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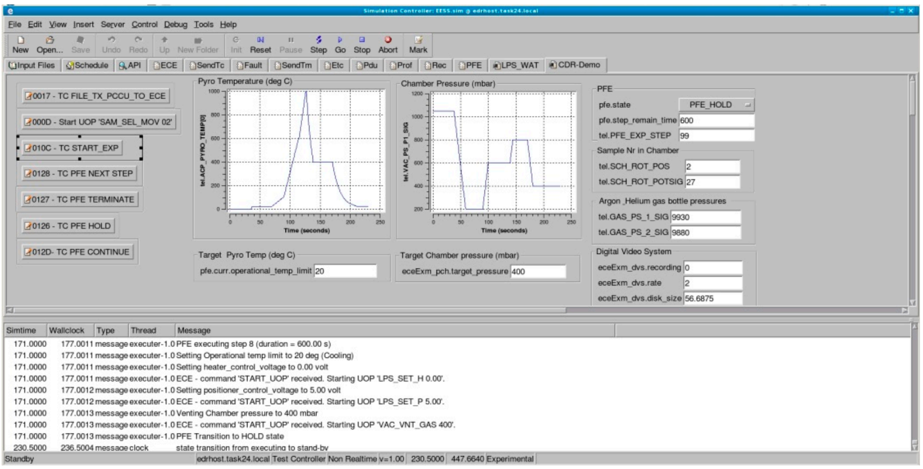
Executive summary

Advances in Columbus internal and external payload simulation for EDR and EuTEF



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Knowledge area(s)
Geomatics
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Simulation
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Problem area
In order to support the operations of both an external and internal Columbus payloads, simulators are needed for operator training at the Erasmus User Support and Operations Centre (USOC).

Description of work
Progress is discussed on simulation covering the preparations, operations, and post-flight analysis based on experiences for both an internal and external Columbus payload facility being supported by the Erasmus USOC. The Electro Magnetic Levitator (EML) is a new payload for which the EDR EML System Simulator is being development. Post-analysis and visualization for EuTEF data has been analysed.

Results and conclusions
Following previous activities on the EDR Software Simulator and the EuTEF Simulator Model, the EDR EML Software Simulator is being developed. Post-analysis tools are being developed based on flight experiences.

Applicability
The work on simulators and the post-analysis is a suitable starting point for further activities.

This report is based on a presentation held at the Workshop on Simulation and EGSE for Space Programmes (SESP),ESTEC, September, 25-27, 2012.

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Advances in Columbus internal and external payload simulation for EDR and EuTEF

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Summary

In order to support the operations of both an external and internal Columbus payload, simulators have been developed for operator training at the Erasmus User Support and Operations Centre (USOC) at ESTEC. The European Drawer Rack (EDR) is an internal Columbus facility and the European Technology Exposure Facility (EuTEF) is an external Columbus facility operated under responsibility of the Erasmus USOC. EDR is still used in orbit with various experiment facilities. EuTEF has been returned to earth in 2009. Work is discussed covering the preparations, operations, and post-flight analysis based on experiences for both an internal and external Columbus payload.

A complete Engineering Model was not available for EuTEF and therefore a hybrid setup was developed called EuTEF Simulator Model (ESM). This simulator setup was based on the hardware model of the central data handling system and a combination of hardware models and software models for instruments. ESM proved to be of interest for post-flight analysis of engineering aspects after the mission. Triggered by the need for post-flight analysis of scientific and engineering data for EuTEF, a 3D visualization tool was developed in support of data analysis. An extension to combine visualisation with a EuroSim simulation was also studied as a follow-up.

The EDR PCDF System Simulator (EPSS) was the first dedicated software simulator development for an internal payload. It was mainly used for training of operators, and testing during infrastructure preparation at the Erasmus USOC. The Electro-Magnetic Levitator (EML) payload is planned to be integrated in EDR in 2013, and an EDR EML System Simulator (EESS) is being developed. A dedicated EML script and parameter representation needed for experiments has been implemented. Part of the ESM development for importing the TC/TM Mission Data Base will be reused in EESS to ensure consistency with the latest tested databases and test results before EML transfer to orbit.

Contents

Abbreviations

BDE	Batch Data Entry
CCSDS	Consultative Committee on Space Data Systems
CD-MCS	Columbus Distributed Monitoring and Control System
Col-CC	Columbus Control Centre
DEBIE	DEBris In Orbit Evaluator
DHPU	Data Handling and Power Unit
DM	Development Model
ECM	Experiment Controller Module
EDR	European Drawer Rack
EESS	EDR EML System Simulator
EGSE	Electronic Ground Support Equipment
EM	Engineering Model
EML	Electro Magnetic Levitator
EPSS	EDR-PCDF System Simulator
ERB	Erasmus Recording Binocular
ESA	European Space Agency
ESM	EuTEF Simulator Model
ESS	EDR Software Simulator
EU	European Union
EuTEF	European technology Exposure Facility
EVC	Earth Viewing Camera
FIPEX	Flux-Probe Experiment
FRC	Facility responsible centre
HRDL	High Rate Data Link
HRDP	High Rate Data Processor
KID	KUBIK Interface Drawer
KUBIK	A small controlled-temperature incubator
LPS	Levitation Power Supply
MCS	Mission Control System
MDB	Mission Data Base
MUSC	Microgravity User Support Centre
PaCTS	Payload Computer Test System
PCCU	Process Control and Command Unit
PCDF	Protein Crystallisation Diagnostic Facility
PI	Principal Investigator

PLM	Primary Loop Module
STD	State Transition Diagram
TAXI	Transparent Asynchronous Transmit/Receive Interface
UOP	User Oriented Procedure
USOC	User Support and Operations Centre
VMU	Video Management Unit
WAT	Water Pump Module
YAMCS	Yet Another Monitoring and Control System

1 Introduction

In order to support the operations of both an external and internal Columbus payloads on-board of the International Space Station (ISS), simulators have been developed for operator training at the User Support and Operations Centres and other elements of the European ground segment for ISS. The European Drawer Rack (EDR) is an internal Columbus facility and the European Technology Exposure Facility (EuTEF) is an external Columbus facility. Both are operated under responsibility of the Erasmus USOC at ESTEC, Noordwijk. Several simulation setups have been developed for use at the Erasmus USOC for internal and external payload facilities. A mix of software simulation and engineering models are used for operations preparation and operation support needs.

EDR is a rack facility internal to Columbus in which experiment payloads can be integrated. The Protein Crystallisation Diagnostic Facility (PCDF) was the first payload integrated into EDR. The EDR PCDF System Simulator (EPSS) was the first dedicated software simulator development. The EuTEF Simulator Model (ESM) has been developed in support of EuTEF operations. Both were mainly used for training of operators, and testing during infrastructure preparation at the Erasmus USOC. EuTEF was launched together with Columbus in February 2008 and installed on an external platform. EuTEF has been returned to earth in 2009. EDR is still used in orbit and preparations for new experiment payloads are on-going. The Electro-Magnetic Levitator (EML) payload is planned to be integrated in EDR in 2013, and an EDR EML System Simulator (EESS) is currently being developed.

In the following the Erasmus USOC infrastructure and the first two simulator developments EPSS and ESM are described for the payloads support (Fig. 1). This is followed by a presentation of the progress in the EESS development aimed at training EML operators at the Erasmus USOC. Post-processing and integration with visualisation taking EuTEF post-flight data as a reference concludes the overview.

2 USOC INFRASTRUCTURE

In preparation and during the in-flight operations simulators or engineering models are used for training of operators, testing and trouble-shooting. The Columbus Distributed Monitoring Control System (CD-MCS) is used for remote operation.

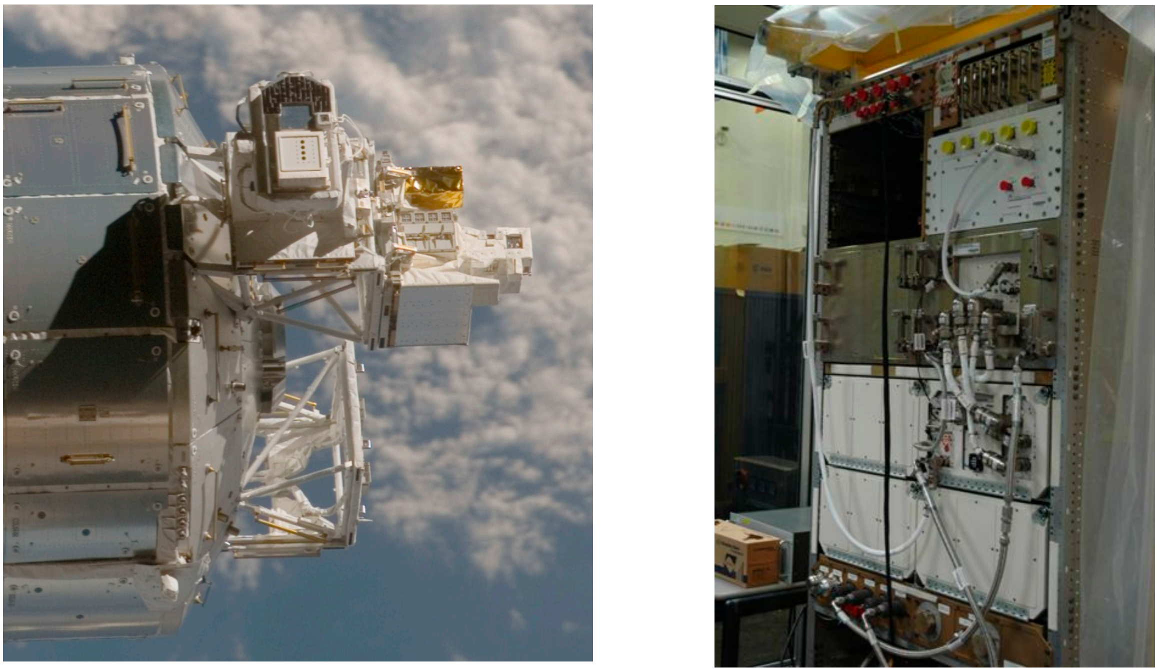

Fig. 1. EuTEF integrated with Columbus and EDR-PCDF Engineering Model

CD-MCS includes a set of standardized data displays and commanding tools. A dedicated network allows the European entities of the ground segment to connect to and control their experiments on board the Columbus Module of the ISS and to retrieve data in real-time and playback mode via NASA. The Columbus Control Centre (Col-CC) located in Oberpfaffenhofen in Germany is responsible for the ground segment coordination of multiple USOCs. Next to simulation needed for training and preparation of co-ordination between various ground segment elements, there proved to be a need for local training and preparation at the USOCs [1, 2].

Engineering Models(EMs) are used in combination with a set of generic simulators dedicated to the USOC tasks. General purpose tools are available which can be used in combination with all Columbus payloads. The Columbus Emulator is a hardware setup consisting of 4 PCs integrated in a rack which represent the Columbus infrastructure for payload facilities. It includes a representative hardware interface to the payload models including the Mil-Std-1553 bus and Ethernet. Separately the bit stream data over a TAXI interface in ISS can be connected to payloads and converted to the data format used for distribution by Col-CC. In addition a generic software tool called YaMCS was available for interconnecting various elements of CD-MCS and simulation setups [3]. The above elements were used for integration with the simulation infrastructure. Internal interfaces were verified using a demonstration payload [4] next to software simulation for the image data formats.

3 EDR SOFTWARE SIMULATOR

The EDR Software Simulator (ESS) has been developed at a time when there was no engineering model of EDR available and EDR was still in a development stage. ESS contains models of the central processor (PCCU), the Power Distribution Unit (PDU) , the Video Management Unit (VMU) and interfacing to payloads via the EXPRESS Rack Protocol.

The models are implemented in the EuroSim[5] environment. Caution and Warning tables were implemented to allow operator training. An interpreter was included in the simulator to be able to simulate the execution of scripts used to describe automated sequences. The interpreter could execute scripts fully compatible with the real EDR. In ESS other payloads could be integrated according to a dedicated interface control document. The PCDF was the first one for which a software model was developed. The PCDF consisted of one drawer and one locker. The simulator was used less frequently after the arrival of an Engineering Model of the PCDF which was integrated into the EDR EM.

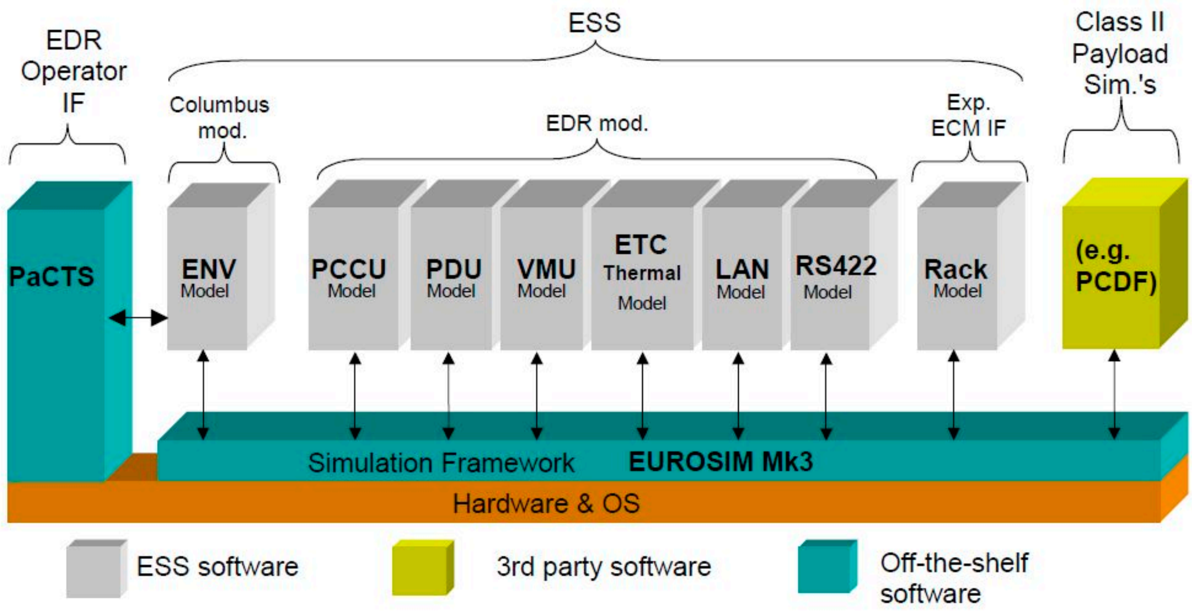

Fig. 2. Modular EDR Software Simulator

Gradually sufficient functionality was implemented in ESS to allow integration of a PCDF software model for use for training of integrated operations with B-USOC (Belgium USOC in Brussels) and the Erasmus USOC. A full EDR PCDF System Simulator (EPSS) was used to support the development and training at the USOC in case the EDR EM was in use for other activities or the PCDF-EM was not available. Once the EDR-EM became available a software simulator was useful in the context of fault-injection simulation, training of new operators, refreshing training and testing. For a number of EDR payloads, the Erasmus Recording Binocular (ERB-2) and the KUBIK

Drawer (KID), realistic hardware models were available. Other payloads required alternatives.

4 EuTEF SIMULATOR MODEL

A complete Engineering Model was not available for EuTEF and therefore a hybrid setup was developed called EuTEF Simulator Model (ESM). This simulator setup was based on the hardware model of the central data handling system and a combination of hardware models and software models for instruments. The approach taken with the EuTEF simulation was different compared to the EDR software simulation as a full EuTEF engineering model was definitively not available. The approach is to be contrasted with a full software simulation and a full instrument payload development model with representative hardware. The main design drivers for the ESM were:

1. Reuse the EM of the EuTEF DHPU (Data Handling and Power Unit) as a central core for the simulator to guarantee the required hardware compatibility with the RS-422 and Mil-Std-1553 standards for the data handling interfaces.
2. Use of an Earth Viewing Camera Development hardware model which would generate data via the TAXI bit stream interface in-orbit.
3. Use of an instrument Mission DataBase(i-MDB) for Telecommand(TC) and Telemetry(TM) to ensure consistency for the instrument interfaces with other Erasmus USOC developments and to reuse potential improvements as the information about the specific instruments was limited at the start of the project.

The architecture contains a generic part including a model for data interfacing with the EuTEF DHPU and an instrument specific part implemented via a high level rule-based coding formalism. The ESM implements all the interfaces of the EuTEF DHPU EM. Both the RS-422 and Mil-Std-1553 type instrument interfaces have been implemented within an EuroSim simulation environment. Stimuli to represent the power usage of instruments and thermistors for EuTEF monitoring have been implemented also. The Earth Viewing Camera (EVC) Development Model (DM) is a realistic model for the data handling of the EVC Flight Model as integrated in EuTEF for which realistic hardware interfaces would be needed.

As part of the design an i-MDB import capability was added to ensure that the simulator would be consistent with validated TC/TM databases. During the period in which EuTEF was operated in flight, ESM was used for training of new operators and to test software and database upgrades. The interface to one of the instruments, DEBIE-2, was upgraded next to system updates and software was uploaded to the EuTEF flight segment requiring dedicated testing using ESM. After EuTEF was returned to earth ESM was used in a dedicated test campaign to confirm resolution of a problem identified during flight in view of a reflight of similar hardware.

5 INTEGRATION OF EML INTO EDR SOFTWARE SIMULATOR

Fig. 3 gives an overview of the integrated configuration with EDR simulation and ESM. Based on the EDR Software Simulator EESS is being developed and integrated in the infrastructure. The Electro-Magnetic Levitation (EML) will be integrated with EDR in-flight after testing on-ground. The experiment facility allows for container less processing of metals and alloys in alternating magnetic fields which positioning and heating in the range between 200°C and 2100°C. The EML modelling for use with ESS is based on reusing the experiences gained in ESM and EPSS. The science operations for EML will be performed remotely by DLR MUSC in Germany while the co-ordination aspects with EDR will be handled by the Erasmus USOC. The modelling is focusing on the tasks the Erasmus USOC operators need to execute. In the following some background of EML is discussed and modelling aspects.

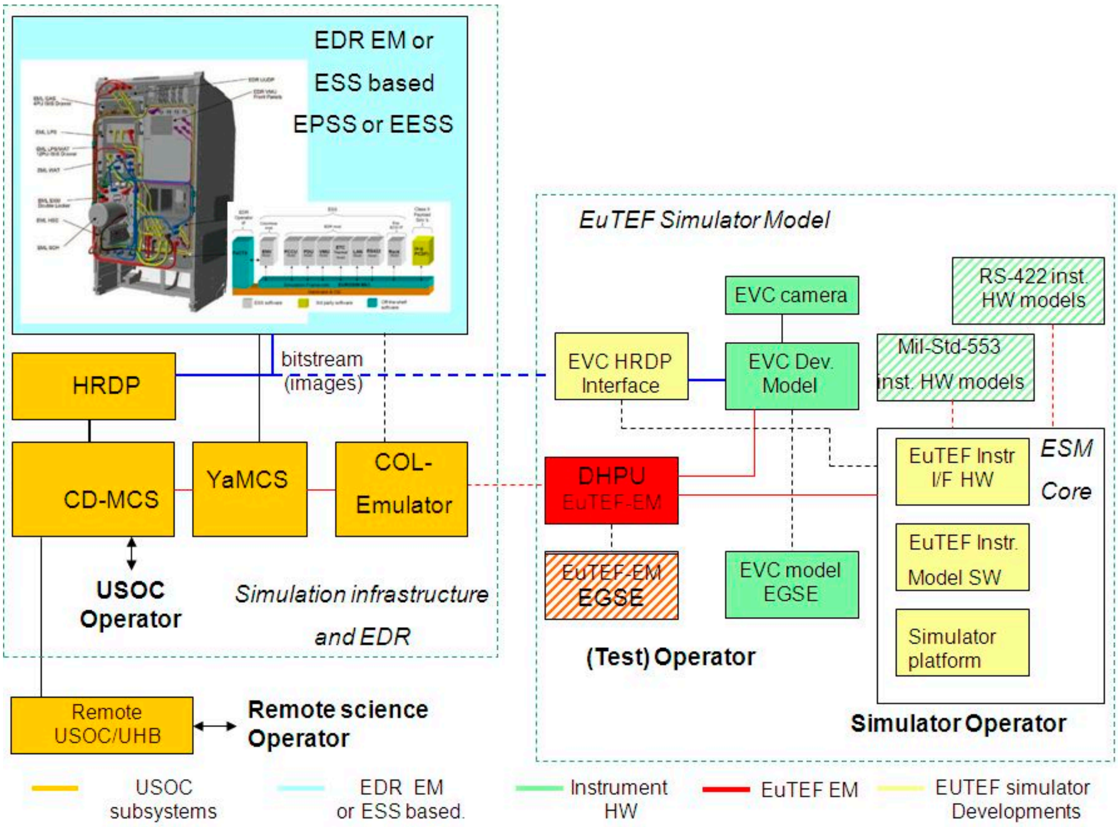

Fig. 3. Integration of engineering models and simulators in Erasmus USOC infrastructure.

In EML a quadrupole field is used for positioning and a dipole magnetic field is used for heating (Fig. 4). The sample diameter is between 6 and 8 mm. An ultra-high vacuum is needed with some gas flow possible to remove particles from the chamber. Using a Pyrometer contactless temperature measurements are performed. A trigger needle and a chill plate are part of the sample enclosure. A first batch of experiments has been identified and contains typically a number of samples with some backups. The typical scenario is that after container installation by crew all activities are fully commanded by ground. The sample processing is to be executed during crew sleep during periods in which data links are available so that ground operators can control and monitor experiments. In general, there is one run per sample with several melting cycles. The operators at the Erasmus USOC need to be able to understand the related functionality in so far as to be able to support the science operations and impact on EDR resources provided via Columbus and the ISS. EML has a heritage in previous activities and now consists of four containers with different sizes: a Gas Supply, a Levitation Power Supply (LPS), an Experiment Module (EXM) and an Experiment Controller Module (ECM) box.

The ECM box contains two computer boards with water cooling. In EML time lines are described in an experiment parameter file which is modelled in the EDR-EML simulator. A dedicated Python interpreter has been integrated within the EuroSim platform to enable implementation of the scripting available in the EML facility. The User Oriented Procedures (UOP) will implement automated sequences and are implemented in either C code or as Python scripts. A large part of the UOPs implemented by the EESS are implemented in C code for efficiency (faster and more compact). However they can be overridden by a Python script if available in the appropriate EESS directory.

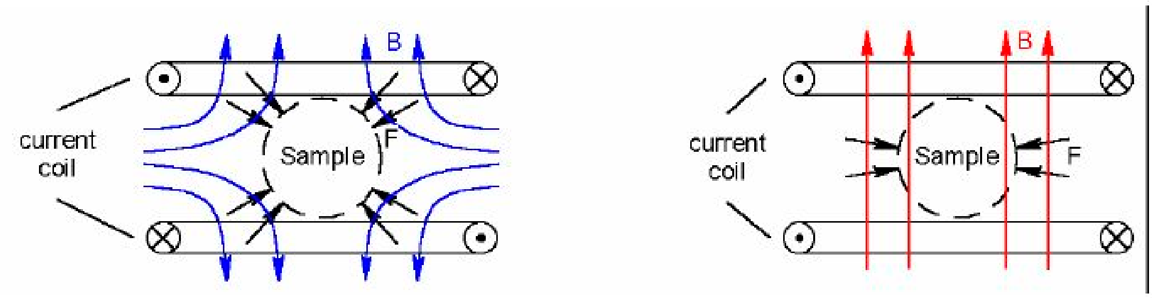

Fig. 2. Sample positioning (left) and heating (right) using magnetic fields.

The LPS contains a Water Pump Module (WAT), Primary Loop Module (PLM) and heat exchanger. The EXM contains a Vacuum System, Gas Circulation System, Coil System Module, Sample Coupling Electronics, Radial and Axial Video observation, Axial Pyrometer for contactless temperature measurement, and Process Chamber. A High Speed Camera, a filter and Exchangeable Sample Chamber are installed on-board on the front. The level of detail for modelling has been limited to a set of representative parameters for each component such that realistic telemetry can is generated. The focus for the models lies on the simulation of EML power usage, temperature readings (including pyro readings), video bandwidth and gas pressures. The main functionality which is represented is the state of the facility and the real-time execution of EML experiments defined by Experiment Parameter Files.

To be able to handle TC/TM changes and improvements in a later stage a dedicated import facility is specified. This allows to import validated TC/TM databases making EESS suitable for pre-validation using the displays and command stacks planned for use by the operators. In a pre-processing step model code is generated based on exporting the MDB part related to the payloads integrated in EDR like with ESM. A script file takes an-export of the MDB for the EDR payload part and generates automatically TC/TM related code. This code has to be linked with simulator model software. During the build process of the simulator this code is integrated in the simulator.

6 POST-ANALYSIS OF EXPERIMENT DATA

In an FP7 EU project called ULISSE (USOCs Knowledge Integration and dissemination for Space Science Experimentation) valorisation, dissemination and exploitation of scientific data from space experiments was explored [7]. Tools for post-analysis were developed for metadata representation, description of distributed datasets, experiment data integration, Augmented Reality and Virtual Reality, knowledge representation using Topic Maps and web services. As a contribution to the project the experiment data integration was studied for EuTEF data. Triggered by the need for post-flight analysis of scientific and engineering data for EuTEF based on spatial relationships, a 3D visualization tool prototype was developed in a follow-up. . A typical dataset with temperature data for the EuTEF platform and instruments depending on the influence of the sun during orbits was used as a study case.

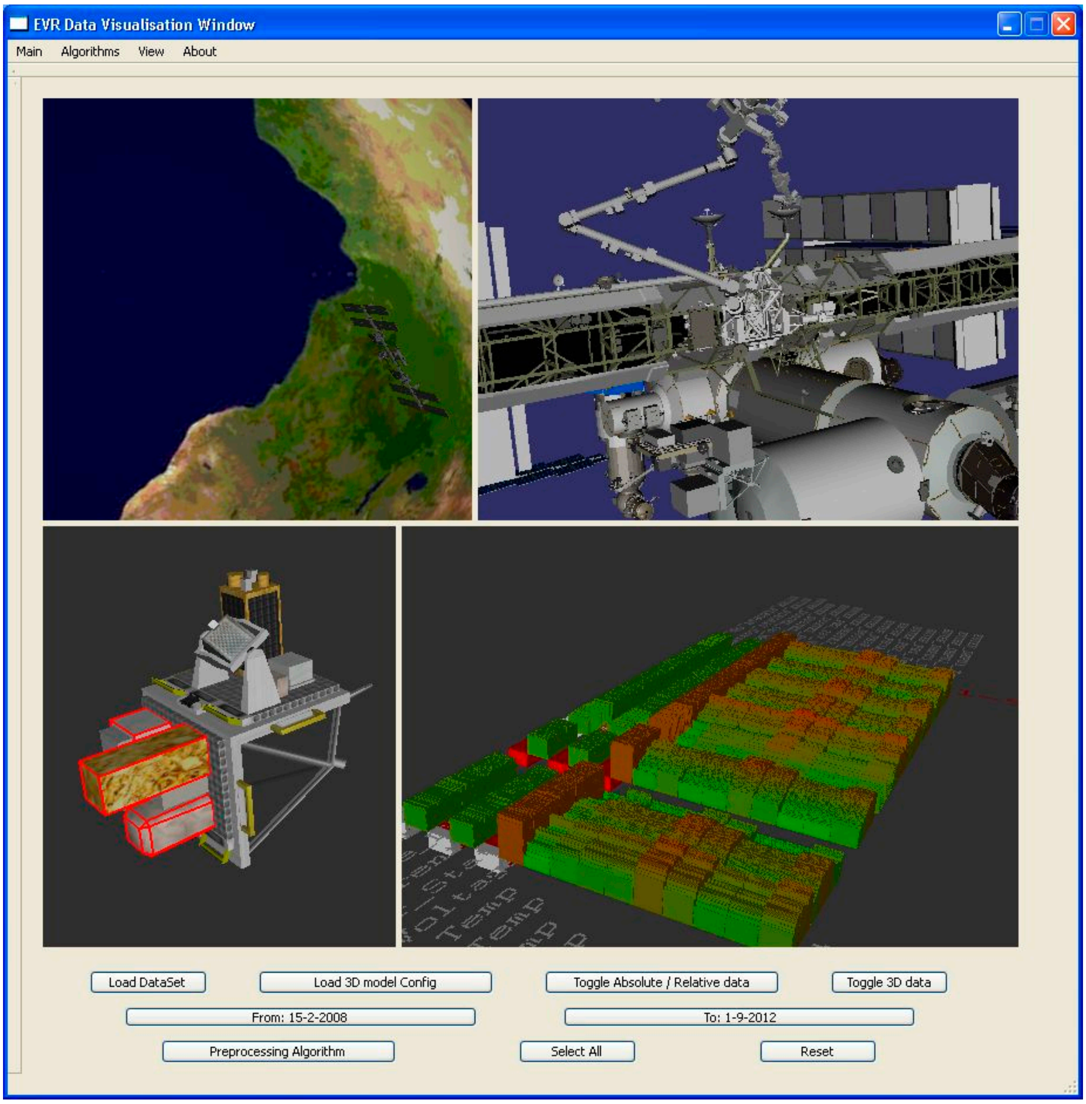

Fig. 5. Post processing and visualisation prototype to improve spatial understanding.

Interviews with operators and engineers that used the data were the basis for the user interface design analysis[8]. 3D visualisation should allow the user to better understanding the temperatures as a function of the angle between the orbit and direction of the sun. This resulted in a prototype user interface (Fig. 5) which was further extended to include 3D data presentation compatible with the formats and interfaces used in ULISSE. The user could select instruments by pointing to the models and corresponding datasets are visualized. The software is based on OpenSceneGraph and Qt which allowed porting to both a Linux and Windows environment. A 3D visualization interface to EuroSim simulation was developed before to study combinations of tele operation and automated diagnosis for instruments on a Mars rover [9]. The experiences were used to extend the interface visualization tool for broader application.

7 CONCLUSIONS AND FURTHER WORK

For a period of around ten years simulators have been developed and used for training of operators. The first generation of simulators were developed without in-flight experience. New simulators are being developed taking into account operational experience at the Erasmus USOC for external and internal Columbus payloads. This includes designing for flexibility taking into account TC/TM updates, flight experience and availability of ground models. The open architecture was demonstrated for the EDR Software Simulator with new payloads such as EML being integrated. Starting with a case study on post-processing, simulation and 3-D visualisation were explored for further work and applications.

Acknowledgements

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Appendix A Presentation