COLUMBUS SYSTEM SUPPORT FOR TELESCIENCE OPERATIONS

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ABSTRACT

With the given constraints of the space environment, the telescience concept aims at providing a space mission user with optimum flexibility and responsiveness for space-borne investigations. The concept includes automated system management functions, which allocate and monitor planned resources and time windows, within which the investigator can perform his science interactively responding "on-line" to experimental data. During the telescience operation, the user is given the capability to send telecommands to the payload from the User Home Base with transparency to the rest of the system. Any violation of the "booked" time and resources will be detected by the system, and reported back to the user for appropriate action. Ultimately, the system will react to maintain the integrity of the system and its payload. Upon completion of the telescience session, the system management function reverses the system configuration and deallocates resources automatically.

Keywords:
COLUMBUS, APM, Telescience, Principal Investigator, Payload Operations

1. INTRODUCTION

The ESA COLUMBUS Attached Pressurised Module (APM), the European contribution to the Space Station Freedom, provides for an inhabitable laboratory environment and is conceived to be operated automatically, from the ground, and by the on-board crew.

The operation of on-board payloads can be done:

- either through pre-programmed automatic operations, invoked by the Space Station master timeline (Onboard Short Term Plan - OSTP), and processed accordingly by the APM element manager;
- or through telescience operations, defined as "the fully interactive mode of science operations whereby investigations on the Space Station and COLUMBUS elements are carried out under the effective scientific control of the investigator teams" {ref.1}. This involves payload user operations via telecommands, issuing payload internal commands, with complete transparency of the rest of the APM system.

Both types of operation are supervised by automatic management functions to set and monitor operations envelopes, within which scientists can undertake their scientific investigations. Telescience is used for shorter duration payload activities such as swapping samples in an automated material processing furnace, whereas payload operations via the OSTP are used for long duration payloads and are characterised by Principal Investigator monitoring.

This paper outlines the COLUMBUS approach towards telescience operations, and the operational procedures, functions and communication services required to support the concept.

2. COLUMBUS APM OVERVIEW

Following complete attachment to the SSF node, activation and checkout, the APM will be ready to support payload activities as required by the SSF mission operations schedule. The payload activity support provided by the APM will include the operation of payloads from the International Partners (NASA, ESA, and CSA). The APM system will be under the control of the APM System and Mission Management (SMM) Software, which will respond to messages and commands sent from the SSF Integrated System Executive (ISE), the crew and ground. APM on-orbit servicing and maintenance will be planned and provide for the full 30 year operational life. It will be serviced and maintained during 90 day (*tbc*) increments, enabling the resupply of consumables, the changing of International Standard Payload Racks (ISPRs) or of individual payload subunits within the rack, and hence supporting a diverse range of scientific operations in the life sciences, space biomedicine and material sciences.

3. COLUMBUS OPERATIONS CONCEPT

3.1 APM Automatic Command Execution

In order to increase operational flexibility, automated system level management functions are provided, serving as a tool for a safe and consistent implementation of external commands (ground, crew). In the APM this function is performed by the SMM which includes executable software and associated system and mission data. The SMM is responsible for:

- command processing (checking and execution);
- resource provision and allocation;
- failure management (system level Failure Detection, Isolation & Recovery - FDIR);
- reporting APM system data to the ISE.

This enables the APM to be operated as a ground-based laboratory without the continuous commanding and monitoring that has characterised previous spacecraft missions. This reduces the impact of limitations of up/downlink capabilities, and loss of signal (LOS).

Pre-planned automatic on-board operations within the APM are nominally invoked by the OSTP, running within the Space Station Manned Base (SSMB). Commands that are applicable to the APM are sent to and processed by the SMM, and may comprise time-tagged *Action_Names* or *Operational Task_Names*. An Action is the lowest operational step by which the APM can be controlled and operated within the context of nominal operations. It is associated with a step change in resource allocation/deallocation, and a functional process to be performed utilising this resource. An Operational Task (OT) groups together Actions related to the same mission goal.

3.2 APM Resource Management

The resource management function of the SMM handles all aspects of on-board resource management, including:

- resource allocation checks;
- resource allocation data management;
- resource consumption monitoring;
- resource reporting and logging to SSMB/crew/ ground.

For the APM, the following principal resources are provided and managed:

- power distribution;
- data management services;
- cooling (air and water);
- vacuum line allocation;
- venting line allocation;
- nitrogen (purge gas) distribution to payloads.

Other resources are more effectively managed by the on-ground planning process (e.g. crew time, data relay satellite utilisation, microgravity environment), or by the SSMB (e.g. power provision, waste water removal, potable water supply).

Resource management is based upon operational resource envelopes. These are distributed amongst the individual users, and may be summed at either User Home Base (UHB) or at the collective User Support and Operations Centres (USOC) level. This is shown in figure 1. The sum of all the individual resource envelope allocations (e.g. USOC_a plus USOC_b) makes up the envelope for utilisation (i.e. the total amount of resources allocated to APM users).

Against these resources are set "soft" (operational) limits which are the limitations imposed upon the user of the particular resource, and "hard" (design) limits which represent the fixed thresholds of the resource, the exceeding of which may result in damage to the consumer.

4.0 TELESCIENCE OPERATIONS

4.1 Telescience Concept

The fundamental idea of telescience is to exploit the advances in both communications, and information technology to enhance the scientific return from space-based activities; the former are related to the exchange of information, the latter related to on-board data processing such as data reduction and ground-based user workstation software support. This forms the basis for a wide range of telescience applications, enabling the Principal Investigator (PI) to conduct scientific investigations in a decentralised manner (i.e. not in the SSCC or Payload Operations & Integration Centre - POIC) from a facility applicable to his particular scientific discipline, as shown in Figure 2. This may invoke the services of:

- quasi real-time/near real-time operations;
- teleoperations;
- telemanipulation (robotics);
- ground-based expert systems/AI.

The expected net benefits of this would include an optimisation of the utilisation of crew time, and an increase in the efficiency of the results obtained (both qualitative and quantitative) through the direct involvement of the PI in on-board payload operations.

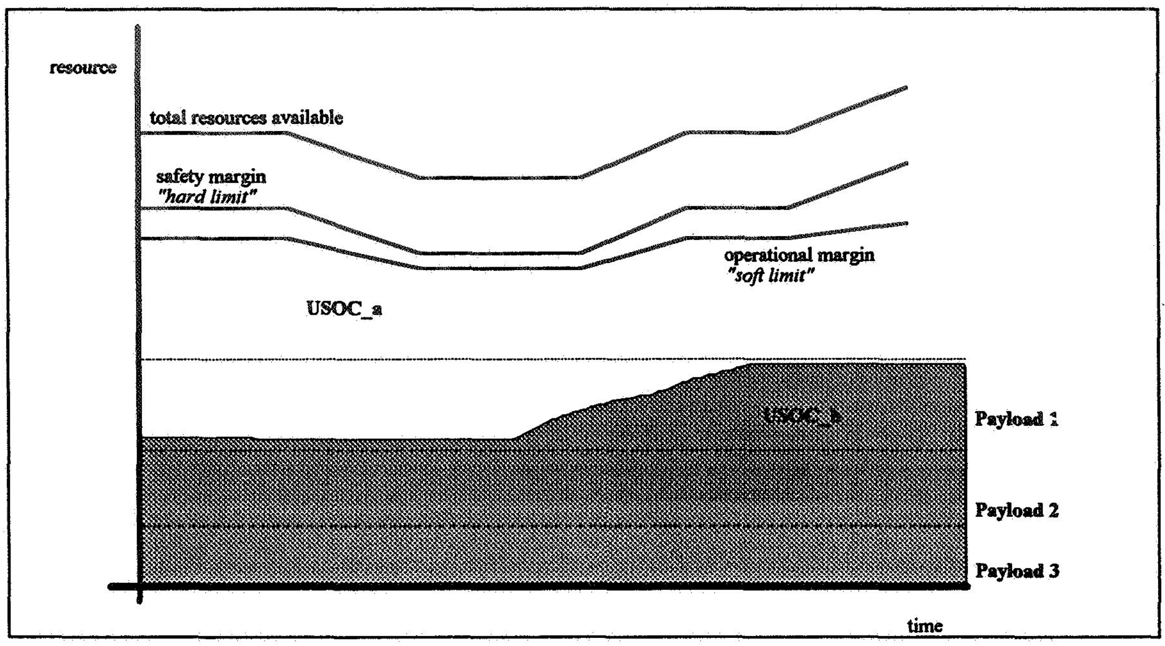

Figure 1 *Resource Envelopes*

A general telescience scheme, in which there is a mission operations control centre responsible for the monitoring and control of the flight system, and a set of PIs at their home bases is shown in figure 2. The users would receive the scientific data applicable to their particular experiment, whilst having the capability to directly send telescience commands to their experiments. This is performed with complete transparency to the rest of the ground infrastructure, comprising the mission control centre for the system and payloads, and the ground stations providing the up/downlink. The expected duration of a telescience session is in the order of 15 minutes to 8 hours {ref. 1}, dependent upon the scientific discipline under investigation.

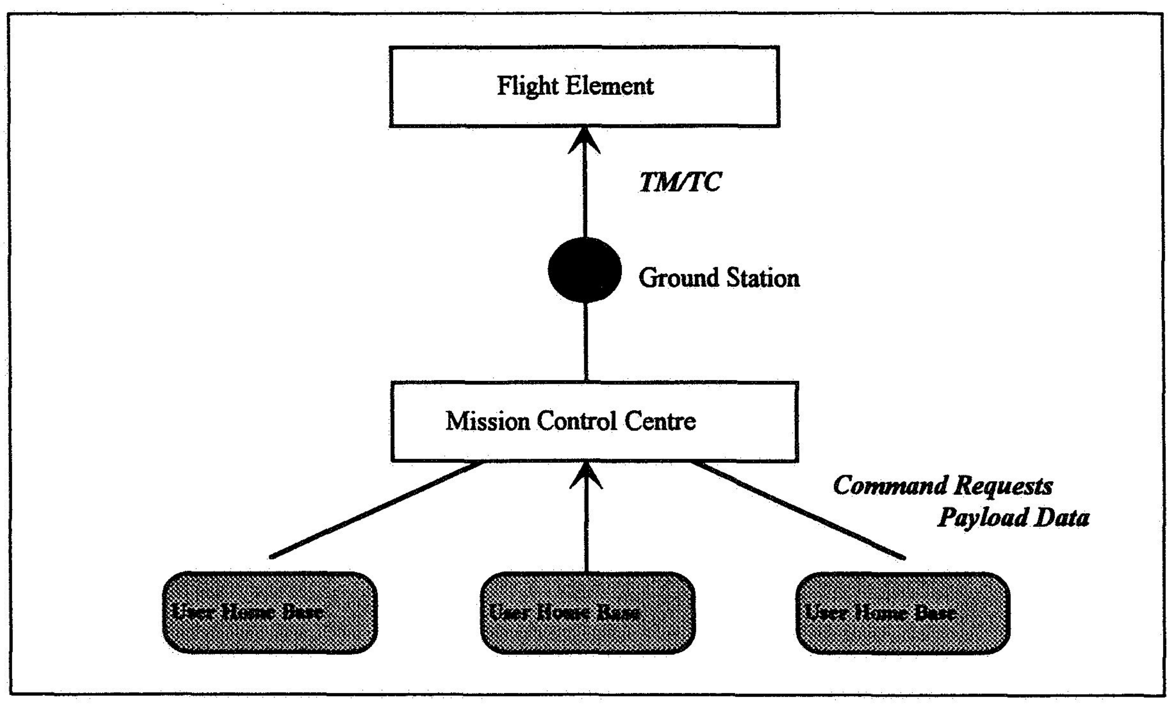

Figure 2 *Basic Telescience Concept*

4.2 APM Telescience Operations

4.2.1 Set-up of reference configuration and telescience mode

The operation of a particular payload in telescience mode will be identified in the OSTP, which will result in the set-up of a 'telescience mode' for the payload concerned, and its associated reference configuration. Attached to this will be the resource allocations for its particular operational period or window. This forms the boundary or envelope for the payload to operate within. The telescience period may run in parallel with the automatic operation of other payloads, defined within the OSTP. At the beginning of the operational window, as directed by the Actions and OTs, there will be an automatic configuration of the APM to support the payload operation, and the PI will be informed, when the system is configured for commencing telescience operations. The telescience operations themselves however, are left with the user. At the end of the operational period, the payload will be configured by telescience commands or the OSTP to a configurational status such that it is left in a stable state, and the APM system will be configured by the OSTP according to the next set of pre-planned operations.

4.2.2 Command authorised system resources for payload execution

As with the automatic operations mode, the APM system will be responsible for commanding those core system resources required to support payload execution (e.g. power, DMS services). The resources agreed by the ground will form operational and design envelopes which cannot be transgressed, but within which the PI will be able to operate, utilising those resource envelopes in real time. Transgression of these limits, including "booked time" would result in a warning being issued by the system requesting correction back to within the agreed margins. Failure to perform this would result in the system reacting to maintain the integrity of the system and the other payloads. The system will also initiate predefined responses if a system resource cannot be provided.

For telescience operations, resource management will be performed in two ways:

- *pro-active* checking, performed before execution;
- *reactive* checking performed on-board, but also on the ground (@ POIC/USOC) in real-time.

It is obviously desirable to eliminate as much redundant checking as possible, since this will impose additional time delays upon the end-to-end data flow.

4.2.3 Direct provision to payload of payload-specific commands

The required types of direct activity are expected to include:

- transmission of on/off commands;
- setting of variable experiment parameters
  - furnace temperature,
  - time durations,
  - rotation angles;
- setting of on-board payload software control parameters;
- payload re-programming;
- continuous control (e.g. syringe control).

Commands and messages will be routed directly to the payload, without any intervention or checking by the SMM, which simply monitors resource consumption. Telescience commands comprise of 'real data' which are unintelligible to the system. They may form parametric values which are interpreted directly by the payload or by a payload-provided command sequencer. In the case of the latter, theses sequences may issue internal commands held on-board, with interactive control by the PI (e.g. insertion of parametric values to the stored payload commands).

4.2.4 Optimised Onboard Data Routing

For telescience operations, optimised data routing with a minimum end-to-end communications delay is a pre-requisite for both uplink as well as downlink. From the user community's point of view, a forward link time delay of 2 seconds maximum and a return delay of 1 second maximum are preferable. At present, this is not supported, with a total end-to-end loop delay in the order of 10 seconds {ref. 2}. Ground links are considered in section 5.

The current onboard forward link response is dependent upon two factors:

- the performance of the onboard routers and associated protocols;
- the number of database accesses which any of the command processing elements will have to make (SSMB RunTime Object Database - RODB, SMM Onboard Database - OBDB), and the corresponding LAN loads.

An outline of the onboard routing (according to the architecture presented at COLUMBUS System Requirements Review (SRR) in July 1992), is shown in Figure 3:

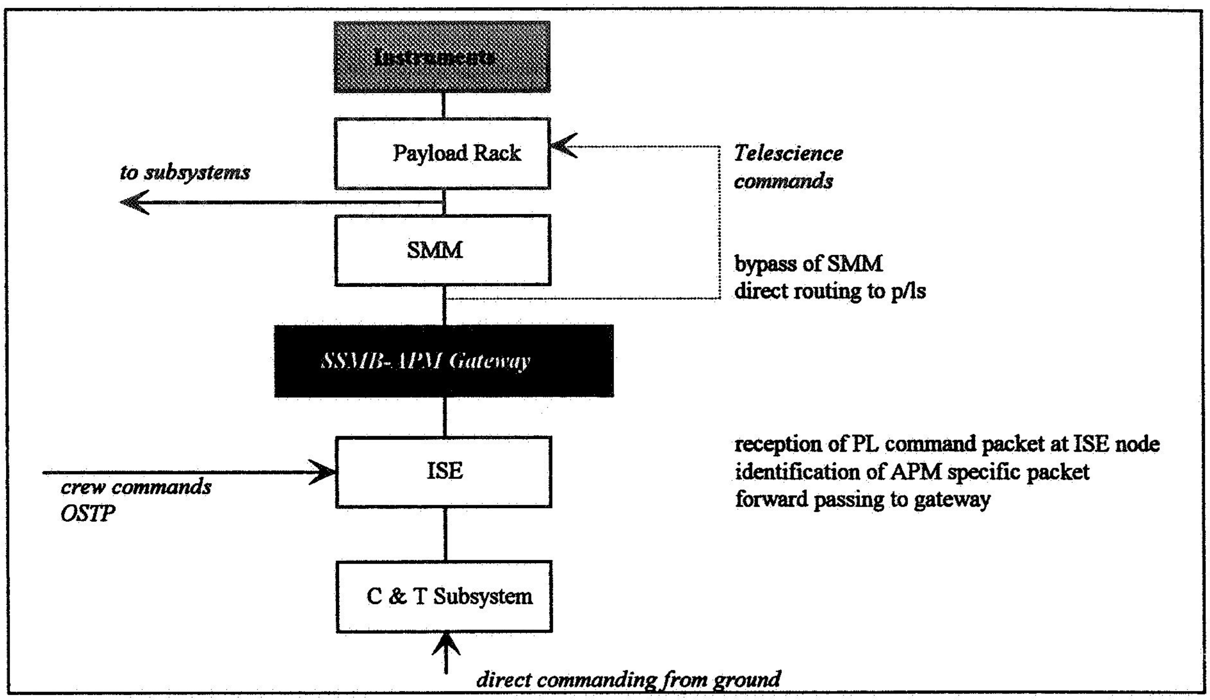

Figure 3 Telescience Command Routing

4.2.5 Overall Telescience Operations Concept

A general schema for the operation of the payload is shown in figure 4.

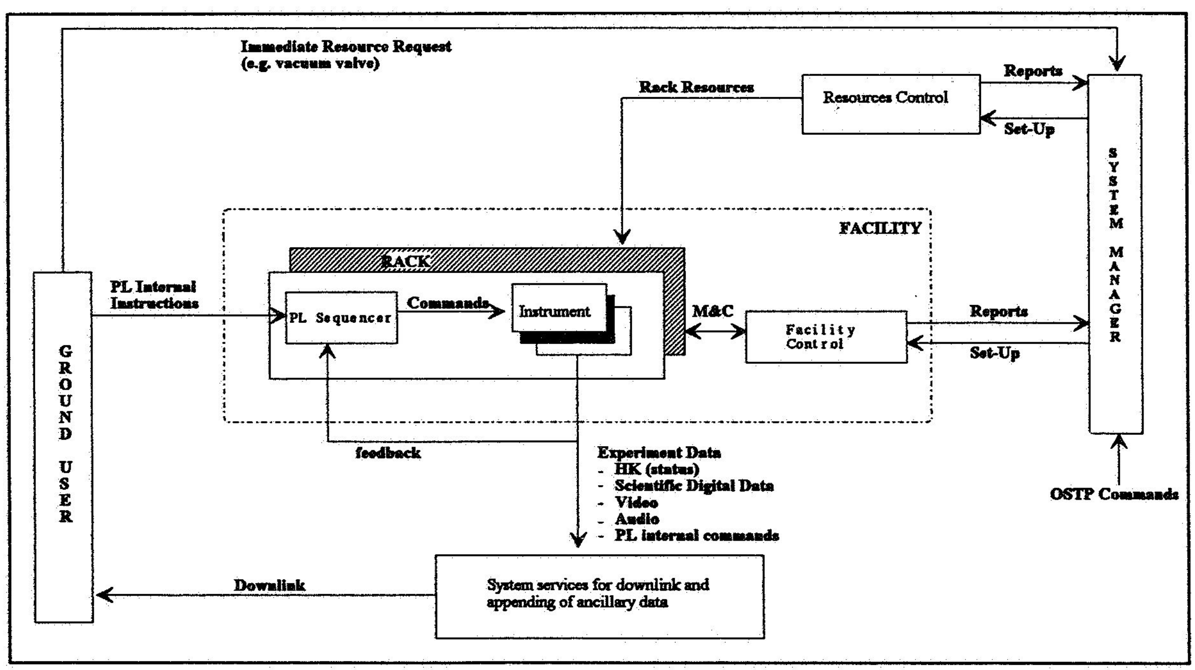

Figure 4 Telescience On-Board Operations Concept

5. SUPPORTING INFRA-STRUCTURE

5.1 Overview

The supporting European ground infrastructure for telescience operations is based upon a network connecting UHBs, USOCs and the Manned Space Laboratories Control Centre (MSCC). The UHB will be responsible for the health and use of its particular instrument, whilst the USOC is responsible for the payload facility in which the instrument may be contained. The MSCC (*tbc*) coordinates all European users of the SSF, and hence has to ensure that the resource budget that is allocated to the APM is adhered to, and coordinates the UHBs/USOCs accordingly.

5.2 User Home Bases (UHBs)

The UHB will have the following responsibilities:

- for a single experiment;
- execution of experiment;
- evaluation of scientific results;
- off-line planning interaction.

5.3 User Support and Operations Centres (USOCs)

A particular USOC will have the following functions:

- responsible for an onboard facility, containing a set of payload subunits;
- facility operations (including all system resources);
- facility checkout;
- facility support.

5.4 Operations Scenario

Interactive payload operations are based upon the ability of the user within the UHB/USOC to utilise an authorised set of commands which are routed through the POIC/CCC in the USA for authentication and authorization. The command set would be accessed via a user Work Station (UWS), allowing the control of the payload. These commands would have been validated off-line within an integrated simulation of the APM and would be checked on-line only for their source/destination authority.

Return data, comprising of payload housekeeping data and scientific data (up to 30.85 Mbps) is routed from the ground station directly to the USOC/UHB concerned.

6. CONCLUSIONS

Current telescience concepts have evolved around the use of manned and non-manned laboratories to be used primarily for microgravity disciplines in the Space Station context. However, current on-board design limitations and lack of continuous coverage inducing data relay satellite switchover problems impact end-to-end transparency to the user, as well as end-to-end commanding delays. This is compounded by discrepancies between national ground communication networks characteristics and mode of implementation, resulting in discrepancies for different users in terms of access to telescience operations, quality of service, and data capacity.

ACRONYMS

AI	Artificial Intelligence
APM	Attached Pressurised Module
CCC	Control Centre Complex
C&T	Comms & Tracking Subsystem
CSA	Canadian Space Agency
DMS	Data Management Subsystem
ESA	European Space Agency
FDIR	Failure Detection, Isolation & Recovery
ISE	Integrated Station Executive
ISPR	International Standard Payload Rack
LAN	Local Area Network
LOS	Loss of Signal
MMC	Mission Management Computer
MSCC	Manned Space Laboratories Control Centre
OBDB	Onboard Database
ODF	Operations Data File
OSTP	On-Board Short Term Plan
OT	Operational Task
PI	Principal Investigator
PL	Payload
POIC	Payload Operations & Integration Centre
RODB	Run Time Object Data Base
SMM	System and Mission Management
SRR	System Requirements Review
SSCC	Space Station Control Centre
SSF	Space Station Freedom
SSMB	Space Station Manned Base
UHB	User Home Base
USOC	User Support and Operations Centre

REFERENCES

1. Telescience Working Group Results, May 14-15, 1991
2. Columbus Users End-to-End Telematic Network *(COUETTE)* Final Report, July 1991