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AUTOMATION AND ROBOTICS FOR EXPERIMENT OPERATIONS IN AN ENHANCED MAN TENDED FREE FLYER (EMTFF)

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ABSTRACT

As a baseline for investigations into automation an robotics for microgravity experiment operations an enhanced version of the COLUMBUS Man Tended Free Flyer is used. Four relevant experiments are selected as a basis for detailed analysis to derive typical classes of experiment tasks which have crucial importance for the identification of automation and robotics concepts. The description of the Enhanced MTFF (EMTFF), a definition of a reference payload and the derivation of a preliminary concept for EMTFF automation is presented in this paper as results of an appropriate study funded by ESA/ESTEC.

1. INTRODUCTION

The Man-Tended-Free-Flyer (MTFF) is an essential part of the European Space Station Programme COLUMBUS. It presents a free flying microgravity laboratory for material science, fluid physics and life science payloads and consists of a 2 segment Spacelabtype Pressurized Module (PM-2) and an unpressurized Resource Module (RM).

Experiment operation will be provided by automated or teleoperated processing in the free flying mode while experiment processing set-up and payload servicing is conducted by astronauts in a shirt-sleeve environment when the MTFF is connected to a servicing base.

In this paper results of an ESA/ESTEC funded Study on "Robotics Spacecraft Servicing and Assembly in Space" (ROSSA) will be presented, dealing with automated microgravity experiment operations within an enhanced version of the MTFF. This Study was performed by MBB/ERNO as prime contractor with major contributions of the IPK and SENER.

2. ENHANCED MAN TENDED FREE FLYER

The Man Tended Free Flyer (MTFF) is an essential part of the European Space Station programme COLUMBUS. It is an orbiting laboratory which offers its payloads an ultimate quality microgravity environment within a pressurized module.

The flight configuration of the MTFF is illustrated in Figure 1, showing the Resource Module with deployed solar arrays and antenna, connected to the two segment Pressurized Module which houses the laboratory. The experiments and corresponding facilities to be accommmodated within the Pressurized Module cover a large spectrum of material and life science experiments.

Object of investigations within this paper is an Enhanced version of the Man Tended Free Flyer (EMTFF), which uses as a basis the MTFF of the COLUMBUS IOC-Phase (Initial Operating Capability).

The reference scenario is assumed to start a few years after the IOC-MTFF has started operation in space and after the system and subsystems have been proven and the initial problems have been solved.

The following assumptions and basic requirements were taken as a baseline:

- Starting point is the current definition of MTFF as core element of the enhancement
- Scenario stars a few years after the MTFF has started operations in Space.
- ARIANE V and HERMES are available for assembly tasks for enhancement and servicing

Identical to the MTFF of the IOC-Phase, the mission objective of the EMTFF is basically to offer extended uninterrupted and high quality microgravity environment of a duration between 1 and 6 month for very precise science and research experiments in the field of microgravity. Compared with the MTFF of the IOC-Phase, the EMTFF will offer a more effective scientific utilization and a transition to first space production systems (pilot plants). This will be possible by the enlargement of the resources on the one hand, and by the application of improved and extended suitable/adapted robotic systems and techniques, on the other.

Figure 2 shows the architecture of the EMTFF together with HERMES docked for servicing activities. Apart from the subsystem enlargement of the Resource Module and the reconfiguration inside the Pressurized Module, the major changes against the IOC-MTFF version will take place on the free end of the Pressurized Module, opposite to the Resource Module. A Multi-Berthing Node (Interconnecting Element) with 6 berthing ports in total - permanently berthed to the Pressurized Module - will give the flexibility for the attachment of additional elements.

In particular, the EMTFF consists of the following elements:

- Resource Module (RM)

  Compared to the IOC-version the Propulsion Subsystem have to be enlarged by exchange of four relevant subsystem ORUs.

- Pressurized Module (PM)

  The 2-segment primary structure as well as the subsystems of the IOC PM will not (or only slightly) be affected by the enhancement.

- Multi-Berthing Node (MBN)

  The MBN with six berthing ports in total will be permanently berthed to the free end of the PM, opposite to the RM.

- Dedicated Airlock (DAL)

  The DAL, berthed to a port of the MBN, is necessary for rack/equipment transfer to/from the PM to space.

- Payload Carrier (PC)

  A PC, berthed to another free port of the MBN, offers the possibility to accommodate external payloads, utilizing the ambient vacuum and clean environment, as well as the effects of space radiation.

  Unmanned Capsule Reentry System for Sample Return (UCRS)

  The UCRS offers the possibility of sample return during the unmanned operation phase of the EMTFF.

3. PAYLOAD DEFINITION

The users have identified experiment proposals for the MTFF. The corresponding facilities which cover the current scope of the Material and Life Science are compiled to missions called MAT 140 and LIF 141. Experiment groups of Material Science MAT 140 are: Metal Lab, Crystal Lab and Fluid Lab. Life Science LIF 141 consists of the following experiments and experiement groups: Aquarack, Cells Test Facility, Gravitational Biology, Biotechnology. This payload combination, which is called MIC 400 makes up the accommodation reference for COLUMBUS-IOC. Table 1 compiles the individual experiments of MIC-400 with its abbreviations and Figure 3 shows the accommodation of the experiment facilities and the subsystem allocation inside the Pressurized Module of the EMTFF.

Whilst laboratory integration, initial technical and scientific tests, maintenance and repair as well as payload exchange will be done by astronauts, extensive automation and robotics is needed to operate the laboratory in an autonomous mode in absence of man. The work of payload specialists as known from Spacelab have to be performed by intelligent automation and robotics systems supervised by man on ground.

The reference payload mission MIC-400 was taken as a basis for the appropriate investigations and the following four representative experiments have been selected as relevant for an analysis of automation and robotics applicability to microgravity payloads:

- Containerless Processing
- Protein Crystal Growth
- Critical Point Facility
- Cell Fusion

These experiments present - more or less - the whole spectrum of automation and robotics applications during the unmanned experiment operation phase of the EMTFF. The main tasks of experiement operations for theses four experiments are listed in Table 2.

These experiments were selected as basis for following detailed analysis:

- identification of components to be handled.
- analysis of handling operations in relation to their frequency, distance, number of cycles and their duration.
- formulation of automation possibilities for components and handling operations.
- elaboration of concepts for automation.

As an example the functional structure and operations of the Critical Point Facility is shown in Figure 4 and Figure 5 illustrates a principal rack and facility design with the required working room and handling motions.

4. CONCEPT FOR EMTFF AUTOMATION

The fundamental requirements for the identification of robot types is the definition of tasks to be executed by robots.

The analysis of the four selected experiments shows that they differ not only in relation to their experimental tasks, but also in the handling operations. The different aspects in handling operations are:

- type of operation, mass of object, distance, frequency, cylce number and process restrictions.

Nevertheless, similar handling operations representing typical operations to the executed automatically can be clustered:

- sample preparation, sample exchange, sample magazine exchange, sample magazine transport, sample storage module transport.

The most important factor concerning the working room of the handling device are the locations, where the handling operations have to take place, and their distance. In Table 3 typical handling operations for each experiment and its location are listed.

Identification of Robot Types

As a result of the analysis of the experiment operations in principal two different mechanical systems have been identified for the mechanical support of the experiments:

- rack internal handling devices
- rack external robot systems.

The analysis shows that rack internal handling devices are rarely required. Nevertheless, there will be a need for the automation of simple repetitive tasks inside the experiment which could be performed by dedicated mechanism like revolver magazines, pick and place devices, actuators for drawer extension/insertion etc.. The development of special handling devices for each experiment should be avoided. A better solution is a modular concept which consists of translational, rotational and components combined and arranged to fulfill the experiment specific handling requirements.

For the rack external robot systems two possible general concepts for experiment execution are possible:

- 1. A central robot system for the execution of tasks to be automized in all experiments
- 2. Decentralized robot systems for each experiment or set of experiments and a centralized robot system for general logistics.

Although the decentralized concept has disadvantages in relation to mass, volume and energy consumption, it has significant advantages due to the important aspect of the higher autonomy of the experiments. From the overall system point of view, the decentralized concept is favourable due to reliability, timelining interferences and operational costs. Therefore the decentralized concept will be considered as baseline for the automated operation of the EMTFF.

Based on a detailed experiment analysis the following three different rack external robot types have been identified as the most suitable ones for the relevant experiement tasks:

- 1. Single - Rack Dedicated Robot (SDR)
- 2. Multi - Rack Dedicated Robot (MRD)
- 3. Central Transport Robot (CTR)

The first type of robot is suitable for experiment with many handling operations per cycle, time critical operations and precise motions.

The second one is designed to execute middle distance and low capacity handling operations for several different experiments.

The third type of robot serves all experiments and is foreseen to execute long distance transport tasks and low frequency handling operations.

Overall Kinematic Concept Aspects

Examples for kinematic concepts of the a.m. three robot types are illustrated in Figure 6.

The single rack dedicated robot should consist of an universal arm which is fixed in a gantry or on a rail. The operational tasks of the selected experiments are similar. Therefore one universal robot arm could be used at all single experiments where automation is necessary.

In the case of servicing a set of experiment racks, the working room of the robot must be enlarged. This can be done by extension of the gantry in which the universal robot arm is movable. With this concept only one type of robot arm and a gantry adapted to the required size is necessary to fulfill the automation of rack external handling task at one or a set of experiments.

For the central transport robot mobility along the floor of the PM has to be added to the articulated universal robot arm. In this case the robot moves on rails covering the whole extension of the Pressurized Module of the EMTFF.

The components of such a modular concept as drive units, rails, measurement elements and control could be the same as proposed for the a.m. gantry motion. Thus, a high degree of standardization concerning the hardware is reached.

Automation and Robotics Concept

The combination of the three above mentioned types of robots together with the rack internal hardautomation provide the complete automation of the experiments operation inside the Pressurized Module of the EMTFF (Figure 7).

For a number of experiments and servicing tasks there will be unpredictable operations which cannot be pre-programmed or executed in the near future. In these cases and in contingency cases intervention of human operators on ground is required. To make this possible, means for teleoperation/telescience have to be provided.

Special care has to be taken into account regarding the design of the experiment facilities, as they have to be operated not only by robots, but also by astronauts during the servicing period between two missions. The design of experiment facilities should be oriented and optimized for automation, but including the possibility of manual execution.

The automation and robotics concept presented in this paper is a high flexible tool to organize and support experiment operations within MTFF/EMTFF during both unmanned and man-tended phases.

This concept is based on the interaction and cooperation on following elements:

- internal experiment dedicated hardautomation
- single or multi-rack dedicated robots
- central transport robot
- astronaut for installation and check-out of A&R equipment on-board
- man on ground for supervision and telescience

This concept will be applicable to both development stages of the MTFF to the early IOC configuration as well as to the later EMTFF configuration.

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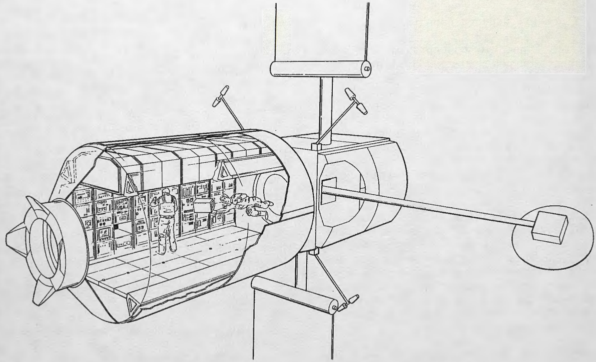

Figure 1: COLUMBUS Man Tended Free Flyer

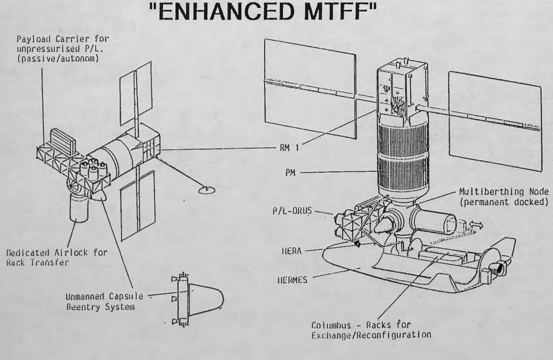

Figure 2: Enhanced Man Tended Free Flyer and its Elements

FACILITIES OF MIC – 400 FOR EMTFF

ABBR.	FACILITY NAME MATERIAL SCIENCE MAT 140:
	Metal Lab:
GFA	o Gradient Furnace
CLF	o Containerless Processing Facility
TPP	o Thermophysical Properties
	Crystal Lab:
PCF	o Protein Crystal Facility
SGF	o Solution Growth Facility
VGF	o Vapour Growth Facility
LPE	o Liquid Phase Epitaxy
FGF	o Flux Growth Facility
TSF	o Travelling Solvent Facility
	Fluid Lab:
CPF	o Critical Point Facility
CFF	o Continuous Flow Facility
TPF	o Transport Properties Facility

ABBR.	FACILITY NAME LIFE SCIENCE LIF 141:
AR	o Aquarack
CLS	o CELLS Test Facility
	Gravitational Biology
GBL 1	o Biochamber
GBL 2	o Plant Facility
GBL 3	o Incubator Facility
	Biotechnology
BPF 1	o Cell Fusion
BPF 2	o Phase Partiioning
BPF 3	o Downstream-Process
BPF 5	o Cell Cultivation
Analysis	Common Analysis Facilities

Table 1: Facilities of Reference Payload Mission MIC-400

EMTFF : Internal Accommodation of Facilities and Subsystems

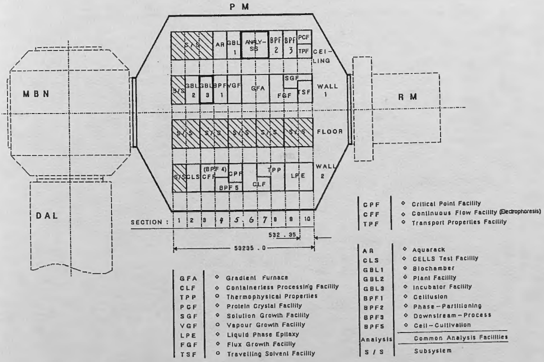

Figure 3: EMTFF Internal Accommodation of Facilities and Subsystems

Abbreviation	Experiment Name	Main tasks of experiment operation
CLF	Containerless Processing	o 13 individual experiment cycle campaigns o Exchange of experiment chambers/samples o In-orbit analysis of samples o Sample return by Reentry System
PCF	Protein Crystal Growth	o 4 experiment cycles o Exchange of experiment chambers/samples o Sample return by Reentry System and controlled temperature conditions
CPF	Critical Point	o 6 experiment cycles o Exchange of experiment chambers
BPF1	Cell Fusion	o 5 individual experiment cycle campaigns o Sample transfer from supporting facilities to experiment facilities o In-orbit analysis and sample return by Reentry System under controlled conditions.

Table 2: Selected Reference Experiments

	Location of Handling Operation		
Experiments	Operation within a Rack	Operation at One Rack	Operations at a Set of Racks
Containerless Processing	Sample Exchange	Exchange of Sample Magazines	Sample Magazine Transport to Payload Contain.
Protein Crystal Growth	-	Preparation and Exchange of Samples	Sample Storage Module Transport Between Racks,to Payload Contain.
Critical Point Mesurement	-	Exchange of Samples	-
Electro Cell Fusion	-	Preparation and Exchange of Samples	-

Collection of Handling Operations and Their Locations for the Four Investigated Experiments

Table 3: Handling Operations and their Locations

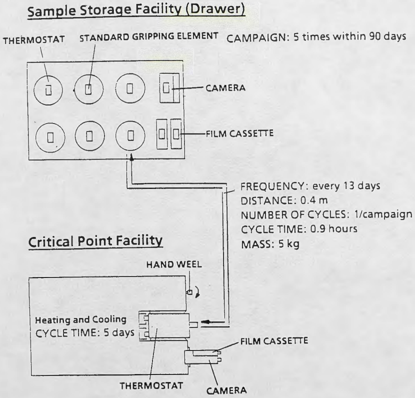

Figure 4: Functional Structure and Operations of the Critical Point Facility

–PRACTICABLE RACK AND FACILITY DESIGN–

THE OBJECTIVE OF THIS EXPERIMENT IS THE INVESTIGATION OF CRITICAL PHENOMENA AT A GIVEN TEMPERATURE AND IN A MICRO–GRAVITATIONAL ENVIRONMENT. THE MAIN FUNCTIONS OF THE CRITICAL POINT FACILITY ARE :

- TO SUBMIT FLUID SAMPLES TO PRECISE TEMPERATURE CYCLES DEFINED IN ADVANCE
- TO ANALYSE THE BEHAVIOUR OF THE FLUID NEAR OR AT THE CPT WITH OPTICAL METHODS

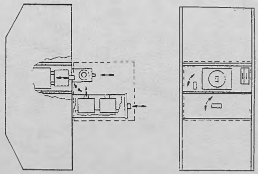

Figure 5: Principal Rack Design of the Critical Point Facility with Required Working Room and Motions

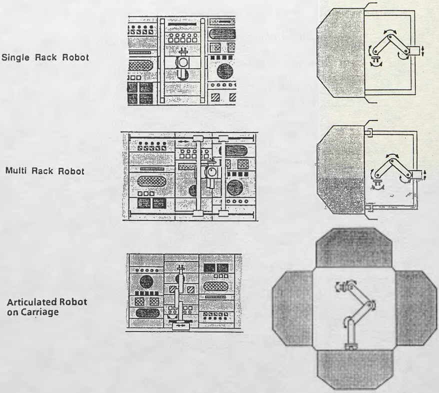

Figure 6: Example for Kinematic Concepts of EMTFF Robots

Robot and Automation Concept for MTFF

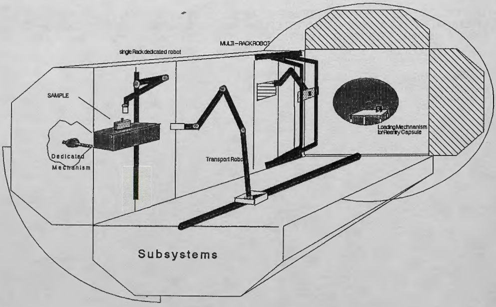

Figure 7: Automation and Robotics Concept for MTFF/EMTFF