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ISS Industry Day: Special Issue

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ESA's ISS Industrial Partners at ESTEC

This issue of *On Station* is dedicated to the third International Space Station Industry Day, held at ESTEC in The Netherlands on 19 September. In particular, it focuses on the contributions prepared for this year's event by ESA's industrial partners.

What is an Industry Day, and what is its purpose?

The sheer size and complexity of ESA's manned spaceflight activities – as represented by Europe's participation in the International Space Station Programme, including the related Microgravity Programmes – requires the engagement of nearly all of Europe's aerospace companies, large, medium and small, as well as a number of non-aerospace companies. These activities are being implemented as an integral part of a global partnership involving the United States, Russia, Europe, Canada and Japan, and will continue throughout the completion of the operational life of the International Space Station, until the 2015-2020 timeframe.

Given the global nature of the International Space Station Programme, and the complexity of the development and operational interfaces involved, the routine flow of information between ESA and industry, as well as between the industrial partners themselves, cannot provide an adequate picture of the status of the overall programme.

Industry Day provides an important opportunity to fill this information gap. Representatives of all companies working on the programme, large or small, are invited to join ESA in an informal gathering to be briefed on the overall programme status and to discuss and exchange information about their particular activities in the programme.

It provides an ideal event at which ESA can brief all of the industrial partners working on the programme about:

- the overall status of the International Space Station Programme, including Station assembly, upcoming major milestones and potential problem areas;
- the status and progress of the activities of the other International Space Station partners;
- International Space Station Programme-level bilateral and multi-lateral agreements involving ESA, such as Barter Arrangements;
- ESA's overall assessment of the technical and programmatic status of the European part of the programme, together with an outlook towards the future.

It also provides an opportunity for industry to present to ESA and other industries the status and progress of their activities, and to raise points of concern that they may have. Over the three Industry Days to date, the scope and depth of the inputs prepared and presented by industry have gradually increased, and now represent a significant part of the material presented on these occasions.

The first ISS Industry Day, held at ESTEC in October 1996, a year after the Toulouse ministerial decision on the European Participation in the International Space Station Programme, was dedicated entirely to ESA presentations on key elements of the programme. The primary objective of these presentations was to provide industry with a broad overview of the ISS Programme, including the role played by Europe.

The second ISS Industry Day, held at ESTEC in June 1998, followed a similar format to that used for the first ISS Industry Day. However, in addition to the ESA overall programme briefings, selected Prime Contractors were invited to present the status and progress of their respective development activities in order to provide a broader view and better balance of the overall programme status to the other participants.

For this third ISS Industry Day, the format was considerably modified to make room for a greater number of industry presentations covering a wider range of subjects. The ESA briefings were limited to those areas of the programme that are primarily ESA's responsibility, plus short overview presentations to introduce the presentations prepared by industry. Articles based on these industry presentations form the main content of this issue of *On Station*.

We will continue with this tradition of Industry Days and hope that we will see even more contributions demonstrating the capabilities of European industry. ■

The Transition from Development to Exploitation

A Challenge for Industry and ESA

Armand Carlier
Chairman & CEO, Astrium

If I had to single out the one dominant word of the last 18 months in the area of International Space Station (ISS) exploitation, it would be 'industrialisation'. Recent years were dominated by the development programmes, their progress and their problems. Their operational and utilisation perspectives were limited to meeting set dates for the launch sequence. Relatively few people focused on preparing for the operation and utilisation of the hardware being built. The teams were almost 'whistling in the dark' – everything seemed so far ahead. An effort on streamlining operations was eventually terminated in 1998 because there was no pressing need for it.

In the course of preparing for a decision on the ISS Exploitation Programme at the Council Meeting at Ministerial Level in Brussels in May 1999, it became evident that the scope of Europe's ISS obligations had significantly increased but that ESA's contributing member states showed no signs of increasing the budget identified in the Ministerial Meeting of 1995.

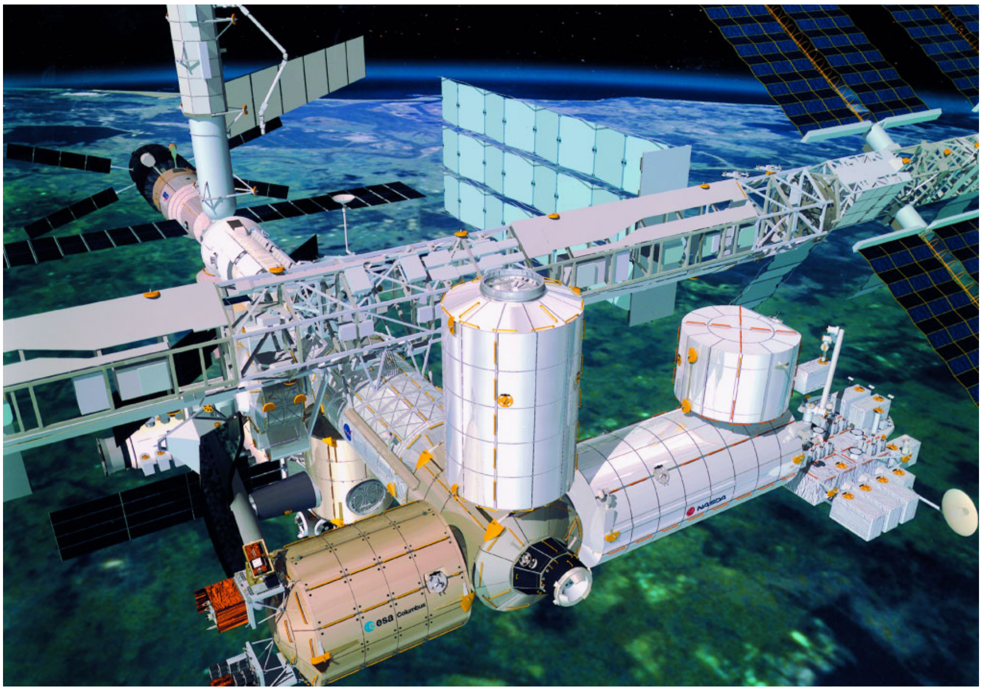
The political pressure increased and, of course, ESA and industry were highly motivated to obtain a budget decision from the Council in order to stabilise the programme.

The common interest then was – and still is – to balance the reduction in cost and the increase in scope by finding more effective and efficient ways of conducting operations and utilisation.

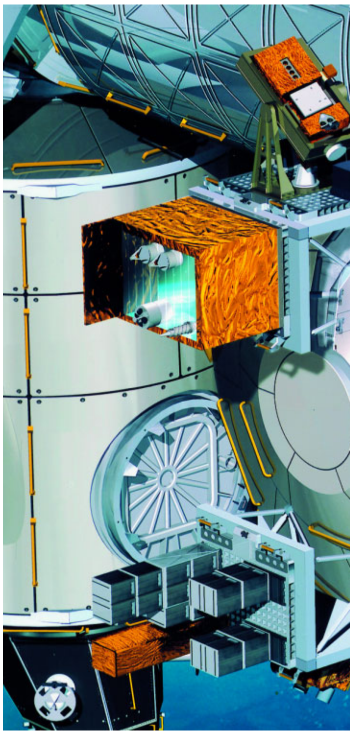
'Industrialisation' seems to be the key.

What does 'industrialisation' mean? Well, first of all, it does not stand for deleting ESA. It means defining processes for performing the tasks connected in the value chain in order to make them as efficient as possible. This will be achieved by minimising the number of interfaces requiring 'handshakes' and transfer of know-how and learning, but also by performing such processes as much as possible within a single organisation. It is further implied that the relationship with ESA will be based on process performance criteria and not by a prescription of how to do the tasks. That is consistent with ISO 9000 practice and with the intention of the European Cooperation for Space Standardisation.

Space Station development is heading towards completion. The new challenge is to exploit the facilities...



ESA/D. Ducros



The infrastructure is on target for Columbus utilisation to begin once the module is attached to the Station. (ESA/D. Ducros)

Industrialisation also means the application of 'secondary processes', containing all the elements needed to perform the value-chain tasks in a controlled manner. These secondary processes include programme control, contracting, scheduling, product assurance, inspection, reviews, etc. In this area of secondary processes, 'industrialisation' infers that other industries – perhaps I should say normal industries acting in a normal competitive market – already apply such highly efficient processes. We have all recognised that the mechanisms of the past 25 years of manned spaceflight in Europe were designed for and applied to a unique and protected field.

We are convinced that significant improvement in industry's cooperation with ESA can and will be achieved – but this still has to be proved.

Let me return to the brief history of the industrialisation of ISS exploitation, from its begining in early 1999 to the unanimous approval of the ESA procurement proposal on 29 June 2000.

The nucleus of the industrialisation initiative was probably DASA-RI's overall commitment to the ISS Exploitation Programme for the full content, the full duration and at the 1995 ministerial meeting budget.

Since then, Astrium has been founded and its Space Infrastructure Division has taken over the rights and obligations previously covered by Matra Marconi Space. Today, this industrial

The Columbus Control Centre, ATV Control Centre and the ALTEC logistics facility will be operated under contract.

commitment is carried by Astrium, Europe's leading space company – with its capabilities as a global actor, but also with strong national roots. Astrium's strength and size allows Europe to conduct such large and long-term operations and utilisation programmes despite the significant risk. Astrium and its joint ventures such as BEOS (Bremen Engineering Operations Science) are the most able to pave the way for commercial utilisation in both research and innovative markets.

In parallel, we have close links with our industrial partners Alenia Spazio and EADS Launch Vehicles (formerly Aerospatiale Matra Launchers), resulting in a Memorandum of Understanding between us for further cooperation.

We were happy so see ESA's early interest in the initiative, which resulted in the Agency's direct participation in developing the concept.

Finally, our High-Level Commitment in March 2000 for industrialising the ISS Exploitation Programme and the subsequent approval by ESA's Council, formed the basis for the Agency's Industrial Policy Committee to obtain approval for procurement.

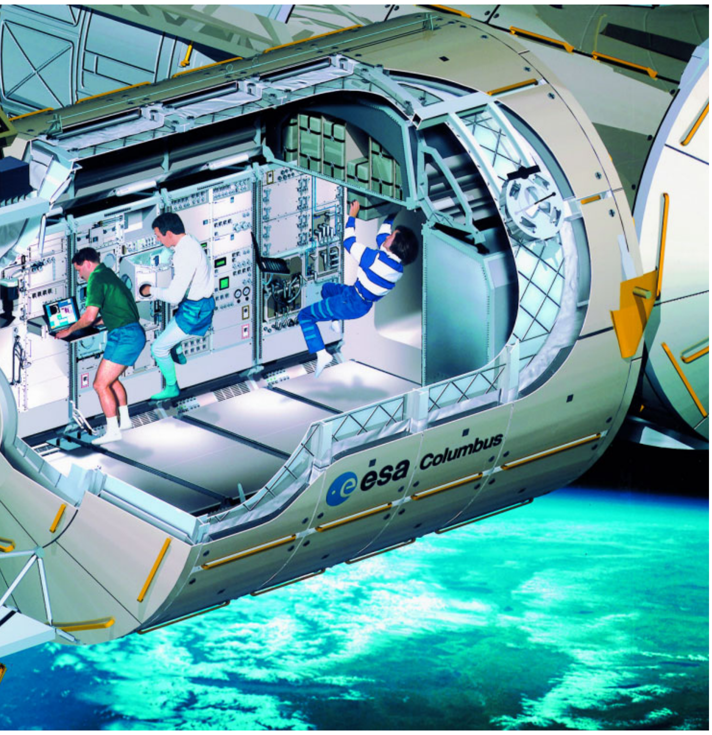
As the effort evolved among the industrial team, the national Agencies in Italy, France and Germany have adopted this approach for their own facilities, deciding to operate them under contract with Industrial Operators: the Columbus Control Center, the ATV Control Center and the ALTEC-facility for Logistics.

The spirit and dedication of such a high-performance team can achieve results beyond the original assignment. The team did not stop once the industrialisation concept for ISS Exploitation had been developed, but complemented it by integrating the separately financed existing operating contracts into the overall concept. The team even addressed the later integration of development contracts into the concept with a view towards more efficient operation.

In the same team spirit, ESA issued an authorisation to start work on preparations for operations in July 2000.

The progress achieved by the team during the past 18 months is excellent, serving as a demanding baseline for other efforts.

It is very important to note that this cooperation between industry and ESA – the heart and the backbone of what has been achieved – was made possible by a small



number of dedicated individuals. I take this opportunity to mention Bob Chesson, leading the ESA team, and Hans Stephan, leading the industrial team. It goes without saying that it has been a team effort.

The approach of stabilising the industrialisation concept via a 'High-Level Commitment' – a now-famous term coming out of this concept development – has proved to be very attractive and efficient. ESA's team expressed its needs in terms of what should be committed by industry and which conditions would be acceptable for the Agency. The trust among the industry team – and it really was only one team although members still defended their own interests – allowed the creation of a High-Level Commitment, now carried by Astrium, Alenia and EADS-Launch Vehicles. In fact, the dialogue with Deutsche Zentrum fur Luft- und Raumfahrt (DLR) for the Columbus Control Centre at the German Space Operations Centre (GSOC) even allowed DLR/GSOC to agree to this High-Level Commitment.

The delivery to ESA on 3 March 2000 built the platform for ESA's formal proposal of the concept to the Council for approval at the end of March 2000.

I have expressed my appreciation and thanks to the Concept Team. Now it is time to extend my thanks and appreciation to the ESA Management and Executives who successfully carried the concept through ESA's controlling bodies – the Council and Industrial Policy Committee.

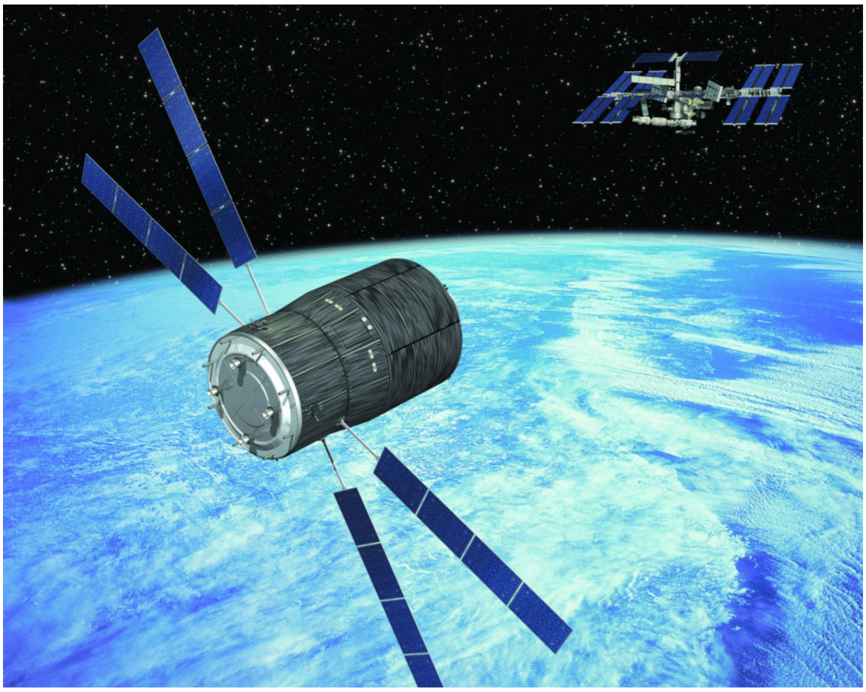
So where are we today?

The development programmes of the on-orbit and ground infrastructures are underway. Columbus, the facilities for science and research and the ground infrastructure are all on target for utilisation to begin once Europe's module is attached to the ISS. The Columbus launch date is more influenced by the Station assembly flight manifest than the module's development schedule.

Europe has an obligation to NASA to upload mass to the Station using the Automated Transfer Vehicle (ATV) on Ariane-5. The primary delivery is propellant for ISS reboosts – a crucial capability and required as early as possible. However, the ATV development programme is undergoing technical reconsideration that will be manifested in an agreed set of Systems Requirements by the end of 2000. Together, we also have to formalise a revised budget for the development programme that maintains ATV's early capability for resupply missions – and Station reboost in particular.

On 26 July 2000, Russia's 'Zvezda' Service Module with our European Data Management System onboard successfully rendezvoused and docked with the Station elements already in orbit. The ISS can now host its own crews [the first crew arrived 2 November - *Ed.*].

ATV is an important element of the Space Station infrastructure. (ESA/D. Ducros)



The BEOS centre for commercial space utilisation was established in 1998. (Astrium)

International cooperation and partnerships are complex. ESA and European industry together broke new ground 25 years ago during the Spacelab era. This partnership has lasted since then and the trusting cooperation has to be carried forward into Station operation and utilisation for at least the next 12 years. As the ISS grows, utilisation will begin to dominate. The industrialisation process described earlier provides the orbital infrastructure, up/down services and mission preparation and execution for the users. However, it is limited: it provides the complete environment for the user but it does not provide the users. The Member States were willing to approve budgets for utilisation covering two-thirds of the available resources. This will allow the traditional utilisation of fundamental research that we have all come to know with Shuttle and Mir missions. It is now up to industry and ESA to attract commercial users for the remaining resources. Of course, industry – and particularly Astrium – has always been interested in commercial utilisation.

Therefore, we welcome the current developments towards promotion and business development to attract commercial users in research, technology and innovative markets.

The results of the ESA studies addressing the potentials of such commercial utilisation are both comforting and challenging for all of us. They indicate that potential commercial utilisation is initially mainly in the non-science, non-research areas. Applied research by private industry can be envisaged only for later. So we take comfort in the fact that commercial utilisation will happen, but we are challenged to attract commercial users and markets using mechanisms quite different from our traditional way of doing 'space business'.

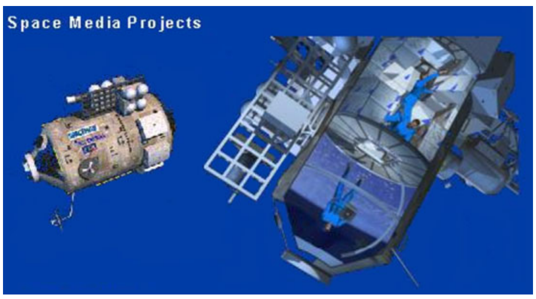
Significant efforts are underway in ESA and industry to prepare us for this new era of commercial utilisation. ESA is thinking along the lines of freeing up a set portion of European resources for commercial utilisation, then handing that package over to a Commercial Business Development Organisation with responsibility for marketing and selling the resources to markets beyond ESA's reach. The Call for Interest was issued in June 2000.

We at Astrium applaud this move by ESA, as it reconfirms our approach on commercial utilisation. Together with our local partners, we set up the BEOS centre for commercial space utilisation in Bremen in 1998. We, too, have recognised the need to market to and do business with commercial users in a different way than our traditional organisation could handle.

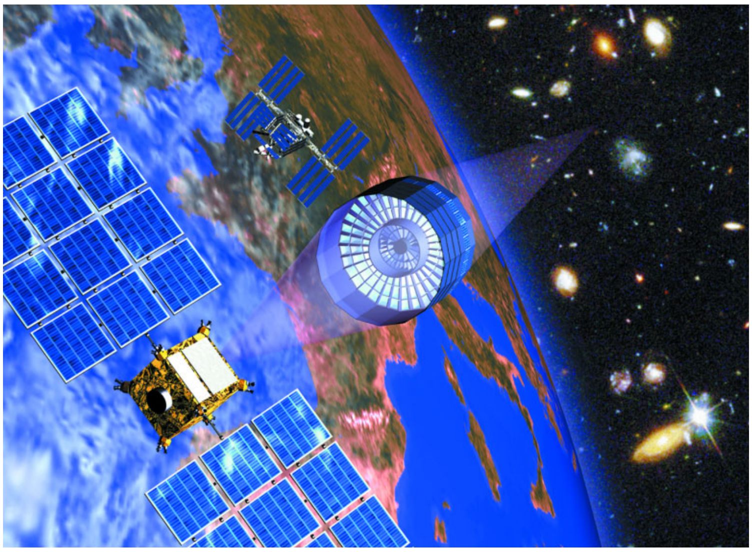
In the meantime, we have refined and expanded our concept for BEOS, tying in our local and international partners, such as Spacehab, and establishing a network of flight opportunities and space services. In addition, we are now expanding our network beyond the confines of aerospace markets.

All in all, we believe that a different way of approaching the market plus a critical mass in the services offered sends the best signal to the market that we are 'ready for ISS business'. Needless to say, we would be delighted to offer our services to ESA for placing some European ISS resources in the commercial market.

It has to be added, though, that, in addition to a suitable pricing policy, a vital ingredient for successful business development in this area is a reliable legal framework. In simple terms, the framework must allow bankable business cases for commercial utilisation. 'On-condition' situations, veto-rights over other independent organisations and so on prevent the closing of such business cases. Agency and industry teams have recognised these problems; they are being worked on but the solutions are still pending.



The Space Station offers opportunities for new types of space users.



'The Transition from Development to Exploitation' is a challenge and will continue to be a challenge. Industrialisation is in its advanced conceptual stage; the coming 18 months will start to prove the concept. Changes will be introduced as we continue into operations and utilisation, so we will need dedicated and innovative teams – a 'learning organisation'.

Perhaps a result of developing the industrialisation concept is opening the doors on critical assessments of the concepts in place for other projects and space programmes.

My title implies the phased transition between development and exploitation. We are all used to phasing concepts including a full contractual separation between phases. The development of operations industrialisation shows that the full life-cycle has to be addressed. On the other hand, the earlier phases must have a clear focus on operation and utilisation.

The concepts for integrating the interests of different industrial partners and ESA – as achieved for ISS Exploitation – will also prevail for other projects at the level of ESA and the European Union, such as the planned network of technical centres.

XEUS would require the International Space Station.

And the future?

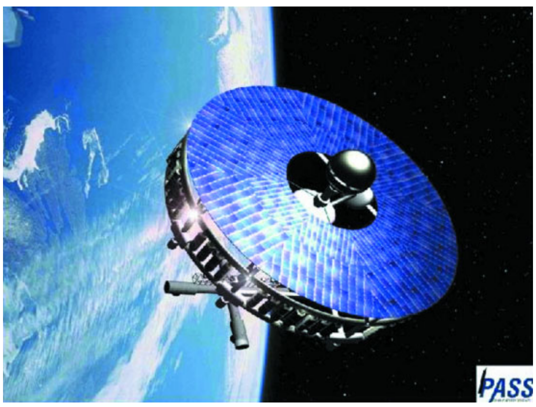
I am convinced that manned spaceflight makes an important contribution to mankind's scientific knowledge and to performing scientific and applied research for the benefit of all. Also, it will provide fundamental knowledge for future manned missions – back to the Moon or on to Mars, for example.

We have to realise, though, that our community will be judged first by the way the International Space Station is going. As such, it will pave the way to the future not only technically but also programmatically and politically. Hence, proper management of ISS operations, a sound balance of traditional research and new commercial utilisation plus a properly tuned public awareness campaign for the Station will be the key levers in ensuring its success.

And success will attract more success: the possibilities of what ISS can do will expand continuously. For example, one fascinating project in fundamental research is the forthcoming XEUS new-generation X-ray astrophysical satellite. The need for assembling a 10 m-diameter mirror to detect faint objects calls for combining the scientific element with our manned Station. It combines feasibility and economical ways of reaching this goal – and needs man-in-space. The astronauts would perform the assembly using the Station's range of manipulators and possibly EVA. Only humans can cope with the unexpected and prevent potential losses.

This example highlights only one feature offered by the ISS – the weightless environment – while others are less well-known to potential users.

Reflecting on what has been achieved so far towards exploitation and what is still ahead, I would again like to thank the participants. You have broken fresh ground to create a new dimension for operating and utilising the ISS in a fully integrated international community. Maintain your momentum! ■



The future? A space hotel.

Columbus Integration and Testing

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Introduction

The Columbus system consists of the Pressurised Integrated Columbus Assembly (PICA) and the functional elements of data management, power, video & communications, flight application software and ground facilities. PICA itself comprises primary and secondary structures, thermal control system (TCS) and environment control & life support (ECLS) system. Most of these elements were previously qualified and the flight units are being manufactured, so the next step is their integration into a working system, and its test and qualification.

Most Columbus items are now qualified and the flight units are being built; the flight software is coded and undergoing final tests. The challenge now is to integrate everything into a system and qualify the system-level functions....

At product level, integration and test are performed by the supplier. Alenia Aerospazio is currently integrating the secondary structures, brackets, ducts, lines, harness and TCS and ECLS equipment into PICA's primary structure. At Astrium's final integration site in Bremen, the avionics will be added, the flight software loaded and the entire system tested. After this, Columbus is ready for integration of the payload facilities. The final compatibility testing completes the flight hardware activities in Europe. The integrated module will then be shipped to the launch site.

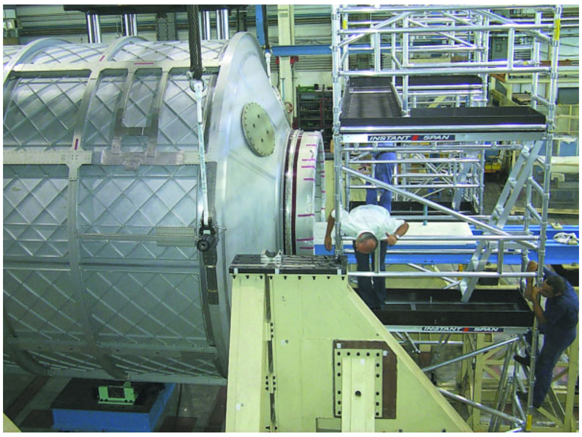


Fig. 1. The Modal Survey Test is underway at Alenia Aerospazio.

Flight Unit Integration Flow

Following the current Modal Survey Test (Fig. 1), holes will be drilled for the brackets to install the Meteoroid & Debris Protection System (MDPS) panels, ducts and lines, harness and Multi-Layer Insulation support structures. Installation of secondary structures, thermal control and ECLS equipment, port cone entrance hatch and harness will follow. After proof testing of the liquid cooling loop, harness continuity and isolation testing, and mass and balance measurements, the module will be shipped to Bremen for final integration and test.

At Bremen, the first installation will be of avionics equipment such as power distribution units, data management equipment, and video and audio (intercom) equipment. In parallel, the Fluid and Gas Support Equipment (FGSE) will be connected to the module's Station interfaces. The FGSE provides basic resources for cooling, gas and air supply. The Electrical Ground Support Equipment (EGSE) will be attached to the bulkhead interface connectors to provide the resources for power and data exchange. System-level testing can now begin.

System-Level Testing

System-level testing begins with power polarity tests to ensure that equipment receives its correct voltage level and polarity. Having activated the onboard equipment, the Mass Memory Unit can be loaded with the entire flight software image via a network connection from the EGSE.

At this stage, the test crew can exercise all system functions one after the other by executing the various test procedures (Fig. 2).

The greatest effort is dedicated to verifying the hardware/software compatibility. This includes certification of the Mission Data Base (MDB) contents. The software system is

Fig. 2. System test in progress.

composed of the Operating System, Standard Services and Application Software, each a software program and Configuration Data Items, which configure the software. The software products, and all data such as sensor information, command definition, downlink telemetry packet definition and event messages are collected in the MDB.

The mission simulation test, operating the system under flight operations conditions, requires a similar effort.

The system-level test programme includes compliance verification of all systems with the electromagnetic environment and proof that the generated EM disturbances are within specified limits.

As part of the Flight Unit functional qualification and acceptance process, several tests under the Bilateral Interface Verification Plan (BIVP) will be carried out jointly with Station prime contractor Boeing to ensure compatibility between Columbus and the Station.

The formal Flight Acceptance Review #1 can now certify compliance of the Columbus system with the System Requirements Document and its supporting documentation, including the external interface requirements.

The module is now ready to accept the payload facilities for installation and compatibility testing.

The final system-to-payload compatibility testing concludes flight segment activities in Europe. Flight Acceptance Review #2 formally terminates these activities and authorises shipment of Columbus to Florida.

Support Facilities

Parallel flows have been established to prepare and support the mainstream Assembly, Integration and Test (AIT) flow:

TCS Test Bed: provides all components of the liquid cooling loop (water lines, valves, pumps, cold-plates, controllers) for performance optimisation, hydraulic characterisation and definition of control software parameters.

ECLS Test Bed ('Boiler Plate'): a full-size mockup to measure air velocity in all areas of the crew cabin, to avoid dead air pockets dangerous to the crew. Hydraulic characterisation and definition of control software parameters will also be performed.

Software Integration & Test Equipment: SITE provides an environment to integrate and test system software. There is a ground version of the data management system, limited EGSE simulates the Station and ground station, and a simulator acts as the 'rest of the system'. All system software versions are tested on SITE before loading on the actual system.

Electrical Test Model: ETM (Fig. 3), operational for some time, is functionally identical to the Columbus Flight Unit. All avionics are represented by engineering models complemented by functionally identical standard equipment and by a dynamic simulation of the liquid cooling and cabin air loops. ETM does not represent the module physically: the equipment and harness are mounted in standard racks for easy access. The goal is functional qualification and acceptance testing up to the cooling and air loops.

After that goal, the facility will be supplemented by the Rack Level Test Facility (RLTF), providing all the features for testing payloads under realistic conditions. Missing payloads in any mission slice can be simulated to generate a realistic scenario for the payload under test.

Fig. 3. The Electrical Test Model.

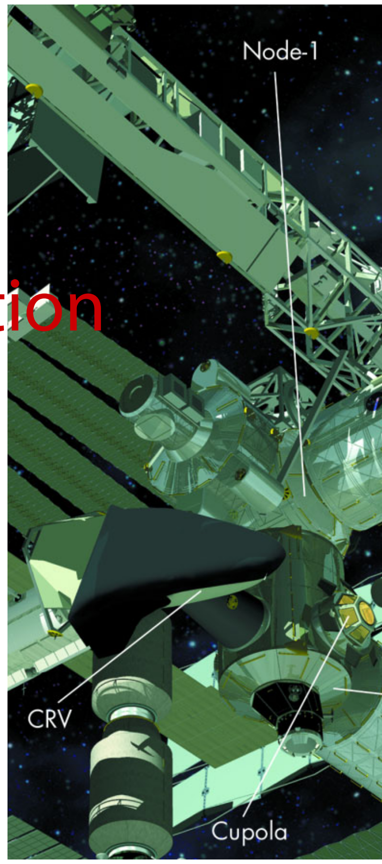
In parallel with payload dedicated testing, operations products such as inflight procedures will be tested.

Conclusion

The Columbus integration and test programme has a 'classical' approach, although a real system-level Engineering Model is missing – those objectives are assigned among the other facilities described above. The advantage of this approach is the early start on parallel integration and testing, and the accompanying early identification of incompatibilities and deficiencies.

Nodes-2 & -3

Resource centres for the Space Station



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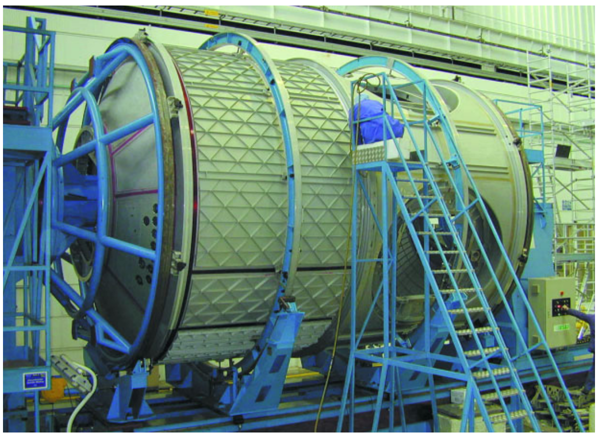
Nodes-2 & 3 will provide important on-orbit resources for operating other Space Station elements. In particular, Node-3 will provide water processing and oxygen generation for the US segment, avoiding sole dependence on the Russian segment.

Nodes-2 & -3 are vital elements of the International Space Station...

When Italy began developing Node-2, based on a NASA design concept, it was structurally identical to Node-1. Stretching provided additional locations for stowage. Node-3 was intended as a Node-2 recurring unit for future Station use. The stowage capability was then made configurable for accommodating Crew Quarters, so that Node-2 could provide early Station habitation. That decision was the basis for NASA to migrate most of the former Habitation module functions into Node-3, making it a redundant Station element for air revitalisation and water processing. Eventually, Node-3 was configured with resources for other attached elements: Cupola, Crew Return Vehicle (CRV) and a future Habitation element, in addition to providing redundant ports with growth utilities for docking of Multi-Purpose Logistics Modules (MPLMs, Shuttle or another Station laboratory.



Node-2's welded primary structure.

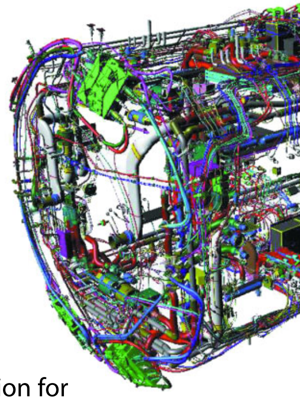
Station Configuration

Nodes-2 & -3 have the same basic geometry of a cylindrical pressure shell capped by two end-cones with axial ports. The cylinder is a two-bay section for accommodating eight racks plus a section with four radial ports.

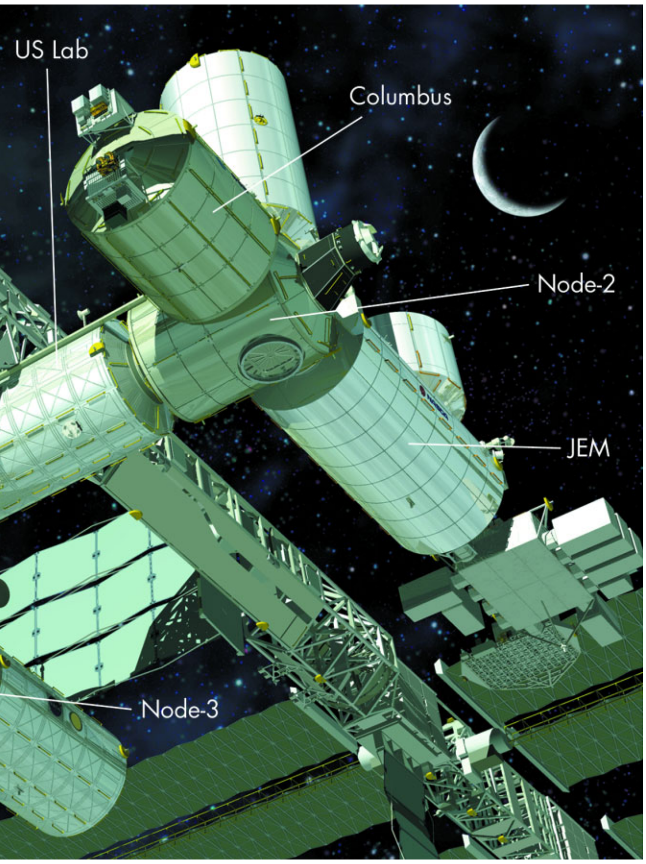
Node-2 will be attached in front of the US Lab, with its longitudinal axis along the Station's velocity vector. The forward port supports Shuttle or US Propulsion Module (USPM) docking, via a Pressurized Mating Adapter (PMA). The starboard side provides resources for Columbus, and the port side for the Japanese Experiment Module (JEM). At the zenith position, Node-2 will initially accommodate Japan's Experimental Logistics Module-Pressurized Section (ELM-PS), before JEM appears, and later the Centrifuge Accommodation Module (CAM). Finally, the nadir port will allow temporary docking of MPLM or Japan's HII Transfer Vehicle (HTV).

When Node-2 is delivered to the Station, its aft port will be docked first to Node-1's port side so that Shuttles can continue docking with the US Lab's forward port. The Station's arm will then move it to the final position.

Node-3 will be attached to Node-1's nadir, with its radial ports closer to the Earth. To starboard, Node-3 accommodates the CRV, while the port side is reserved for a future Habitation module. The forward position includes utilities for docking Cupola, MPLM or a future laboratory. The aft port can be used for temporary parking of Cupola. Nadir offers a redundant location for Shuttle docking, via PMA.



Node-2 fluid and electrical lines.

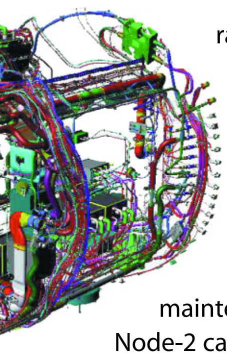


Locations of the three Nodes. (ESA/D. Ducros)

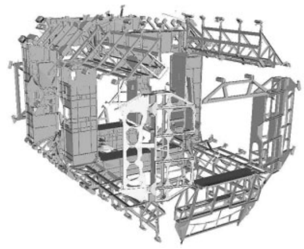
Nodes Configurations

Each Node is 7.19 m long overall. and 4.48 m in diameter. Externally, the layout includes almost 100 panels with thermal blankets underneath, to minimise external heat flux and to protect against meteoroids and debris. Five fittings, reworked from MPLM, hold it in the Shuttle bay. Heat exchangers between the external panels and the pressure shell reject heat from Node internal equipment and from attached elements. Connectors radially positioned on both cone rings allow EVA astronauts to attach utilities from the Station Truss and PMA. There is also a Grapple Fixture for moving the module from the Shuttle bay, and another with avionic utilities to serve as a basepoint for operations with the Canadian robotic arm.

The cylindrical shell was created by combining MPLM-derived panels with integrally machined radial ports.



Each Node accommodates eight racks and 18 major structural assemblies for equipment packaging. This outfitting design involved a noticeable interdisciplinary effort to ensure, simultaneously, the required system performances, no interferences, accessibility for on-orbit maintenance and feasibility of integration. Node-2 carries four avionic racks and four rack locations for either stowage or crew quarters. Node-3 has two avionic racks, four racks for environmental control and one Waste & Hygiene Compartment packaged in two rack locations.



Node secondary structure.

Design and Development Highlights

Node-2's primary structure, now fully welded, is being equipped with reinforcements and interfaces for installation of secondary structures. A ready Structural Test Article will undergo tests to verify the static behaviour of the radial and axial ports under on-orbit loads. Off-line tests are being conducted with the flight computer in a simulated environment, with the goal of identifying potential functional problems before on-line integration and testing begins.

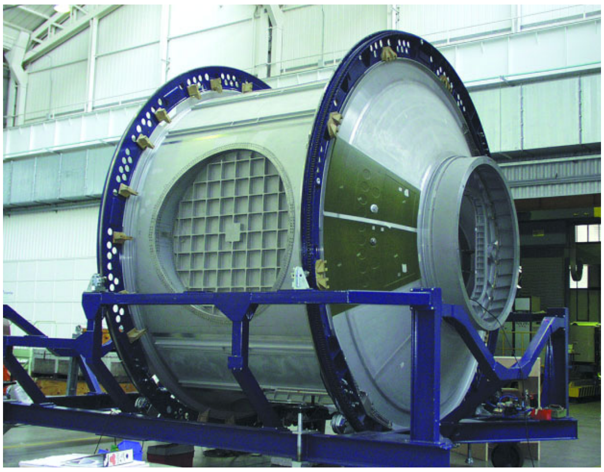
Node-2 Major Capabilities

- regulation and distribution of electrical power to attached elements and internal Node loads (sized for 56 kW);
- active thermal control of coolant water for heat rejection from internal Node equipment and from attached elements;
- temperature, humidity and revitalisation control of cabin air and air exchanged with attached elements;
- atmosphere pressure control during Shuttle transportation;
- distribution lines for cabin air sampling, oxygen, nitrogen, waste water and fuel cell water;
- data acquisition and processing to support power distribution, thermal control and environmental control functions inside the Node, as well as data exchange between the US Lab and Node-attached elements. Physical layers comprise 1553, Ethernet, fibres and discrete lines;
- audio and video communications, involving optical fibres, analogue lines and co-axial lines.

Node-3 Major Capabilities

Featuring the same basic Node-2 capabilities, Node-3 manages less power but has additional capabilities:

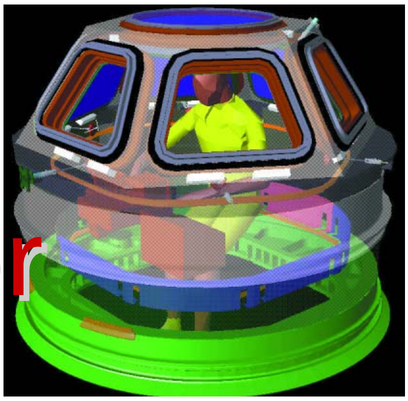
- on-orbit air pressure and composition control, including carbon dioxide removal;
- oxygen generation, based on a dedicated rack also scarred for future water generation;
- waste and hygiene compartment;
- urine and water processing;
- controlled venting of byproducts from environmental control functions;
- potable water distribution;
- audio and video recording;
- on-orbit reconfiguration of utilities provided to Cupola, MPLM and TransHab.



The Node Structural Test Article.

Node-2 will be delivered to NASA at the Kennedy Space Center in March 2002, and launched in November 2003. Node-3 delivery is scheduled for July 2003, and its launch July 2005. ■

Cupola: Space Station's Stargazer



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Introduction

As a key Station element, Cupola is a pressurised observation and control zone for the crew to perform remote robot arm operations. Cupola has six trapezoidal side windows and a circular top window, each protected by external shutters manually operated from inside. NASA workstations and other hardware installed on-orbit will allow the crew to observe the Earth, Universe and Orbiter/Station, and to help assemble Station hardware. Not least, the shirtsleeve observation post offers priceless psychological benefits to the crew during their long stays in space.

Cupola will provide the Space Station with a window on the Universe...

ESA is providing Cupola to NASA in a cashless exchange for the launch and return of up to five external payloads. Alenia, leading a consortium of six European companies, is responsible to ESA for the design, verification and delivery of the Cupola System, and for providing support to NASA for tests, pre-launch activities and in-orbit commissioning. Once integrated and tested at Alenia's Torino (I) facility, Cupola will be transported to the Kennedy Space Center to be prepared for its 2005 launch.

Cupola Characteristics

Mission Objectives
Provide a pressurised observation and work site for crew. Provide interfaces for command/control workstations and other hardware to observe Earth, celestial objects, Station, Orbiter and EVA

Operational Lifetime
15 years (with maintenance)

Size
Height 1.54 m; diameter 2.23 m ; mass 1805 kg (excludes equipment added in orbit)

On-Orbit Outfitting
Dedicated Cupola Crew Restraint supports crew operations. Audio Terminal Unit + 2 Utility Outlet Panels. Periodically outfitted with Robotic Work Station and other portable items (not formally part of the Alenia Cupola System)

Fig. 1. Produced from a single forging, Cupola's dome requires no welds. The fully machined forging for the Qualification Model is shown. From left: L. Basile (Alenia), D. Laurini, C. Soulez-Lariviere and G. Woop (ESA).

Overall Configuration

The competition for Cupola's contract demanded innovative concepts that met not only stringent technical requirements but also produced a high-quality product on schedule and at minimum cost. One innovation is the primary structure's single forged/machined dome (Fig. 1). Compared with a welded dome, it has superior structural characteristics, shortens the production schedule and lowers overall cost. The largest windows ever used in space require a complex design to defend sensitive glass panes from micrometeoroid and debris impacts. The 15-year lifetime calls for user-friendly replacement of windows in orbit. Limited space for the crew and equipment dictates optimised man-machine interfaces for crew ingress, workstation tasks, maintenance and egress.

Cupola's internal layout (Fig. 2) is dominated by upper and lower quasi-circumferential handrails supporting most of the equipment and by close-out panels (secondary structure) covering the harness and water lines attached to the structure. Together with the primary structure, the close-out panels form a 'plenum' for air distribution and are removable to allow inspection and connection of utilities to the Node bulkhead.

The Mission

Cupola will be launched in the Shuttle bay attached to a Spacelab Pallet by a Manual Berthing Mechanism. At the Station, it will be lifted out by Shuttle's robot arm for the Station's arm to grab its second Grapple Fixture. After it is attached via the Common Berthing Mechanism (CBM) to Node-1, the crew will pressurise it, open the Node hatch, connect the electrical and water lines, activate window heaters, fill the water loop and install additional close-out panels. Cupola is then ready for outfitting with NASA hardware launched separately: an Audio Terminal Unit (ATU, ground and crew communications) and two Utility Outlet Panels (UOPs, power and data interfaces for portable equipment).

Alenia must guarantee the proper functioning of the ATU and UOPs as specified by the NASA/ESA implementation agreement. The Robotic Work Station and other portable equipment will also be furnished by NASA and installed on-orbit; Alenia's responsibility for these items is limited to providing the interfaces.

Initially, Cupola will be berthed and commissioned at Node-1's portside location. It will then be relocated to Node-3's forward port – its normal position and the best site for robotics operations and external viewing (Fig. 3). Moving it means the removal and reinstallation of the outfitting equipment. As a contingency, Cupola can also be sited at Node-3's aft port, but there it will not have its installed equipment and Node interfaces are limited to window heater control.

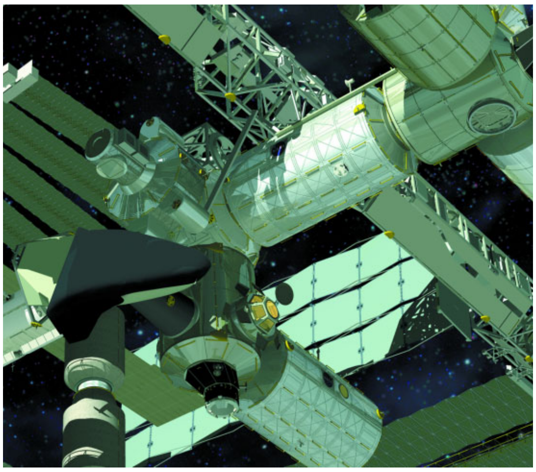
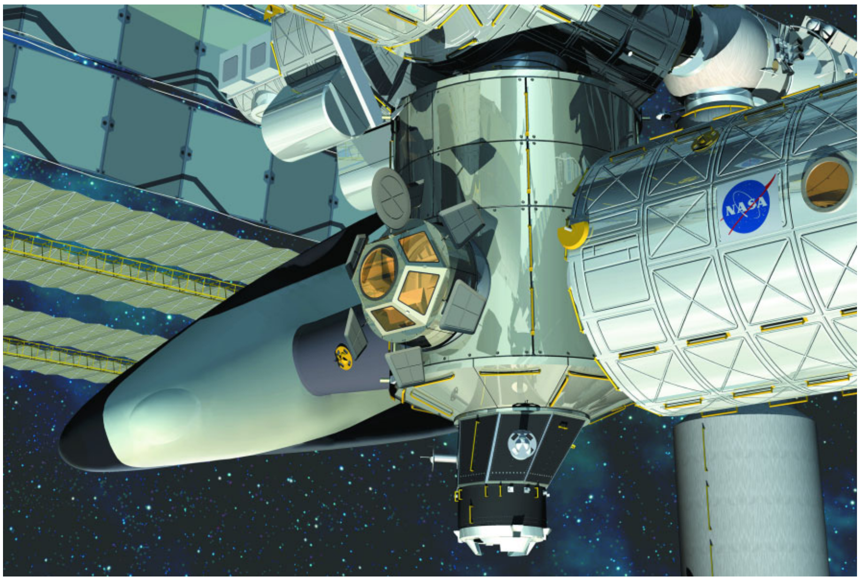


Fig. 3. Robotics operations and external viewing are best supported by Cupola at Node-3's forward port. (ESA/D. Ducros)



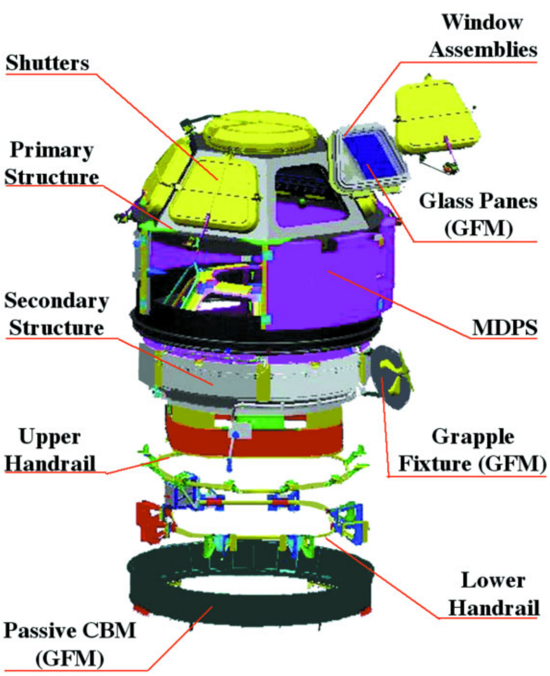


Fig. 2. The Cupola System is complemented by NASA Government Furnished Material (GFM) as part of the ESA/NASA bilateral agreement. MDPS is the Micrometeoroid Debris Protection System.

Milestones

Cupola's Qualification Model is being manufactured and, after completing tests, will be delivered to NASA in summer 2001. Following the Acceptance Review, the Cupola Flight Model will be delivered in September 2002 to be readied for launch in early 2005. ■

Ariane-5/ATV Optimisation

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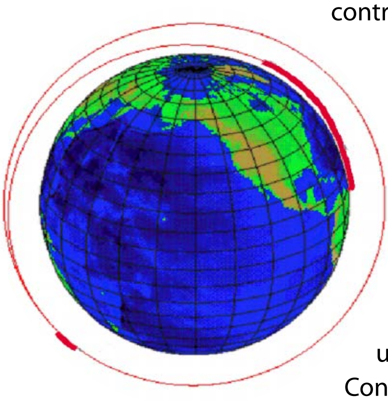
What is Arianespace doing for ATV?

The Automated Transfer Vehicle (ATV) is one of the most important elements of Europe's contribution to the International Space Station (ISS). ATV's mission is to deliver goods, fluids and gases to the astronauts, cosmonauts and other Station residents, and propellant for refuelling Russia's Zvezda module, as well as to provide a large propulsion capacity for ISS reboost during its attached phase of up 6 months. During this phase, ATV will be loaded with unwanted items and rubbish to burn up in the atmosphere during the controlled destructive reentry.

The Automated Transfer Vehicle places special demands on its Ariane-5 launch vehicle...

For crew safety, the 20.5 t ATV will be launched by the powerful Ariane-5 into a slightly lower orbit than the Space Station's typical 450x450 km, inclined at 51.6° to the equator. It will then cruise autonomously under the ultimate control of the ATV Control Centre (ATV CC) in Toulouse, France.



The Ariane-5/ATV path around the Earth. The thick red lines mark the propulsion phases.

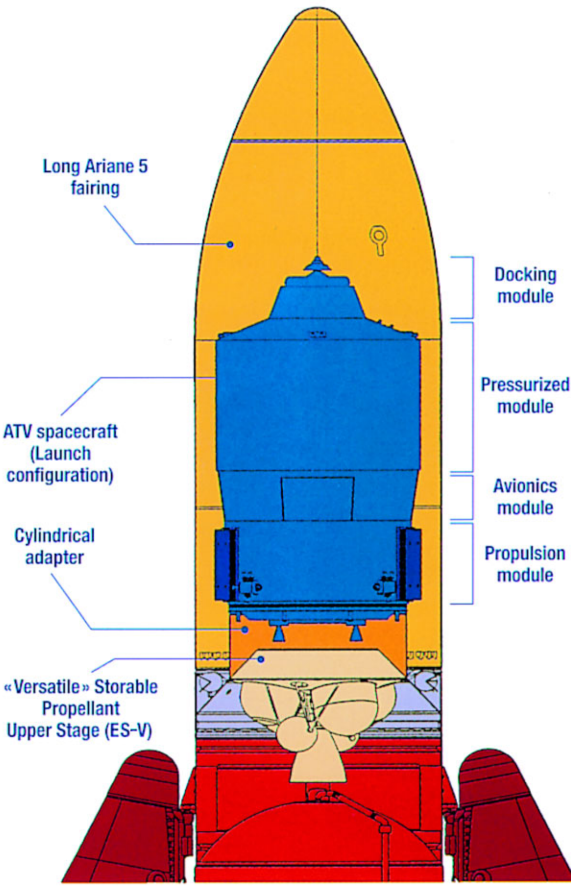
Initial Situation

The ATV and Ariane teams began working together early on in the project. Their initial studies demonstrated in 1994 that the most efficient mission was, at the time, launching ATV using a non-standard Ariane-5 composed of the:

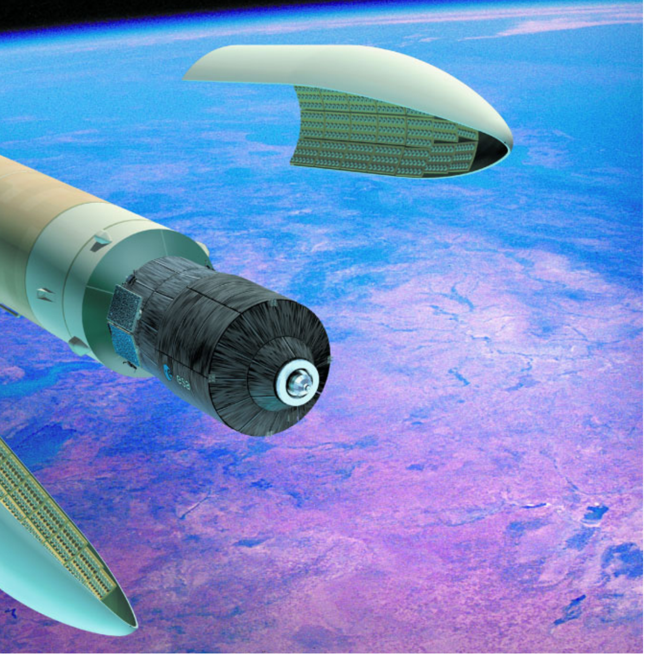
- two EAP solid strap-on boosters,
- EPC main cryogenic stage and its Vulcain-2 engine,
- VEB electronics and avionics bay,
- long fairing.

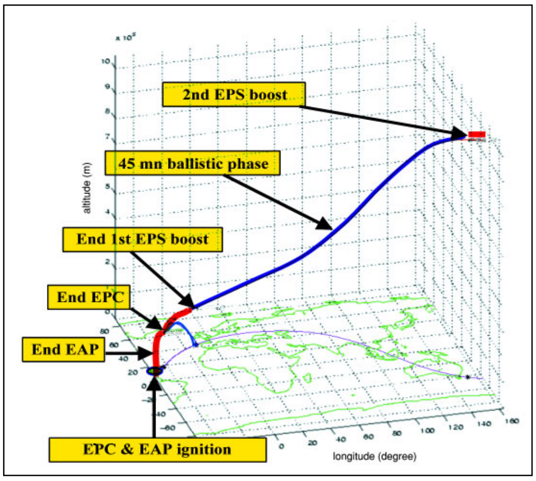
The EAP, EPC and VEB were already planned under the Ariane-5 Evolution programme. This concept did not require the EPS storable-propellant upper stage, with its Aestus engine.

In this configuration, ATV was delivered into an untenable orbit of 50x300 km, 51.6º, leading to reentry at the first perigee. With such an orbit profile, a demanding operational consequence was the need for a mission-critical Perigee Raising Manoeuvre with a go/no-go decision window of only about 10 min. In those few minutes, the ATV Control Centre had to assess the vehicle's complete



How ATV will be accommodated on Ariane-5.





The Ariane-5 trajectory for the ATV mission. EPC is Ariane's cryogenic core; EAP is the strap-on (paired); EPS is the reignitable upper stage.

health status through telemetry (relayed by the US Tracking & Data Relay Satellite system) and compute its position using GPS data. This meant the critical decision path was a complex operational structure. If any data were unavailable (never mind any sort of failure), the decision loop would have aborted the perigee manoeuvre and the mission would have been lost.

New Factor in the Equation

Following that original ATV launch scenario, Ariane-5's commercial market evolved so much that the vehicle's design was extensively reconsidered. In May 1999, after this wide series of improvement studies by CNES and European industry, ESA decided on several modifications. The direct consequence for ATV is that Ariane-5's EPS upper stage can now be reignited at the first apogee to circularise the orbit, cancelling the need for ATV's own do-or-die perigee burn.

Using this Ariane-5 'ES-V' (V=Versatile) configuration, the 20.5 t ATV can be released into a stable orbit of typically 300x300 km, 51.6º. This means that the Control Centre team now has all the time it needs to check the vehicle's condition in orbit and to prepare thoroughly for the next stage – the cruise to the Station. A margin for failure or temporary data loss is built into the global mission, significantly increasing the chances for complete mission success.

Situation Today

Having carefully weighed the pros and cons of this new option, ESA-MSM agreed to the proposed scenario, and selected 'Option C' shortly before the beginning of ATV's Preliminary Design Review in March 2000.

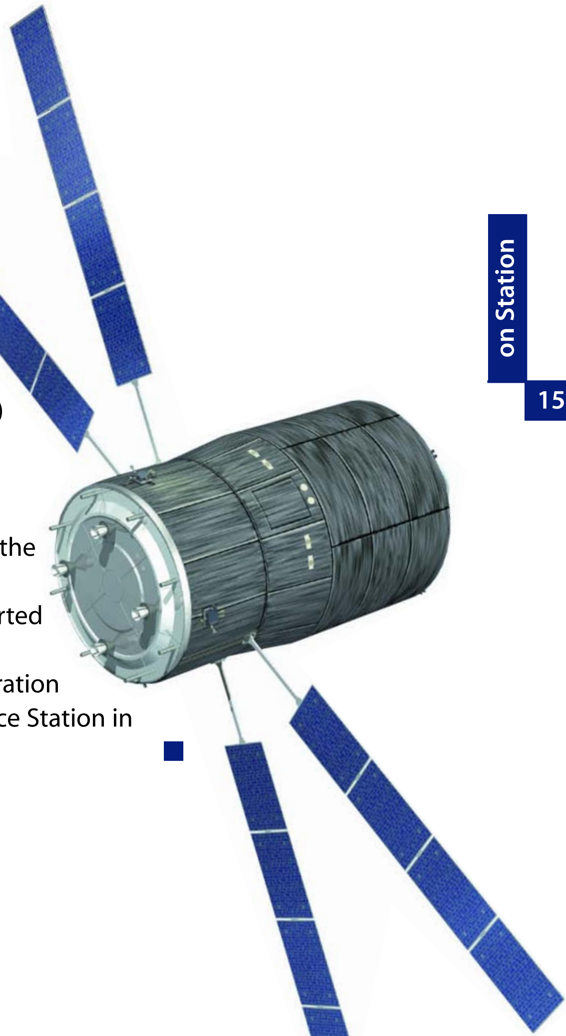
This option also allowed the mechanical constraints at the lower ATV interface to be reduced, so ESA could also quickly decide on an optimised configuration of the ATV separation system – the Separation & Distancing Module.

The Launch Contract for nine vehicles was signed with Arianespace in this final configuration:

- dedicated flights on an Ariane-5 ES-V,
- EAP, EPC & VEB developed under the Ariane-5 Plus Programme,
- EPS in its Versatile (reignitable) version,
- long fairing,
- launch services adapted to ATV specific requirements.

As of September 2000, work is underway on the Ariane-5 ES-V programme for ATV between ESA's Launcher Directorate in Paris (F) and the Direction du Développement Ariane (DDA) common directorate of CNES and Arianespace at Evry (F).

On the ATV side, ESA-MSM, EADS LV/ATV Les Mureaux (F; the ATV prime contractor) and Arianespace, Evry (F) have started the mechanical, electrical and operations activities in preparation for the first launch to the Space Station in April 2004. ■



Crossing the Threshold

Applying CMCs to Space Vehicles

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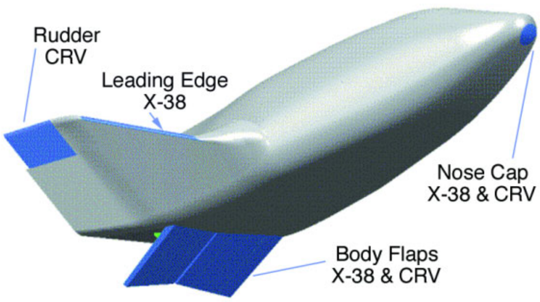


Fig. 1. CMC components on X-38 and CRV. CMC components have reached maturity: technically, economically and operationally. X-38 V201 is the final verification of their maturity and reliability. With its successful flight, a new family of high-temperature, high-durability yet lightweight material systems will cross the threshold, opening new and exciting opportunities for future space vehicles.

Introduction

The use of fibre-reinforced composite materials in high-temperature heatshields and structures is not new: the Space Shuttle has been demonstrating the maturity of carbon-carbon (C/C) nosecaps and leading edges for more than 20 years. Their success and (from experience) limitations formed the basis for improving the state-of-the-art, concentrating on the critical characteristics of strength, oxidation resistance, operational temperatures and cost-efficient manufacture. This led to the new class of 'ceramic matrix composites' (CMCs), which replace the previous organic, resin-carbon matrix with a more stable, oxidation-resistant ceramic matrix, such as silicon-carbide (SiC). CMCs are more than an order of magnitude stronger, operating temperatures exceed 1600°C, and fabrication times and costs are lower.

CMC hardware will soon demonstrate its readiness for future space vehicles...

For heatshields and load-carrying 'hot structures', MAN Technologie AG (MT) has concentrated on the development and continuous improvement of C/SiC (carbon/silicon-carbide) CMCs for more than a decade, while other European companies have pursued similar material approaches. So far, however, the various development and verification efforts have been limited to either manufacturing demonstrations (Hermes, FESTIP, Ceramic Heatshield Assembly, Hot Structure Flap) or subscale material coupon flight demonstrations, such as 1998's successful test of multiple C/SiC specimens on ESA's Atmospheric Reentry Demonstrator. The X-38 programme is a significant step: functional CMC hardware has been designed and qualified for an operational spacecraft for the first time.

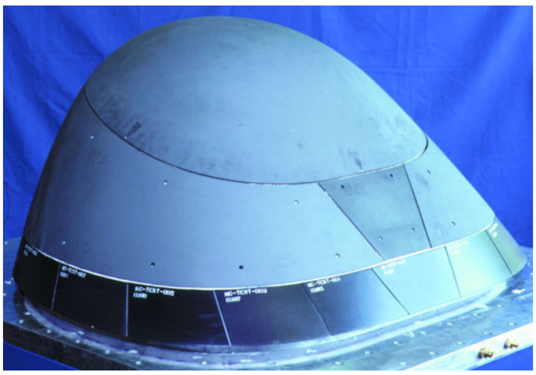
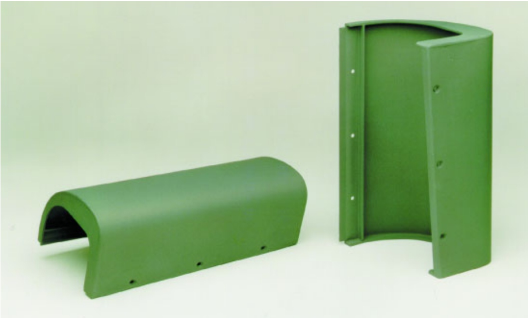


Fig. 2. Nosecap and nose-skirt assembly (qualification test units).

X-38 CMC Components

In a coordinated European effort, consisting primarily of ESA's participation in the X-38 programme (including the Applied Reentry Technology Programme) and the German/DLR TETRA (TEchnologieprogramm für zukünftige RaumTRAnsportsysteme), a diversity of flight-critical, baseline hardware CMC elements has been developed for integration and flight demonstration on X-38 Vehicle 201, the prototype for the Space Station's Crew Return Vehicle (CRV). They are now being prepared for shipping to NASA. They include the nosecap (provided by DLR-Institut für Bauweisen und Konstruktionsforschung, Stuttgart), the nose-skirt/chin (a joint Astrium-MT development), two leading edge segments (MT) and the twin bodyflaps (MT) for vehicle control during reentry and descent (Fig. 1).

Their development and manufacture is a milestone in the application of CMC materials: each was subjected to rigorous specifications, extensive quality control and comprehensive qualification and acceptance tests. Also, the



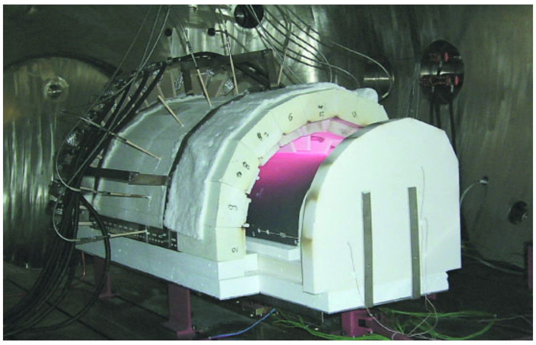


Fig. 3. C/SiC panels of the Leading Edge Units, and the thermal qualification test.

stringent requirements and constraints imposed by the complex vehicle interfaces demanded high-precision manufacture.

Nosecap and Nose-Skirt

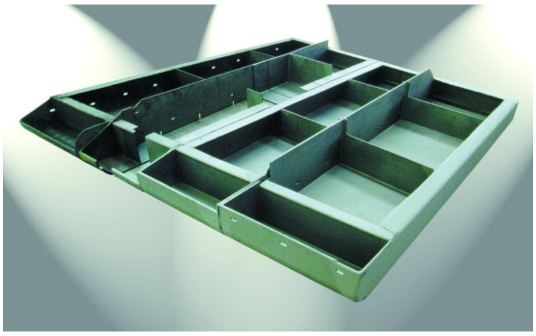
The nosecap and its skirt interface (Fig. 2) provide the critical aerodynamic shape and protect the supporting airframe at the vehicle stagnation point. The combination of extreme surface temperature gradients (600°C to >1600°C) and crucial thermal and mechanical interfaces with the fragile, neighbouring thermal protection tiles and the metallic nose structure, led to an innovative blend of CMC component designs. While the integral, semi-spherical C/C-SiC nosecap is at the stagnation point, the C/SiC skirt provides protection where temperatures are <1400°C. The high thermal gradients around the nose require a 3-segment skirt: two bi-directional side panels (Astrium) separated on the windward surface by a central chin panel (MT). A combination of ceramic fibre blankets and Internal Multiscreen Insulation (IMI) provides insulation beneath the composite surface, and a complex sealing system controls venting of the total system, while preventing hot gases penetrating from the adjacent boundary layer.

Leading Edges

The X-38 fins contribute to the lift and provide aerodynamic stability and control. The consequences are extreme pressure gradients (providing steering) and high heating transients along the fin leading edges. MT has developed a demonstration Leading Edge Unit (LEU; Fig. 3) to validate the feasibility and advantages of a C/SiC-based design. A robust, damage-tolerant yet lightweight rigid C/SiC outer shell attached via redundant C/SiC fasteners, combined with internal fibrous insulation, provides a low-maintenance, highly supportive system with outstanding reliability because of its fail-safe design and high structural and thermal margins. The LEUs have completed a comprehensive qualification campaign, including surface loads up to 540 mbar (equivalent to 800 kg over its 500 mm length), vibration loads >63 *g* and cyclic temperatures >1030°C.

Bodyflaps

Whereas conventional control surfaces are cold metallic structures insulated by thermal tiles or blankets, the two X-38 V201 C/SiC bodyflaps are revolutionary (Fig. 4). Their all-composite, load-carrying hot structures need no additional thermal protection and thus offer considerable mass savings. The system is simplified and lightened by using ceramic bearings for rotation about V201's aft structure hinge line via eletromechanical actuators. These large (1600×1600 mm) C/SiC bodyflaps will be subjected to 1800°C and 300 mbar during their imminent qualification tests. The CMC bearing is designed to carry up to 40 kN.



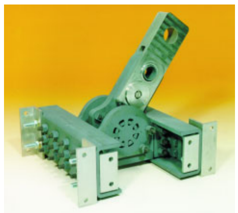


Fig. 4. The X-38 C/SiC bodyflap and (right) the electromechanical actuator bearing model.

The Outlook for CRV: C/SiC Rudder

Another CMC component is planned for CRV: a hot-structure rudder (Fig. 5), where a stiffened C/SiC structure forms the exterior, over an internal titanium 'strongback' metallic structure core that connects to the electromechanical actuator. This ESA project will be performed jointly by Fokker Space and MT. The two 850×720 mm rudders will replace X-38's conventional design, saving mass and increasing operational flexibility through higher temperature and mechanical margins.

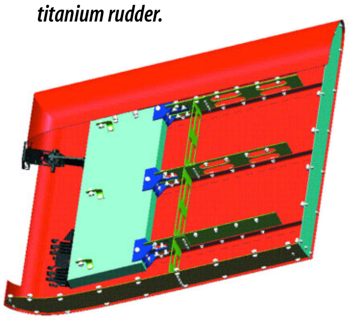


Fig. 5. Layout of CRV's CMC-titanium rudder.

The CRV Landing Gear

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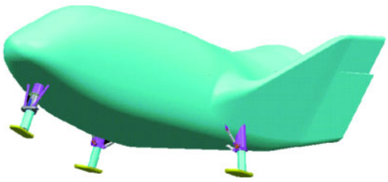
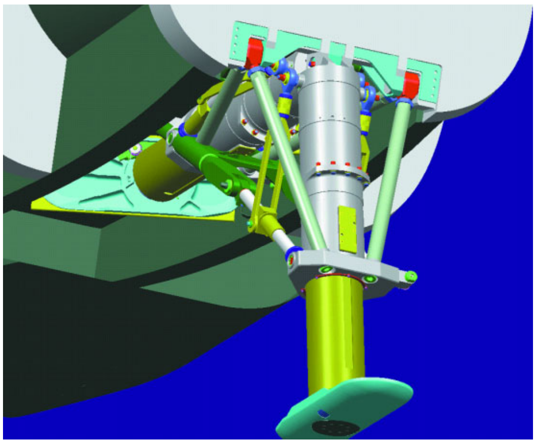


Introduction

European participation in the X-38/Crew Return Vehicle (CRV) includes responsibility for the landing gear. This consists of three legs in a typical aircraft configuration (two main and one nose), deployed shortly before touchdown. As an emergency return vehicle, the CRV must be able to land on unprepared surfaces with a wide range of ground characteristics and touchdown conditions. Energy absorption by crushable expendable dampers provides a soft landing under normal conditions and reduces crew loads to within acceptable levels for off-normal landings.

The landing gear is a major element of the Crew Return Vehicle...

The gear is compactly stowed between CRV's internal and external skins. It is released during the parafoil flight, and locked in position ready for landing. At touchdown, the CRV is flying with a horizontal speed of 15 m/s and sink rate of 4 m/s. In less than 1 s, the sink rate is absorbed by the crushable dampers, limiting the vertical shock and deceleration on the crew to 4 *g*, respectively. CRV slides to a stop after about 6 m.



Nose gear in stowed and deployed positions.

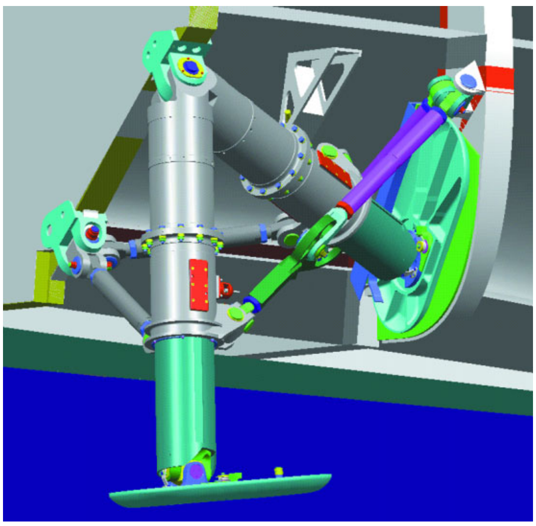
Stowage of the Landing Gear

Stowing the gear between CRV's shells requires a highly compact design for the structural elements and deployment mechanisms while still providing a 450 mm damping stroke and 350x720 mm skid size.

The shape of the available stowage volumes means that the deployment mechanisms have a large number of parts and dynamically-linked joints: the movements of the main cylinder, telescope, drag link struts and skid plate are synchronised to pack the gear in the small volume. Detailed analysis was necessary to avoid interference between all the parts and to identify potential sticking points.

Deployment of the Landing Gear

The gear is deployed by gravity combined with spring-loaded mechanisms. Each 120 kg leg has two distinct deployment phases. The first is a 1 degree-of-freedom movement in which skid rotation is synchronised around the main rotation axis by a cam. The skid is locked in its final position pointing along the flight



Main gear in stowed and deployed positions.

direction at touchdown. Gravity provides most of the energy for this phase.

In the second phase, the main gear continues deployment mainly by gravity and is locked by a spring-loaded mechanism. The nose gear reaches its final position by a spring mechanism. Once the three legs are locked, CRV is ready for touchdown. The whole process takes less than 1 s. The skids are free to rotate in two axes to allow for ground irregularities.

Limiting Crew Accelerations

CRV velocity at touchdown is defined by the parafoil performance and weather conditions. Owing to the range of possible landing parameters (vehicle and wind speed, ground characteristics, CRV mass, etc), the required damping forces have been subjected to careful dynamic analysis. The minimum damping value is defined by the worst landing condition and the maximum by the *g*-level acceptable for the crew (4 *g* in nominal landings; 10 *g* in backup conditions). In the X-38, the available stroke is too short to provide a constant soft deceleration, so each damper cartridge (60 cm long and 15 cm diameter) has two different damping forces: one soft (around 200 kN) for low *g*-levels in normal landings and the other hard (about 500 kN) for worst-case conditions.

Nose landing gear parts before assembly.

Port and starboard gear parts before assembly.

CRV Slide

The horizontal speed is removed by friction of the skids with the ground. At first contact, each skid applies a very high load to the ground defined by the damper force. Once the vertical speed is zero, the force on each skid is defined by CRV's mass (9 t on three legs) and is much lower than the damper force.

The high damping loads produce a large deformation to soft ground that increase the loads in the gear structure. This ground deformation at first contact has been analysed to define the minimum ground requirements, skid size and shape in order to limit the loads on the structure and crew.

Project Status

The X-38 landing gear is now under Assembly, Integration and Test with the goal of integrating it on the X-38 V201 orbital test vehicle in mid-2001 for flight aboard Space Shuttle *Columbia* in mid-2002. Engineering activity on the CRV gear will begin in 2001. ■

NASA

Returning to Earth

CRV MMI and Display Technology

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An ESA, NASA and Belgian industry team is developing man-machine interfaces (MMI), display techniques and cockpit concepts for the Crew Return Vehicle (CRV), the next generation of manned spacecraft. ESA astronauts are closely involved in this effort. The team began work only in January 2000 but it is already producing tangible results.

Work is underway on the crew flight displays for the Crew Return Vehicle...

The CRV allows the 7-strong crew of the International Space Station (ISS) to leave at a few minutes' notice at any time in case of emergency, damage to the Station or if one of the crew requires specialist medical attention on Earth.

The team is designing and developing advanced man-machine interfaces that will allow the Station astronauts to operate the Crew Return Vehicle via keypads and hand controllers during its return to Earth. It is identifying the activities the crew must perform and what information they need in order to make the correct decisions in the various mission phases, and it is specifying the MMI architecture and developing the display techniques.

Two of the astronauts are 'operators', who monitor mission progress and can override the CRV automation. The roles of the crew and the level of automation are important issues in designing the cockpit. The technologies being investigated include flexible displays, 3D and augmented reality displays (e.g. for trajectory and landing terrain visualisation), as well as predictive displays and symbology that show the consequences of crew decisions.

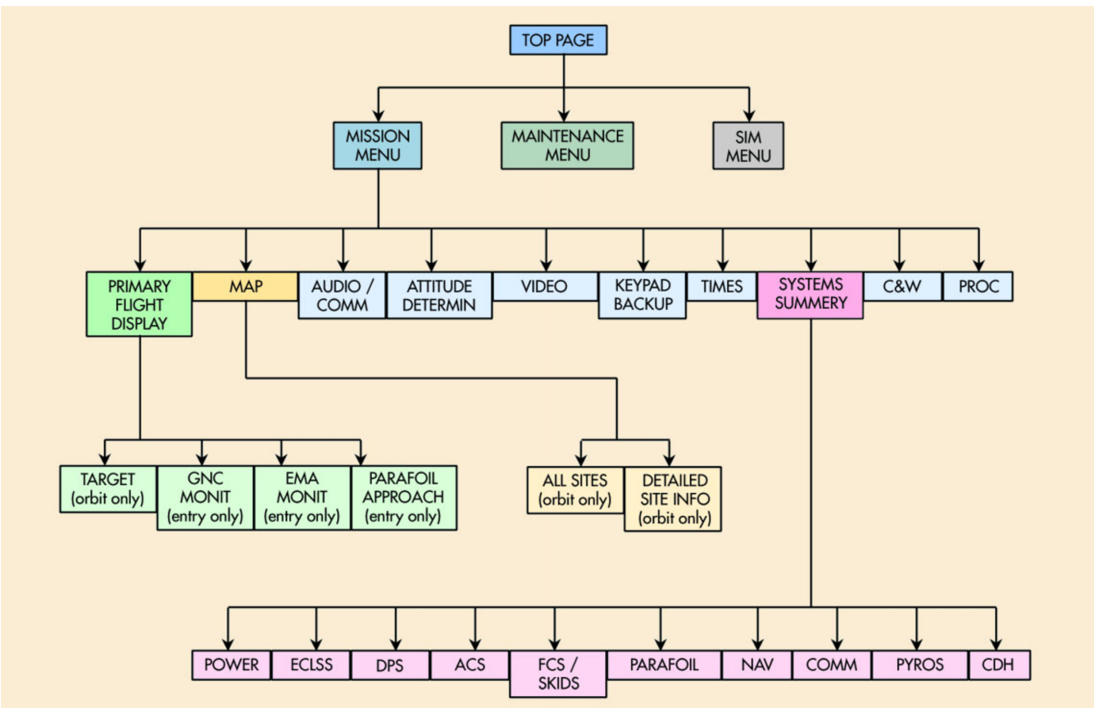

Fig. 1. The hierarchy of CRV's cockpit displays.

Fig. 2. The deorbit planning page of the map display.

Architecture

The present CRV cockpit concept is based on the use of multi-functional displays. The architecture (Fig. 1) is designed so that each display layout can be seen on each of the six display screens in front of the two CRV operators (two per operator and two shared). The features of the primary flight display and the map display are slightly modified according to the particular flight phase. All displays include a link to the menu page, and to previously displayed pages. The starting point for the Station crew to interact with the CRV on orbit is a choice between departure mission, on-orbit maintenance and checkout or simulation activities. The hierarchical architecture of the overall displays is illustrated in Fig. 1. The small number of displays required to operate such a complex vehicle is noteworthy.

Deorbit Planning Page (Map Display)

The CRV's orbital position, deorbit burn opportunities and landing site positions are displayed on a continuously-updated moving world map (Fig. 2). Each of four orbits can be viewed independently on the map. Detailed information about each available landing site can be consulted from this display. The CRV footprint and Deorbit Propulsion Stage impact area can also be displayed on the map by using zoom capability.

Reentry Page (Primary Flight Display)

In addition to attitude, speed and altitude information, the Reentry Page (Fig. 3) presents azimuth changes (ΔAZ) and drag boundaries (DB), defining a box around the CRV icon. A dashed line shows the normal drag level. Each point of the landing area can be defined as a delta azimuth, range and drag value, which means that a slightly distorted map of the landing zone is drawn in the box. Predictors and a flight director help the operator to monitor the system.

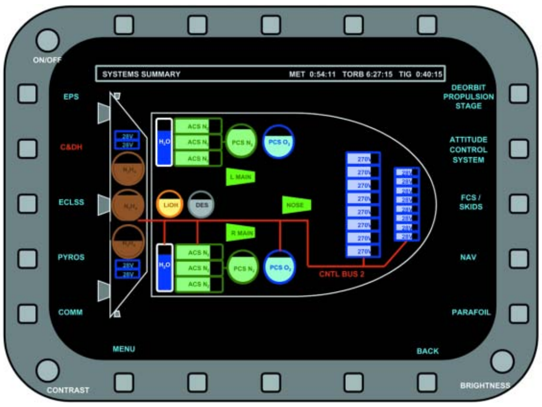

Fig. 4. The systems summary page.

Systems Summary Page

Consumable levels at any moment of the mission are displayed on this (Fig. 4) high-level systems page. In order to make the screen easy to read, information about other system features is displayed only in case of failure, with a suitable colour (yellow for caution, red for warning). Details can always be consulted on the ten system-level pages directly accessible from this summary page.

Conclusions

The team's work will be evaluated in a physical mock-up at the NASA Johnson Space Centre, making use of software simulators to provide realistic dynamic data. The man-machine interface for the landing phase will be used during flights of the X-38 test vehicle in November 2000 and January 2001.

This work is an excellent example of the collaboration between ESA and NASA engineers and astronauts to develop technology that will contribute to safe operation of the International Space Station. ■

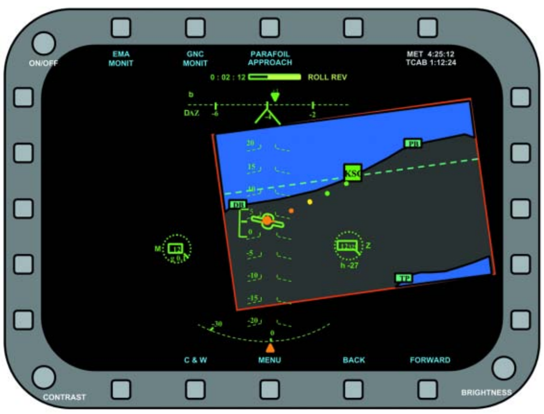

Fig. 3. The reentry page of the primary flight display.

ERA's Development Programme

Frank P. Meiboom
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The European Robotic Arm is moving into the final stages of development...

The European Robotic Arm (ERA) is being developed under ESA contract, with Fokker Space as prime contractor, as a crucial element of the Russian Segment of the International Space Station (ISS). The Flight Model (FM) has recently completed integration and is now in the middle of its (protoflight) qualification programme; the Engineering Qualification Model (EQM) continues its extensive functional test programme at the ERA flat-floor test facilities at Fokker Space in Leiden.

Fig. 2. ERA wil help to install Russia's SPP solar arrays.

ERA and its capabilities were described in *On Station* #2 (March 2000). This article focuses on the recent developments in the ERA qualification programme.

ERA Characteristics and Basic Capabilities

ERA is a robotic arm that can move around the Russian modules using standard basepoints. For the early ISS, it will be used to integrate elements of the Russian Segment, such as the solar arrays of the Solar Power Platform (SPP) and their drives (Fig. 1 & 2). Other tasks include inspections, crew transport and support during EVAs and the installation and transport of dedicated experiments and equipment.

With its 6 degrees-of-freedom and total length of 11.4 m, ERA has an operating reach of 10 m. By relocating from one basepoint to another, it can extend its range dramatically. ERA can be controlled from inside the ISS, using the Internal Man-Machine Interface (IMMI) at Zvezda's central control post. IMMI's synoptic display provides computer-generated detailed and overview pictures of ERA and its surroundings (Fig. 3). In addition, monitors display video images from ERA and the Station's external cameras.

Alternatively (or in combination with IMMI), ERA can be operated by an EVA cosmonaut via the External Man-Machine Interface (EMMI) control panel. The EMMI can survive long periods of space exposure, totalling up to 18 months. ERA commands are entered via toggle switches, while LEDs display arm status and operations progress.

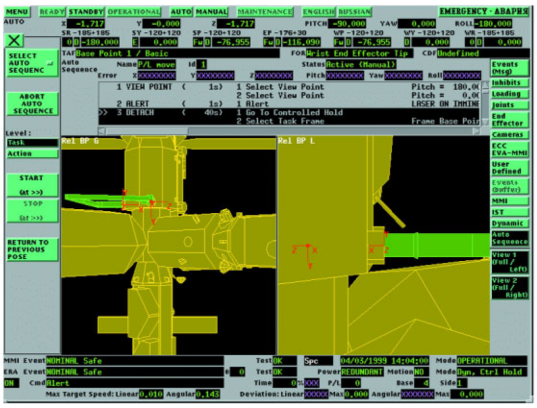

Fig. 3. Computer-generated views will assist ERA's operators.

Fig. 1. ERA has an important role to play on the Russian Segment.

ERA Characteristics and Capabilities

Total length:	11.4 m
Launch mass:	630 kg
Operational mass:	639 kg
Stiffness (fully stretched)	>0.4 N/mm
Reach:	10 m
Payload capability:	8000 kg
Maximum tip speed:	0.2 m/s
Lifetime:	10 years
Accuracy (open loop)	± 4 cm
Accuracy (closed loop)	± 0.5 cm

Either approach offers an automatic mode (using prepared mission plans), semi-automatic mode (standard autosequences) and manual mode (controlling the individual joints).

Development and Verification

Qualifying ERA is a combination of a classic approach and a protoflight approach. The EQM is assembled from all the subsystem qualification models, which have been used for thermal, structural, mechanical and functional qualification at subsystem level. After integration (mid-1999), the EQM has been used for an extensive (development) functional test programme, using Fokker's special flat-floor facilities. In November-December 1999, the EQM underwent a system-level thermal balance qualification test in the Large Space Simulator at ESTEC (Fig. 4). The results validated ERA's thermal mathematical model, which in turn is generating thermal predictions for actual operations. Now back at Fokker, the EQM is being used continuously in the functional test programme. Once the final software is installed early in 2001, it will also be used for functional qualification tests.

The remaining qualification activities will use the Flight Model. After considerable delay, mainly caused by EEE part problems, all subsystems were delivered by May 2000, and integrated on the flat-floor test facility. Fig. 5 shows the unique situation of two (EQM and FM) ERAs simultaneously operational on the flat floor.

The FM arrived at ESTEC in September 2000 for vibration and EMC qualification testing. In principle, all of ERA's elements have already been subjected to qualification levels using the subsystem EQMs. The system-level structural qualification was therefore limited to a modal survey test to validate the ERA Finite Element Model, followed by a boosted modal survey test. This test programme is designed to qualify the ERA subsystem interfaces and the ERA and Russian launcher interface points that had not previously been subjected to qualification load levels in lower level test programmes. During the boosted modal survey test, ERA was

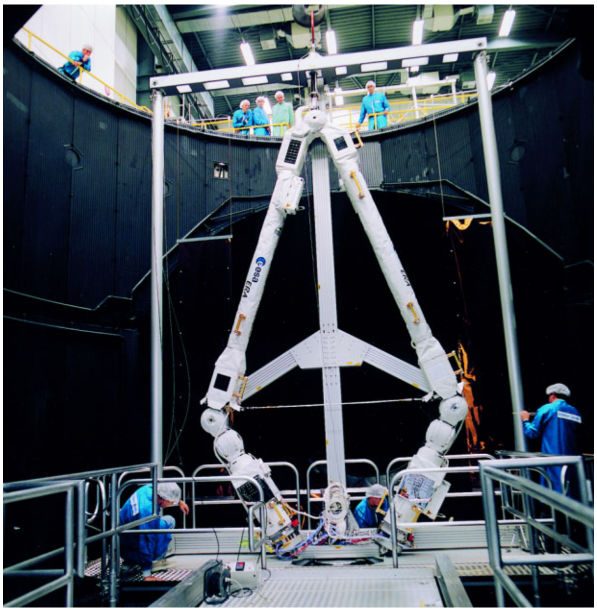

Fig. 4. EQM thermal balance testing at ESTEC.

Fig. 5. The EQM (right) and FM on Fokker's flat-floor facility.

ERA Major Development Milestones

ERA FM integration	May 2000
FM Test Readiness Review	August 2000
Boosted modal test prog.	October 2000
Delivery pre-flight MPTE	October 2000
EMC test programme	November 2000
Final software delivery	December 2000
FM functional qualification	February 2001 -July 2001
FM Qualification Review/ Acceptance Review	August 2001 -September 2001
Final MPTE delivery	September 2001
Flight Spare test programme	September 2001 -December 2001

mounted on a special vibration adapter in the Large European Acoustic Facility, with a set of flight-representative Russian launch fixation brackets (Fig. 6). ERA's natural frequencies were excited by mini-shakers at several load points. The strains were closely monitored to prevent overloading the flight hardware. This modal survey test programme was completed at the end of October, after about 4 weeks.

ERA remained at ESTEC for its electromagnetic compatibility (EMC) testing, confirming that the flight configuration does not suffer electromagnetic interference or affect other systems around it.

The FM returned to Fokker in December for installation of the final software for the functional qualification programme. This will culminate in qualification and acceptance reviews in September 2001.

MPTE Delivery

A current major milestone is delivery of the pre-flight version of the ERA Mission Planning and Training Equipment (MPTE), a realistic simulator of the arm and its environment. At its core is a fully flight-representative ERA onboard computer using the full flight software. The ERA Simulation Facility (ESF) replicates the arm's dynamics and control. The MPTE includes mock-ups of ERA's IMMI and EMMI, using their flight software. The MPTE will be located in Russia (RSC Energia and the Gagarin Cosmonaut Training Centre) and at ESTEC, in the ERA Users Centre.

The Russian MPTEs will be used to train ERA's cosmonaut operators and generate ERA flight procedures for transmission to the Space Station. The MPTE can also provide on-line support during ERA operations, and play back and analyse actual operations. ESTEC's MPTE will support these activities.

The MPTE facility is being developed by the National Aerospace Laboratory in The Netherlands, using the ESF developed by Fokker Space. MPTE's pre-flight version was delivered to ESA in October 2000, to begin commissioning tests and to train future users, notably the Russian Instructors who will themselves later train the Cosmonaut Operators. The pre-flight MPTE is an intermediate version of the facility, containing most of the functionality but lacking the full scope of the final, verified flight hardware, notably the collision avoidance software. The final version of MPTE will be delivered during the course of 2001. This will also satisfy the maintainability needs of ERA's flight software.

Conclusion

The extensive system-level qualification programme using the EQM and FM hardware will allow delivery of the Flight Model in September 2001, in good time for its use on the International Space Station.

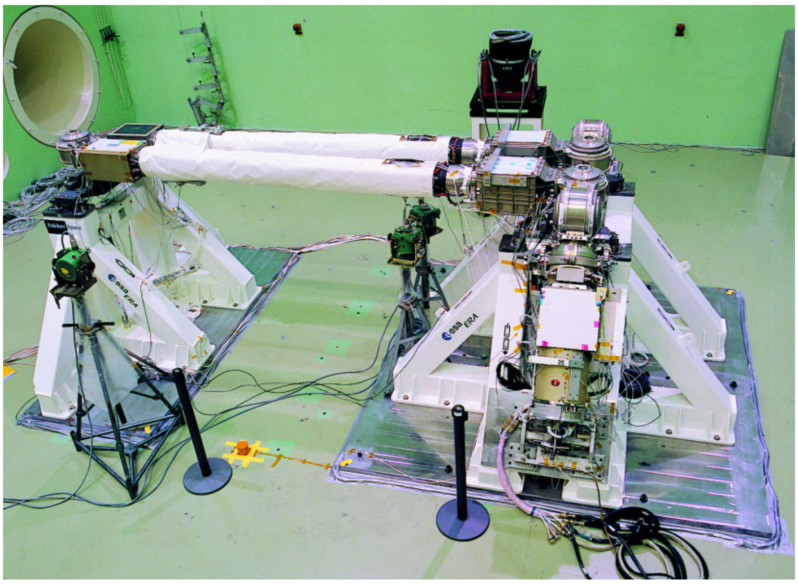

Fig. 6. ERA mounted in its 'Charlie Chaplin' launch configuration (mimicking the film comedian's splayed-feet stance) for vibration testing at ESTEC.

Announcement of Research Opportunities in Life Sciences and Space Science

In the second half of 2002, the European Space Agency (ESA) will fly a scientific payload on the Russian recoverable satellite Foton M-1. The spacecraft will carry equipment to accommodate exposure experiments of two different types:

1. exposure to the harsh space environment ("Biopan"),
2. exposure to the reentry environment ("Stone").

ESA announces an opportunity for proposing experiments in the field of exobiology for Biopan and Stone. Proposals in the fields of chemical evolution, meteoritics, geochemistry, radiation biology and radiation dosimetry will also be considered. Send your proposals to:

Secretariat, MSM-GAL, ESTEC

mail address:	e-mail address:	fax number:
Keplerlaan 1 NL-2201 AZ Noordwijk	msmlife@estec.esa.nl	(+31) 71.565.3661

The closing date for submittal of proposals is 19 January 2001

Biopan

ESA's Biopan is a pan-shaped container for exposure experiments in space. In orbit, Biopan is opened to expose the test samples to space vacuum, solar UV and space radiation, or a selection thereof.

Stone

Experiment samples can be mounted in the skin of the reentry capsule of the Foton spacecraft to test the effects of atmospheric entry on mineralogical and biological materials ("artificial meteorites").

Information on this Announcement is available via the Internet at:

http://www.spaceflight.esa.int/biopanstone

This announcement is coordinated between the Directorate of Manned Spaceflight & Microgravity and the Directorate of Science. These research opportunities are also open to non-ESA member states.

esa

ERA's Joint Subsystem

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The joints for Europe's robotic arm have demanding requirements...

ESA's European Robotic Arm (ERA) will be attached to the Russian Segment of the International Space Station, supporting cosmonauts building that segment, inspecting Station elements and changing Orbit Replaceable Units. SABCA has developed ERA's Manipulator Joint Subsystem (MJS) under prime contractor Fokker Space.

The Manipulator Joint Subsystem

Each of ERA's two wrist assemblies consists of a pitch joint, a yaw joint, a roll joint and an electronics box (Fig. 1); the single elbow assembly has a pitch joint and an electronics box. ERA's main design constraints are:

- total mass must be less than 650 kg; MJS accounts for 57%;
- tracking and proximity control; dedicated joint control software maintainable in-orbit;
- in-orbit life is 10 years;
- reliability and safety;
- launch vibration, thermal vacuum (-55°C to +90°C), low Earth orbit environment (micro-meteoroids, debris, atomic oxygen, radiation).

Fig. 1. Wrist Assembly without MLI thermal blankets.

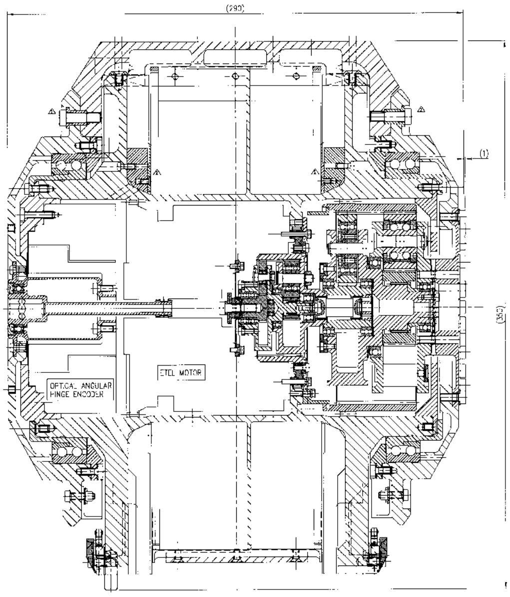
Joint Mechanism

Each MJS joint (Fig. 2) includes:

- brushless DC motor;
- resolver (velocity measurement and motor commutation);
- high-precision joint position sensor, to feed the joint position to the joint control electronics;
- 4-stage planetary gearbox (ratio 454) for torque capability and speed reduction;
- friction brake;
- EVA shaft for manual override in case electrical power is lost;
- cables harness, including power, data and video lines;
- joint thermal control (heaters);
- position limit switches.

Joint Performances

- available output torque at minimum speed: 550 Nm average;
- available output torque at maximum speed: 180 Nm average;
- minimum controllable joint speed: 4.5×10^{-5} rad/s;
- maximum controllable joint speed 0.05 rad/s;
- brake torque: 550 Nm average;
- power consumption: 165 W (six joints running simultaneously at 70 Nm, minimum speed);
- joint backlash (at 18 Nm): 3 arcmin average;
- joint stiffness: 110 000 Nm/rad average for pitch, 160 000 Nm/rad average for roll;



- mechanical efficiency at full torque: higher than 90% over the full thermal operational range (-40°C, +75°C);
- joint operational range: ±120° pitch/yaw; ±185° roll;
- elbow joint operational range: +30° to -176°;
- static accuracy: 800 µrad;
- tracking error at high speed: 3.4 mrad.

Mass Budget
The masses of the ERA joints are:
- pitch 37 kg; yaw 36 kg; roll 38 kg;
- elbow joint and brackets: 43 kg;
- elbow electronic box: 24 kg;
- wrist electronics box: 33 kg.

Total MJS (2 wrists + 1 elbow): 355 kg.

Joint Life Tests in Vacuum
Pitch and roll joints have been functionally life-tested at SABCA in a thermal vacuum chamber at 10^{-6}-10^{-7} mbar and -55°C to +90°C, which includes the qualification margins. Typically, the following duty cycles were performed on each type of joint:
- rotation, 350 Nm, 12.5 mrad/s, 198 hr;
- rotation, 110 Nm, 50 mrad/s, 148.6 hr;
- 786 dynamic braking operations;
- 200 brake slipping operations on 3 degrees-of-freedom;
- 9464 brake engagement/release operations;
- 5945 static brake torque measurements;
- 229 limit switches activations;
- 62 hardstop commands.

For the rotation duty cycles, the tests demonstrated at least twice the specified lifetime (1000 hr, low speeds). In order to reduce the test duration, increased speed and torque values were used, higher than specified.

Safety and Reliability
The following data are monitored:
- joint position (optical encoder); each joint includes position limit switches to prevent any motion beyond the operational range;
- joint speed (resolver); any speed above the limit triggers the safety barrier;
- motor current (torque); over-torque turns the joint off;
- motor temperature; overheating in the drive electronics turns the MJS off;
- electronics temperature.

High-reliability electronic and electrical parts are used.

Fig. 2. Cross section of a pitch joint (Stork Product Engineering)

Environmental Constraints
The MJS joints and electronic boxes are designed to survive the vibrations and shocks of launch, as well as the orbital environment. In particular, the vacuum, large thermal range, micrometeoroids and debris, atomic oxygen and radiation have all been taken into account.

Thermal Vacuum
The MJS electronics boxes and joints are equipped with multi-layer insulation (MLI) blankets and/or painted white for thermal control. The operational heat is dissipated by a conductive thermal network, radiated away by Optical Sun Reflectors on the side panels of the electronics boxes. These measures keep the joints below 75°C. In hibernation, the joints and electronics boxes are kept above -35°C by thermostats and heaters, consuming about 69 W power.

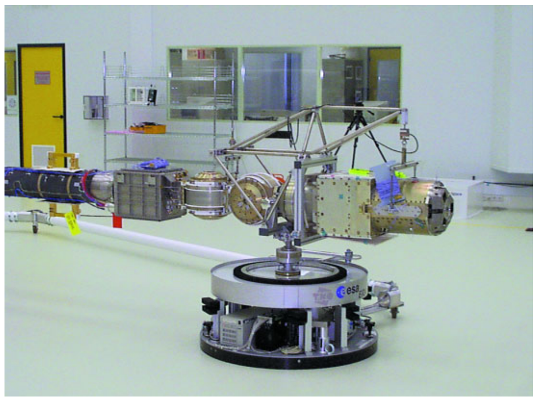


Fig. 3. MJS Wrist integrated in the ERA EQM for flat-floor testing. In order to satisfy EVA requirements, the MJS design includes manual overrides on each joint, handrails, bevelled edges, chamfers, rounded corners on exposed surfaces and visible angular position marks (Fokker Space)

Programme Status
The ERA Engineering and Qualification Model (EQM; Fig. 3) was assembled in early 1999, and the MJS joints passed their subsystem level qualification tests campaign. Production of the Flight Model joints was completed in early 2000, and the ERA Flight Model is now under acceptance testing at Fokker Space and ESTEC.

Recent & Relevant

ISS: A New Era Begins

The long-term occupation of the International Space Station (ISS) is now well underway as the first resident crew brings the orbital complex to life. This 'Expedition 1' crew of Station commander Bill Shepherd (US), Soyuz commander Yuri Gidzenko (Russia) and flight engineer Sergei Krikalev (Russia) will work aboard the Station until their Expedition 2 replacements take over next February.

The flawless launch of the Soyuz-TM31 spacecraft at 07:53 UT on 31 October from the Baikonur Cosmodrome in Kazakhstan was followed by an automatic docking with Zvezda's aft port at 09:21 UT on 2 November. After testing the pressure integrity, the crew opened the hatch into Zvezda at 10:23 UT and Gidzenko and Krikalev were the first to float through to occupy the new outpost. This crew is spending most of its time activating and outfitting the Station, although it does have a modest scientific programme.

During their 4-month tenure, the crew will host three visiting Shuttle crews delivering the first large solar arrays, the Destiny US Laboratory, Destiny's first science racks and the first Italian-built Multi-Purpose Logistics Module (Leonardo).

Their first major task on the first full day aboard was installing the Vozdukh regenerative carbon dioxide scrubber in Zvezda, replacing the disposable lithium hydroxide canisters. It was activated on 4 November and confirmed by Russian mission control as operational. Krikalev spent most of the day installing the two Control Post Computers of the ESA-provided Data Management System – Zvezda's 'brain' and of the entire early ISS.

The Elektron system was installed on 4 November, to generate oxygen by the electrolysis of water. It was activated 9 November but will probably not work continuously until the next Shuttle mission, STS-97, adds the first set of US solar arrays – the largest ever flown in space – to raise the Station's power supply.

Before Expedition 1's arrival, the ISS had seen a major increase in activity triggered by the crucial appearance of Zvezda (*On Station* #3) in July. The Progress-M1-3 ferry docked with Zvezda carrying 615 kg of supplies for Expedition 1 (including the two DMS-R computers, Elektron and Vozdukh) and 655 kg of propellant for pumping into the Zvezda and Zarya tanks. Its engines were used to fine-tune the Station's orbit in preparation for the docking with Shuttle STS-106 in September. Atlantis also delivered supplies, using a Spacehab Double Module as a cargo carrier. A primary goal was to prepare Zvezda for the first resident crew. This included a 6-hour EVA by Lu and Malenchenko to hook up external power, data and communications cables between Zvezda and Zarya. They mounted an external magnetometer on Zvezda to provide 3-axis attitude data using Earth's magnetic field for Zvezda's control system. All EVAs are still being made from the Shuttle airlock, until the Russians attach their Docking Compartment next March and NASA the Joint Airlock in May.

Expedition 1 crew (from left): Krikalev, Gidzenko and Shepherd.

How the Space Station looks after the arrival of the first residents. (ESA/D. Ducros)

Following the spacewalk, the STS-106 crew opened the 12 hatches through to Zvezda and into Progress. Like setting up home for the first time, they unloaded clothing, medical kits, food, a ham radio, personal hygiene kits, laptop computers, a colour printer, vacuum cleaners and a food warmer for Zvezda's galley. The Station's first toilet was transferred into Zvezda to await the first Expedition.

Electrical work covered the installation of three more batteries in Zvezda, replacing two of Zarya's six batteries, and installing solar array power converter and switching units in preparation for the first large solar arrays in December.

Gas masks and fire extinguishers were installed in Zvezda as standard emergency equipment for Station crews. Finally, medical equipment including the Crew Health Care System, a treadmill and a bicycle ergometer were installed in Zvezda.

Surplus items such as packing materials were loaded into Progress for incineration during its destructive reentry over the Pacific.

Recent & Relevant

In October, Shuttle STS-92/3A brought the Z1 Truss segment and Pressurized Mating Adapter #3. Over the course of four spacewalks, Z1 was added on top of Unity and PMA-3 underneath. Z1 is the first part of the Truss, acting as the anchor for future sections as well as the platform for mounting the solar arrays.

The Z1 houses four Control Moment Gyros – providing non-propulsive attitude control – and the Station's main Ku-band communications equipment. Z1 also carries two dc-to-dc converter units (DDCUs) that will eventually provide power conditioning for the Station's systems and payloads. Ten electrical umbilicals to provide power to heaters and conduits were installed on Z1, and two Plasma Contactor Units were power cycled. These discharge electrons to control the potential between the Station and its plasma environment, which could otherwise reach -150 V.

The final spacewalk included tests of the Z1 latches that will hold the solar array truss and of the manual berthing mechanism latches on Unity that will hold Destiny. The pair also demonstrated the SAFER (Simplified Aid for EVA Rescue), a small backpack with nitrogen thrusters that could allow a drifting astronaut to return to safety.

Internal Station work included collecting surface samples inside Zarya to look for microbial growth. Final connections were made inside Unity with Z1.

Before the hatches were closed, the first microgravity science experiment to use the Station – the Protein Crystal Growth Experiment, brought up by STS-106 – was moved into Shuttle Discovery for return to Earth.

Umberto Guidoni will be the first ESA astronaut aboard the ISS as part of the Shuttle STS-100/6A mission in April 2001.

April will also see a Progress supply vehicle carrying the electronic unit for the European Global Time System (GTS) experiment. GTS will allow the synchronisation of radio-controlled clocks and watches from space and, in the longer term, the disabling of stolen cars and credit cards. ■

ISS Milestones

20 Nov 1998: Zarya launch, first ISS element.

4 Dec 1998: STS-88/2A launch, docks Unity Node-1 with Zarya 7 Dec. First crew aboard ISS 10 Dec. 3 Shuttle EVAs made external connections.

27 May 1999: STS-96/2A.1 launch, docks with Unity/PMA-2 29 May carrying logistics in Spacehab module. Shuttle EVA installs 2 external cranes. Undocks 3 Jun.

19 May 2000: STS-101/2A.2a Atlantis launch, docks with Unity/PMA-2 21 May carrying supplies and to perform maintenance (including EVA 22 May from Shuttle). Undocks 26 May.

12 Jul 2000: Zvezda launch; Zarya/Unity docks with it 26 Jul.

6 Aug 2000: Progress-M1-3 launch, docks with Zvezda aft port 8 Aug carrying cargo/propellant. Undocks 1 Nov.

8 Sep 2000: STS-106/2A.2b Atlantis launch, docks with Unity/PMA-2 10 Sep carrying logistics in Spacehab module. Shuttle EVA makes Zvezda/Zarya external connections. Undocks 17 Sep.

11 Oct 2000: STS-92/3A Discovery launch, docks with Unity/PMA-2 13 Oct. Attaches first Truss section (Z1, with CMGs and Ku-band comms system) to Unity zenith port 14 Oct. 4 Shuttle EVAs make Z1/Unity connections, attach PMA-3 to Unity nadir, and prepare for future attachments. Undocks 20 Oct.

31 Oct 2000: Soyuz-TM31 launch, Expedition 1 crew (Gidzenko, Shepherd, Krikalev) docks with Zvezda aft port 2 Nov.

Planned

16 Nov 2000: Progress-M1 launch, docks with Zarya nadir port 18 Nov carrying cargo/propellant. Undocks 1 Dec.

30 Nov 2000: STS-97/4A Endeavour launch, docks with Unity PMA-3 2 Dec. P6 Truss segment with solar arrays installed in 2 EVAs. Undocks 8 Dec.

12 Dec 2000: Progress-M1 launch, docks with Zarya nadir port 14 Dec carrying cargo/propellant. Undocks 11 Jan.

25 Dec 2000: 'internal EVA' by Gidzenko & Krikalev transfers Zvezda's forward docking cone to nadir port to accommodate Russian Docking Compartment in March 2001.

18 Jan 2001: STS-98/5A Atlantis launch, docks with Unity PMA-3 20 Jan. US Destiny lab installed; PMA-2 moved from Unity nadir to Destiny forward. ISS attitude control transferred from Zvezda to Destiny. Undocks 26 Jan.

27 Jan 2001: Soyuz-TM31 moves from Zvezda aft port to Zarya nadir port.

1 Feb 2001: Progress-M1, docks with Zvezda aft port 3 Feb carrying cargo/propellant.

15 Feb 2001: STS-102/5A.1 Discovery launch, docks with Destiny PMA-2 17 Feb. First MPLM (Leonardo) moved to Unity nadir. Expedition 2 crew (Voss, Helms, Usachev) swaps with #1 crew. Undocks 24 Feb.

Do You Want to See the Space Station? Then go to *http://www.heavens-above.com/* and it will show you when the Space Station is next visible from your location.

Recent & Relevant

ISS Virtual Campus

ESA inaugurated its Virtual Campus for the International Space Station (ISS) on 8 September at ESTEC, in the presence of leading European scientists, ESA's Director General, Mr Antonio Rodotà, and the Director of Manned Spaceflight and Microgravity, Mr Jörg Feustel-Büechl.

The Virtual Campus will be the main European source for validated information on the ISS and its utilisation. It will be a forum where users can share their knowledge and find new partners. The 'campus' is managed and operated by the ISS User Information Centre, located at ESTEC.

As a resource centre, the Virtual Campus will provide ISS information and advice. It will explain the various experiment facilities of the Station's pressurised laboratories available to European scientific researchers, development engineers and service providers. It will not only focus on the technical aspects of Station utilisation, but also help interested users to find scientific, operational, financial and political support for their experiments. Through the Virtual Campus, users can build contacts with the engineers in European industry and space agencies who are working on the development and operations of the European research facilities. They will also be able to establish links with the programme managers and scientists at ESA and at the national space and research organisations in Europe who are involved in the strategic planning and the attribution of resources and access rights for Station utilisation.

Particular efforts will be made to distribute the knowledge already gained by scientific experimentation and technology demonstration in other projects such as Spacelab, Spacehab, Foton, sounding rocket flights, parabolic aircraft campaigns, drop towers and ground laboratories. ESA's Microgravity Data Base (accessible at *http://www.esa.int/cgi-bin/mgdb*) is the starting point. It will be made more user-friendly for the general public and will evolve into a general database on scientific results from Station research.

The Virtual Campus will offer its infrastructure for establishing Virtual Institutes in scientific disciplines that can benefit from the Station research facilities. The Virtual Institute for Health Care is the first planned; others might follow.

Using the campus, ESA will publish the announcements for space research opportunities and for ground research opportunities that could be used for preparing future Station experiments. Users can receive additional information and advice to help in responding and in developing their experiments.

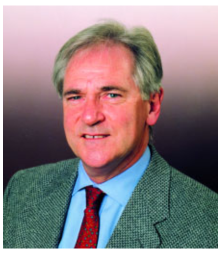
The campus will play an important role in building up joint research teams by giving users access to the information available at ESA on planned and intended research and applications themes of other users. Within the Microgravity Applications Programme, ESA has already introduced the idea of 'Topical Teams' in which fundamental researchers from academia are teaming together with more application-oriented researchers from industrial laboratories on topics of common interest which often have a commercial perspective. A significant number of Topical Teams have been created and more are expected.

More information on the Virtual Campus can be found at:

http://www.spaceflight.esa.int/virtualcampus

New Head of Manned Spaceflight Programme Department

Alan Thirkettle took over the reins of the Manned Spaceflight Programme Department on 1 September 2000, following the pending retirement of Frank Longhurst.



Alan began his aerospace career by working for 8 years on Concorde structural design with British Aerospace at Filton (UK). A year on the Shuttle Orbiter Phase-C/D proposal followed, with BAe at Rockwell in California, before becoming Project Controller on BAe's OTS satellite proposal. He joined ESA in December 1973 as Principle Structures Engineer on Spacelab. After 5 years in Noordwijk, he transferred to ERNO in Bremen (D) as Head of the ESA Resident Team on Spacelab Integration and Test. When the Spacelab Engineering Model was ready for shipping to the Kennedy Space Center in 1980, he created the European Resident Team at KSC, staying there for 4.5 years and the first four Spacelab missions.

Alan returned to ESTEC in 1985 to help begin the Columbus programme, and transferred to the Directorate of Space Transportation Systems in 1987 to start up the ERA, EVA Suit 2000 and ATV projects. Following the merging of all manned space programmes into D/MSM, he returned to Columbus, becoming Project Manager in 1986, and later added responsibility for MPLM/ECLS, Nodes-2/3 and CRV. The new position adds ATV and the general task of supporting the Directorate's future planning, exploitation programme preparation and infrastructure enhancement.

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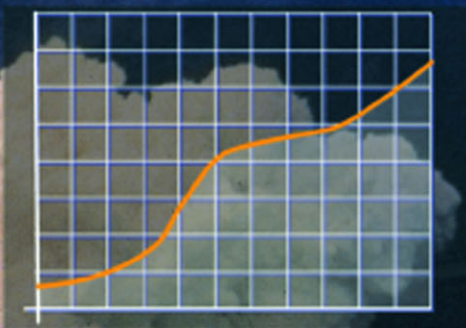

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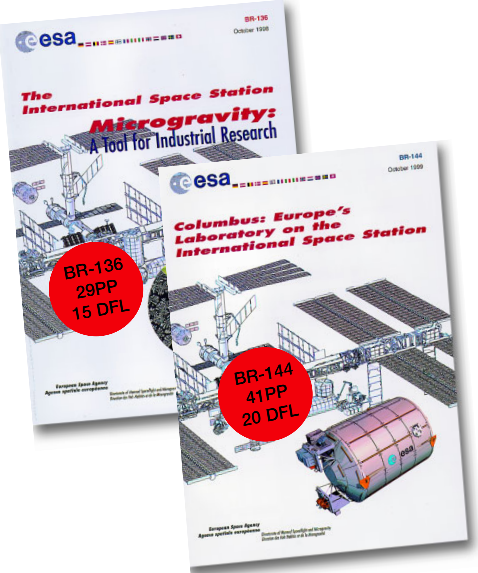

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