N90-29844

CONCEPT SYNTHESIS OF AN EQUIPMENT MANIPULATION AND TRANSPORTATION SYSTEM EMATS

W. De Peuter, ESTEC, The Netherlands
E. Waffenschmidt, Dornier Federal Rep. Germany

Abstract

The European Columbus Scenario is established. One of the Columbus Elements, the Man Tended Free Flyer will be designed for fully autonomous operation in order to provide the environment for micro gravity facilities. We discuss the Concept of an autonomous automation system which perform servicing of facilities and deals with related logistic tasks.

1. Introduction

The importance of Automation and Robotics (A&R) has grown rapidly in recent years due to challenging demands for autonomous serivicing in space.

Many of the techniques and experience gained from industrial development will be used in space application, as indicated by various robotics activities at the US., Europe and Japan.

The extensive use of robots in future space production, research and exploration and their importance for servicing and maintenance of autonomously operating facilities is obvious.

Running such space facilities with minimal human involvement is a unique challenge and opportunity to apply intelligent robotic techniques in experiment and processing systems.

At present, the use of robotics in the European space scenanrio concentrates on the Columbus Man-Tended Free Flyer (MTFF). The MTFF is a free flying "quiet laboratory" in orbit which provides the environment for microgravity experiments with only very low disturbances (10^{-6} g). The MTFF is planned to be unmanned for a time period of 6 months and man-tended during the servicing events (when it is attached to the ISS or docked to HERMES).

During the absence of men, the MTFF must be operated autonomously by an automation system installed inside the Module, which performs all required manipulation and transportation tasks. This paper deals with a first concept synthesis for this Equipment Manipulation and Transportation System (EMATS) for the internal servicing of the MTFF Laboratory.

2. MTFF Servicing Scenario and Model Mission

The first stages in European manned space flight where extensive A&R systems are needed will be (see Figure 2-1)

- MTFF in nominal unmanned period
- MTFF/HERMES during manned Servicing

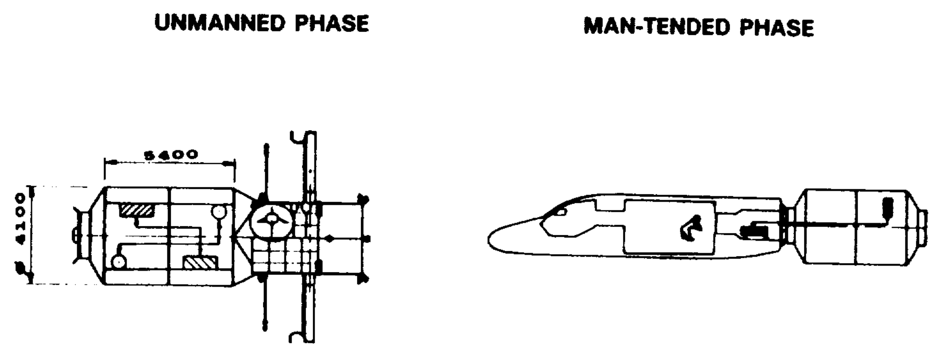


Figure 2-1: EMATS Application Scenarii

They represent the basic MTFF scenarii and hence they are the most relevant scenarii for the applications of EMATS.

It is assumed that the reference payload for the first mission of the MTFF will be a mixture of Materials Science facilities and Life Science facilities called M/C 400. The principle accommodation of these experiment facilities inside the Pressurized Module of the MTFF is shown in Figure 2-2.

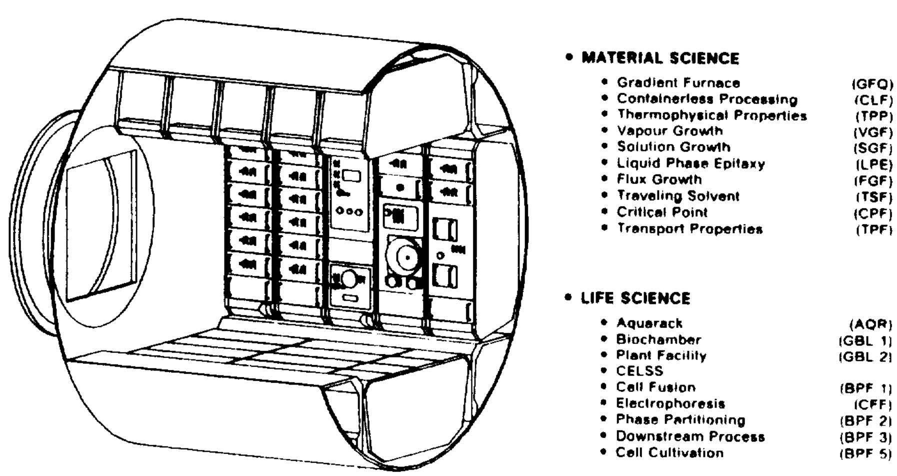


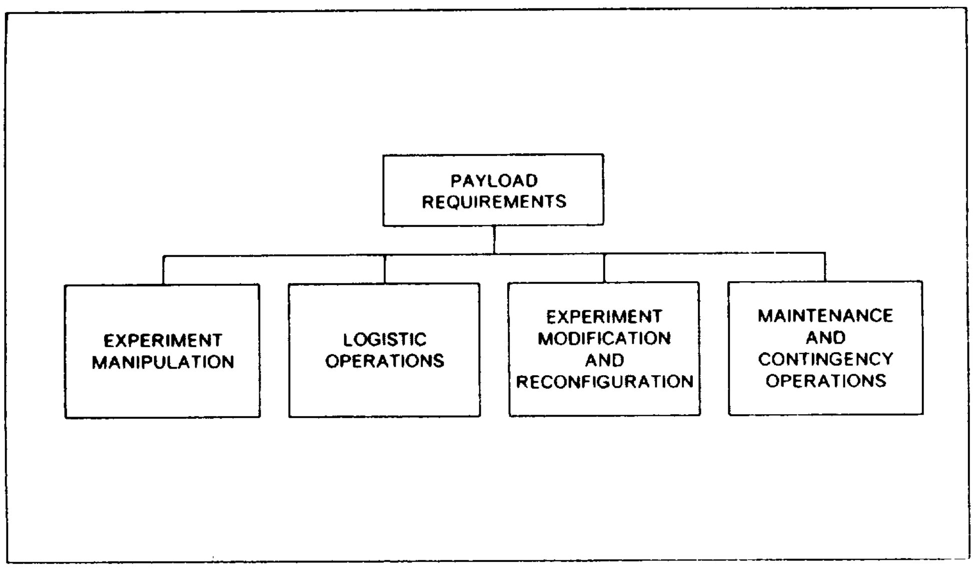
Figure 2-2: Accommodation of MIC 400 Payload

3. EMATS Tasks and Functional Requirements

Based on the analysis of the application of A&R for the MTFF Model payload and the MTFF servicing scenarii the tasks for robotics can be identified by answering the both questions:

- What shall be done?
- How and where shall it be done?

Analysing "what" the manipulators shall do, leads to the classification of the tasks in the following four groups:

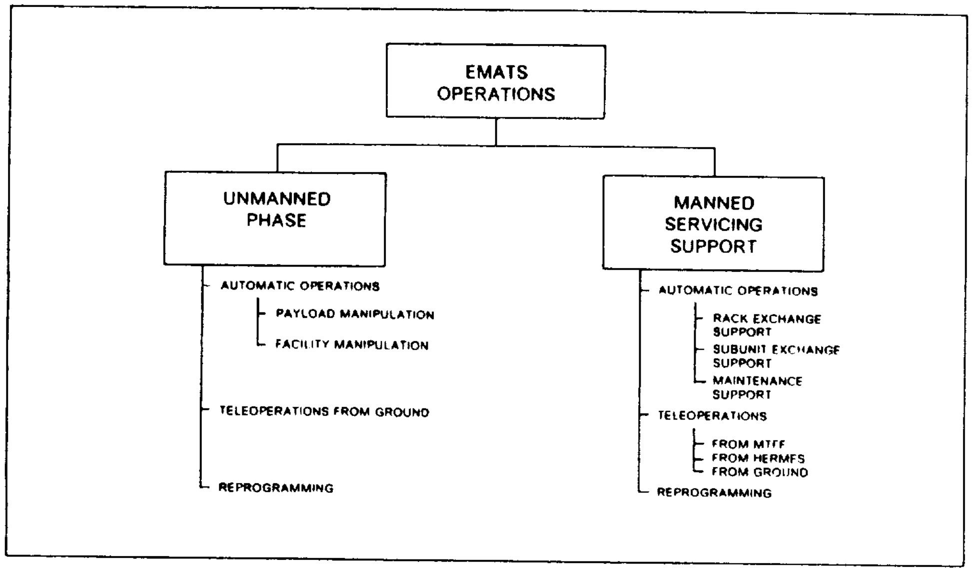


Based on the major Payload Requirements the Generic Functions of the Equipment Manipulation and Transportation System like

- MOVE MANIPULATOR TO PAYLOAD POSITION
- REMOVE PAYLOAD (e.g. Sample)
- INSTALL PAYLOAD
- TRANSPORT PAYLOAD
- PAYLOAD INSPECTION
- OPEN DOOR
- CLOSE DOOR
- FACILITY INSPECTION WITH EE CAMERA
- FACILITY CLEANING WITH SPECIAL TOOL
- TELEMANIPULATION
  - SINGLE JOINT CONTROL
  - CARTESIAN CONTROL
  - END EFFECTOR CONTROL
  - CAMERA CONTROL
- CONTINGENCY HOLD

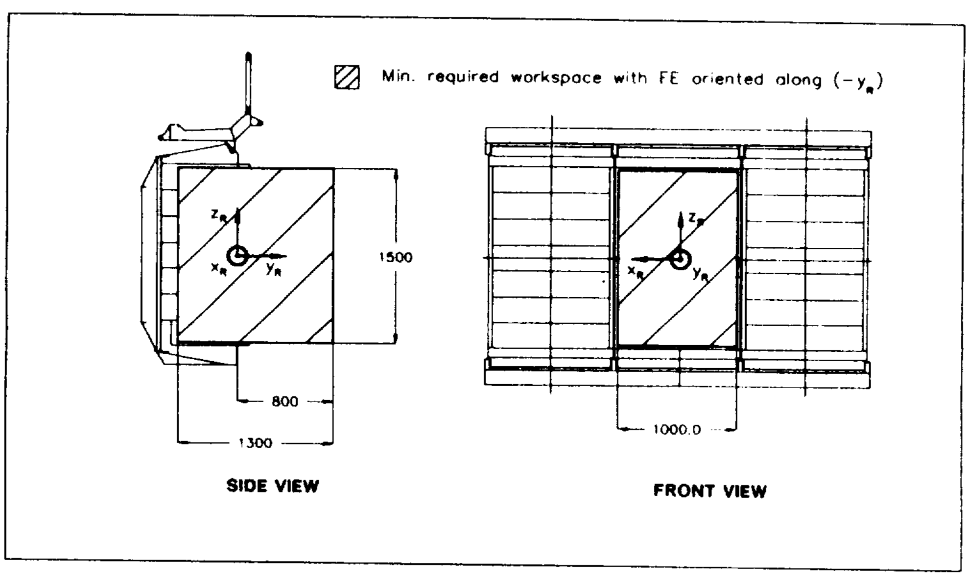
were generated.

These "Generic Functions" leads to the EMATS Operations namely



Analysing "how" and "where" the tasks shall be done leads to the identification of robotic requirements

- workspace needed
- orientation performance



4. EMATS Concepts and Trades

The Results of the Analysis of EMATS Tasks and functional Requirements form the basis of the Concept development.

In order to illustrate the systematic and evolutionary synthesis of an EMATS concept, the following classification of A&R Systems was applied.

D: Dedicated Mechanism

F: (Permanently) Fixed Manipulators

R: Rail-based Manipulators

T: Manipulators with Transplantable Base

C: Climbing Manipulators

E: Exotic Concepts (e.g. free flying robots...)

The evolution starts from class "D" which can be seen as the ultimate of a "convential" non-robotic approach. The next classes add more and more sophistication, intelligence and flexibility while in general reduces the "volume" of apparatus or devices needed.

The upper end is represented by fictitious "exotic" concepts with ultimate flexibility, but for the time being also imense development risk. They are supposed to indicate a "ceiling" for technology and show that the class "R" and "C" concepts are indeed the current peak of the evolution.

Figure 4-1 gives an overview of the different concepts.

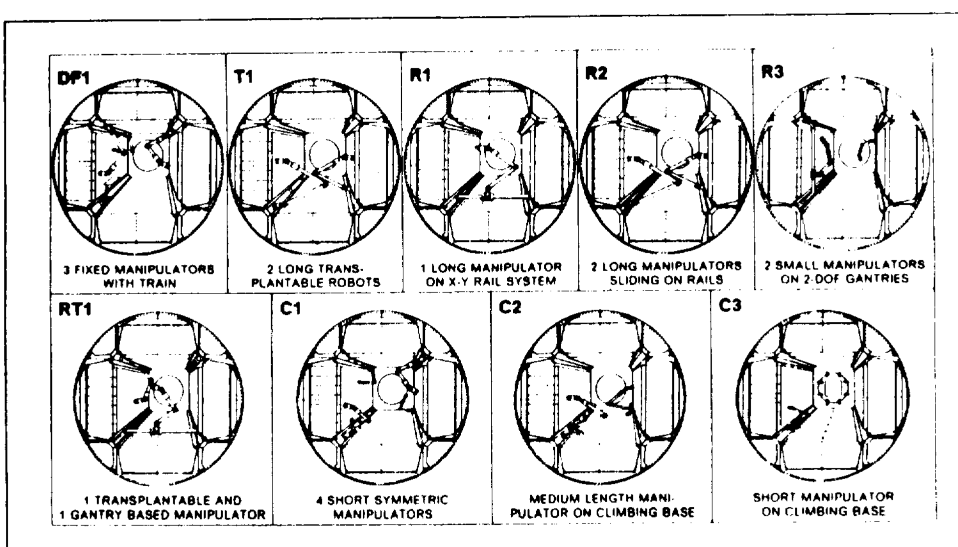


Figure 4-1: EMATS Manipulator Concepts

A trade off, based on some typical MTFF relevant criteria like:

	CONCEPTS										
CRITERIA	D	DF1	T1	R1	R2	R3	RT1	C1	C2	C3	E
MINIMUM PM IMPACT	- -	0	0	0	--	+	0	+	+	+ +	+ +
FULFILLMENT OF USER REQUIREMENTS	+	-	0	+	+	+ +	+	+	+ +	+	+ +
RELIABILITY	+	0	0	-	0	0	+	-	-	-	-
FLEXIBILITY	- -	- -	0	0	0	+	+	+	+	+	+ +
FEW IN-ORBIT OPERATIONS	-	-	-	+	0	+	-	-	0	+	0
DEVELOPMENT COST/RISK	+	+	0	+ +	+	+	0	- -	- -	- -	- -
OPERATIONAL COST	- -	-	0	0	0	+	0	0	+	+ +	0
APPLICATION/DESIGN GROWTH	- -	- -	+	-	0	-	+	+ +	+ +	+ +	+ +

results in the selection of Concept R3 and C3 for final comparison. Figures 4-2 and 4-3 show the preselected concepts

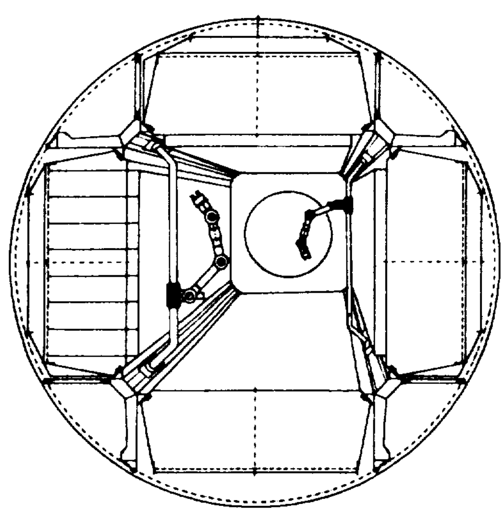


Figure 4-2: Gantry Based Concept R3

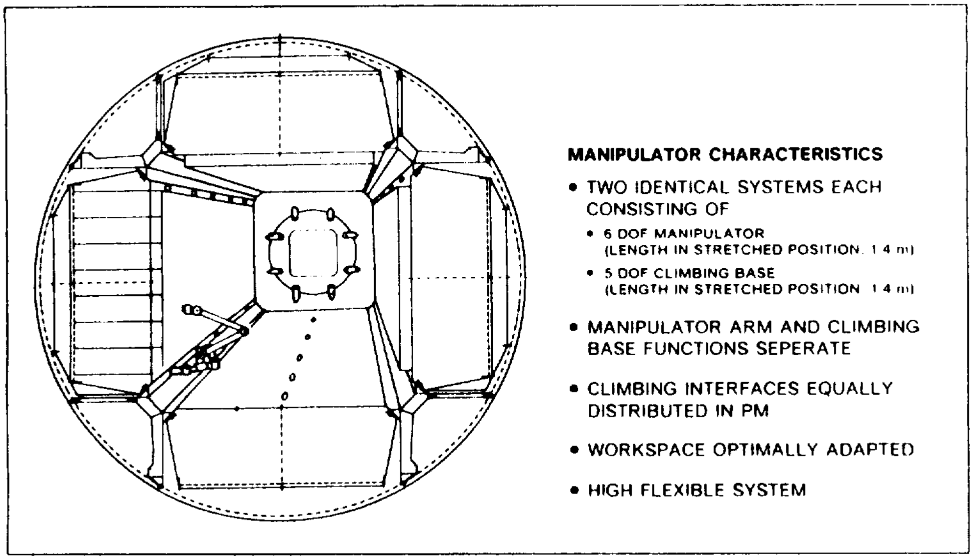


Figure 4-3: Climbing Concept C3

The criteria and weighing factor for the final trade are given together with the evaluation in Figure 4-4.

MARKINGS FROM 0 TO 10:
10 = ALTERNATIVE MEETS CRITERION BEST
0 = ALTERNATIVE MEETS CRITERION LEAST
CONVERSION CODE:
10 = +++ 4 = -
8 = ++ 2 = --
6 = + 0 = ---

	CRITERIA	IMPORTANCE %	ALTERNATIVES 1 (P 1) M	ALTERNATIVES 1 (P 1) I*M/10	ALTERNATIVES 2 (C 3) M	ALTERNATIVES 2 (C 3) I*M/10
A11	LOW IMPACT ON PM SPACE SEGMENT DESIGN	3.48	7	2.4	9	3.1
A12	COMPATIBILITY WITH MICRO - G LEVEL	6.42	9	5.8	7	4.5
A13	EASE OF IMPLEMENTATION	3.88	9	3.5	8	3.1
A14	EASE OF ADAPTATION AND MAINTENANCE	2.52	5	1.3	10	2.5
A15	SAFETY	8.22	10	8.2	6	4.9
A21	FULFILMENT OF USER REQ.	4.98	8	4.0	7	3.5
A22	LOW IMPACT ON EXP. CONCEPTUAL DESIGN	5.10	8	4.1	4	2.0
A23	LOW IMPACT ON EXP./PL DEVELOPMENT	1.92	10	1.9	3	0.6
A24	HIGH RELIABILITY/AVAILABILITY	7.32	5	3.7	4	2.9
A25	HIGH FLEXIBILITY	4.62	7	3.2	9	4.2
A31	IMPROVEMENT OF PL. & ASTRONAUT OPS.	5.40	9	4.9	8	4.3
A32	LOW IMPACT ON SPACE SEGMENT OPERATIONS	4.50	7	3.2	10	4.5
A33	LOW IMPACT ON USER/GROUND SEGMENT OPS.	1.68	10	1.7	4	0.7
B11	LOW DEVELOPMENT COST	1.44	10	1.4	3	0.4
B12	LOW TECHNOLOGICAL RISK	6.08	10	6.1	2	1.2
B21	LOW OPERATIONAL COST	4.72	8	3.8	7	3.3
B22	LOW LOGISTICS COST	4.84	7	3.4	10	4.8
B31	GOOD EVOLUTION TIME PHASING W.R.T. USER REQ.	2.32	8	1.9	6	1.4
B32	GOOD BENEFIT RETURN	4.24	10	4.2	7	3.0
B33	SPIN - OFF TO OTHER FIELDS	1.68	2	0.3	6	1.0
C11	GOOD REUSABILITY FOR F.O. GENERATION OF PL	3.76	8	3.0	8	3.0
C12	GOOD ACCEPT. OF NEW FUNCTIONS/APPLICATIONS	3.64	2	0.7	10	3.6
C21	SERVICEABILITY AND UPGRADEABILITY	3.64	6	2.2	8	2.9
C22	EXTENDABILITY	3.64	6	2.2	6	2.2
	Score :	100.00		76.9		67.7
	Rank :			1		2

Figure 4-4: Concept Trade off

5. Conclusions and Outlook on Future Work

Concept R3 comes out as prefered system. Its major advantages are:

- No safety concerns
- Low technological risk and development cost
- Very low impact on experiment/payload design and development (including good 1 g compatibility)
- Very good µg compatibility
- No serious impact on user/ground segment operations
- Very high improvement or payload and astronaut operations
- Uncritical stowage and implementation
- Completely satisfactory flexibility and manipulation/transportation capability at low complexity and low operational cost

Points of relative weakness are:

- Reliability/availability strongly determined by reliability of the rail and gantry subsystems
- Possible maintenance problems in case of rail failure
- The need for PM interfaces at the bottom standoffs for rail attachment (at the moment, no MTFF document seem to prohibit this, though)

The major disadvantage of R3 is

- Transport capability into servicing vehicles can only be performed with the help of dedicated devices inside those vehicles. This, however, seems an acceptable penalty.

On the other hand, concept C3 offers as advantages:

- Very high flexibility
- No problem with implementation or maintainability
- Good improvement of payload and astronaut operations
- Excellent acceptance of extended vehicles tasks
- No logistic problems
- Very good serviceability, upgradeability, reuseability.

These, however, are overshadowed by serious drawbacks:

- Very high technological risk and development cost, mainly due to the complex control of the redundant d.o.f. for climbing coordination
- For the same reason, doubts on reliability/availability and possibly high ground control operations impact
- Need for rack center I/Fs that may restrict experiment design (or, restricting center I/Fs, significantly reduced flexibility)
- Not completely negligible safety hazard.

This results in a final score for R that is 13 % higher than C. This lead is very robust against perturbations in the criteria weighing. R3 dominates C3 by 17 % in the "technological" criteria and by 8 % in the "programmatic" criteria. Finally, there does not seem to be any serious and unrepairable deficit in R3, this being a very straightforward and conservative approach for which good confidence is derived.

Therefore, we recommend as the preferable EMATS concept:

> R3 (Double Manipulator on longitudinal rails)

with its main characteristics:

FIRST TECHNICAL DESIGN DATA

STRENGTH AND REACH	
STATIC FORCE/TORQUE CAPABILITY	
Max Force at EE (all axes)	20 N
Max Torque at EE (all axes)	10 Nm
LOAD CAPABILITY	
Max payload mass (0-g) (TBR)	200 kg
Max payload mass (1 g)	1 kg
REACH CAPABILITY	
Min envelope of constant EE orientation ($W_x \times D_y \times H_z$)	7.075 × 1.880 × 3.085 m³
STIFFNESS	
Typical stiffness with EE at workspace boundary	0.01 mm/N

ACCURACY AND SPEED	
ACCURACY	
Min EE accuracy (all axes)	
Robot internal	
before calibration (0 g)	± 1mm/ ± 0.1°
after calibration (0-g)	± 0.5mm/ ± 0.05°
before calibration (1-g)	± 2mm/ ± 0.2°
after calibration (1 g)	± 1.5mm/ ± 0.15°
Against facility (without contact)	
before calibration (0 g)	± 2mm/ ± 0.2°
before calibration (1 g)	± 3mm/ ± 0.3°
after calibration (0 g, 1-g)	± 1mm/ ± 0.1°
Against facility (with contact)	
accuracy achieved by virtue of active compliance (f/t sensing wrist)	
SPEED	
Maximum EE speed (1-g)	25 cm/s
Maximum EE speed (0 g)	1 cm/s

RESOURCE NEEDS	
MASS	
Mobile Base Assemblies (2)	92.0 kg
Manipulator Arm Assemblies (2) (incl. joint electronics and tools)	83.0 kg
Central Control Subsystem (1)	30.0 kg
Flight Teleoperation Facility	5.0 kg
Total EMATS Flight Segment	210.0 kg
STOWAGE VOLUME	
Mobile Base and Manipulator Arm Assemblies (outside Payload Volume)	0.1 m³
EMATS Central Control Subsystem	0.04 m³
Flight Teleoperation Facility	0.02 m³
Total EMATS Flight Segment	0.16 m³
POWER	
Mean on board power consumption	120 W
Peak on board power consumption	160 W
COMMUNICATION	
Maximum TM data rate	24 kBaud
Maximum TC data rate	20 kBaud

The future planned activities are:

- definition of the EMATS hierarchical control structure
- definition of the Central Control Subsystem configuration
- definition of Arm Controller and Mobile Base Controller
- preliminary mechanical design
- preliminary specifications