ERA, the Flexible Robot Arm

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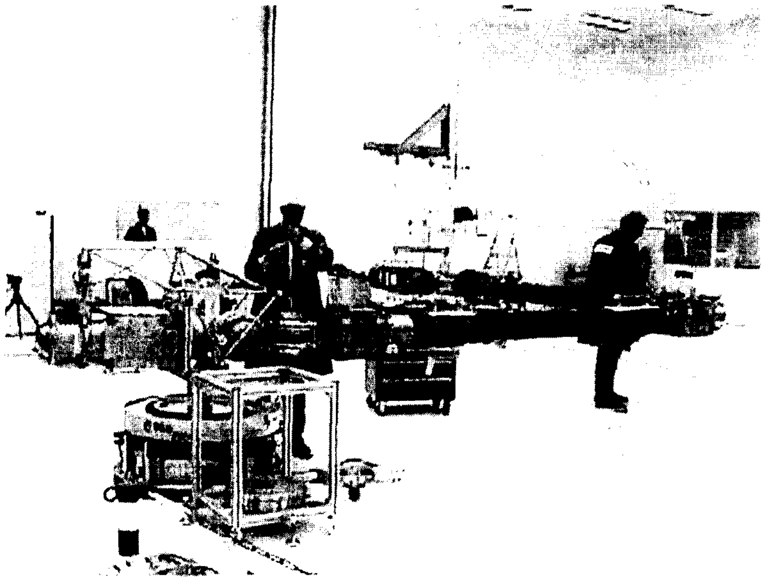

Abstract
The **European Robotic Arm** [ERA] is being built for use on the Russian Segment of the International Space Station. The project is commissioned by ESA as part of their manned-space program, with Fokker Space as Prime Contractor, and 23 companies from 7 European countries participating in the development of the arm. The ERA is scheduled to be launched by Space Shuttle to the ISS early in the next millennium. The system CDR was held at the same time as the I-SAIRAS conference. This paper focuses on the operational capabilities of ERA, ranging from fully automatic (monitored by a cosmonaut) to fully manual.

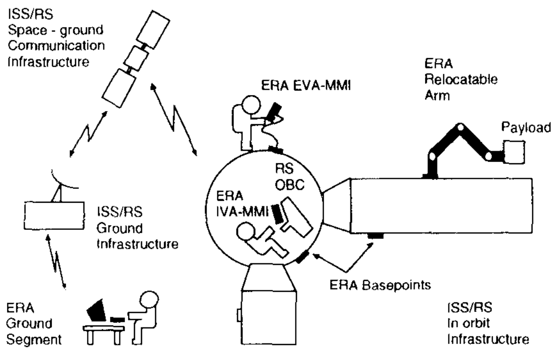

Fig 1: The ERA system

1. Introduction
The ERA system (Figure 1) consists of an arm, an EVA Man Machine interface , an IVA Man Machine Interface, a Refresher Trainer [RTR] and a Mission Preparation and Training Equipment [MPTE]

The ERA arm is a 11 meter, 6 Degree-of-freedom arm , whose most striking feature is the ability to cover large distance on the ISS by "hopping" from on basepoint (which supplies the power and communication interface) to another. Table 1 shows the ERA key performance parameters

Parameter	Required performance
positioning open loop	< 40mm, 1° [all axes]
positioning closed loop	< 5 mm, 1° [all axes]
maximum speed	0.2 m/s
maximum transportable mass	8000 kg
clearance	0.9 m
stopping distance	0.15 m
outer loop control frequency	20 Hz
inner loop control frequency	300 Hz

Table 1: ERA required performance

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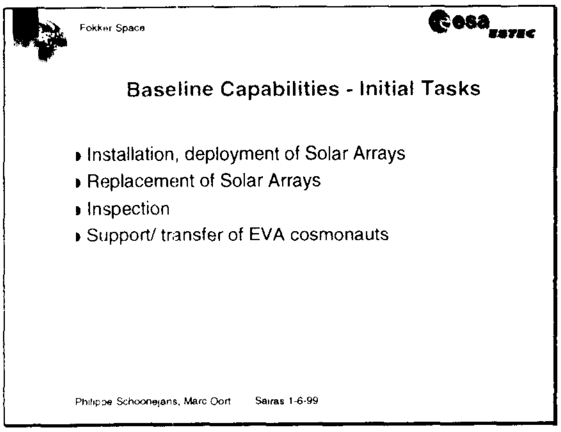
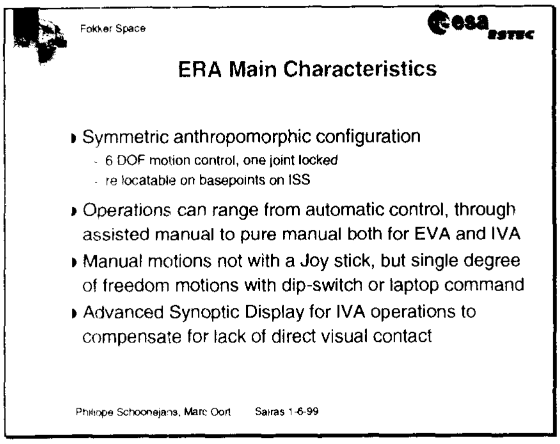
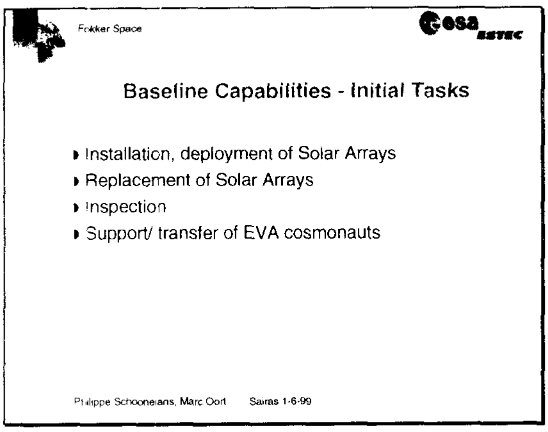






2. Operational design drivers

One of the important design drivers for any space-based robot arm is that it should significantly reduce the strains associated with operations during EVA, or even to do away with EVA operations altogether. This has as a consequence that the active operator involvement in operating the arm should be minimized as much as possible, while leaving a maximum of monitoring and intervention capability. The operational flexibility, coupled with the limitations of the processing and memory resources which are common in space applications due to the severe environmental conditions, pose a great challenge to the functional design of the arm itself and the controlling Extra Vehicular Man-Machine Interface (EVA MMI).

Additionally, it is also possible to operate ERA from inside the ISS, using a dedicated IBM 760 laptop, the IVA MMI. This laptop has more monitoring and commanding capabilities than the EVA MMI, but has been designed to resemble the latter as much as possible, this to insure commonality in operations from the IVA MMI and EVA MMI.

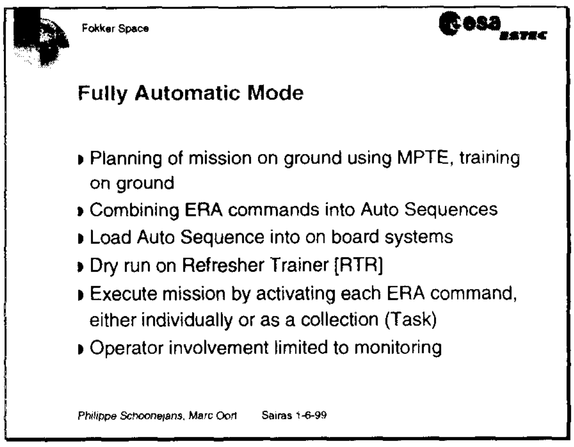
A layout of both the EVA MMI and IVA MMI can be found in the appendix of the paper

It is possible to operate ERA in three operational modes:

- Fully Automatic mode, using Auto Sequences
- Partially Manual mode, supported by Mini Auto Sequences [MAS]
- Fully Manual mode

Each of these three will be addressed below.

3. A flexible arm: Pre-planned Operations in Fully Automatic Mode



As part of planning an ERA mission, the ground segment can combine all commands to the ERA Control Computer, and the characteristics of up to four payloads into one or more "files", and load these into the on-board computer as dedicated ***Auto Sequences.*** The limitations in CPU capabilities prevent the Auto Sequences from acting as a pseudo programming language, with conditional branching or looping). The correctness of these sequences has been verified on the ground, and the supervisory task of the operator is thus limited to starting actions and to monitor the general progress of the mission. To compensate for the lack of direct visibility, the IVA operator has TV cameras and an (IVA MMI generated) geometrical world model available for monitoring. The operator has the choice to either explicitly activate each single command in an Auto Sequence, or the command the ERA to automatically a set of commands in sequence (a Task). At any time, the operator can take over command and continue manually, after which he can resume the Auto Sequence.

Below is an example of a Task in an Auto Sequence (Table 2). The first task could typically be executed at task level, the second one at action level. A snapshot of the procedure for the EVA MMI cosmonaut, in the ISS Standard Ops Data Format is given in Table 3.

Task 13 Preparatory
113 Set Max Speed Discrete
325 Check Active Basepoint
328 Check Initial Pose
114 Set Payload Class
331 Download Frames
200 Go to Controlled Hold
304 Load Working Data Base
305 Enable New Data Base
323 Select FOR
300 Select TAF (Target BP, or PMU)
322Direct Bus Command (Wrist TFS ON)
4000 Select Viewpoint
Task 12 Transfer:
107 Free Move
108 Single Joint Move
126 Pitch Move
203 Go to Standby
206 Go to Shoulder Yaw Joint Hold
108 Single Joint Move
203Go to Standby
200 Go to Controlled Hold

Table 2: An example of a part of an Auto Sequence

ER - EMMI 'MENU'
Scroll 'SEL AS'to Center Window, then to Left Window
√ '01' in Center Window
Scroll '01' TO Left Window
Verify 'START' LED flashing
Press 'START' Switch for 2+ seconds
ERA STATE'
√ Verify 'INFO DUMP'
After ~ 40 seconds, √ 'PL move' in Left Window (Name of AS)
√ 'TOP' in Top Window
√ 'T013 01' in Center Window
√ 'T018 02' in Bottom Window

Table 3: Example of an operational procedure

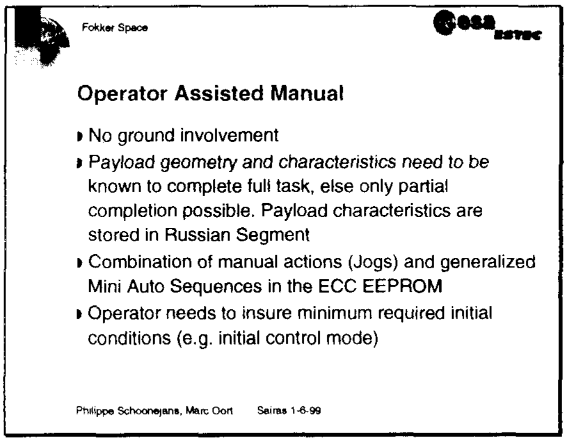
4. A flexible arm: Operations in Partially Manual Mode
It is also possible to operate the ERA without the help of pre-planning by the ground. These operations use hard-coded Auto Sequences inside the ERA ECC, each of which are designed to complete a partial mission objective (see Table 4.

6 ATTACH_BP	attach to basepoint
7 ATTACH_GF	attach to grapple fixture
8 DETACH_BP	detach from basepoint
9 DETACH_GF	detach from grapple fixture
10 INSTALL	install PL on PMU
11 REMOVE	remove PL from PMU
12 SCLU OFF	emergency CLU off
13 ESCLUOFF	emergency CLU off
14 INSPECT	inspect surface
15 POPIN	popin screwdriver
16 FIRMFLEX	firm/flex TFS

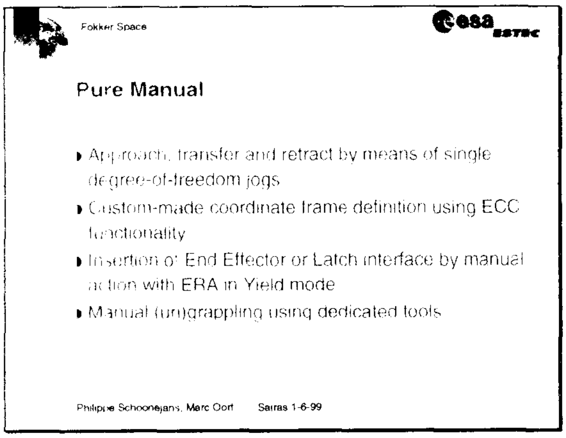
Table 4: Available Mini Auto Sequences in ERA

The commands inside these Mini Auto Sequences are designed to be independent of the desired position for the arm and/or its payload. A selectable list of hard-coded coordinates of basepoints and payload mounting units, allows the operator to specify the final position without having to determine or type in coordinates. If a position is not in the list, the ERA can "build" a target position from the end-effector camera's image of a standard reflective pattern which is located next to each Grapple Fixture.

The ERA Control Computer, and its counterpart in the IVA MMI, also keep track of the position of payloads moved within its model of the space station, thus keeping the on-board collision avoidance routines up to date, provided the objects are moved using ERA.

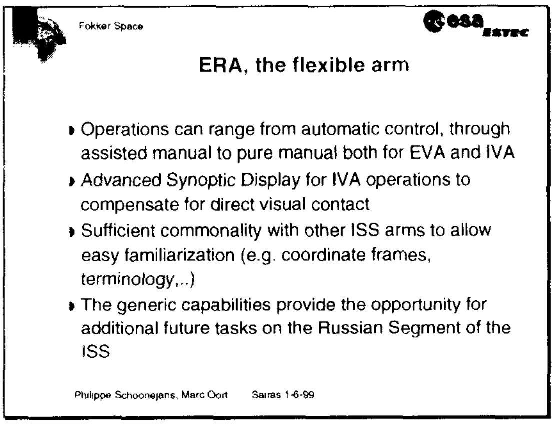


5. A flexible arm: Unplanned Operations in Fully Manual Mode
If even the hard-coded sequences are not sufficient or usable , it is possible to move the arm manually using keys and/or switches (no joy stick). Both long motions (up to 10 meters) or short steps (10 mm, 1 degree) are possible. Motions can be commanded both in a frame of reference coupled to the arm, and one fixed to the ISS. As the motions of the arm happen under full control/responsibility of the operator, the rotations have been limited to one degree of freedom at a time. The arm can even be operated in this manner when the Russian Segment Central Post Computer (which is in charge of the communications between the MMIs and the ERA) has failed. The EVA MMI can be connected directly to the ERA bus, and commanded from there. If all else fails, mechanical overrides (using EVA) are possible as well, requiring no SW at all.



6. Conclusions

The ERA has been designed to cope with a wide range of operational conditions, from fully planned to unplanned manual contingency operations, thus making a truly flexible robot arm. Astronaut reviews of the MMI designs have shown that the ERA is operable and user friendly, at least as seen in simulated conditions. Man-in-the-loop testing planned next year will show to what extent this is true for the full system when a complete mission has to be executed.



Annex: Man Machine Interface Layout