ABSTRACT

MUST, the Mission Utility & Support Tools, is a collection of tools that support the analysis, visualization, exploration and exportation of telemetry and ancillary mission data. MUST was initially developed for the SMART-1 mission and by now it has also been deployed for INTEGRAL, ROSETTA and VENUS EXPRESS. MUST is also a framework. In fact, the modular architecture of MUST, the central repository, containing calibrated data, as well as the available interfaces facilitate the development of new applications accessing the data from MUST. MUST has proven to be an ideal platform for the assessment of new technologies in the form of client applications.

1. INTRODUCTION

As aerospace missions are becoming increasingly complex and demanding, new technologies are needed in order to manage these challenges. However, in order to use new technologies operationally they have to be proven suitable and beneficial. The best way to evaluate the usefulness of a new technology is to develop a prototype application and let the intended users validate it, i.e. operational validation. The prototype should run complementary to the operational infrastructure in a non-invasive way in order not to conflict with the standard infrastructure [1], [2].

One issue in the assessment of advanced technologies for operations is the availability and the access to mission data. Different missions provide different data distribution systems. They can range from real-time data streams to request-based offline systems. Accessing data from these systems can represent either manual work, or development of an interface for automatic retrieval. Also the data format can change, depending on the mission and the type of data, and has to be considered. Often, data retrieval and interface development represent a major workload in these investigations, while the implementation of the core algorithms to process the data is only a minor part.

MUST [3] – the Mission Utility & Support Tools – is a collection of tools that support spacecraft performance assessment, anomaly investigation, and mission data analysis in general. Following a client/server architecture MUST imports telemetry and ancillary mission data from available data providers and stores it in a central repository as calibrated parameter data. The MUST clients then retrieve the data through standardized interfaces from the repository via TCP/IP.

Currently, MUST includes five mature client applications supporting flight control teams, mission project teams, industry and principal investigators. Developed for the SMART-1 mission, the MUST operational prototype has gone through a period of operational validation of more than 20 months, and it has recently been deployed for INTEGRAL, ROSETTA and VENUS EXPRESS. There are plans to deploy MUST for other missions in the future, e.g. CRYOSAT, MARS EXPRESS.

The MUST clients provide essential benefits to their users and have become important tools in the day-to-day work performed by the various mission teams [4]. Among the most important benefits are:

- Efficient performance assessment and anomaly investigation
- Fast and remote access to telemetry data
- Integration of different data types
- Stress and cost reduction for on-call services
- Simplified collaborative discussions

However, MUST also provides another fundamental advantage. MUST takes care of the data importation from the mission's data provider, extracts and calibrates the data, and stores it in the repository as engineering values. Once in the repository, all parameters can easily be accessed through standardized interfaces that allow automatic retrieval. Therefore, MUST, as a framework, facilitates the development of data-driven applications for the assessment of new technologies, because no further interface development is needed to access the data. The development efforts can be concentrated on the core technology, which in turn leads to more fine-tuned applications and faster development cycles.
This paper introduces MUST as a platform to validate the usefulness of new technologies to support innovative operations concepts for future missions.

1.1 Mission Control Technologies Unit

MUST has been developed within the ESA OPS-OSC Mission Control Technologies Unit at ESOC. The term of reference of this unit is to investigate feasible innovative operations concepts and promote the beneficial application of new technologies for ESOC’s core business in spacecraft and ground segment control. Prime objectives are the enhancement of overall system performances, for meeting increasing demands from ongoing and future missions and the reduction of cost and/or risk, as well as the contribution to the necessary modernisation of ESOC’s mission control approach.

2. TECHNICAL IMPLEMENTATION

MUST is designed in a modular client/server architecture. The server imports telemetry and ancillary data from the mission's data providers and stores it in a central repository. Once in the repository, the data is available to the MUST clients for further processing according to the purpose of the application. See Fig. 1 for a schematic of the architecture.

Currently, there are two interfaces to data providers in place and others could be developed if needed. The DDS [7] is based on requests, and supports the retrieval of historical data. The missions SMART-1, ROSETTA and VENUS EXPRESS are using the DDS. The INTEGRAL FRD system [8] is a real-time data stream. Both systems provide CCSDS packets. In order to extract the engineering values, the packets have to be de-packetized and the raw data has to be calibrated using the mission database. Then, the calibrated data is stored in the MUST repository.

In addition to telemetry, the repository can also contain other mission data, e.g. orbital information from flight dynamics or any other data that are valuable for the MUST clients.

The data is imported from the data provider to the MUST repository only once keeping the load on the data provider, and therefore on the Mission Control System, to a minimum. Once it is in the MUST repository, the MUST clients and their users can retrieve and use this data without loading the original data provider anymore. Therefore MUST can provide data much faster than other services that request the data from the Mission Control System, and have to extract and calibrate the parameters for every request.

The MUST clients can retrieve the data from the MUST Repository through standardized application program interfaces (APIs) over TCP/IP. Thus, MUST supports remote access, i.e. the clients can be installed and used at a remote location. The APIs can easily be re-used for any new client.

Due to the fact that the MUST Repository contains calibrated data, it is ready to use and can be retrieved by the MUST clients very fast. No further processing is needed.

The repository supports multi user access in parallel without losing much on the performance.

For more details on the technical implementation of MUST, see [3].

Fig. 1. Architectural Layout of MUST
3. MUST CLIENTS

Currently, MUST includes a set of five consolidated client applications that retrieve their data from the MUST Repository through TCP/IP. Descriptions of these clients are given in the next sections, followed by a section on current and planned client development.

3.1 GRAINS

GRAINS is the data analysis and visualisation tool of MUST. It supports telemetry as well as auxiliary data and provides various tools, including statistics, and options to investigate, display and export the data. GRAINS provides an easy and intuitive graphical user interface, see Fig. 2. It can be used instantaneously by new users and does not require any training. Having GRAINS and a regular internet connection is enough to explore and work with telemetry and auxiliary mission data available in the MUST repository. Users can run it from their office and are not required to be in the control room to have a look at the data. Moreover, it can be helpful to display data while on mission or even at home, in case of an alarming condition, to decide if a visit to the control room is required. Access control is, however, configurable and can be restricted if needed. GRAINS particularly supports the creation of reports, spacecraft performance assessment and anomaly investigation.

3.2 Alarming System

MUST provides an alarming system that scans the incoming data during the importation process and validates it against a user-configurable set of alarming rules. In case an alarming condition is fulfilled, emails are sent to a list of recipients, e.g. flight control engineers on call. Using an email/SMS gateway, the alarms can also be sent to mobile phones.

3.3 MUST Website

The MUST Website includes general information on MUST, e.g. news, information, downloads. It also displays telemetry data at a selectable point in time in tabular format, as well as information about the spacecraft events. Naturally, it can be extended to provide more information. The website enables remote access, e.g. from home, to telemetry data via an Internet enabled computer or mobile phone.

![Fig. 2. GRAINS, the data analysis and visualisation tool of MUST](image-url)
3.4 Virtual Spacecraft

Virtual Spacecraft [6] is a web browser-based virtual reality model of the SMART-1 and the ROSETTA spacecraft in 3D. Satellites are displayed in transparent textures to let the users see the internal components. The 3D model visualization allows zooming, rotating, jumping to viewpoints, moving, as well as navigating through the spacecraft. Furthermore, colour-coded mapped sensor values overimposed on the spacecraft provide the state of health of the thermal subsystem. The thermal information, as well as other data, is retrieved from the MUST Repository and can be displayed in near real-time or playback. Depending on the user needs, models can be extended to support more subsystems and orbital information.

3.5 RadMon

RadMon is a tool that runs standard models for trapped radiation in the Earth magnetic field. This radiation can be a real hazard for spacecrafts, since it leads to degradation of sensors and solar arrays, single event upsets (bit flips in the onboard electronics) and spacecraft charging. Having an estimate of the current and future radiation levels around the spacecraft can support the decision-making about how to counteract these effects and increase the awareness of possible cause-effect relationships. RadMon plots radiation against time along the spacecraft’s orbit and displays the spacecraft’s position in the orbit synchronized with the radiation graphs. All data produced by RadMon is stored in the MUST Repository and is therefore available to the other MUST clients.

The radiation model implementations used by RadMon are taken from the SPENVIS models package [5]. It is possible to expand RadMon to run further models.
3.6 Current and Future Developments

Three new MUST clients are under development and more clients are planned for the future.

Automatic Report Generator:
An automatic generator of reports will support the flight control teams in writing their recurrent reports. The tool will retrieve the necessary data from the MUST Repository using the already available interfaces. After processing and formatting the data for the reports, e.g. graphs, it will automatically be copied to the report template. The flight control team then only has to complement the report with some text interpreting and explaining the data. The automatic report generator is expected to bring timesavings in the order of several man-days every week.

MUST Excel Link:
Since a great part of the data analysis is done using MS Excel, an interface between Excel and MUST is under development that will allow direct data retrievals from MUST into Excel.

Thermal Forecasting Tool:
A tool predicting the status of the thermal subsystem will retrieve the input data from MUST. Using neural networks to produce forecasts, the tool will support the flight control teams in the evaluation, if the thermal constraints are fulfilled during the planned manoeuvres.

The development of a data mining application to find cause-effect relationships in telemetry data has just started and more MUST client applications are planned for the future.

4. MUST AS A PLATFORM

Originally, RadMon was an independent application and MUST has been developed in order to complement the radiation data from RadMon with telemetry data. Therefore a telemetry importation process was needed and a repository to store the telemetry, as well as the radiation data. As shown in [3], having calibrated parameters ready to use in a central repository could bring fundamental benefits for MUST, compared to importing telemetry packets on demand.

GRAINS was then developed as the data visualisation and analysis application that supports the integration of all data stored in the repository. After deployment of the first versions of MUST, a major code refactoring was performed in order to clean up the code,
standardize the interfaces and produce APIs to facilitate re-using the interfaces in other applications. From then onwards, accessing telemetry and other data from MUST was very simple and also the APIs could easily be integrated in other applications. Some existing applications, e.g. Virtual Spacecraft and also RadMon, were modified to retrieve their data from MUST, i.e. the MUST APIs were integrated. Then it became clear that using MUST could also speed up the development process for new applications.

The aim of ESOC's Mission Control Technologies Unit, OPS-OSC, is to improve and prepare mission operations for the future using advanced technologies. One of OPS-OSC's paradigms is that there is no better proof of a concept than showing actual results. In order to evaluate the feasibility of an advanced operations concept and the usefulness of an associated technology, OPS-OSC is developing operational prototype applications. These applications are then extensively validated by the final users. Requirements consolidation, technology assessment and evaluation of the operations concept are the major expected outputs from this operational validation [1].

Many of the advanced technologies tested by OPS-OSC are data driven and therefore they require access to the data. However, developing the necessary interfaces and converting the data into the right format are, unfortunately, usually very time consuming activities and represent a major effort for small projects and teams.

With MUST there is now a platform that facilitates the access to data. The required interfaces for data retrievals already exist and are very performing, and all the data in the MUST Repository is in a known and common format. Future investigations will therefore benefit from the MUST platform by saving substantial effort usually required for interface development. These saved efforts can be used to focus more on the technology and its exploitation for advanced operations concepts.

The MUST Server supports concurrent access of multiple users and it's easy to store and integrate other information in the MUST Repository. MUST is therefore a highly extendable system that can be adapted to the requirements of new clients.

5. CONCLUSIONS

We have introduced MUST, the Mission Utility & Support Tools. The available mature clients of MUST support mission operations in general and have proven to be of essential benefit regarding spacecraft performance assessment, anomaly investigation and cost reduction of on-call services. However, MUST, as a platform, has also shown to provide another very important benefit.

ESA's Mission Control Technology Unit addresses future demands of space missions and their operations. The increased complexity and needs that future missions will bring can be met by more sophisticated software applications using advanced technologies to support the operations. In order to evaluate the benefits and usefulness of a technology, OPS-OSC produces prototype applications for the users in operations. The relatively small OPS-OSC team is carrying out concurrently various projects across missions and in short time. Most of the assessed technologies are data-driven or depend on input data from the missions in another way. It is usually not trivial to get access to this data, because different systems, networks and formats are involved. Dealing with data access and conversion is therefore a big issue in each of the projects and a huge issue for the unit in general.

MUST contains a repository with calibrated telemetry data, as well as ancillary mission data. Furthermore, there are APIs available to access the repository and retrieve the data. These APIs are re-usable and can easily be integrated in other applications.

Using MUST as a data source and integrating the MUST APIs can facilitate the development of new applications and reduce the efforts needed. The developers can focus on the exploitation of the application's core technology and can minimize the effort on interface development and data conversion. The projects are therefore not only more efficient, but also more interesting, and lead in the end to better products for the users.

6. ACKNOWLEDGEMENTS

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7. REFERENCES


7. **SMART-1 Data Delivery Interface Document (DDID), S1-ESC-ICD-5003 issue 1.3**, Technical Document, ESA/ESOC.