# ESOC End-to-End Ground Segment Reference Facility

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## INTRODUCTION

Ground Segments for Mission Operations are complex Systems of Systems (SoS), including a significant variety of elements. At the European Space Operations Centre (ESOC) of the European Space Agency these elements are developed based on a generic, complex Mission Operations Infrastructure (MOI) and reused across missions, following adaptation to meet missions or family of missions specific requirements and configuration. For such SoS the availability of a reference environment where ground segment components can be deployed and tested throughout the systems engineering lifecycle, both at subsystem level and in integrated test chains up to a complete End-to-End Ground Segment, is critical. Also the representativeness of such environment, including the representativeness of the test scenarios with respect to the end-user use cases, is critical.

While ESOC track record demonstrates the suitability and high standard of its ground segment engineering processes and systems, recently stronger focus has been placed on the E2E integration and testing of the Mission Operations Infrastructure. As a consequence, an initiative has been launched aimed at the establishment of the ESOC End-to-End Ground Segment Reference Facility (E2E GSRF) as the one-stop environment where the system level integration and testing of the Mission Operations Infrastructure takes place. The E2E GSRF effectiveness is guaranteed primarily through its representativeness, while efficiency is aimed at through convergence of the various integration and test environments used throughout the systems engineering lifecycle, and deployment of automation wherever possible. The ultimate goal is to achieve the highest quality of the Mission Operations Infrastructure at minimum cost.

## THE ESOC END-TO-END GROUND SEGMENT REFERENCE FACILITY

ESA Ground Segments are based on a generic, complex Mission Operations Infrastructure, whose elements are customised to meet mission families or specific mission requirements. The ESOC End-to-End Ground Segment Reference Facility (E2E GSRF) is the result of an initiative born from the following concerns:

- Often during their engineering process, from industrial supplier, to customer and final end-user, Ground Segment infrastructure systems are tested in a much simplified environments and configurations than the target operational environment. Consequently:
    - Certain issues with infrastructure systems are only detected by missions in the operational environment, at a later stage of the mission ground segment development and validation, or even during mission operations;
    - More complex issues can hardly be reproduced and investigated outside the operational environment.

- Engineering testing of ground systems during development and evolution is mainly requirements driven. It is believed that significant advantage can be obtained by enhancing the integration of the operational usage perspective in the engineering processes [5], and adopting mission representative test chains and scenarios as early as possible in the systems' engineering lifecycle.

The E2E GSRF is a response to the above concerns. It is a coherent Ground Segment Integration and Test as a Service (ITaaS) system, comprising the following main elements:

- Ground Segment E2E reference, mission representative Integration and Test Environment;
- Reference Test Scenarios and Test Cases on mission-based configurations;
- Highly automated environment and test execution;
- Platform for sharing knowledge, experience, efforts and expectations among a multi-disciplinary team. This is crucial also for cross-fertilisation among engineering domains, and between engineering and operations.

It constitutes a single, standardised reference throughout the systems lifecycle – from industrial supplier to end-user. It provides the ability for early detection of ground systems functional, performance or integration problems, avoiding their exposure to the mission specific developers and operational teams. It also provides the means to reproduce and investigate more complex problems discovered by the operational team which are not reproducible in development environments.

The following sections provide insides into the E2E GSRF technical aspects, focusing in particular on the overall E2E GSRF architecture, how representativeness, both for the environment and the test scenarios, and automation are achieved. Finally an overview of the remaining challenges and the outlook of its intended evolution are given.

**E2E GSRF ARCHITECTURE**

The E2E GSRF comprises the full spectrum of systems constituting a Ground Segment and the simulated space segment, ranging from Monitoring and Control systems, to ground station equipment and operational simulators. These systems are assembled in representative test chains, comprising the whole or part of the Ground Segment. Fig. 1 below provides a representation of the typical systems' chains.

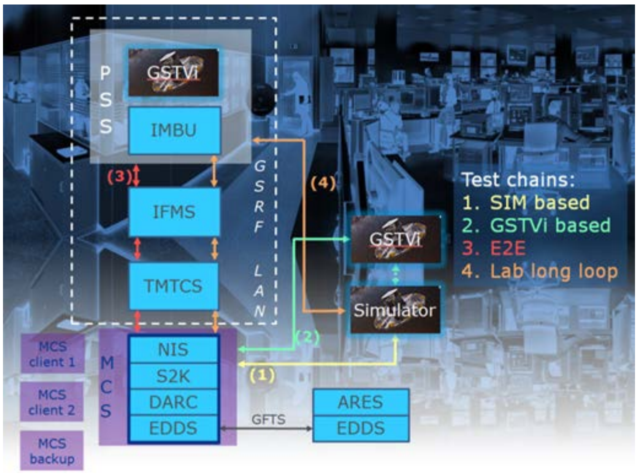

Fig. 1. GSRF E2E Test Chains

These chains range from the simpler chain that bypasses the ground station equipment, to the complete E2E chain including ground station hardware as well as mission specific satellite simulators. In between these two extreme multiple chain variants are possible. One option is to replace the spacecraft simulator with the ESA Ground Test & Validation System TEVALIS, as known as GSTVi, acting as TM source and TC sync. The use of TEVALIS makes it possible to tweak the configurations in order to test corner cases not fully supported by specific missions, a feature that turns particularly useful when it comes to preparing for future missions or testing new MOI features. Also spacecraft simulators are much more complex, and therefore the effort to include them in the test execution is only justified where higher modelling accuracy is required or when it needs to be ascertained that a version of a given system or set of systems is compliant with specific mission requirements.

## E2E GSRF REPRESENTATIVENESS

### Mission Configuration Capture and Deployment

In order to achieve full mission representativeness, in the E2E GSRF MOI systems are deployed with configurations that are captured from the missions operational environment, including the System DB. This is possible thanks to a Centralised Configuration Management (CCM) tool which has been developed under the E2E GSRF initiative. A schematic view of a configuration capture process using CCM, detailed in [1], is given in Fig. 2. When a client starts CCM, it contacts the CCM server to automatically update its product specific definitions, called Descriptors, to their latest version in the operational environment. Afterwards, the unit-specific scripts will be executed to copy the configuration files to the staging area and replace machine and context-dependent variables by their tags, as defined by the descriptor. This configuration will then be stored in a local reference repository and synchronised with a central repository.

For configuration deployment, the same process is reversed. The reference configuration is checked out, it is moved to a staging area and untagged before it gets deployed to its final location. CCM also allows file transfer via ftp in case a client does not allow the installation and running of a local CCM client. As mentioned the E2E GSRF is concerned not just with single ground systems, but also and most important with systems' assemblies. Therefore in addition to the capture and deployment of single systems configurations, CCM also allows the configuration of multiple connected units in one go. In this case the configuration also captures the additional aspects relevant for the systems interfaces and interaction in more general terms.

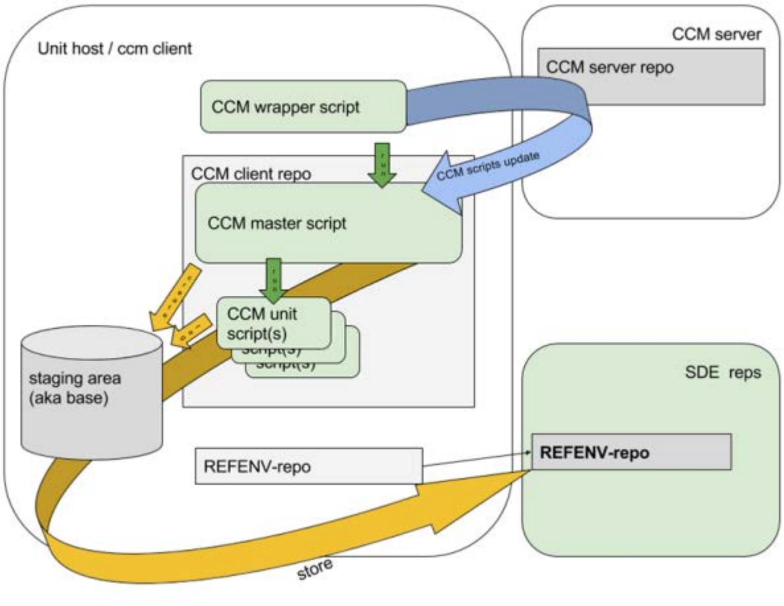


Fig. 2. CCM Capture Sequence

**Test Chains**

Currently, the E2E GSRF includes different test chains based on different mission specific configurations e.g. GAIA, Bepi Colombo, Exomars. The different chains are used depending on the test purpose, e.g. the Gaia chain is required to test high data rates (up to 8.7Mbps), or on the MOI infrastructure version under test, e.g. different OS and OTS stacks, like SLES11 and SLES12 baselines. Multiple chains are also used if required for specific test campaigns, like it is the case for the on-going tests of the new generation Telemetry and Telecommand Processor (TTCP), to be performed against multiple reference missions.

**Test Scenarios and Test Cases Suite**

As stated earlier the E2E GSRF has been designed with the main objective to integrate and test the MOI systems through test scenarios and associated test cases representative of the typical mission operation scenarios, throughout the different mission phases, and usage of the systems by the end-users. A suite of test cases has been developed to support this goal, partly derived from operational tests and procedures designed in the context of mission specific ground segments, and made generic and portable across different test chains and mission configurations deployed in the E2E GSRF. The tests already defined and validated can be split into the three categories below:

- Confidence Tests. Test cases in this category are used to perform sanity checks with respect to environment, systems deployment and configuration readiness, before running more complex and effort intensive tests;
  System Tests. These tests are targeted to specific system elements e.g. for non-regression testing. Generally they require limited systems assemblies.
- E2E Tests. These tests are the most complex, since they involve the full E2E chains. They typically cover mission scenarios, e.g. LEOP scenarios, or cover performance testing.

**TEST AUTOMATION**

The E2E GSRF is a complex environment, including multiple diverse systems. Testing in such environment is effort intensive, and therefore automation at all level is key to efficiency. Taking advantage of the effort devoted at ESOC in the last years to the advancement of test automation capabilities, a status-of-the-art test automation infrastructure [2] [3] has been deployed in the E2E GSRF and further advanced to support the automation of tests targeted to assemblies of systems and true replication of user actions performed via system GUI controls. This is a real breakthrough towards tests representativeness. This is expanded in more details in the section below.

**The Automation System**

The test automation system deployed in the E2E GSRF is called Automated Regression Testing (ART) Framework. This system runs sequences of commands executing basic actions on specific controls. The term “control” has to be understood as any widget that can be accessed by a user through the GUI. The actions are injected in the system via an eclipse plug-in. The ART Framework comprises the following elements:

- An application that executes the actions in sequence and keeps track of the outcome. This application is known as the Test Commander and is depicted in Fig. 4. It is used to run test schedules by reading an XML file with the schedule. Each line represents an invocation of a test script or a call to a test programme that connects to the system under test via the relevant test interface and performs an action on it.
- Test drivers to interface with the eclipse-based GUIs of the system under test, based on the SWTBOT tool.

In addition to executing commands and providing results, the test commander supports the following functionalities:

- Step-by-step execution and breakpointing.
- Production of test reports in XML and HTML format.
- State recovery of the system under test if a problem is detected by an automated test case (the automated test will not complete and a special procedure is performed to bring the system under test back to the initial status).

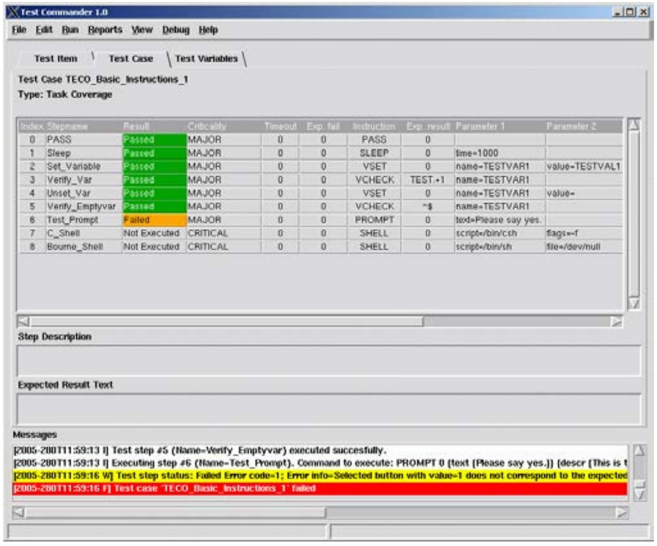


Fig. 3. Test commander GUI

While the above would be enough to create a wide range of automated tests, it alone would be completely impractical for three reasons 1) actions on controls are very low level and writing a test case would be extremely demanding. It has been estimated that ~1000 basic actions are often required for a medium size test case 2) reusability of tests would be low 3) interacting with controls requires some form of mapping of the controls themselves to recognition parameters. These points have been addresses by adopting the TEMPPO Designer tool from Atos, which offers a graphical interface to build test cases from a collection of building blocks. Each building block encapsulates a call to an underlying script or a sequence of building blocks, which in turn can also contain additional sequences of nested building blocks. This solves issue 1) as large sequences of actions can be combined into one single building block. Furthermore, each building block can be parameterised, addressing point 2. In conclusions test sequences can be constructed by reusing building blocks, as show in Fig. 5, while test schedules can be constructed as sequences of building blocks libraries.

TEMPPO Designer can also read and manipulate objects maps. This solves issue 3 above. Objects maps can be originally defined using a widget recorder part of the ART Framework, and then imported and maintained in TEMPPO designer. Fig. 6 shows an example of object map with a specific widget, characterised by a collection of attributes. These maps link each specific control to a collection of recognition parameters. On the left pane, the control is displayed as part of a hierarchy of objects. On the right, the recognition parameters are displayed.

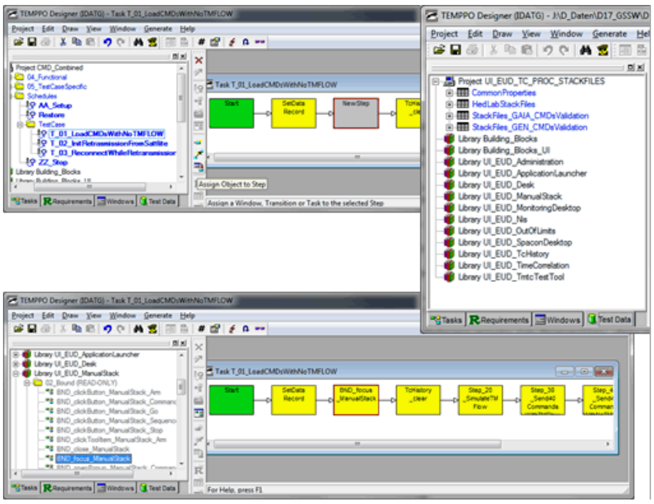

Fig. 4. TEMPPO designer

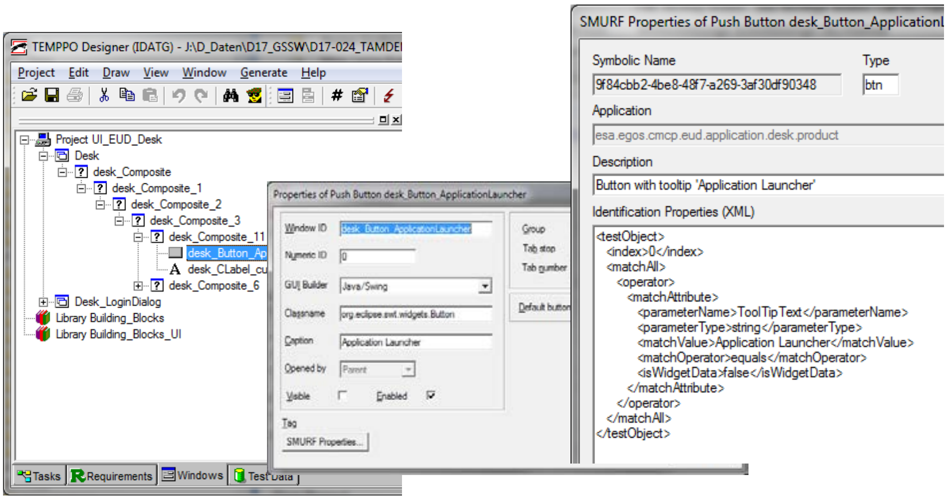


Fig. 5. TEMPPO Designer

To make the overall system scalable a tier- based approach has been defined. The first tier defines actions that can be performed on most controls. This tier is common to every single system under test. A second tier links actions to specific widgets and a third one combines several actions into more elaborated ones. Tier 4 combines complex actions together to provide functionality traceable to requirements. Tiers-2-4 are defined for each application. A 5th tier can also be used to combine functionality from several applications into commonly executed test sequences. This is most valuable in testing systems assemblies.

The test automation system has been successfully used to automate most of the tests currently included in the E2E FSRF Test Suite. The automated tests are executed daily on different systems versions. This has resulted particularly valuable in assessing new versions of ground systems with respect to robustness, reliability and non-regression of the systems.

Main Lessons Learned so far are:

- Changes to the systems GUI heavily impacts the automated tests. GUI standardisation is critical and will be pursued.
- Non-deterministic scenarios refer to test runs that behave in an unexpected and non-reproducible manner. In most cases, this is related to the robustness/reliability of the system under test and is difficult to tackle because the behaviour is not systematic. The only successful approach identified so far is to repeat the test a number of times to be able to separate spurious errors from real regression.

Future work on test automation will put focus on improving reporting, by automatically identifying and processing failed test steps. In addition a new tool is under development, which will offer different testing views with different levels of resolution granularity. Low granularity can be used to understand the overall test flow and identify the problems on the systems under test. High granularity, showing failures at low level, can instead be used to troubleshoot the systems under test.

## CONCLUSIONS

In the last years stronger focus has been placed at ESOC on the E2E integration and testing of the Mission Operations Infrastructure. As a consequence an E2E Ground Segment Reference Facility has been established and developed towards a high degree of representativeness and automation. This facility offers Integration and Testing as a Service of ground segment systems. It is intended to be used throughout the systems engineering lifecycle, from industrial suppliers to end users, on the one end for testing of systems under development in a reference, representative environment, on the other end for reproduction and troubleshooting of complex problems identified during the development of mission ground segments or during operations. While considerable progress has been achieved so far, areas that will be focus of future developments are further automation of the systems deployment and configuration to fully enable continuous integration and testing, test automation to include automated problem root cause analysis and forecasting, security testing. In addition the E2E GSRF will be evolved towards the future ground segment architecture based on new major developments, in particular EGS-CC based Monitoring and Control. It is strongly believed that the E2E GSRF will play a key role in ensuring the highest quality of new infrastructure systems at minimum cost and adoption risk for missions.

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