A new Generation of Monitoring and Control System for ESTRACK

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For the supervision of ESTRACK, its network of ground stations, ESA/ESOC is developing a new system, the Ground Station Monitoring and Control system (GSMC).

The monitoring and control systems for the spacecraft missions and for the ground stations were traditionally two distinct fields. This new system builds on existing frameworks and exploits synergy between the two areas. A Common Monitoring and Control Platform (CMCP) has been implemented, starting from the infrastructure used for the spacecraft operations and complementing it with operational concepts currently in use for the ground station domain. This approach brings benefits both for spacecraft operations and for ground station operations.

Whereas the previous systems focused on the operations of a single ground station in isolation, this new system provides as well an overall view of the entire ground station network. This gives a better support for the automation of the operations, with enhanced capabilities to coordinate the execution of the scheduled activities prepared by the ESTRACK planning and scheduling system.

In addition, the project took into consideration constraints imposed by the transition from an existing infrastructure and configuration, with the goal to provide means to support the migration and to re-use the logic and procedures developed over the years for configuring ESTRACK ground stations for spacecraft support.

This paper presents the main elements of the GSMC, providing an overview of the overall monitoring and control concepts for ESTRACK ground stations, highlighting automation aspects for the configuration of the ESTRACK network.

I. Introduction

THE European Space Agency (ESA) develops, maintains and operates a ground-segment infrastructure to support its space missions from the European Space Operations Centre (ESOC) located in Darmstadt, Germany. As part of this infrastructure ESA operates a network of tracking stations (ESTRACK) to support the spacecraft operations of its own missions as well as non-ESA missions. A ground station monitoring and control system supervises all equipment of the ground stations, along monitoring and control (M&C) concepts[1] established over the years. Besides, the Mission monitoring and Control Systems (MCS) used to operate the spacecraft are typically based on the SCOS-2000[2] kernel belonging as well to the ESOC infrastructure.

Maintained and operated by different teams, along a variety of different technologies and policies, these two types of M&C systems have evolved independently. There has been the dream for a long time to support the monitoring and control of both domains with a common platform. A few year ago, to address the question of the evolution of the ESTRACK M&C system, a study[3] showed that indeed both areas could benefits from synergies between the two fields. The concept of a Common Monitoring and Control Plaform (CMCP) was defined and how the Ground Station Monitoring and Control system (GSMC) could be built on it was outlined. The subsequent development project has started the implementation of the GSMC and of the CMCP along these lines, in the context of the design of a new deep-space ground station located in Malargüe, Argentina.

II. GSMC overview

All the various devices installed in the ESTRACK core ground stations are monitored and controlled by the monitoring and control system to ensure local (i.e. from the ground station) and remote (i.e. from ESOC) operations. Most of the operations are performed remotely. The environment of the ESTRACK M&C system is outlined in Figure 1. The GSMC has an operation subsystem (GSMC-O) complemented with a tailoring subsystem (GSMC-T).

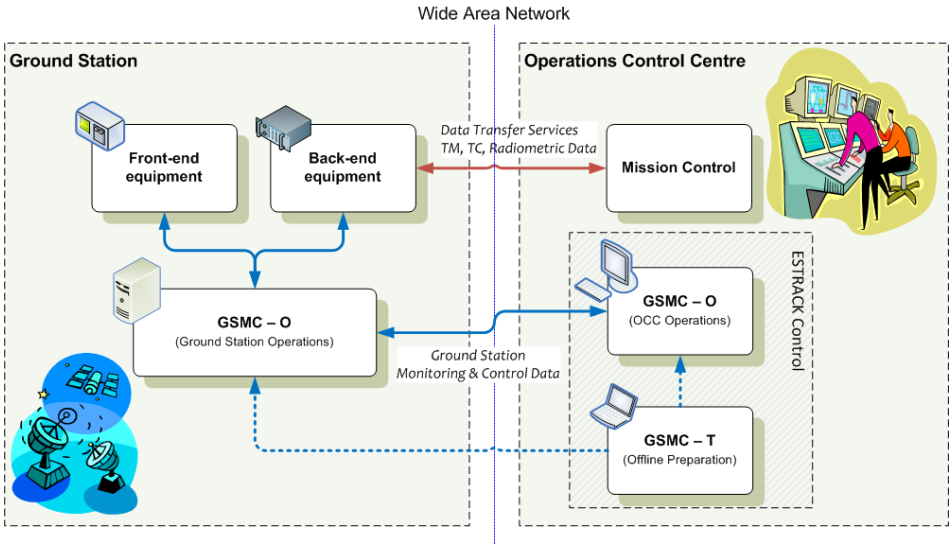

Figure 1. GSMC environment

A. Operation subsystem

The operation subsystem, the GSMC-O, detailed in the paragraph III, is deployed over a Wide Area Network (WAN); it is based on two redundant servers (GSMC-S) with operator client workstations (GSMC-C) located in each ground station and remote operator workstations (GSMC-OCC) located in the control centre. It interfaces with the front-end and backend equipment in particular to get and set parameters or invoke requests on the ground station devices. As the routine operations are automated, it executes in the ground station the schedule that is prepared by the ESTRACK Planning and Scheduling System (EMS, ESTRACK Management System)[4] taking into account requirements from all supported missions. An interface is also foreseen to exchange parameters with other systems of the Operation Control Centre (OCC). The GSMC-O gets its configuration data from the tailoring subsystem.

B. Tailoring subsystem

The tailoring subsystem, the GSMC-T, further presented in the paragraph IV, is essential for the preparation of the ground station operations: it enables to configure the generic M&C facilities to the special characteristics of the ground stations and of the supported spacecraft, allowing adaptation to the frequent changes in the configuration of the ground stations or to new operation requirements. The GSMC-T can be run standalone (typical offline preparation activities) or together with the GSMC-O (usage during testing and validation phases). The configuration data includes essentially the definition of the M&C data (parameters, alarms, …), of procedures, of displays and of equipment interfaces.

C. Development approach

The detailed design has followed an incremental approach, with close cooperation of user representatives and developers. A period of two months has been selected between incremental deliveries of the software. This approach has been crucial in the project, allowing to build the system step by step.

The GSMC has been developed using a number of existing infrastructure software, taking advantage of these assets. At the same time adapting some of the infrastructure software, developed with a given scope, to the special needs of the ground station M&C, implied to overcome challenges.

III. The GSMC-O and the CMCP

The GSMC-O is based on a Common M&C platform (CMCP) for spacecraft and ground stations operations, with the addition of specific features to cover ground station M&C needs.

A. The Common M&C platform (CMCP)

The CMCP re-uses the ESOC infrastructure software used for spacecraft operations. The Figure 2 shows the scope of the CMCP. The kernel is primarily provided by the SCOS-2000, offering in particular live monitoring, data archiving and retrieval capability, as well as the basic features expected from such a system like event logging and user management. The Mission AuTomatIon System (MATIS)[5] provides the capability to execute schedules. The Man Machine Interface (MMI) is based on the Egos User Desktop (EUD)[6, 7], which is built on top of the Eclipse framework and is used to design displays. Other ancillary applications are also in use (FARC, File Archive; SMF, Service Management Framework). On top of this infrastructure software used for the spacecraft domain, a number of concepts and features coming for the ground stations M&C experience have been added, in particular for the monitoring, for the schedule handling and for the procedure execution.

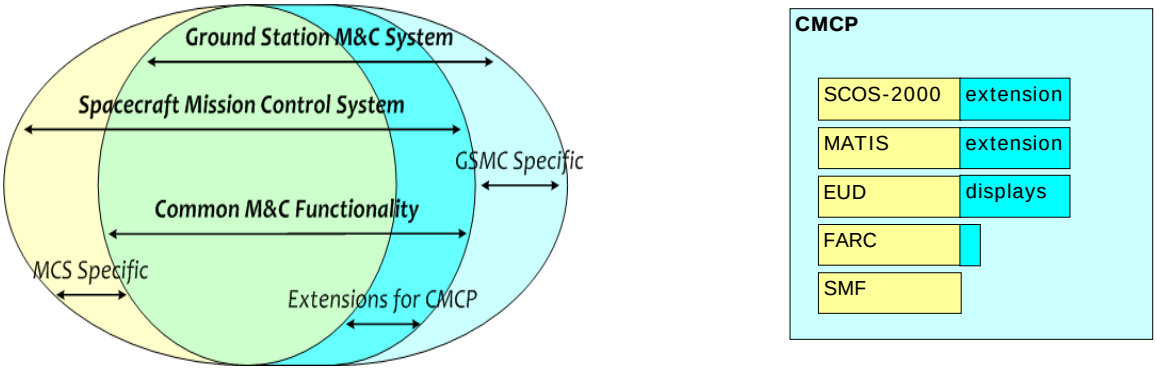

Figure 2. CMCP

1. Monitoring

The monitoring capability of the SCOS-2000 has been extended with several valuable features present in the previous ground station M&C system:

- The data model of the M&C information, consisting of a flat list of parameters in the SCOS-2000, can be structured to allow containment of parameters in "system elements", as the data models in use in the ground stations are structured. For example, the parameters of a given piece of equipment can be organised in functional blocks or subsystem units, corresponding to different functions of the device.
- In addition to the existing behaviour checks already available in the SCOS-2000 (e.g. limit checks verifying that a value is within a certain range, status consistency checks reporting if a parameter deviates from a nominal value and delta limit check evaluating the rate of change of a parameter value), checks on parameters can be based as well on alarm algorithms, defined with the language used for synthetic (derived) parameters (SCOS-2000 OL expressions, OL standing for Operation Language).
- In the SCOS-2000, the monitoring data is injected via telemetry. The CMCP can handle also monitoring data injected only when there are changes in values; this is the typical mode of data delivery from the ground stations, adopted to reduce network traffic across the WAN. The notion of "variable list" in use for the M&C of the ground stations to deliver sets of parameters has been introduced.
- Several types of monitoring displays based on the EUD have been adapted, including mimic displays, Alpha-Numerical Displays (ANDs), graphical displays (GRDs), scrollable displays (reporting all changes of a parameter) and the monitoring parameter query display (providing all static information and dynamic attributes of a parameter).
- An alarm display shows all parameters for which the checks have revealed an "alarm" or "warning" condition; the alarms can be acknowledged in this display by the operator. This ground station M&C operations concept is added to the traditional acknowledgment of alarm messages of the SCOS-2000.
- In addition to individual configuration parameters (cf. SCOS-2000 "user-defined parameters"), it is possible to define tables of configuration parameters.

- Handling of user accounts, roles, and privileges is provided by the User Manager inherited from the SCOS-2000, which has been extended to be able to cope with the ground station operations. A role can be requested and transferred between logged users and the multiplicity of roles is configurable. In particular, the Master Control Position (MCP) role can be used only by one user at a time and is transferable.

2. Schedules

Several functionalities have been added as well to the MATIS for schedule execution, to benefit from the long experience of schedule automation in the ground stations. A MATIS schedule contains essentially PLUTO procedures (PLUTO[8]: Procedure Language for system Under Test and Operations). The schedule format has been carefully revisited to take into account the elements of the schedule in use for ground station operations automation, in a backward compatible way in order to preserve the operations for the spacecraft schedules. Among the extensions:

- The notion of "operational session" (e.g a pass) has been added in the schedule definition to be able to correlate operations execution to a specific spacecraft pass.
- Operator instructions can be included in the schedule and displayed in an Operator Instructions Display, to notify the operator of special alerts or manual tasks that need to be performed.

3. Procedures

Between the execution of schedules of PLUTO procedures and the low-level commanding, the SCOS-2000 was lacking a mechanism to execute the various kinds of low-level procedures used in the operations of the ground stations. This capability has been present in the ground station M&C systems for years. As a consequence, a script execution environment (SEE) based on Rhino has been added to the SCOS-2000. JavaScript, a script language already used in the infrastructure software for the spacecraft simulator (SIMSAT), has been selected for the definition of the procedures. It allows to define various kinds of control activities, setting parameters, invoking tasks, calling more complex sequences of operations that have to be executed by the equipment. The Control Activity History Display shows the status and history of scripts execution. It is possible to invoke scripts from menus attached to parameters appearing in ANDs or mimic displays, or by selecting them in a tree view. The execution of scripts generates so-called "automation messages", reporting about the successful completion or failure. The event log can also be filtered to retrieve specific messages related to the script execution.

The schedule executed by the GSMC is produced by the ESTRACK Management System, according to various planning and scheduling rules and needs for the different spacecraft operated at ESOC. A ground station schedule contains so-called scheduling jobs expressed with PLUTO procedures and invoking in turn scripts which are executed in the given ground station, as illustrated in the Figure 3. The scheduling jobs correspond to a set of well-defined operations, e.g. to assign a spacecraft pass to a ground station, configure a ground station, start or stop uplink. The combination of the schedule execution triggering the execution of scripts interacting with the ground station devices is the corner stone of the automation concept.

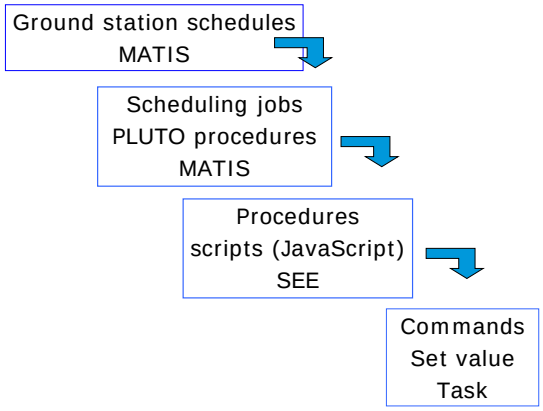

Figure 3. Schedules and scripts

4. Synergy

The resulting CMCP enables the GSMC to benefit in particular from the existing data archive and retrieval capability, feature that was very limited on the previous ground station M&C systems. The MCS (Mission Control System) used for the spacecraft operations will be able to take advantage of the extended monitoring capability and above all of the script execution environment newly developed. It is expected that the use a common infrastructure and similar GUIs with common displays will bring convergence for the teams operating the ground stations and the spacecraft. Finally sustaining costs for the M&C systems will be reduced as less applications will have to be maintained.

B. Ground station M&C specifics

If the CMCP can be used as a kernel for the GSMC-O, a number of aspects are specific to the ground station M&C and have to be addressed separately as the GSMC and the MCS have differences besides the commonalities.

1. Interface to ground station equipment

One difference between the MCS and the GSMC is the interface to the "system under operation". On one side the MCS sends telecommands and receives telemetry from the spacecraft (typically according to CCSDS defined formats). On the other side, as a result of a couple of decades of engineering in the ground station M&C domain[1], the M&C interfaces of the main equipment of the ESTRACK ground stations have been "standardized" and a particular M&C interface control document (ICD) is applicable (called "ESA M&C ICD", currently based on CORBA). A specialized infrastructure software package, that takes care of the interface to the M&C system, can be used when developing devices that have to comply with this ICD. The GSMC can interface with devices compliant with this ICD thanks to a specific Monitoring and Control Interface (MCI) component. A key concept of the approach is that the list of parameters and tasks exposed by the devices can be configured (definitions encapsulation in a Management Information Base file).

Other devices exposing other interfaces (e.g. private TCP/IP or GPIB protocols) communicate via acquisition nodes acting as gateways.

2. WAN

The MCS is deployed on a Local Area Network (LAN), where bandwidth restriction and network latency can be ignored. Conversely the GSMC is deployed over a WAN, which implies specific network constraints. The design has to be tuned to cope with the worst case scenario, which is namely the operations with network backup lines: the requirement that has been retained is a maximum latency of 800 ms (which could be the case when the communication network to ESOC includes satellite hubs), with a maximum bandwidth of 100 kbps. The architecture of the CMCP takes these constraints into account. Various services offered by the ground station server are mirrored (bridged) at the OCC as illustrated in Figure 4. The bridge software transparently optimizes the communication overhead between a client and a server by compressing data and selectively buffering resources. Each mirrored service is developed on a case by case basis. The client applications, whether running in the OCC or in the ground station, uses the same interfaces.

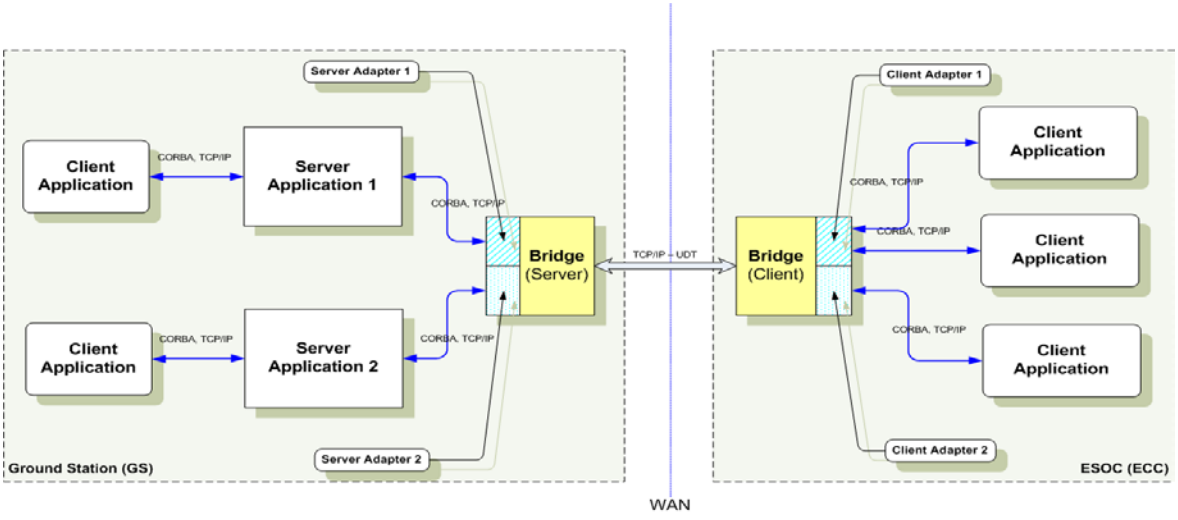

Figure 4. Bridge

3. ESTRACK Monitoring and Control

The previous M&C system of ESTRACK has visibility of one ground station site only; there is an independent system for each site, including a ground station part and OCC workstations, configured for the special needs and operations of this particular site. A strong requirement of the evolution was to get a system able to provide M&C features at ESTRACK level, presenting an overview of the overall operations. To address this need, the GSMC provides on the OCC workstations the capability to M&C a given ground station and provide as well an overview of the complete ground station network. Using this feature, it is possible to define ESTRACK displays, combining information from the various ground stations and showing an overview of the tracking network. Besides, the plan of activity and a centralized schedule monitoring is included in order to monitor the schedule execution for the entire network from a single operator position. Furthermore, an interface to other OCC systems is foreseen in order to monitor with the MCS ground station related parameters.

This functionality is achieved with the following deployment of the CMCP based on the multi-domain feature of the SCOS-2000, a "domain" being assigned to each ground station:

- A "single-domain" CMCP is installed in each ground station, each one corresponding to a certain "domain" identifier.
- A "multi-domain" CMCP is installed in the OCC, with as many domains as the number of ground stations in ESTRACK. One OCC workstation has access to all ground station servers, with the bridge mechanism mentioned above in the paragraph B.2 above.

4. Pass management

The GSMC enables to assign resources (i.e. devices) together with the required configuration to spacecraft operational sessions. This feature takes advantage of the configuration parameters tables that can now be defined as part of the tailoring.

IV. GSMC-T

The GSMC-T is as well based on ESOC infrastructure software (see Figure 5):

- A generic framework for Database Manager, called the DABYS and based on MySQL, provides database (DB) features to e.g. store the configuration data, compare, merge and branch DB versions.
- The MMI is implemented with the Eclipse based EUD framework. In addition, the MMI of the previous operational tailoring tool has been taken into account as far as possible in order to provide to the users a similar look and feel and a similar tailoring process.

The GSMC-T is used to define the configuration data needed by the GSMC-O.

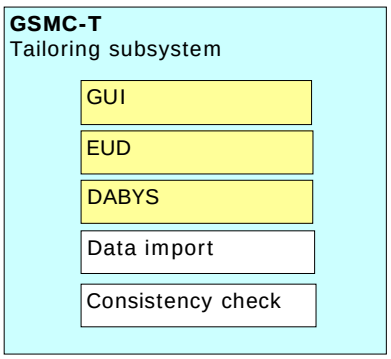

Figure 5. GSMC-T

A. Functionality overview

The features of the GSMC-T includes:

- Editing of the monitoring configuration: it is possible to define the various types of objects that can be monitored by the GSMC-O, parameters, system elements (SE), SE template, object selector, enumerations, alarms, configuration parameters and configuration tables. Several options are possible for alarm definitions, including definition of an algorithm (based on the SCOS-2000 OL expressions) and standard SCOS-2000/CMCP behaviour checks as explained in paragraph III.A.1.
- Editing of the displays: it is possible to define displays of different types, ANDs, scrolling displays, graphical displays, XY displays and mimic displays that will be available on the GSMC-O.
- Editing of the scripts: a JavaScript editor is provided to allow the definition of the scripts that are executed on the GSMC-O.
- Editing of the PLUTO procedures: a PLUTO editor supports the definition of the PLUTO procedures referenced in the schedule and executed on the GSMC-O. The PLUTO procedures correspond to scheduling jobs and invoke scripts.

- Consistency check: a consistency check can be triggered to verify the coherence of the tailoring data, e.g. verify that a parameter used in a script is actually defined in the monitored objects.
- Export of the tailoring data: the GSMC-T generates the tailoring data that is subsequently imported in the GSMC-O for the tuning of the operations.
- Editing of the ground-station subsystem interfaces: an import mechanism reads the Management Information Base (MIB) files defining the M&C interfaces exposed by the various devices. The GSMC-T allows to specify, with the managed objects, the M&C interfaces that will be used between the GSMC-O and the different pieces of equipment. This information can be used as well to generate the starting point of the monitoring information, parameters and system elements that will be handled in the GSMC-O.
- Import of configuration data: besides the equipment MIB files for the definition of the managed objects, configuration data exported from the predecessor system can also be imported in the GSMC-T to generate automatically the monitoring configuration, displays and scripts contained in databases used operationally.

B. Data conversion

A strong requirement was the preservation of the existing configuration data, which is the result of men-years of investment in the construction of the precise monitoring model with its ANDs presentation and the elaboration of the automation concept with the numerous procedures. As the predecessor system uses an object-oriented DB, an Object Relational Mapping (ORM) has been used in the architecture of the GSMC-T (Hibernate is the product that has been selected). Besides, an importer tool allows to convert tailoring data exported from the predecessor system. The mapping of the structures already configured to the GSMC-T structures has been carefully studied. In particular, analysis of the mapping of the proprietary tailoring language of the predecessor system to JavaScript was essential in the success of the conversion of the procedures. Thanks to this mechanism, the parameter model (including synthetic parameters definitions and alarm definitions), the ANDs and the scripts can be imported automatically, actually with a much larger scope than initially thought possible.

C. Online and offline tailoring

With the previous ground station M&C system, the tailoring is always an offline activity, which involves certain delays for the availability of a new configuration on the operation subsystem in case of change of configuration. A requirement for the evolution was to introduce more flexibility to allow quick changes especially during testing and validation phases. Besides the offline tailoring, corresponding to modifications done on the MySQL DB in the GSMC-T, there is now the notion of online tailoring: persistent modification of the XML configuration data in the GSMC-O is supported for the definition of monitoring parameters, for displays, and for scripts.

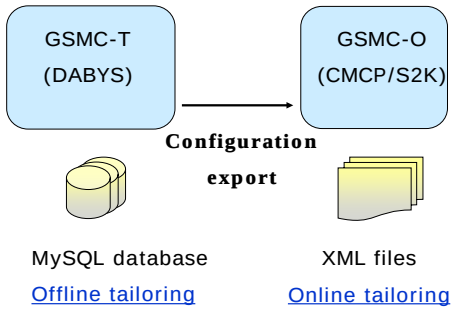

Figure 6. Different tailoring activities

V. Conclusion

The development of the Ground Station Monitoring and Control system based on a Common Monitoring and Control Platform is an ambitious undertaking following the strategic objective of using the same infrastructure for the M&C systems of the ground stations and of the spacecraft. The concept proved to be sound as it allowed to implement a first version of the system in less than two years. The GSMC is being installed in the deep-space ground station of Malargüe.

The evolution will be highly beneficial for the ground stations operations as the GSMC offers, in addition to the features exposed by the predecessor systems, new functions such as the monitoring data archiving & retrieval capabilities in use in the spacecraft Mission Control Systems, as well as an ESTRACK level overview feature which strengthens the automation of operations. Conversion of the existing configuration data, a major requirement of the project, is ensured.

At the same time the features derived from the ground station M&C concepts and included in the CMCP will be a benefit for the spacecraft operations.

This project paves the way to a convergence of both type of M&C systems, which is at ESOC a cultural change.

Appendix A
Essential Acronym List

AND	AlphaNumerical Display
CMCP	Common Monitoring and Control Platform
EMS	ESTRACK Management System (planning and scheduling system)
EUD	EGOS User Desktop
GSMC	Ground Station Monitoring and Control system (ground station operations)
MATIS	Mission AuTomatIon System
MCS	Mission Control System (spacecraft operations)
M&C	Monitoring and Control
PLUTO	Procedure Language for system Under Test and Operation
SEE	Script Execution Environment

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