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Current Status of the European Robotic Arm (ERA), its Launch on the Russian Multi-purpose Laboratory Module (MLM) and its Operation on the ISS

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Introduction

The European Robotic Arm (ERA) programme has undergone some significant changes since the 2004 ASTRA conference. This paper summarises the current status of the ERA project, its tasks on the Russian Segment of the International Space Station (ISS) and recent developments in operations testing and instructor training.

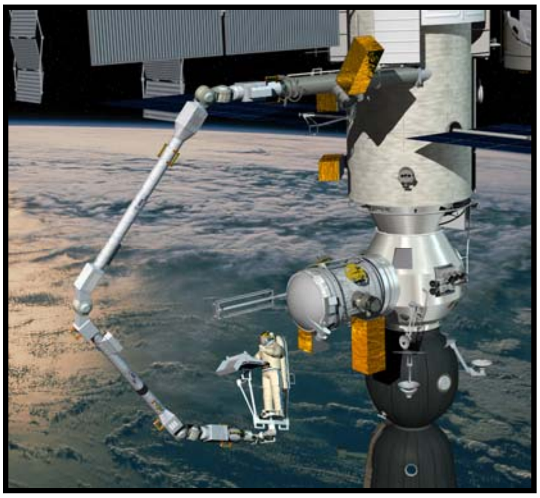

Fig.1, ERA on the Russian Multipurpose Laboratory Module (MLM) during an EVA

Programme Status

In November 2004 the ERA development has been completed at the prime contractor's site and ERA is ready for delivery to Russia. After that a programme of further operational simulation software improvements and training has been performed. Neutral Buoyancy testing took place in the Hydrolab facility at the Gagarin Cosmonaut Training Centre (GCTC) near Moscow in November 2004. The test took place in the neutral buoyancy tank to simulate weightlessness, with the overall aim of determining how an astronaut would be able to help with the installation of ERA and carry out possible maintenance on the robotic arm when in orbit. The Neutral Buoyancy testing used the Weightless Environmental Test or 'WET' model of ERA. This test involved the dismantling and assembling of ERA and swapping out various different subsystems using a range of specially designed tools. The manual override controls were also checked.

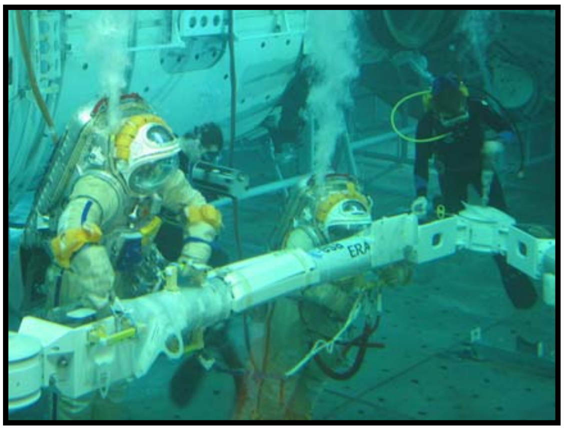

Fig.2, Neutral Buoyancy testing at GCTC near Moscow with ESA astronaut André Kuipers (left)

In March 2005, ESA was informed that the ERA spares will be launched on an ‘as needed’ basis after ERA’s launch. On the 27th October 2005, Mr Daniel Sacotte, ESA’s Director of Human Spaceflight, Microgravity and Exploration, and Mr Ben Spee, Director of Dutch Space, signed a contract for the launch preparations and first operations of the ERA on the ISS. The contract, worth 20 million Euro, was signed with Dutch Space, the Industrial Prime Contractor leading an industrial consortium of European companies.

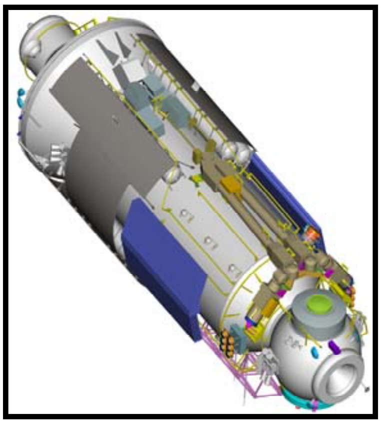

Fig.3, ERA in its launch configuration on the Russian MLM

Under the contract the consortium will delta-qualify the ERA flight and ground segment for a launch on Proton, and will deliver the ERA hardware to Russia. The consortium has also implemented most of the ERA training for the Russian cosmonaut instructors and will support the training of Russian cosmonauts on ERA operations. It will also support ground processing and launch preparations in Russia. This will take place at various locations: at the Khrunichev premises, where the Proton launcher is built; at RSC/E, which together with Khrunichev builds the MLM; at GCTC in Star City; and at the launch site in Baikonur, Kazakhstan. Under the new contract, In-Orbit Validation of the robotic arm is the final activity to be performed by the consortium. This involves participation in, and analysis of, the first operation of ERA after launch when the performance of ERA will be validated under real space and operational conditions.

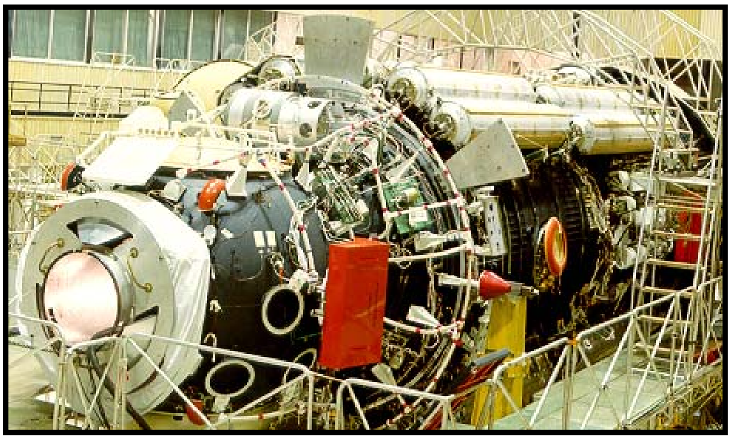

Fig.4, MLM being modified for launch

The launch configuration is unchanged, with ERA still in the Charlie Chaplin pose and the mounting interface mechanisms maintained from the previous launch configuration on the Solar Power Platform (SPP) module in the Shuttle. The loads during launch and for the in-orbit operations are being reassessed. No show-stoppers have been identified, but some adaptations are being made, for example to avoid interference between ERA handrails and the MLM / Proton fairing.

The ERA operations on the Russian Segment of the ISS are being augmented with the advent of the new MLM operational environment. The MLM features a payload airlock for automatic transfer of payloads between the pressurized environment inside and the vacuum outside together with new payload mounting units for temporary storage. Payloads can be retrieved from and returned to the MLM airlock by ERA without a direct need for human EVA. A new payload mounting mechanism has been designed for this purpose, with its latch mechanically actuated by ERA’s built-in “screw driver”. The EVA support function of ERA is also extended with a new operational concept of control by a cosmonaut standing on the end of the ERA arm (acting as a “cherry picker”).

Fig.5, ERA moving a payload from the equipment airlock located on the MLM

In March 2006, two complete sets of ERA Mission Preparation and Training Equipment (MPTE) have been successfully delivered to Russia, one at RSC/E and the other at GCTC. In the mean time upgrades to the MPTE systems are being made to replace ageing computer hardware. Most of the computers in the MPTE are approximately 10 years old and are difficult to maintain as spare parts become obsolete. Some of the key MPTE components are being enhanced, for example the geometry preparation will be allocated to a dedicated workstation to reduce the workload on the instructor workstation. The ERA software maintenance facility is being completely upgraded with state of the art software development tools to ensure that the ERA flight software can be maintained 10 years into the future.

The communications infrastructure of the Ground Segment and the connectivity of the three MPTEs is also being established between ESTEC, RSC/E and GCTC. This is being done to support software maintenance, In-Orbit Validation (IOV) and subsequent operations. An upgrade of the existing inter-Agency communication system will allow exchange of missions and mission data between the three MPTE facilities.

The Russian instructor training has been completed and instructor certification is on-going. Once certified, the instructors will start crew training for ERA operations. Two instructor training courses have been held at ESTEC in 2005 for a total of nine Russian instructors from both RSC/E and GCTC. A follow on refresher training course was held in June 2006 in Russia.

Let’s recall briefly what ERA is and what it does. ERA is a robotic servicing system, which will be used in the assembly and servicing of the Russian Segment of the ISS. The robotic arm together with its control interfaces will be launched from the Baikonur Cosmodrome to the ISS on a Russian Proton rocket in 2009. With its seven joints, tools and electronics, the arm can move hand-over-hand between fixed base points around the Russian Segment and will be used for a variety of tasks. The robotic arm can be operated either from inside or outside the ISS using the Man Machine Interfaces and it can be controlled in real-time or can be pre-programmed.

The impressive robotic arm is over 11 metres in length and weighs 630 kg. With an accuracy within 5 mm it is capable of installing, removing or replacing external experiment payloads and large station elements of up to 8000 kg. ERA will be able to work with the new Russian equipment airlock, being able to transfer small payloads directly from inside to outside the ISS and vice versa. This will reduce the EVA set-up time and allow for cooperative tasks with astronauts. ERA will be able to transport astronauts or cosmonauts like a “cherry picker” crane to the position where they are supposed to perform their work, or from one external location to another. This again saves time and effort during spacewalks. ERA will use its infrared cameras for carrying out inspections of space station external surfaces.

The MLM shall now be launched and docked to the nadir docking assembly of the Russian Service Module (Zvezda) unlike the previously considered option for the MLM docked to the nadir port of the Functional Cargo Block Module (Zarya). This will make it possible to avoid ISS programme risks by eliminating the coordination of timeframes for launching the MLM and Node 3. It will create a fourth ISS docking port and expand the MLM capabilities as a science laboratory. This allows the ISS Russian Segment to develop in the most optimal configuration. However, it will take Russia up to two years to prepare for this new Russian Segment design, leading to a delay in launching MLM and ERA. This new configuration is outlined below.

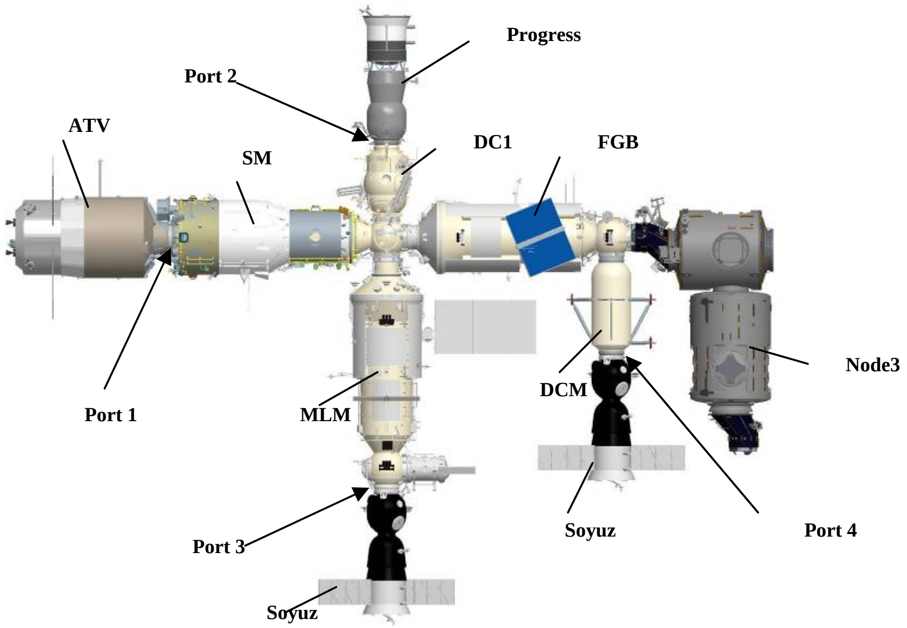

Fig.6, Latest configuration of the ISS Russian Segment

The MLM will be the home base of ERA and its design and flexibility provide it with the freedom to move hand-over-hand around the Russian part of the station, attaching to base points in different locations. ERA will be operational in the harsh environment of space for at least 10 years and during this time its operations will be monitored from the ERA support room at the Mission Control Centre (TsUP) in Moscow. Relevant data can also be uploaded to ERA from TsUP. Controlling ERA from the ground is also the subject of a current study to reduce the demands on the time of the ISS Crew. ERA will complement the existing Canadian Mobile Servicing System, which services the US Segment of the station.

To complement cosmonaut training on the ground, the Refresher Trainer (a software application running on a laptop computer) will provide the crew onboard the ISS with the capability to rehearse their missions. The Refresher Trainer contains simulators for internal and external Man Machine Interfaces, a session manager to prepare, store and replay mission sessions, and all relevant reference documentation about ERA. The acceptance test campaign of the Refresher Trainer was finally completed in 2006.

Let’s also briefly discuss the MPTE. The MPTE is a facility used for mission preparation, operator training, on-line mission support and evaluation of ERA missions and operations. The MPTE also maintains the ERA ground and flight operational software. Three separate sets of MPTE have been built: One set is located at RSC/E. This set will be used for mission preparation purposes. Part of this set of equipment is located in TsUP, the Russian ISS Mission Control Centre in Moscow where it will be used for mission monitoring purposes. The second set of equipment, is located at GCTC in Star City near Moscow, and will be used to train astronauts/cosmonauts. The third set of equipment is located at ESA's research and technology centre at ESTEC in Noordwijk, The Netherlands for instructor training, operational support and software maintenance. The Software Maintenance Facility at ESTEC provides the capability to maintain the operational flight and ground software during the complete life of ERA.

In-Orbit Validation

In 2004 Russia introduced the MLM as a new module to be added to the ISS and proposed also the possibility that ERA could be installed, launched and operated on the MLM.

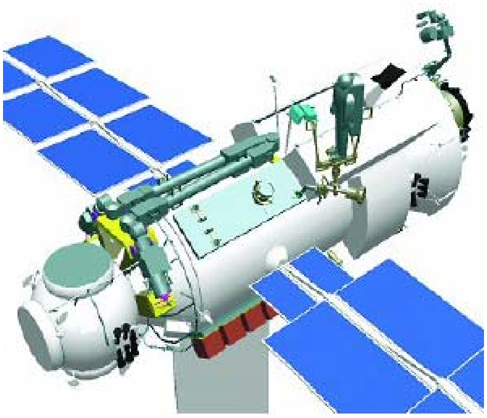

Fig.7, ERA on the MLM at the start of the In-Orbit Validation

Once in orbit the MLM will take about two weeks to slowly raise its orbit and catch up with the ISS. On arrival the MLM will be automatically docked to the nadir (Earth facing) port of the Russian Zarya module, the first ISS module, which was launched in November 1998.

Once the MLM is installed, In-Orbit Validation of ERA can take place prior to it becoming operational. This is necessary in order to establish the on-orbit performance of ERA and ensure that it can perform its functions, in conjunction with the ERA ground equipment. ERA will be thoroughly checked out to ensure that it is safe to move from its launch position to its first in-orbit home base position. Then a series of performance tests will be carried out from the home base position. All of this will occur within 6 months of the MLM docking with the ISS. These performance tests will be followed by 8 weeks of on-ground post analysis to analyse the data recorded on-orbit.

The validation operations are covered by five different stages which are as follows:

1. Connecting and testing of ERA and its control interfaces.

   The first part of this operation will be performed by an astronaut from inside the ISS. This is the first overall checkout that ERA is in good shape and that communication can be properly established between all the different subsystems. The second part of the initial check is to validate that the external Man Machine Interface can communicate properly whilst connected to a base point outside the ISS. This operation will therefore be carried out during an EVA.

2. ERA Installation and validation of ERA transfer capabilities.

In this stage the operation of ERA using the external and internal Man Machine Interfaces will also be evaluated. An astronaut will install the cameras on the wrists and elbow of ERA during an EVA and remove the launch restraints which help to keep it fixed in its 'Charlie Chaplin' launch configuration. Single joint tests will be carried out followed by multiple joint tests.

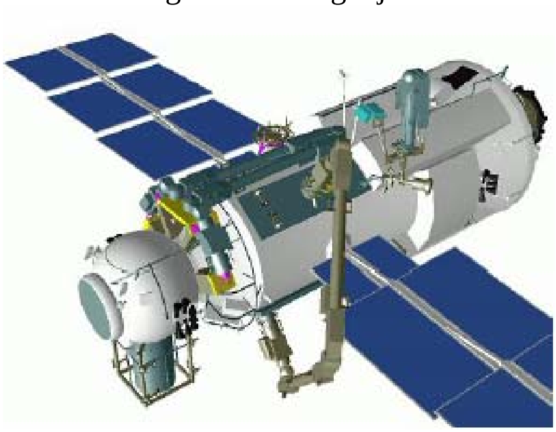

Fig.8, As part of installation and validation procedures, ERA will be commanded to deploy and then grapple various base points

ERA will be commanded to relocate by grappling base points on the external surface of the ISS. The next check will be to command ERA to grapple and relocate a Portable Work Platform. On completion ERA will be placed in hibernation mode.

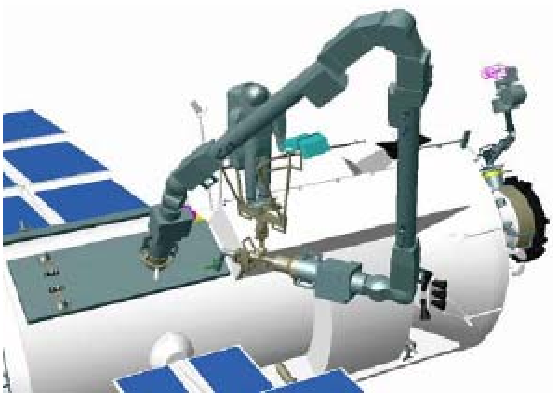

Fig.9, Cosmonaut monitoring ERA checkout

3. Brakes run-in, Thermal Validation and Imaging Quality

ERA's brakes will be run-in so that they function correctly to manipulate heavy payloads. In parallel, thermal parameters will be monitored inside ERA at different points. This will be carried out under different lighting conditions, and extremes of temperature in addition to being exposed to other environmental conditions such as vacuum and cosmic radiation. The performance of the ERA cameras will also be evaluated under different lighting conditions. This will include the accuracy in proximity targeting by the end effector camera as well as image clarity.

4. Motion Performance

This is a check on the motion performance of ERA, including brake and emergency stop performance. Single and multiple joint motion will be carried out at different speeds in addition to undertaking a stepping motion and the grappling/ungrappling of fixed base points under different misalignment conditions.

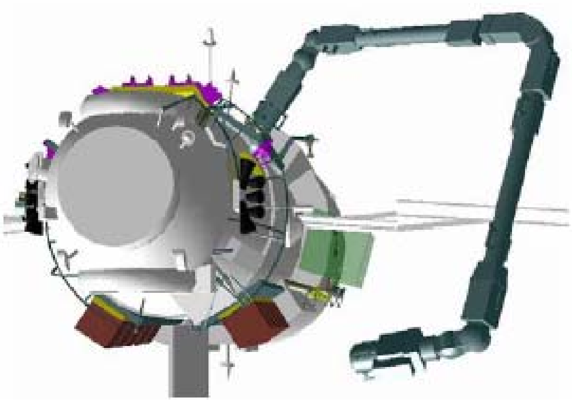

Fig.10, ERA during validation of motion performance, including emergency stop checks.

5. Data processing on ground

The data acquired during the first four stages will be processed using the MPTE facility at ESTEC in The Netherlands. The actual ERA behaviour is compared with the MPTE simulation prediction. If required, the MPTE simulation models are adjusted to better match the actual ERA behaviour and updated control parameters are provided to the Russian facilities for up-loading to ERA.

Operations

Once all five stages of the In-Orbit Validation have been satisfactorily performed, the ERA validation ends and the ERA system can be considered ready for operational use. The key operational tasks for ERA are summarised below:

- Move cosmonauts during space walks
- Inspection
- Move equipment up to 8000 kg for construction, maintenance and operations on the ISS e.g. deploying solar arrays / radiators
- Transfer items inside/outside the ISS using an equipment airlock on the MLM

Current planning to achieve operational readiness includes the following activities:

- Completion of the ground segment in Russia
- Additional Russian instructor training
- Final Flight Model pre-shipment tests at Dutch Space
- ERA shipment to Russia and integration on MLM
- Software interface tests in Russia
- Mission preparation and verification of the In-Orbit Validation
- Crew training in Russia
- Russian Segment safety review
- ERA/MLM/Proton launch preparation in Baikonur, Kazakhstan
- Launch of ERA/MLM on Proton rocket
- Deployment and In-Orbit Validation

Summary

The ERA programme has undergone significant changes since 2004. The ERA flight equipment has been in storage at the prime contractor's site ready for delivery to Russia. Neutral Buoyancy testing took place in the Hydrolab facility at the Gagarin Cosmonaut Training Centre (GCTC) near Moscow. A contract was signed in October 2005 for the launch preparations and first operations of ERA on the ISS. Under the contract the consortium will re-qualify the ERA flight and ground segment for a launch on Proton, and will deliver the ERA hardware to Russia. The ERA operations on the Russian Segment of the ISS are being augmented with the advent of a new payload airlock on the MLM. In March 2006, two complete sets of MPTE have been successfully delivered to Russia. The Russian instructor training has been completed and instructor certification is on-going. The connectivity of the three MPTEs is also being established between ESTEC, RSC/E and GCTC to support the In-Orbit Validation and subsequent operations. Due to a reconfiguration of the ISS Russian Segment the launch with the MLM on a Proton launch vehicle is now planned for 2009.