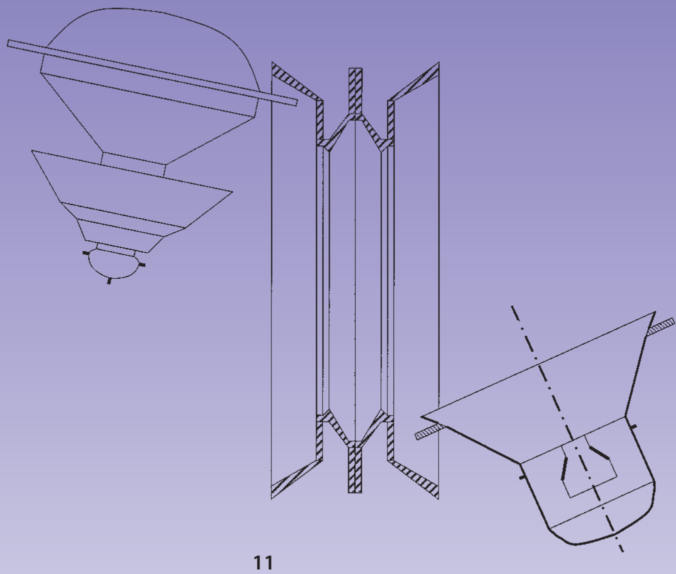

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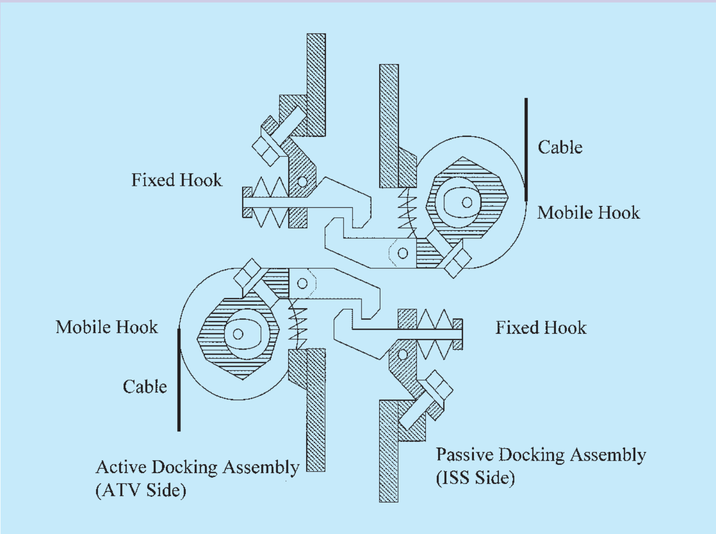


manual plug can be used on the RDS (Fig. 10). Integrity is verified by monitoring for any pressure decay.

The PDA hatch is opened manually by swinging it into Zvezda. With a long tool, the ADA hatch is unlocked from the outside, and the hatch is swung into the ATV (Fig. 11). Finally, the astronauts install 16 clamps on the housing's internal circumference to create the greatest possible stiffness for the connection.

ATV unloading, reloading, reboost and attitude control activities can now begin.

Undocking

When ATV separation is imminent, the crew remove the clamps and close both hatches. The volume between the hatches is depressurised by opening the ADA valve (Fig. 10) and the pressure integrity of the hatches is confirmed. The PDA's eight active hooks are opened. On opening the ADA's eight active hooks, the springs (compressed at docking) push off the ATV and the two vehicles separate.

Failures

The track record of the Russian Docking System is remarkably trouble-free. The last documented failure is the Kvant 1 docking with Mir in April 1987. The latches were prevented from closing by a piece of cloth, which was removed by a cosmonaut on an EVA.

One of the major worries is the electric motor that drives the boom's extension. It is not redundant because of lack of space, and a failure could lead to capture without completion of hook closure. However, the ADA hatch contains four pyrobolts that can be fired in an emergency, allowing separation of the ATV from the major part of the ADA. Retreat and destructive atmospheric reentry are then possible.

Another worry is failure to open the hooks. Each ADA/PDA active and passive hook is also equipped with a pyrobolt (Fig. 9), guaranteeing hook opening. These pyrobolts have never been used other than for testing purposes.

Conclusion

The Russian Docking System, originally developed in the late 1960s for the Salyut space station programme, but continuously refined, is a testimony to the ingenuity of the engineers of RSC Energia, who, faced with a daunting task, conceived a simple, robust system, cleverly exploiting all the available volume and keeping the mass low (235 kg). Although the analytical tools at their disposal were probably not of the quality of contemporary Western tools, careful and patient testing and subsequent refinement of the design led to a space mechanism, that – even today – remains an engineering marvel.

FIRST INTERNATIONAL SYMPOSIUM ON

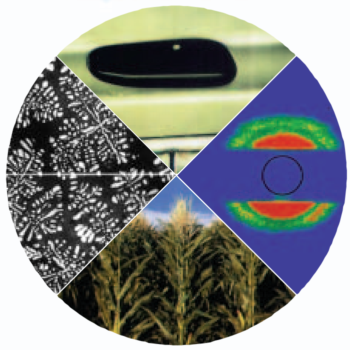
MICROGRAVITY RESEARCH & APPLICATIONS IN PHYSICAL SCIENCES & BIOTECHNOLOGY

10-15 September 2000 Sorrento, Italy

Co-sponsored by
ASI, CNES, CSA, DLR, ESA, NASA and NASDA

Aims and Scope

The Symposium intends to provide a forum for scientists from academia and industry to present and discuss recent advances in their research on gravity-dependent phenomena in Physical Sciences and Biotechnology. Results originating from theoretical work, numerical modelling, ground-based and flight investigations are solicited. The major topics include Fundamental Physics, Fluid Physics, Heat and Mass Transport Phenomena, Physical Chemistry, Fluid Thermodynamics, Thermophysical Properties of Fluids, Combustion, Solidification Physics and the Crystallisation of Inorganic Materials and Biological Macromolecules. Topics in Biology and Bioengineering, which are expected to benefit from cross-fertilisation and synergy with physicists, such as multi-phase flows and surface physical chemistry, including structured deposition of macromolecules, will also be addressed.



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Seconda Università degli Studi di Napoli
SUN

Gravity Triggers Microtubule Pattern Formation *In Vitro*

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The Tubulin experiment on Maxus-3(Fig. 1) demonstrated, in agreement with theory, that microtubule self-organisation by way of dissipative processes is strongly gravity-dependent. Moreover, it revealed that a very simple system, initially comprising only two species of molecules (tubulin and guanosine triphosphate), can function as a gravity receptor.

Introduction

Some theoreticians[1,2] have proposed since the 1950s that some particular types of chemical or biochemical reactions might exhibit non-linear phenomena when they are sufficiently far from equilibrium. Allan Turing[3] predicted that such systems could show macroscopic self-ordering, and that a chemical pattern could spontaneously arise from an initially homogeneous solution[1]. At a molecular level, this process involves an appropriate combination of reaction and diffusion, and the patterns appear as periodic variations in the concentration of some of the reactives. Patterns of this type are known as reaction-diffusion, Turing or dissipative structures. The last term was widely used by Prigogine and co-workers[2] because a dissipation of chemical energy through the system is required to drive and maintain the system far-from-equilibrium. It is this energy dissipation that provides the thermodynamic driving force for the self-ordering process.

Bifurcations and Biology

In addition to self-organisation, these systems can also show bifurcation properties. At a critical moment before the appearance of the self-organised state, the system can bifurcate between several dynamic pathways, leading to self-organised states of different morphologies.

At the bifurcation point, a field too weak to effect equilibrium states can determine which of the possible dynamic pathways the system takes. Furthermore, the weak field need only be present at the critical moment when the equilibrium state is unstable. Once the bifurcation has occurred, the system evolves progressively along the selected pathway to the pre-determined morphology, and behaves as though it retained a memory of the conditions prevailing at the bifurcation.

Theoreticians have predicted that, in chemically dissipative systems, the presence of gravity at the bifurcation point[4] could determine the morphology of the self-organised state that subsequently forms. Turing, Prigogine *et al.* and others have proposed that biochemical mechanisms of this type could provide an underlying explanation for biological pattern formation and morphogenesis. More

Fig. 1. MAXUS-3 was launched on 24 November 1998 from ESRANGE, Kiruna in Sweden to provide five experiments, including Tubulin, with 13 min of microgravity conditions. The 710 kg payload was recovered safely after the perfect 20-min flight.

This article was prepared for publication in cooperation with René Demets, Project Scientist Biology, MSM-GM.

recently[5], it was suggested that a biochemical system acting upon such principles as a gravity transducer could provide a possible physico-chemical explanation for the little-understood phenomenon of gravisensing by single cells. These concepts, although a subject of interest and debate, have never been adopted by the majority of biologists. One reason has been that, until very recently, no experimental examples of this general behaviour were known. For example, it was not until 1990[6] that a variation of a chemical reaction initially discovered by Belousov around 1950 was finally recognised as the first example of a Turing structure. Similarly in biology, no *in vitro* biochemical reactions showing the self-ordering properties owing to these causes were known.

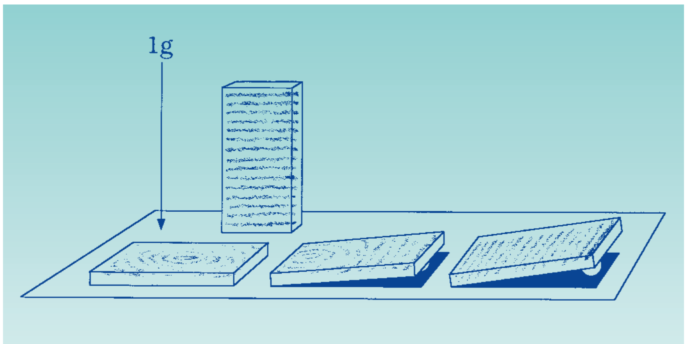

Fig. 2. The direction the g-vector makes with the long axis of the cuvette determines the subsequent morphology. Circles are formed as long as the orientation of the gravity vector is perpendicular to the plane of the cuvette (with a tolerance of only a few degrees), whereas stripes form when the gravity vector is parallel to the cuvette's long axis.

Microtubule Pattern Formation *In Vitro*

We have observed[7-9] that some *in vitro* microtubule preparations behave in the manner expected for chemically dissipative systems. They show the phenomenological properties described above. Spontaneous macroscopic self-organisation occurs, and the morphology of the self-organised state that forms depends upon the orientation of the sample with respect to gravity at a critical moment before its formation. This bifurcation arises from non-linearities in the chemical reactions involving microtubule formation from its molecular constituents. The dependence of the macroscopic pattern, both on the rate of reaction and of diffusion, and on the dimensions of the sample container, are in agreement with the behaviour expected for a reaction-diffusion mechanism. The macroscopic self-organised patterns that form may be observed as variations in optical birefringence due to regular variations in microtubule orientation. Other methods show that periodic variations in microtubule concentration coincide with the pattern of orientational changes.

Microtubules: What They Are and What They Do

Together with actin filaments, microtubules make up the majority of the cell cytoskeleton. They are known to control the self-organisation of the cell and its cytoskeleton. They constitute the mitotic spindle along which the chromosomes move during cell division, and

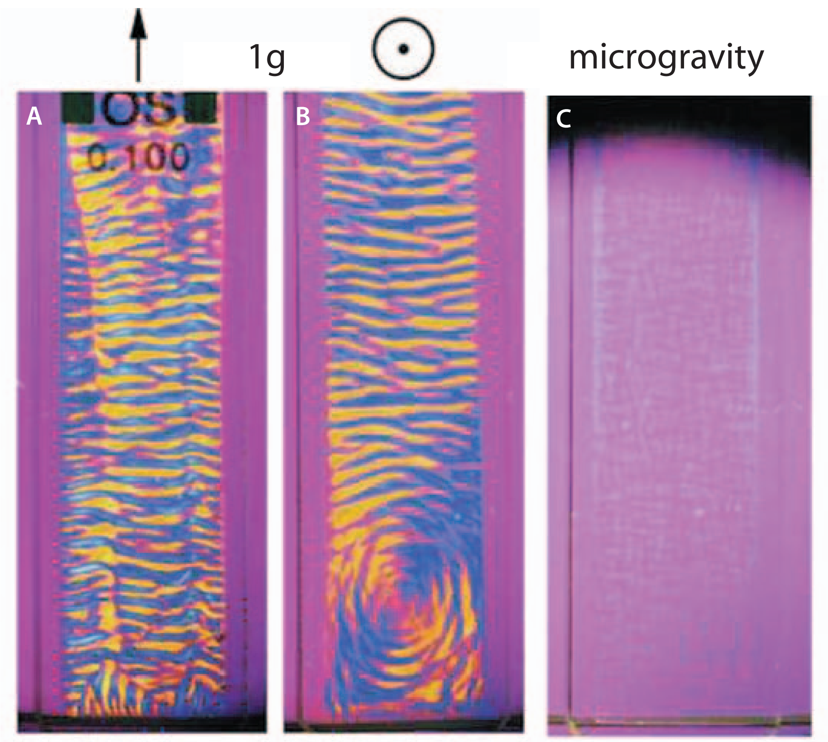

Fig. 3. Microtubule patterns as formed after the 13-min of microgravity available on the MAXUS-3 flight. A and B show the self-organised morphologies in samples carried in the 1g centrifuge, with the centrifugal field along (A) and perpendicular (B) to the long axis of the sample cuvette. The centrifuge was stopped immediately before reentry. After flight, the samples were left under 1g conditions for a further 5 h for the structures to develop. C shows that almost no self-organisation develops for samples subject to weightlessness during the first 13 min. In addition, these samples show very little birefringence, indicating that the microtubules are disordered compared with those formed at 1g. Except for the gravity conditions during the flight, conditions for A, B and C were identical at all times. In each striped band, the microtubules are highly oriented at either 45° or 135°, but adjacent stripes differ in having alternating orientations. The samples are observed between crossed linear polarisers with a wavelength retardation plate at 45° to the polarisers. The wavelength plate introduces a blue interference colour for orientations of about 45° and a yellow interference colour for about 135°. The periodic variations in microtubule orientation are clearly visible as alternating yellow and blue stripes. Variations in the microtubule concentration of about 30% of the mean also occur from stripe to stripe, and coincide with the variations in microtubule orientation.

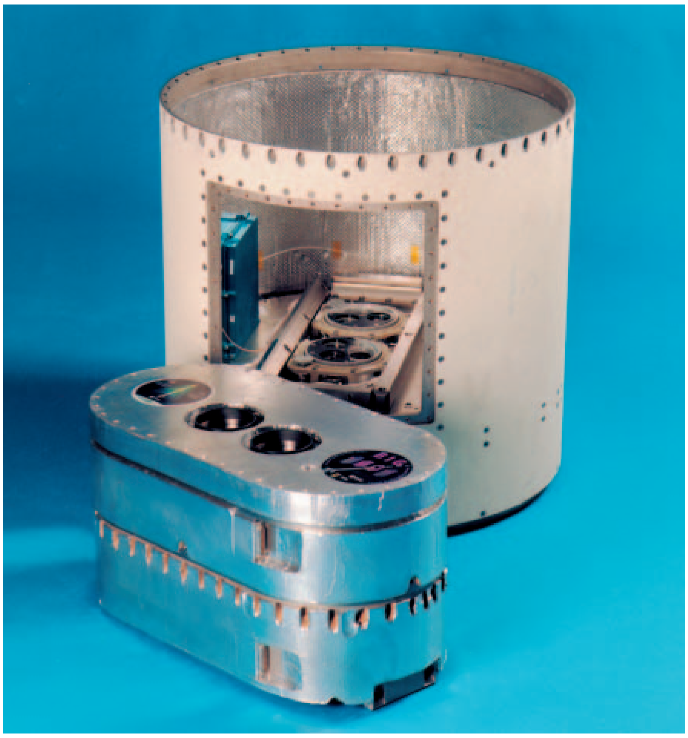

Fig. 4. The BIG module (Biological Gravisensing) used for the Tubulin experiment was one of the five experiment modules on MAXUS-3. The Tubulin test samples were accommodated in the late access unit, which was inserted via the hatch about 90 min before launch. The two openings in the top lid were used for illuminating the observed samples; the corresponding optical elements can be seen behind, between the two rails on the module deck. The BIG module was designed and manufactured under an ESA contract by the Swedish Space Corporation (S) and Ferrari (I). The module's total mass was 100 kg.

are involved in many other important cellular processes. Microtubules are long tube-shaped objects, with inner and outer diameters of 140 Å and 280 Å, respectively. Although their lengths vary, they are often several microns long. They arise from the self-assembly of a protein, tubulin, by way of reactions involving the hydrolysis of a nucleotide, guanosine triphosphate (GTP), to guanosine diphosphate (GDP). Tubulin is readily isolated and purified. It has a molecular weight of about 50 KDaltons, and a diameter of about 40 Å. When warmed from 4°C to 35°C in the presence of GTP, tubulin assembles into microtubules and GTP is hydrolysed to GDP. Once microtubules are formed, chemical activity continues through a process called 'treadmilling' whereby tubulin is added and lost from opposing ends of micro-tubules by reactions involving GTP hydrolysis.

Stripes *vs.* Circles

Under appropriate conditions, the non-linear reaction-diffusion processes described above give rise to spontaneous macroscopic ordering. Following assembly in spectrophotometer cells measuring 4x1x0.1 cm, a series of periodic horizontal stripes separated by about 1 mm progressively develop in the sample over about 5 h. Once formed, the striped pattern remains stationary for 48-72 h, after which the system runs out of reactives. Striped morphologies occur when the microtubules are prepared in upright sample containers, as well as in containers lying on their sides. A different pattern, of concentric circles, arises when they are prepared in the same containers lying flat (Fig. 2). Once formed, the structures are stationary and independent of their orientation with respect to gravity. This behaviour is attributed to the determining role of the direction of the gravitational field during structure formation. Circles are formed as long as the orientation of the gravity vector is perpendicular to the plane of the cuvette, whereas stripes form when the gravity vector is parallel to the cuvette's long axis.

The Bifurcation Point

To establish at what moment the sample morphology depends upon the orientation with respect to gravity, the following experiment was carried out. Twenty samples of purified tubulin together with GTP, at 4°C, were placed in identical optical cells. Microtubule formation was simultaneously instigated with all the cells upright. Consecutive cells were turned from vertical to horizontal at 1-min intervals, and the samples examined 12 h later, after the structures had formed. Twenty minutes after instigating microtubule formation, when the last sample was turned from vertical to horizontal, there are no obvious signs of any structure whatsoever. Since the structures form while all the cells are flat, one might expect that they would all form the horizontal pattern, i.e. circles. This is the case for samples inverted during the first few minutes. However, samples that were upright for 6 min or more showed striped morphologies similar to preparations that remained vertical all the time. The final morphology of the sample depends upon whether the sample container was horizontal or vertical over a critical period of 6 min after instigating assembly and prior to the formation of the self-organised structure. The phenomenon can be described as a bifurcation between pathways leading to two different morphological states, and in which the direction of the sample with respect to gravity determines which morphology[10] subsequently forms.

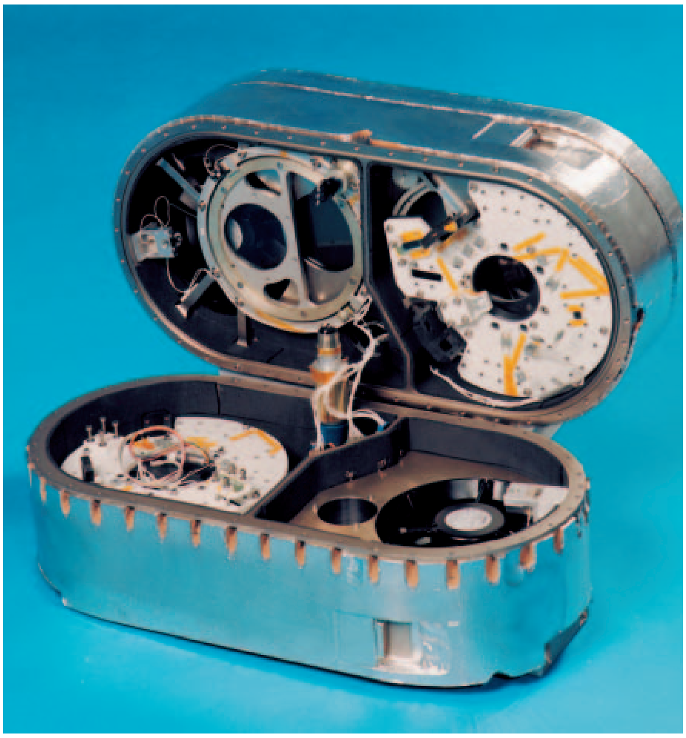

Fig. 5. The 25 kg late access unit of the BIG module consisted of near-identical halves, one hosting the microgravity-exposed samples, the other the 1g reference samples. The Tubulin cuvettes were mounted on the two white platforms, one of which was rotated in flight to provide 1g. To obtain identical temperatures for both sets of samples, the halves were integrated in one single loop of forced air flow. The unit was thermally insulated as the samples must be kept at 5°C up to the start of microgravity and thereafter at 37°C until 12 h after landing.

No Gravity, No Patterns

Knowing that gravity plays a determining role during the first 6 min of the assembly process, a logical follow-up to these experiments was to see what happened when gravity was absent during these 6 min. This question was the scientific rationale of the Tubulin experiment, which was selected by ESA to fly on the MAXUS-3 sounding rocket[11]. The following possible outcomes of the experiment were considered. In the absence of a directing cue (gravity), it could be that stripes and circles are produced at random. Alternatively, it could be that only one of the two morphologies, stripes or circles, arises. Another possibility is that, in the absence of gravity, patterns other than stripes or circles form. Finally, and this was thought to be the most likely outcome, it might be that weightlessness prevents pattern formation.

MAXUS-3 was launched (Fig. 1) on 24 November 1998; the results of the Tubulin experiment were known within 6 h of the 20-min flight. In the samples exposed to weightlessness, no patterns whatsoever formed. The samples in the 1*g* centrifuge formed stripes or circles (depending on their orientation towards the 1*g* vector), identical to those that form on the ground. The experiment therefore unveils the presence of gravity as an instigator of *in vitro* microtubule self-organisation.

Conclusion

The data collected so far suggest that the Earth's 1*g* gravity vector plays a determining role during the first few minutes of the *in vitro* microtubule pattern-formation process. Firstly, as was demonstrated on MAXUS-3, if gravity is absent during the first 13 min, no pattern whatsoever forms. Thus, under appropriate conditions, an environmental factor such as gravity can trigger microtubule self-organisation. This may influence numerous cellular processes in which microtubule organisation is involved. Secondly, as was demonstrated in ground experiments, the direction the *g*-vector makes with the long axis of the cuvette determines the morphology that subsequently develops: parallel yields stripes and perpendicular leads to circles. These experiments demonstrate how a very simple system initially comprising just two molecules, tubulin and GTP, can function as a gravity receptor.

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The MOMO Facility

(Morphological Transition and Model Substances)

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Fig. 1. Astronaut Carlos Noriega connecting MOMO to the onboard computer during STS-84. (NASA)

MOMO is providing fundamental insights into the solidification of metals – crucial for improving industrial casting processes, for example. The facility will soon make its third flight and may be followed by a new design for the International Space Station.

Introduction

The MOMO facility was launched on its maiden flight aboard a Spacehab module on STS-84, the sixth Shuttle-to-Mir mission, in May 1997 (Fig. 1). Its second flight was in the Spacehab module of STS-95 in October-November 1998, accompanied by ESA astronaut Pedro Duque. A third flight is in preparation for STS-101 in early 2000.

MOMO is an experiment facility dedicated to studying the directional solidification of transparent media. Its purpose is to gain fundamental knowledge on the solidification of metals – their mechanical properties depend strongly on the microstructure created during solidification.

MOMO is being used to develop and verify physical models describing the solidification process by using bulk samples of transparent model substances[1,2,3]. These alloys allow *in situ* observation of the developing microstructure at the solidification front. Using transparent instead of metallic samples also has the important advantage that multiple experiment runs can be performed on only one sample without loss of information because the scientific results (essentially image data) are gained and stored during the individual experiment runs.

So far, MOMO has used the transparent succinonitrile/acetone as the sample material. The experiments have focused on cellular growth, which is one of the three basic solidification morphologies (the others being planar and dendritic growth).

During STS-84, MOMO was activated for 209 h of experiments – almost the whole duration of the 10-day mission. Six directional solidification experiments were performed and about 2 GB of mostly digital image data were recorded.

The MOMO Facility Concept

MOMO's scientific requirements can be summarised as:

- the boundary conditions for the solidification process have to be defined exactly. This means the temperature gradient at the solidification front, symmetry and homogeneity of the temperature field, solidification rate and concentration of the

Table 1. MOMO Technical Data

Mass	43 kg
Dimensions	19-inch (48.3 cm) rack drawer, height 356 mm, depth 646 mm
Power	90 W
Experiment cell	
Outer diameter	14 mm
Inner diameter	11 mm
Length	235 mm
Processing length	45 mm
Total volume	42 cm^3
Volume compensation	15%
Furnace	
Heater	66-86°C (related to succinonitrile)
Cooler	30-50°C
Controller accuracy absolute	0.2K
Succinonitrile melting temperature	58°C
Endoscope	
Diameter	4 mm
Aperture diameter	2.7 mm
Viewing angle	10°
Object distance (solidification front-endoscope lens)	15-60 mm
Video observation	
Observation area	8 x 8 mm
Number of pixels	1536 x 1024
Pixel grey levels	12 bits
Maximum integration time	8 s
Spatial resolution	2-8 µm
Data content per image	1 MB full frame, 0.25 MB binning mode (centre part of image, reduced pixels)
Data storage capacity	
Maximum number of images	4000
Storage rate for housekeeping data	1/s

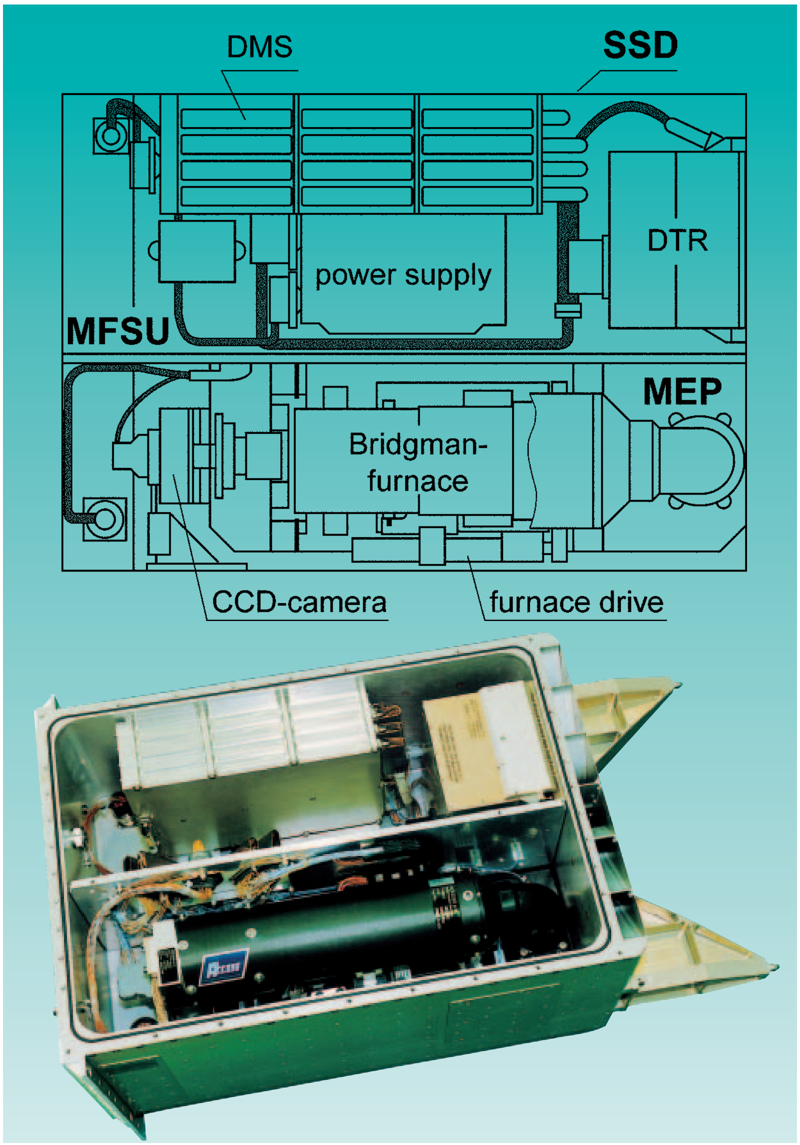

Fig. 2. The MOMO facility comprises the SSD container divided into two compartments for the MEP and its Bridgman furnace, and the MFSU with control unit (DMS) and digital tape recorder (DTR).

alloy all have to be controlled precisely before and during the process. Buoyancy in the melt has to be excluded by processing in a microgravity environment to achieve diffusion-controlled growth;

- boundary effects by the walls of the sample containment have to be minimised;
- microstructures occurring at the solidification front have to be observed *in situ* and recorded.

MOMO meets these requirements by using a:

- a Bridgman-type furnace with a rod-like bulk sample inserted. This furnace enables independent control of the solidification parameters: temperature gradient and solidification velocity. Boundary effects are minimised by using the bulk sample;
- a high-resolution CCD camera coupled with an endoscope and a mass data-storage device to record the solidification process of the transparent sample.

MOMO consists of three main units (Fig. 2): 1. the MEP (MOMO Experiment Proper), containing the furnace with the transparent sample, optics and camera; 2. the MFSU (MOMO Flight Support Unit), the control and data electronics; 3. the SSD (Standard Sealed Drawer), the fixation envelope, double containment and heat sink. MOMO is designed for automatic operation, including complete data storage without telemetry to the ground or operational interface to the crew except for nominal power on/off.[4,5]

MOMO Facility Details

The MEP is shown in Fig. 3. The core is the cylindrical experiment cell of borosilicate glass. Toroidal bellows in the hot end compensate for the sample's volume change. Before integration, the cell is filled from the cold side and closed by a glass plug. It is then placed between two fixed supports in the furnace's central axis. For the best thermal conditions,

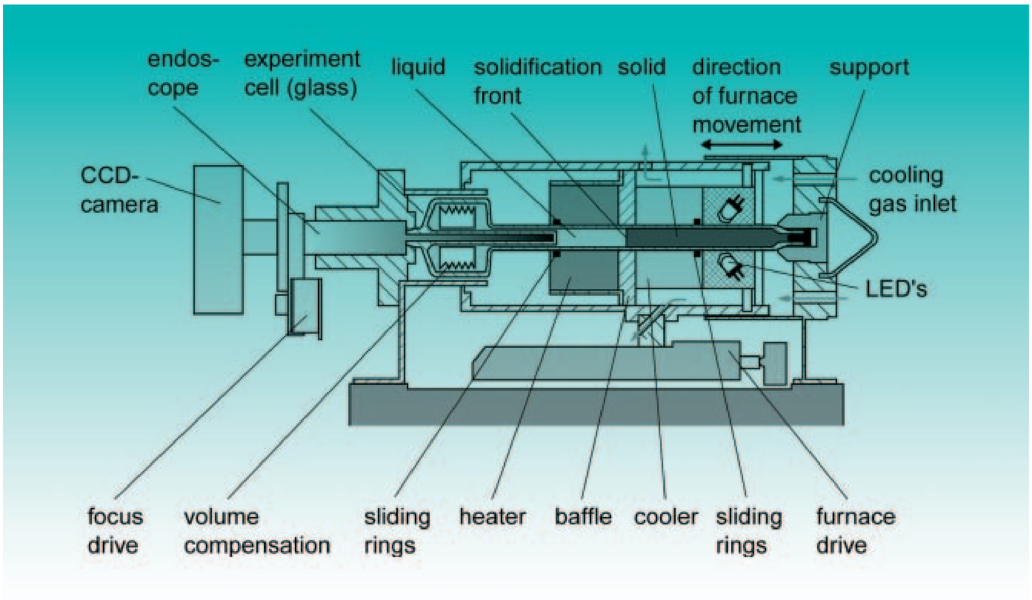

Fig. 3. The principal features of the Bridgman furnace.

the cell is centred in the furnace by two sliding rings at the outer faces of the heater and cooler. Thus there is a uniform gap of only 0.15 mm between the cell and the furnace wall.

A baffle of low thermal conductivity separates the heater and cooler, both made from aluminium. Heating and temperature control is realised by heating foils and PT100 sensors. Circulating dry nitrogen acts as the furnace's heat sink, removing waste heat from the cooler's outer surface. The gas stream transports the heat to a heat exchanger cooled by Peltier elements mounted on the bottom plate of the SSD, which moves the heat via the SSD cooling system to the cabin air.

The furnace is mounted on a drive, which consists of a high-precision linear table for optical applications driven by a geared DC motor. In combination with a velocity- and position-controller, uniform movement of the furnace is achieved, enabling precise adjustment of the solidification rate. A bolt locks the transfer table for launch and landing.

The microstructure at the growing solid-liquid interface is imaged in top view by an endoscope optic, inserted into the cell from the hot side. The cell's internal glass tube protects the endoscope rod from the sample material. The endoscope is equipped with a motor-driven optic to focus on the advancing solidification front.[6]

On top of the endoscope, a modified astronomical CCD camera provides still video pictures with selectable integration times. The solidification front is illuminated by nine red LEDs in a ring support at the end of the cooler. This provides a quasi-darkfield illumination of the solid-liquid interface.

Results

MOMO's first flights were an important proof of the facility's performance and of the selected experimental method. During STS-84 and STS-95, cellular solidification was investigated in its steady state. A cellular solid-liquid interface is typical for solidification processes and thus reveals a deep insight into microstructure formation – very important for industrial castings. Generally, the microgravity environment is mandatory for creating a suitable quantitative database on cellular patterns because the patterns are strongly disturbed by convection under 1 *g* (Fig. 4)[7]. A major result concerns the average primary spacing of the cells. Different theoretical models significantly deviate with respect to predictions of primary spacings. Here, MOMO's experimental results correlate strongly with predictions of the numerical model of Hunt[8]. A more detailed evaluation of MOMO's experiments has been published[3,9].

MOMO will next fly on the STS-101 Shuttle mission in early 2000. This time, it is dedicated to investigating the dynamics of cellular patterns. The first results are expected in Spring 2000.

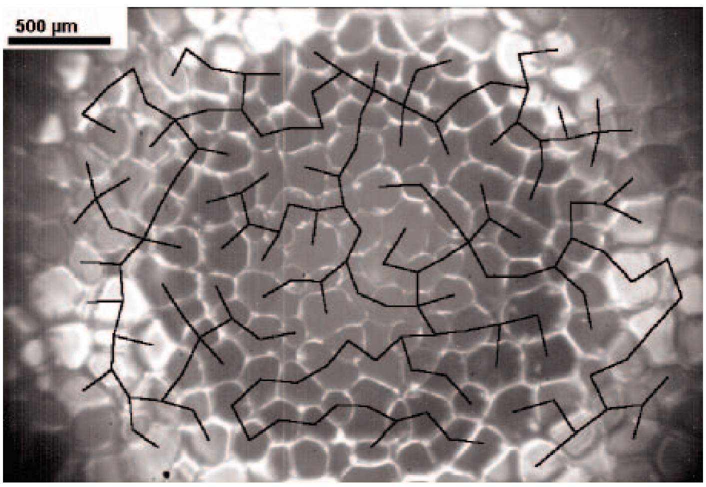

Fig. 4. Cellular patterns evolving under 1 g and µg show significant differences. The order of the structure, validated with the minimum spanning tree criterion m [Ref. 7], is much closer to a regular honeycomb pattern (m = 1.075) under µg conditions (left; m = 0.97) then the 1 g pattern (right; m = 0.87).

Outlook

MOMO can refly with little effort on facility refurbishment and dedicated experiment preparation. A design study is in progress on a follow-up facility, probably realised within the framework of the Fluid Science Laboratory project, for directional solidification of transparent model substances aboard the International Space Station (ISS). This probably requires three important additional features:

1. More complete information on topology, shape and position of the solid-liquid interface, requiring 3D monitoring. Verification of theoretical models, eg the amplitude of the cells is an important parameter as well as the cellular pattern. So far, the only means of measuring cell amplitudes are experiments in quasi-2D cuvettes, but the effect of the cuvette walls is a strong disadvantage.
2. Sample exchange onboard would allow other experiments with different model substances (concentrations, alloys).
3. Teleoperation, at least off-line, would enable direct interpretation of solidification behaviour by analysing images and housekeeping data. New experiment parameter sets could be generated on Earth and transmitted to the facility.

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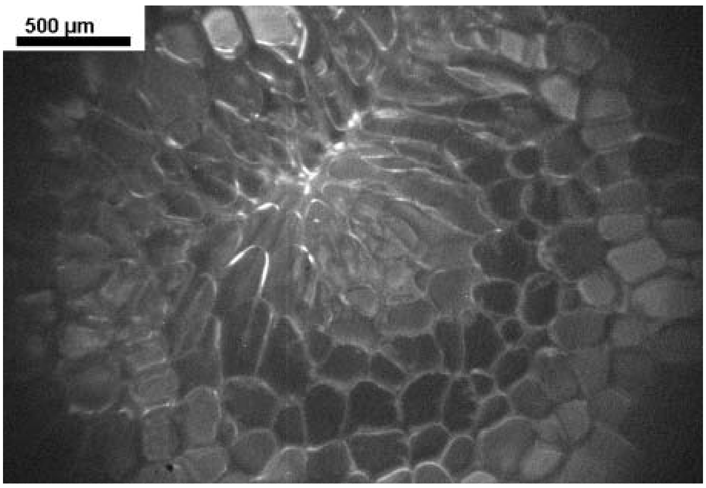

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