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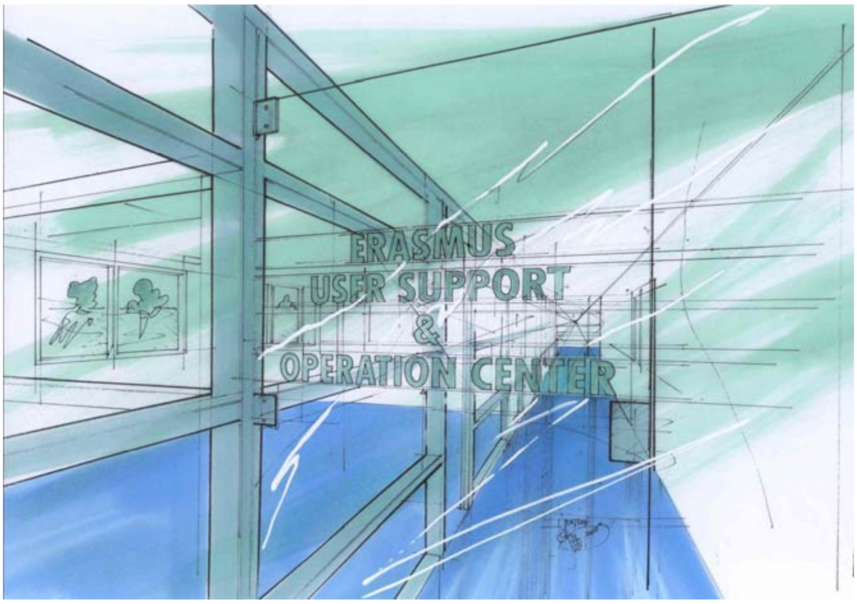
Executive summary

ISS Payload Operations and Support

Experience and Lessons Learned By Erasmus USOC



Problem area
A review is presented of the Columbus payload operations as done by the Erasmus USOC

Description of work
This paper looks back on the period during which Erasmus USOC has been operational and addresses the preparation, implementation, training and execution of the operations performed by the Erasmus USOC. It further describes the experience gained and lessons learned by the USOC to improve its future operations.

Results and conclusions
Erasmus USOC has proven to be a flexible USOC capable of performing two ISS payload missions in parallel for extended periods up to 4 months, running a reliable ground segment, providing direct connections to more than 10 Facility Support Centres and User Home Bases in parallel.

Applicability
The results include recommendations for general Payload Operation centres

Report no.
NLR-TP-2010-139

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Report classification
UNCLASSIFIED

Date
March 2010

Knowledge area(s)
Ruimtevaartinfrastructuur en - payloads

Descriptor(s)
International Space Station
Columbus
Erasmus USOC
Microgravity
Payload Operations

This report is based on a presentation held at the SpaceOps2010 Conference, Huntsville, 24 April 2010.

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Experience and Lessons Learned By Erasmus USOC

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Customer	European Space Agency
Contract number	13980/99/NL/PG
Owner	NLR + partner(s)
Division NLR	Aerospace Systems and Applications
Distribution	Unlimited
Classification of title	Unclassified
	March 2010

Approved by:

Author	Reviewer	Managing department
	16-4-2010	

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ISS Payload Operations and Support – Experience and Lessons Learned By Erasmus USOC

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The Erasmus User Support and Operations Centre (USOC) is the Facility Responsible Centre (FRC) for the European Drawer Rack (EDR) and the European Technology Exposure Facility (EuTEF) on board the ISS. The Erasmus USOC is located in the Netherlands at ESA/ESTEC premises and jointly staffed, under ESA contract, by the Dutch National Aerospace Laboratory (NLR) and the Belgian company Space Applications Services. With the successful completion of the EDR-PCDF mission in July 2009 and the de-installation of EuTEF in September 2009 from Columbus, a temporary end came to, what has so far accumulated to almost two years of continuous 24/7 instruments preparations and operations on the ISS by the Erasmus USOC. During this time the Erasmus USOC has proven to be a dynamic and flexible Operations Centre, able to support and coordinate several long-term continuous ISS payload operations in parallel and in close cooperation with scientists from national institutes, universities and payload Engineering Support Centres (ESCs) who were connected through dedicated User Home Bases (UHBs) to the Erasmus USOC. The Erasmus USOC provides end-to-end services from mission preparation, procedure and operation concepts validation, real-time operations including troubleshooting support during payload anomalies, to data distribution, and archive maintenance. This paper looks back on the period during which Erasmus USOC has been operational and addresses the preparation, implementation, training and execution of the operations performed by the Erasmus USOC. It further describes the experience gained and lessons learned by the USOC to improve its future operations.

Nomenclature

COL-CC = Columbus Control Centre
DaSS = Data Subsystem Services
EAC = European Astronaut Centre
EDR = European Drawer Rack
ERB-2 = Erasmus Binocular Camera - 2
ES = European Simulation
EuTEF = European Technology Exposure Facility
EVC = Earth Viewing Camera
FCT = Flight Control Team

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FOCUS	=	Foam Casting in Space
FRC	=	Facility Responsible Centre
FSC	=	Facility Support Centre
ISS	=	International Space Station
JMST	=	Joint Multi-Segment Training
KID	=	KUBIK Interface Drawer
KUBIK	=	Transportable incubator
OJT	=	On-the-Job Training
PCDF	=	Protein Crystallization Diagnostics Facility
PI	=	Principal Investigator
SAS	=	Stand Alone Simulation
UHB	=	User Home Base
USOC	=	User Support and Operations Center
YaMCS	=	Yet another Monitoring and Control System

I. Introduction

In 1998, ESA's Manned Space Programme board decided to adopt a decentralized Ground Operations infrastructure for the support of European payloads on-board the International Space Station (ISS). This concept was based on operating multiple User Support and Operations Centres (USOCs), each assigned to support a variety of tasks related to the preparation and in-flight operations of European payloads. The USOCs are based in national centres distributed throughout Europe and connected to the Columbus Control Centre (Col-CC) in Oberpfaffenhofen, Germany. The Flight Control Team (FCT) located at Col-CC has the lead responsibility for Columbus nominal and contingency/saving operations on system level, supporting round-the-clock operations, 7 days a week. Depending on the tasks assigned to a USOC, the USOCs have the responsibility of a Facility Responsible Centre (FRC), or Facility Support Centre (FSC). While an FRC is delegated the overall responsibility for a multi-user rack facility or class-1 payload an FSC takes up the responsibility for a sub-rack facility or class-2 payload (e.g. experiment container, drawer payload etc.). The FSC (stand alone or with UHB support) focus lays either on self-standing experiments utilising experiment specific equipment or as individual experiments performed in a facility. A User Home Base (UHB) is mainly focussed on science and experiment operational matters.

Erasmus USOC is located in The Netherlands at ESA/ESTEC premises and jointly staffed, under ESA contract, by the Dutch National Aerospace Laboratory (NLR) and the Belgian company Space Applications Services. In the past two years, Erasmus USOC has functioned as the FRC for the European Drawer Rack (EDR), hosting the Protein Crystallization Diagnostics Facility (PCDF), as well as for the European Technology Exposure Facility (EuTEF), an external platform attached to the Columbus module hosting 9 scientific and technology instruments requiring exposure to the space environment. For PCDF, as class-2 payload located in EDR, the Belgian USOC (B.USOC) has been tasked with being the FSC, hence the EDR-PCDF preparations and operations have been performed in close cooperation between Erasmus USOC and B.USOC. Erasmus USOC implemented for each EuTEF instrument a User Home Base (UHB) at the premises of the instrument Principal Investigators (PIs). All EuTEF preparations and operations were performed in close cooperation with the instrument PIs.

II. Implementation, Preparation and Validation Phase

The Erasmus USOC FCT consists of Operators tasked with payload operations responsibilities and Ground Controllers (GCs) who are in charge of the USOCs ground segment set-up and maintenance. Besides this operational team there are other management and coordination functions, as can be seen from Figure 1. An extensive Definition and Concept Design Phase took place for the USOCs including Erasmus in the years 2000-2004.

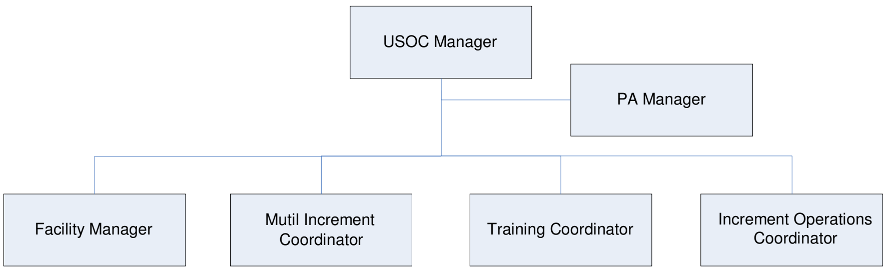

Figure 1. Erasmus USOC Management & Coordination.

During the Implementation, Preparation and Validation Phase that lasted mainly from the years 2005 to end 2007, the main focus of the Erasmus USOC was getting ready to support the EuTEF and EDR operations together with their nine UHBs and FSCs. Emphasis was laid on operations planning, preparation and training of the Erasmus FCT and having a reliable and validated ground system set-up. Following sections will go into the details of this Implementation, Preparation and Validation Phase.

A. Ground System Implementation

Col-CC is connected to other International Partners via the Interconnection Ground Subnetwork (IGS). This wide area network is implemented around a central node in Europe, with relays at major points of data entry (MCC-H, HOSC and MCC-M) and nodes at each of the sites in Europe involved in Columbus and ATV operations, as shown in Figure 2.

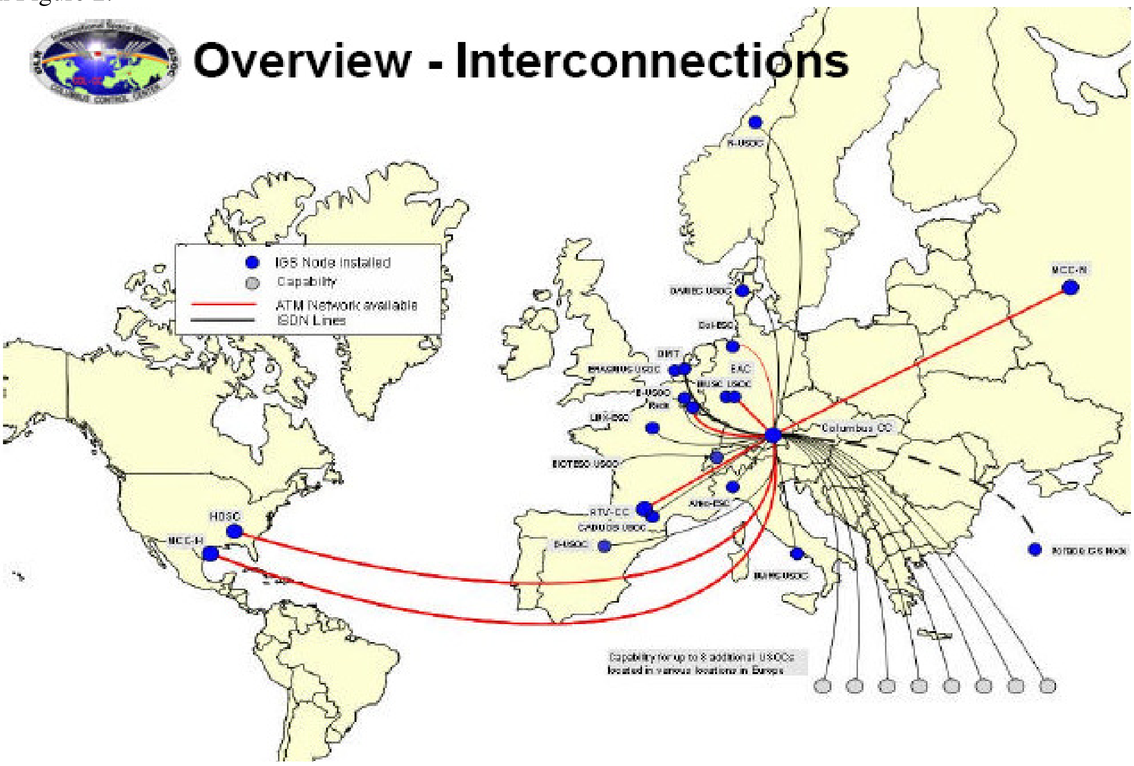

Figure 2. Overview of the IGS network.

The Columbus Distributed Monitoring & Control Subsystem (CD-MCS) is part of the overall Columbus Ground Segment for operations of European payloads within the Columbus module. The CD-MCS is installed at the various USOCs in Europe.

Data coming from Huntsville Operations Space Centre (HOSC) is distributed further downstream through the Data Services Subsystem (DaSS) at Col-CC. The DaSS provides a uniform telemetry distribution service in real-time and playback capability for operations and simulations. The DaSS therefore handles a single European TM interface with external sites for reception of raw telemetry data received from MCC-H, HOSC and MCC-M, and processed/engineering data from Col-CC and ATV-CC. The DaSS also provides remote user access to the telecommand services at Col-CC and NASA.

The CD-MCS provides functions related to online monitoring and control of the payloads. CD-MCS handles, processes, displays and stores payload telemetry and provides facilities for data retrievals and playback of archived data from the off-line archives. These functions also include the multiplexing and release of payload commands originating in external command systems such as a cascaded CD-MCS installed at Facility Support Centres (FSCs) or User Home Bases (UHBs). Although CD-MCS was developed for support of distributed operations, it has restrictions in the number of UHBs and cascaded connections, and it has stability issues when connected to several external sites. Furthermore the newly developed CD-MCS was found to have some shortcomings and needs for improvements in the area of user interface for accessing off-line stored telemetry.

Based on this need, Space Applications Services developed a suite of software tools to complement the CD-MCS. This software suite is called "Yet another Mission Control System" (YaMCS) and copes with the issues the CD-MCS has. YaMCS was installed at Erasmus USOC on the CD-MCS servers and workstations. It was found that YaMCS and CD-MCS together provide a strong and reliable TM/TC interface to Col-CC, cascaded USOCs and to UHBs.

At Erasmus USOC three CD-MCS servers and four CD-MCS workstations are implemented, as depicted in Figure 3. The first CD-MCS server, CDMCS-S, is configured to connect to the DaSS at Col-CC. CDMCS-1 and CDMCS-2 are two workstations used for onboard real-time payload operations which are connected to the CDMCS-S server. The second CD-MCS server, CDMCS-A, is used for simulations with Col-CC and for accessing Engineering Models (EMs) and payload simulators at Erasmus USOC. CDMCS-4 is the workstation connected to this server. Two Columbus Emulators simulate the Columbus interface, one interfaces with the EuTEF EM, and the other one interfaces with the EDR EM. The third server, CDMCS-D, runs data distribution services, file sharing services (dropbox), and provides interfaces to User Home Bases (UHBs) which may connect via a Virtual Private Network (VPN). On CDMCS-S there is a YaMCS server running, while YaMCS client tools are installed on all CD-MCS workstations, to control the functions of the YaMCS server and to access archived data. Via a VPN gateway and a proxy service, the UHBs connect to these YaMCS servers to command their payloads and to retrieve archived telemetry data. Erasmus USOC Operators and Ground Controllers are monitoring these connections and can enable or disable commanding capabilities for the UHBs. After acceptance, commands are forwarded by CD-MCS to Col-CC. YaMCS is then used by Erasmus USOC Operators, Ground Controllers and the UHBs, to easily replay off-line archived data stored in the High Rate Data Processor (HRDP) installed at Erasmus USOC. Beside the two workstations configured for on-orbit payload operations and the one workstation configured for simulations and work on Engineering Models, there is a fourth workstation, called CDMCS-3, which is used as the workstation for the Erasmus USOC Ground Controller. From CDMCS-3 the Ground Controller can monitor and troubleshoot the other three workstations, the CD-MCS servers and the YaMCS servers.

As part of the the Ground Segment implementation, a major validation test campaign took place to ensure that all elements needed for operations were performing safely and consistently in an integrated manner. A series of USOC Validation Tests (UVTs) were performed to demonstrate the availability and correct functioning of the individual services and interfaces. In addition, non-trivial tests involving the Engineering Models (EDR/PCDF EM and EuTEF EM) as well as all the needed components of the Erasmus USOC Ground Segment, also referred to as the 'complex' scenario were successfully performed. The complex scenario tests included validation tests involving FRCs B.USOC and MUSC (Microgravity User Support Centre) in cascaded IGS links as well as UHBs connected via the dedicated Virtual Private Network UHB interface. As such the Erasmus USOC was tested under conditions closely resembling the expected real operational scenario for the first payload operations in Columbus. The Erasmus USOC validation also included the testing of the compliance of the security implementation with the generic USOC's security implementation requirements. In addition to the USOC Validation Test (UVT) conducted by Erasmus USOC, Col-CC initiated a series of System Validation Tests (SVTs), aiming at validating the overall ground segment connectivity.

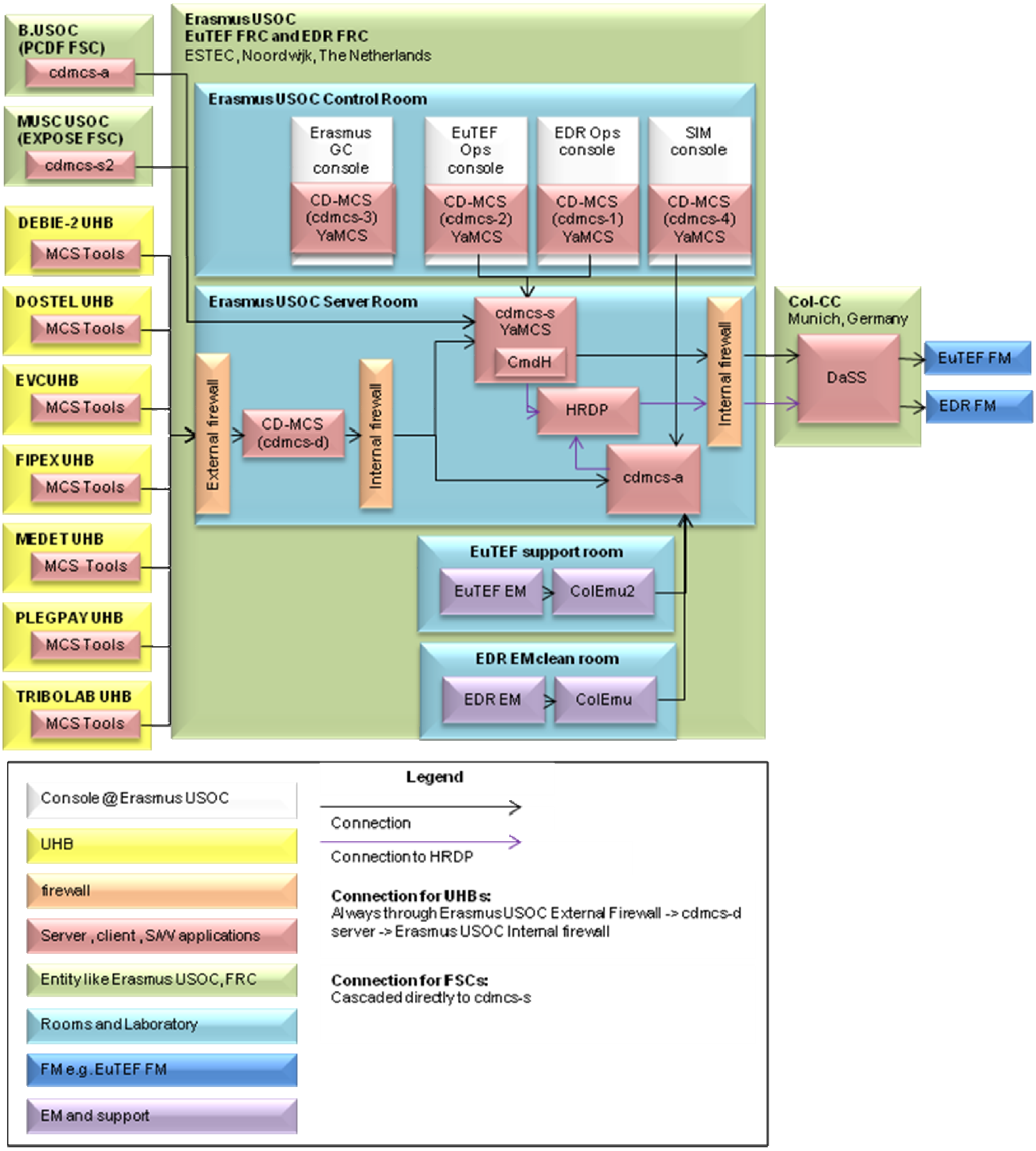

Figure 3. Overview of Erasmus USOC Ground Segment and connecting entities.

B. Experiment Preparation

Besides the set-up and testing of all ground system connections between the Erasmus USOC and the experiment FSCs and UHBs, a major task for the Erasmus USOC was to prepare in detail the EDR and EuTEF onboard activities.

1. Operational requirements definition

For EDR and the EuTEF DHPU (Data Handling and Power Unit, the central computer of the platform) the Payload Developers provided a detailed operations manual including all operational requirements and constraints.

However, for the 9 EuTEF instruments, developed mainly by the Scientific Institutions, operations manuals in the required detail were not existing, and the documentation across the instruments was not harmonised. In order to have all necessary information in the same format, Erasmus USOC wrote an Instrument Operations Interface Definition (IOID) document for each EuTEF instrument. The IOIDs provided input to the Erasmus USOC operations plan (instrument commissioning operations, instrument nominal and contingency operations) and were developed for the purpose of assigning resources (data and power) and defining operational requirements and constraints (e.g. TriboLAB in standby mode during thruster firings, PLEGPay Langmuir Probe measurements during Visiting Vehicle dockings/undockings, etc.).

2. Database implementation

The EDR-PCDF database and the EuTEF DHPU mission database were delivered to Erasmus USOC by the Industrial Operations Team (IOT). Erasmus USOC installed those databases and defined limits for a set of important parameters. The limits were hardcoded in the databases themselves and were shown with color codes in the telemetry displays. Since IOT did not provide the mission database for the nine EuTEF instruments, Erasmus USOC had to take care of this. The Erasmus USOC team developed and implemented the EuTEF instrument mission database, and validated this database on the EuTEF flight model at Carlo Gavazzi Space premises in Tortona, Italy. Also for the EuTEF instruments, limits were hardcoded in the mission database.

3. Operational tools development

Erasmus USOC developed the synoptic displays for EDR and EuTEF using the USS software (provided by ESA). Besides the USS synoptic displays, several other telemetry monitoring tools were developed to support the EDR and EuTEF operations. The Erasmus USOC team developed the *EDR and EuTEF Event Viewer* and the *EOP Tracking Tool (EOPTT)*, respectively to monitor command responses and automatically generated events from both payloads and to follow-up the progress and success of an onboard running EuTEF Operation Program (EOP, onboard script). Furthermore, for the Earth Viewing Camera (EVC, camera mounted on the EuTEF platform) the EVC *Quicklook application* was developed to extract, display and save in real-time the EVC pictures from the incoming EVC high rate data bitstream. In order to easily create EuTEF Operation Programs (EOPs), the Erasmus USOC developed as well the *EOP Authoring Tool (EOPAT)*. This tool provided the EuTEF Principal Investigators (PIs) the opportunity to develop their own Instrument Operation Programmes (IOPs) and provided the Erasmus Operators the opportunity to easily combine the different IOPs in one EOP.

As mentioned in paragraph II.A., *YaMCS* was developed in the first place to cope with the multiple FSC and UHB connections, but YaMCS also contained a user-friendly archive retrieval tool with a graphical user interface. This archive retrieval tool allowed the EDR and EuTEF Payload Developers and PIs to access the Erasmus USOC HRDP (High Rate Data Processor, telemetry archive) from their UHB terminal at any time.

4. Procedure authoring

Based on inputs from the Payload Developers and Principal Investigators and based on the Mission Databases and the displays, the Erasmus USOC Procedure Engineers developed the PODFs (Payload Onboard Data Files, procedures) for both EDR and EuTEF. Since EDR is a rack inside Columbus, both crew and ground procedures had to be developed. For EuTEF, as an external platform, only ground procedures were needed (except for NASA System ODF for the EuTEF platform installation - solely developed by NASA). In order to be allowed for execution the procedures also needed to be validated by Erasmus USOC and distributed to the whole ISS community via the International Procedure Viewer (IPV). For EDR the PODFs were validated on the EDR Engineering Model (EM) located at Erasmus USOC, but for EuTEF the PODF validation was a bit more complex, since no complete EuTEF Engineering Model existed. In the end the PODF validation was done partly on the available Instrument EMs and partly on the own developed EuTEF simulator (see paragraph II.B.8).

5. Flight Rules and Payload Regulations authoring

Based on inputs from EDR-PCDF and EuTEF operation manuals and IOIDs, Erasmus USOC operators developed Flight Rules and Payload Regulations for EDR and EuTEF. The process of writing Flight Rules and Payload Regulations is in cooperation with the COL FCT and the Payload Integration Managers (PIMs) and the rules and regulations are subject to several reviews by the European Flight Rule Control Board (EFRCB) and NASA Flight Rule Control Board. In the end they are published respectively in the ISS Flight Rule books and the Columbus Payload Regulations book.

6. Operations Plan development

In the months prior to the start of the Increment with EDR and EuTEF operations, Erasmus USOC developed the Erasmus USOC Increment Operations Plan. This plan describes the operational scenario for the payloads in that increment, but describes as well the expected on-console staffing, the sharing of responsibilities in the Erasmus USOC team, the required support from Payload Developers for certain operations, etc.

7. Planning Requests development

In order to allow the European Planning Team (EPT) to make a consistent Columbus planning for the next Increment(s), the USOCs need to provide the EPT several months in advance with their payload planning requests. The planning requests are submitted via the OPDCS (Operation Planning Data Collection System), an online tool that allows the USOCs to define their payload activities and provide all required details (duration, crew time needed, procedure link, data and power needs, time-constraints, etc.). The planning requests development is an iterative process between the USOCs and the EPT.

8. EuTEF simulator development

The available EuTEF EM consisted only of the DHPU EM, the DOSTEL, DEBIE-2 and EuTEMP EMs and an EXPOSE emulator. In order to be able to validate all the EuTEF PODFs and also in order to have a good training environment for the Erasmus USOC operators, NLR developed the EuTEF simulator[1] (under ESA Contract): a hybrid simulator combining the available hardware together with software simulators for the missing instrument EMs.

C. Operator Training

All the training activities at Erasmus USOC are coordinated by the Erasmus USOC Training Coordinator[2]. In general the Erasmus USOC is responsible for training support to:

- Astronaut Training
- Payload Operations Training
- User and Scientist Training

Support to astronaut training is provided by Erasmus USOC on request of the European Astronaut Centre (EAC) and is mainly focused on onboard payload facility operations training. The support to the user and scientist training is mainly focused on the use of the operational tools, like the UHB software. However, the main training responsibility of each USOC is the training of its own operators. The generic USOC Training Qualification & Certification Plan (TQCP) contains a list of so-called generic courses to be provided by EAC, Col-CC, the Industrial Operator Team (IOT) and the USOC itself. In addition, Erasmus USOC organizes its own USOC specific courses to get the USOC operators ready and qualified for Columbus payload operations. The Erasmus USOC Training and Qualification Program (TQP) is a document providing identification, description and planning for all training courses to be followed by the Erasmus USOC operators. In the Erasmus USOC TQP, a typical operator training plan is laid out which takes the operator three months to complete, see Figure 4. During the Implementation, Preparation and Validation Phase most of the emphasis was laid on operator qualification through simulations with Col-CC and NASA. Internally, Stand-Alone-Simulations (SAS) without Col-CC were organized allowing fast turn-around simulations for the operators. Sometimes these SAS were organized together with other USOCs. During the Implementation, Preparation and Validation Phase, On-the-Job Trainings (OJT) could not be organized, as in this phase the USOC was not operational. For the operators which joined the Erasmus USOC team after this phase, OJT sessions were held.

Element	Month 1				Month 2				Month 3			
Preparatory activities	x	x	-	x	-	x	-	x	-	x	-	x
Mandatory Courses			x	x	x	x						
Payload specific training		x	x	x			x	x				
Stand-Alone Sims			x	x	x	x			x		x	
OJT sessions (passive)		x			x	x		x		x		
OJT sessions ((partly) active)							x		x		x	
ES sessions						x		x				
JMST sessions										x		x

Figure 4. Erasmus USOC Training Plan (ref. TQP).

Distinction is made between an operator assistant and a certified operator. An operator is certified when he successfully passes two European Simulations (ES) and two Joint Multi-Segment Trainings (JMST), see also Figure 4. An operator assistant is an operator in training, who has participated in the training program, performed some simulations and has the basic knowledge on the payload, but has not yet passed successfully the mandatory European Simulations (ES) and Joint Multi-Segment Trainings (JMST). The operator assistant is not allowed to send commands to the payloads, hence he is mainly used during low activity periods in which no commanding is foreseen and he is backed-up by a certified operator on-call. In the first months of the EuTEF and EDR operations, Erasmus USOC had only 3 certified operators and 3 operator assistants to cover around the clock operations, 7 days a week. This resulted into a tight operations schedule and a high work load on the team. The operator assistants were mainly planned for the morning and night shifts, since the afternoon shifts usually involved a lot of payload interaction.

III. Operations Phase

A. Payload Commissioning

Following the launch of Columbus, including EDR and EUTEF, with STS-122 in flight 1E in February 2008, Erasmus USOC supported the EuTEF installation, check-out and commissioning operations and the EDR installation and commissioning operations. A team of six operators and two ground controllers worked around the clock, seven days a week in order to obtain these objectives. The workload for the two instruments was nicely spread over the day and night shifts of the 1E flight, seen the fact that the EDR installation and commissioning required a lot of crew interaction (during day-time) and the EuTEF check-out and commissioning activities were performed from ground only (scheduled during night-time).

1. EuTEF Commissioning

After the EuTEF transfer from the Shuttle cargo bay to Columbus and installation on Columbus via an Extra Vehicular Activity, the Erasmus Operators, together with EuTEF engineering support from Carlo Gavazzi Space, performed a successful EuTEF DHPU telemetry and telecommand checkout on February 16, 2008. In order to overcome some operational problems discovered very late in the EuTEF operations preparation phase, an onboard EuTEF DHPU Application Software (ASW) update was already needed immediately after the DHPU checkout. This ASW update was only partially successful and left EuTEF in ‘non-nominal’ mode, but not affecting the major functionalities, i.e. working of the heaters and instrument commanding. The decision was taken to go on with the telemetry and telecommand checkout of the nine instruments onboard EuTEF while in parallel the off-nominal situation would be further analyzed on the EuTEF-EM/simulator on ground. Several PIs were supporting the Erasmus Operators at the Erasmus USOC for the instrument checkouts or were monitoring in real-time the first telemetry from their instrument on their UHBs. An extensive commissioning for each instrument was performed in the two weeks after the EuTEF installation. For each instrument one full day (8 hours) was reserved and the PIs were invited to the Erasmus USOC to follow the commissioning of their payload and to provide the Erasmus Operators with their technical support. Beginning of March 2008 EuTEF and its instruments were successfully commissioned and also the problem with the EuTEF ‘non-nominal’ mode was solved.

2. EDR-PCDF Commissioning

The Crew activities for EDR installation and commissioning were performed by Peggy Whitson, the ISS commander at that moment. The Crew moved the complete EDR Rack from its launch position to its final operational position. The next day they connected the EDR to the Columbus’ power, water and data connectors, refurbished all the stowage items inside the rack and installed the water hoses, power and data cables for the Protein Crystallization Diagnostics Facility Electronics Unit (PCDF-EU), see Figure 5. After the completion of this mechanical installation, the Crew started the commissioning on the EDR Laptop. The Erasmus Operators on-console, supported by the EDR engineering support from Thales Alenia Space, monitored all the crew activities closely, answered questions from the crew (via Eurocom at Col-CC) and performed the ground commanding part of the EDR commissioning. Amongst others it contained starting a replay of an EDR video test-file, stored pre-launch on the EDR JPEG Recorder, and the Crew could watch the video on the EDR Laptop in parallel with the Erasmus operators receiving the same video on ground. All activities went nominal and EDR was successfully commissioned on February 16, 2008. Unfortunately, due to issues with other ESA racks inside Columbus, no crew resources were left to perform the EDR-PCDF Electronics Unit commissioning during the 1E mission as well. In the end the EDR-PCDF EU commissioning was performed in May 2008.

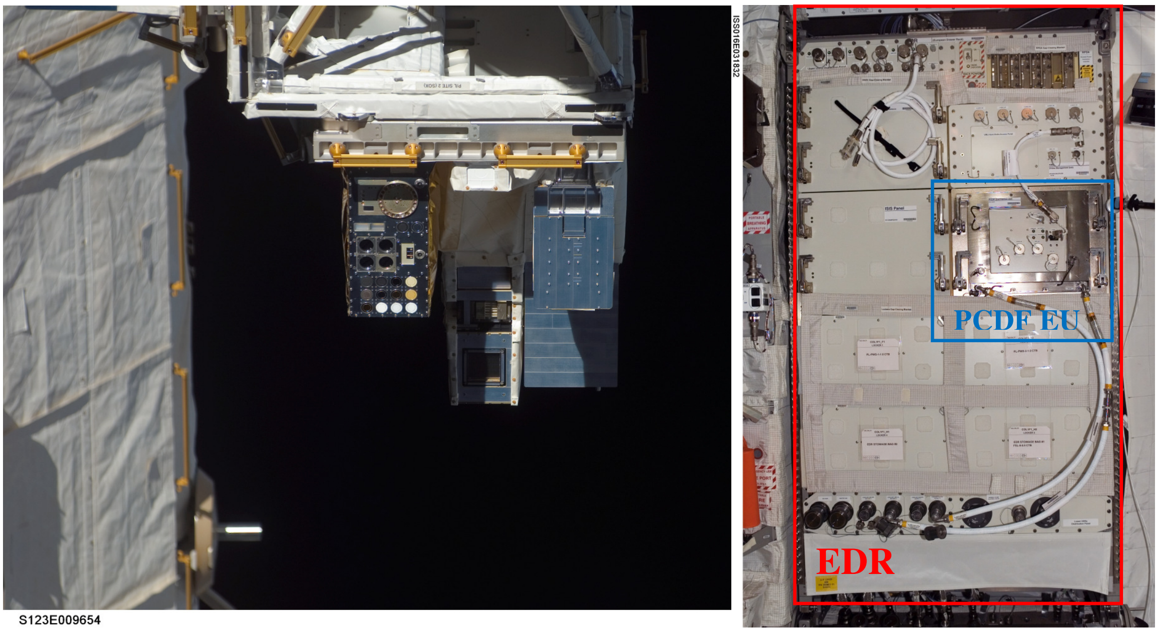

Figure 5. EuTEF on orbit, picture taken during STS-123 mission (L). EDR-PCDF EU configuration installed during 1E flight (R). (credits NASA)

B. Payload Nominal Operations

Upon completion of the EuTEF DHPU and instrument commissioning phase, the nominal operations or science phase for EuTEF immediately took off. For EDR-PCDF, however, the nominal science phase only started in March 2009, after the upload of the PCDF Process Unit (PU) with STS-123 in flight 1J/A and the subsequent installation into the EDR. After the EDR-PCDF EU commissioning in May 2008, the entire rack was deactivated and until the arrival of the PCDF PU, the EDR was only activated a couple of times for the purpose of updating the onboard software of the EDR Rack and its laptop, checking PCDF commanding via scripts, and for testing the rack smoke detector.

1. EuTEF Nominal Operations

The EuTEF science phase lasted for about 18 months with 24/7 support (around the clock, seven days a week) and the return to ground took place with STS-128 in flight 17A in September 2009. The 24/7 support from Erasmus Operators was required since EuTEF was continuously powered and sending data to ground. Several instruments onboard EuTEF had the science objective to run continuously during the 1.5 year on the ISS, amongst those were DOSTEL (DOSimetry TELescope), EXPOSE-E (Exposed Experiment on EuTEF) and MEDET (Material Exposure and Degradation ExperimenT). The other instruments -FIPEX (Flux (Phi) Probe EXperiment), DEBIE-2 (DEBris In-orbit Evaluator), TriboLAB (Tribology LABoratory), PLEGPay and EVC (Earth Viewing Camera)- were intended to operate in a ‘campaign mode’, i.e. alternating several hours/days of operations with several hours/days in standby mode.

For the EuTEF science phase Erasmus USOC developed a nominal operations scheme consisting of weekly EuTEF Operation Programs (EOPs) and daily ‘real-time commanding windows’. Every week a new EOP was prepared and started by the Erasmus Operator, based on the Instrument Operation Programs (IOPs) received from the EuTEF PIs. Once the onboard script was started it ran automatically for a period of usually 5-6 days and the Erasmus Operators were able to follow the progress and successfulness of the script via the EOP Tracking Tool (EOPTT). In case of unexpected EuTEF DHPU or instrument behavior, the Erasmus Operator could always stop the running EOP (or even stop an individual IOPs), to perform troubleshooting via direct commanding and later on, if desired, resume the EOP (or IOP). Because onboard scripts were not suitable for all EuTEF instrument operations, Erasmus USOC developed the concept of a daily one-hour ‘real-time commanding window’: every day one hour was reserved in OSTPV (Onboard Short Term Planning Viewer) for EuTEF operations and the details of the activities had to be provided to Col-CC only 4 hours prior to the start of the commanding window. This concept provided the EuTEF PIs with the opportunity to follow up their experiments from day to day and depending on the telemetry to decide which commands they would like to send in the next real-time commanding window. All commands sent during a real-time commanding window had to be covered in a validated PODF. Although it is still far away from a “telescience” operations concept, the real-time commanding windows provided far more flexibility to operate EuTEF than the nominal ISS planning concept in which an activity needs to be completely detailed and planned days or even weeks in advance. Once every week a 4-hour real-time commanding window was foreseen too, in order to have the opportunity to perform activities needing some longer direct commanding, e.g. a long session of EVC image acquisitions. The EuTEF instrument direct commanding could either be performed by the Erasmus USOC Operators, or by the PIs from their own UHB under supervision of the Erasmus USOC Operator.

2. EDR-PCDF Nominal Operations

The EDR-PCDF science operations lasted from March till July 2009 after which the PCDF-PU returned to ground with STS-127 in flight 2J/A. Also for these operations 24/7 support from Erasmus USOC was needed and thus from March till July 2009 the Erasmus USOC Operators were performing the EDR-PCDF and the EuTEF operations in parallel. For EDR-PCDF operations B.USOC (FSC for PCDF) developed the concept of a 24-hour ‘real-time commanding window’ to have a maximum flexibility. Every night Erasmus USOC together with B.USOC decided about the direct commanding for the upcoming day. Erasmus USOC as FRC for EDR played the enabling role for B.USOC as FSC for PCDF. Typical Erasmus USOC operations involved configuring EDR for PCDF (power, data and water cooling configuration) and the EDR Video Monitoring Unit (VMU) activities like starting and stopping new recordings of PCDF images (high-rate data stream), and playing back recordings on request of B.USOC. Typical B.USOC operations involved uploading and starting of new PCDF scripts and changing of parameters for the PCDF PU experiment boxes and for the PCDF EU diagnostic equipment.

Looking back at the science operations, both EuTEF and EDR-PCDF operations are considered very successful, despite several anomalies encountered in orbit (see paragraph III.C). An overview of the complete mission timeline for both EDR-PCDF and EuTEF operations is given in Figure 6.

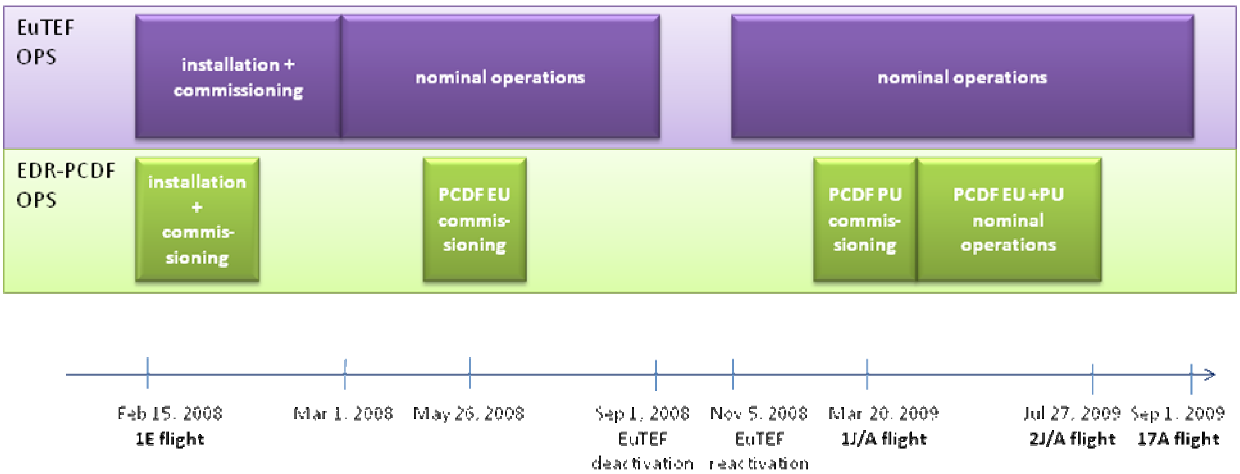

Figure 6. Mission timeline overview of EDR-PCDF and EuTEF operations.

C. Anomalies and Recovery Operations

During the 18 months of EuTEF operations and the 4 months of EDR-PCDF operations several anomalies occurred, requiring recovery operations.

The entire mission EuTEF experienced occurrences of a reset of one of the SPLC boards (Standard Payload Computer), affecting the slave boards and resulting in incorrect (random) values for the analogue parameters acquired by the EuTEF DHPU. Due to these analogue values going out of limits, the DHPU automatic onboard monitoring switched off all the instruments. The only way to bring EuTEF back into nominal operations was to reset the DHPU and to activate the instruments again. Despite several investigations during the EuTEF on orbit mission, no root cause for the SPLC board reset could be found. The occurrences of the SPLC board reset had a random time distribution and no correlation could be made with other ISS events (e.g. crossing the South Atlantic Anomaly or Single Event Upsets). Post-flight the problem is still under investigation by the payload developer.

Also several of the EuTEF instruments showed anomalous behavior. DEBIE-2 and FIPEX suffered from link errors on the RS422 serial line between the two instruments and the EuTEF DHPU. For DEBIE-2 a DHPU software update and regular DEBIE-2 resets solved the problem and for FIPEX the link error could be avoided by doing the data acquisition and the data downlink in series and not in parallel, as originally planned. Furthermore EVC suffered from an unreliable high rate data connection with Columbus, TriboLAB encountered a blocked shaft motor for the ball bearing experiment and PLEGPay, although not showing anomalous behavior itself, was declared a catastrophic hazard for the ISS[3]. Especially the PLEGPay situation was very serious, because PLEGPay and the entire EuTEF platform had to be switched off for several months. Erasmus USOC, engineering support, ESA and the International Partners spent a lot of time and effort to resume in the first place the EuTEF operations and in the second place the PLEGPay operations. In order to resume PLEGPay operations in a safe way also a PLEGPay software update was performed.

For EDR-PCDF several PCDF anomalies occurred which were handled by the B.USOC team and EDR itself only suffered from a re-occurring failure on one of the ESEM (Exchangeable Standard Electronic Modules) boards where PCDF was connected for its power. After several reoccurrences of that failure and with 2 months of PCDF operations still to go, the decision was taken to exchange the EDR ESEM4-E1 board at the end of May 2009.

Thanks to the Erasmus USOC, B.USOC and Engineering Support teams, solutions or workarounds were found for most of the above mentioned anomalies and the mission success objectives for EDR-PCDF and EuTEF were met, except for PLEGPay. For re-occurring anomalies so-called recovery Flight Notes were established between Erasmus USOC and Col-CC, in order to avoid real-time discussions and to work towards consequent and time-efficient anomaly handling.

D. Training of new operators during the Operations Phase

As Erasmus USOC started the operations phase with only 6 operators, the 24/7 operations took a lot of effort from the small team and soon the need for a team of 10 operators was identified. Furthermore Erasmus USOC experienced the effects of the natural turnover of operators and ground controllers already in the first half year of the operations phase: 2 of the original 6 operators left the team. This resulted in a requirement of 6 new operators who needed to be trained and who needed to follow the whole qualification and certification process.

Since a lot of operational experience was gained during the first months of the operations phase, it provided also a lot of input for training the new operators more efficiently. The 'new' training concept still included some familiarization and internal training on the payloads, courses provided by IOT, Col-CC and EAC, and the simulations (SAS, ES, JMST), but the new operators in training could now also enjoy On the Job Training (OJT) which gave them real operational experience during their training. In the passive OJTs, the operator was sitting next to the certified operator and learned during the combined shift. After participating in a few passive OJTs, the operator in training could participate in active OJTs, i.e. he was given the opportunity to do shifts himself with the certified operator sitting next to him. This approach has been generally implemented into the training of all new operators at Erasmus USOC[2]. With the number of payloads growing per USOC, the on-going operations at the same time and the limited opportunities to follow certain courses or to participate in simulations, it became more essential to well plan and organize the training. Although in theory an operator should be able to be trained and certified in a timeframe of 3 months, reality showed that in the operations phase most of the new USOC operators needed at least 6 months to become certified. However, Erasmus USOC managed to bring back the training program for qualification and certification from 8 months to 3-6 months[2]. At the end of the two years of operations, Erasmus had 10 certified operators and one operator assistant. The team is now regularly trained for new payload operations.

During the past half year, Erasmus has further enhanced its training program, by laying more emphasis on the qualification part[2]. This includes more and better structured Stand Alone Simulations (SAS) and internal training courses.

E. Future Outlook

After the completion of the EuTEF and EDR-PCDF mission in 2009, the Erasmus USOC is getting ready to support new payload operations in 2010. Figure 7 shows the payload operations planned for 2010, under responsibility of Erasmus USOC.

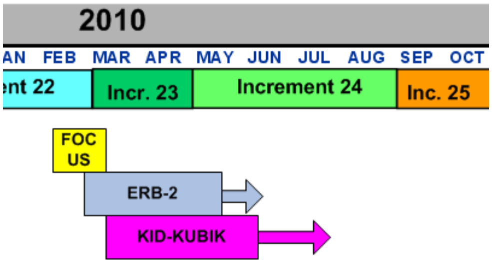

Figure 7. Future outlook for Erasmus USOC.

The Foam Casting in Space (FOCUS) experiment will demonstrate a new technology to produce nano-particle stabilized foams under microgravity conditions. The Erasmus Recording Binocular, ERB-2, is a 3-d stereotypic camera, which will be used to map the ISS and help making better 3-d models of the ISS. It will also be used in public relation events. The KUBIK Interface Drawer (KID) is a mechanically and electronically adjusted drawer which will be mounted in the EDR to accommodate the KUBIK transportable

incubator, in which multiple biological experiments can be performed.
In the 2011-2012 timeframe, Erasmus USOC will also support the FASTER and the Electro-Magnetic Levitator (EML) payload operations. The preparatory work, both on payload operations preparation and on training and qualification of operators, will already start in 2010.

IV. Conclusion

With the successful completion of the EuTEF and EDR-PCDF mission, Erasmus USOC has proven to be a flexible User Support and Operations Centre (USOC) capable of performing two ISS payload missions in parallel for an extended period up to 4 months and running with a reliable Ground Segment, providing direct connection to more than 10 Facility Support Centres (FSCs) and User Home Bases (UHBs) in parallel. The mission success was certainly a result of the close cooperation in training, preparations and operations between the B.USOC (FSC for PCDF) and Erasmus USOC (FRC for EDR) for the EDR-PCDF mission and between the Erasmus USOC and the EuTEF Payload Developers and Principal Investigators for the EuTEF mission.

The 24/7 EuTEF operations for an extended period, i.e. 18 months, have put a high burden on the Erasmus USOC operator team. Originally starting with 6 operators, Erasmus USOC soon identified the need for a bigger team to support long term around the clock operations and the Erasmus USOC operator team gradually expanded to 10 operators. Knowing that SOLAR (external payload on Columbus) had to be operated 24/7 from B.USOC in the same period, a better approach could have been to combine the operations of EuTEF and SOLAR in one USOC (with a bigger operator team) or to combine at least the night shifts, since typically a very low-workload was experienced during those shifts for both EuTEF and SOLAR.

Erasmus USOC implemented for EuTEF a daily one-hour ‘real-time commanding’ window and together with B.USOC a 24-hour ‘real-time commanding’ window was implemented for EDR-PCDF. The concept of ‘real-time commanding windows’ for both EuTEF and EDR-PCDF has been proven very efficient, was welcomed very positively by the scientists, and is already a step closer to a “telescience” operations concept.

The training of new operators during the operations phase took more time than in theory planned, mainly due to parallel on-orbit operations and too few opportunities to participate in specific training courses and simulations. In order to minimize the training time for new operators prior to perform on-console work, Erasmus USOC implemented the On the Job Training (OJT) and involved operator assistants in the on-console work. Thanks to all experience gained during the two years of operations, the training qualification and certification process has been brought back to 3-6 months and more emphasis is being laid on the qualification process.

Acknowledgments

The authors thank the European Space Agency (ESA) Directorate of Human Spaceflight (D/HSF) (ESA Exploitation Programme) for their funding.

Further the authors thank the ESA Payload Operations Management (ESA-POM), the ESA Mission Science Office (ESA-MSO), the Erasmus USOC Operator team, the Col-CC Flight Control Team and the payload developers for their support to Erasmus USOC from the early preparation phase through the entire on-orbit operations phase.

Also a special word of thanks to the ESA USOC management, National Aerospace Laboratory (NLR) management, and Space Applications Services management for their support and for providing the budget and personnel for the activities.

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