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Science and Exploration – Facilities and Operations of Microgravity Experiments (A2.5)

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Fluid Science Laboratory: Ready to fly! Lessons learned on preparatory activities, operations and performances (IAC-07-A2.5.02)

ABSTRACT

The Fluid Science Laboratory (FSL) is a multi-user research facility on board the Columbus Orbital Facility (COF) dedicated to investigations in fluid physics under Microgravity conditions. It can be operated in a fully automatic or semi-automatic mode on the station by the flight crew or remotely controlled from ground in Telescience mode. This essentially resulted in a highly modular concept allowing for continual upgrades of the system capabilities throughout its defined operational lifetime. All these drawer-like modules are integrated in an International Standard Payload Rack (ISPR).

MARS as FRC (Facility Responsible Centre) has the possibility to control FSL totally from ground increasing dramatically its operability in space ensuring, during the nominal operations, the complete independence of the experiment conduction from the onboard crew. These enormous capabilities offered by the equipment impose, on the other hand, a complex interaction between the users and the laboratory for the monitoring of all the processes running in parallel.

On March '06 the Fluid Science Laboratory, after 8 years of development carried out at Thales Alenia Space Italia, was integrated into the Columbus Orbital Laboratory, located in Bremen, and completed the testing activities together with the other European Facilities developed to perform scientific microgravity experiments. In the meantime, the FSL Science Reference Model was hosted in the MARS laboratory for scientific activities based on the use of the optical diagnostic of FSL Few months later, the FSL Engineering Model, another 500 Kg of equipment, was entering slowly into its dedicated clean room to start the preparatory phase for the operative support to the flight unit planned for the next decade. Furthermore, a FSL Training Model was delivered to ESA Astronaut Center in Cologne (D) for supporting the Columbus crew training. Up to now FSL is the most sophisticated Microgravity Laboratory realized.

INTRODUCTION

This paper intends to illustrate the main activities performed in the last years which led from the development of the Fluid Science laboratory up to the final preparation to utilization in the Columbus module.

The activities performed by Payload Developer and the USOC in coordination with the ESA and the Industrial Operators Team are an example of successful synergy between entities with different roles and objectives, but all committed to one goal:" the FSL utilization on-board the International Space Station shall be a success story".

THE FSL DEVELOPMENT

The Fluid Science Laboratory (FSL) is a multi-user research facility on board the Columbus Orbital Facility (COF) dedicated to investigations in fluid physics under Microgravity conditions.

It can be operated in a fully automatic or semi-automatic mode on the station by the flight crew or remotely controlled from ground in the so-called Telescience mode.

The design concept of the FSL facility is based on user requirements as well as the Space Station utilisation requirements and constraints.

This essentially resulted in a highly modular concept allowing for continual upgrades of the system capabilities throughout its defined operational life-time. All these drawer-like modules are integrated in an International Standard Payload Rack (ISPR).

FSL Flight Model has been successfully integrated and tested in Columbus during the first and second I&T campaigns in 2004 and 2005.

After the first Columbus I&T campaign, ESA requested to extend the C/D contract to a Program Extension Phase in order to implement additional instrumentation in support of the fluid science experiments and to improve the already existing functions. Final delivery of FSL FM took place on November 2005.

MVIS, the Microgravity Vibration Insulation System of the Canadian Space Agency, has been enclosed and FSL FM has been integrated and tested in Columbus in May 2006 in Bremen.

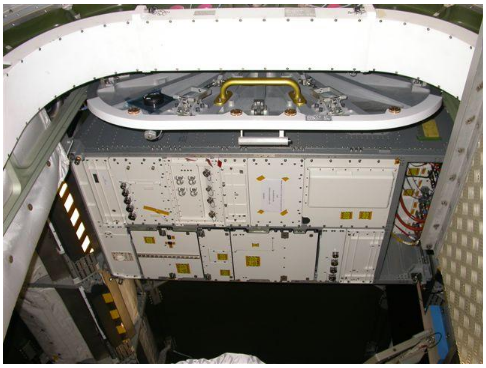

Figure 1 - The FSL Flight Model In the Columbus Module.

FSL and MVIS ground verification activities have been successfully completed in May 2007 at KSC; preparing it for upcoming launch.

Three additional models complete the developments performed by Thales Alenia Space Italia:

- The ***FSL Science Reference Model*** is used to support on ground preparation and validation of experiments and the preliminary definition of hardware and software. The SRM's configuration emulates the Flight Model providing similar equipment. The FSL SRM has been delivered to the FSL FRC on November 2004.

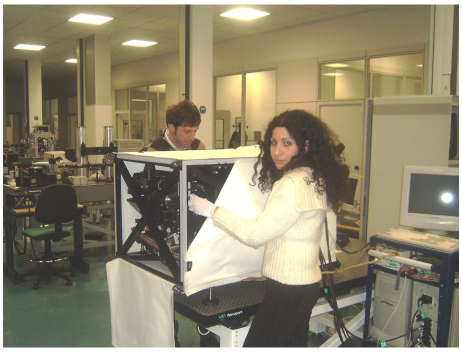

Figure 2 - The FSL Science Reference Model at MARS

- The ***FSL Engineering Model*** is a fully functional unit and has been subject of a refurbishment plan in order to align it to the upgraded Flight Model. The qualified EM has been delivered to the MARS on June 2006.

Figure 3 - The FSL Engineering Model In the MARS Clean Room

- The ***FSL Training Model*** is designed to provide flghtlike crew interface and to allow the representative reproduction of the FSL on board crew operations in order to support training activities. The FSL TrM has been delivered on December 2003 to the ESA/EAC in Cologne; upgraded model has been released on September 2007.

Figure 4 - The FSL Training Model at European Astronaut Center - in Cologne

FSL SRM AND EM UTILIZATION

In order to assist present and future FSL users, some case-study experiments have been devised and performed with the available FSL models, to achieve a deep feeling about the performance of its optical diagnostics.
Following this preliminary phase, a group at MARS have conceived a new experiment that takes advantage of the FSL diagnostics **[1]**. The experiment has been performed with FSL SRM. Its scientific objective was to investigate the behaviour of electric charges within an insulating liquid, under the combined action of an external electric field and of liquid flows [See Ref.]. But in reality the experiment had a manifold purpose:

1. To serve as a practical test bed for any future FSL experiment preparation.

Under this aspect the experiment serves as an opportunity to show how some of the FSL diagnostics and mechanical constraints can be tested since the very preliminary phases of an experiment definition, without the need to access the FSL EM.

2. To compare the performance of different optical diagnostics, which are available in FSL.

Given a physical phenomenon, with the FSL ground models, one has the possibility to evaluate in advance how the FSL diagnostics perform in that particular case and to properly design his experiment container.

3. To demonstrate the feasibility of shadowgraphy.

Such technique is not foreseen by any of the automatic optical modes that are selectable with FSL, nevertheless an ad hoc procedure has been set up to perform it by means of the available FSL diagnostics.

4. To give new insights of the investigated charge transportation mechanisms.

Such mechanisms may find an application in different fields such as, e.g., novel, alternate electrophoresis techniques, and represent also an additional means to modify the shape of free liquid surfaces in space.

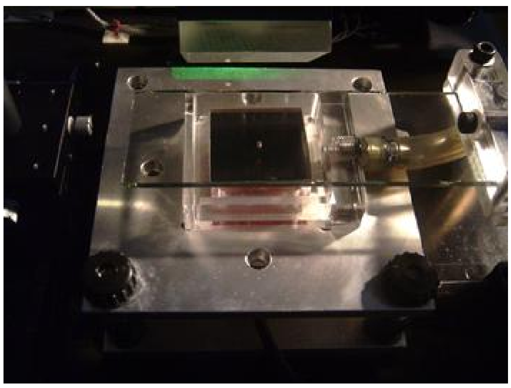

Figure 5 An experimental cell purposely built for the FSL SRM. This FSL model has the advantage to allow preliminary

tests in an FSL-like environment, without the risk to damage the FSL EM.

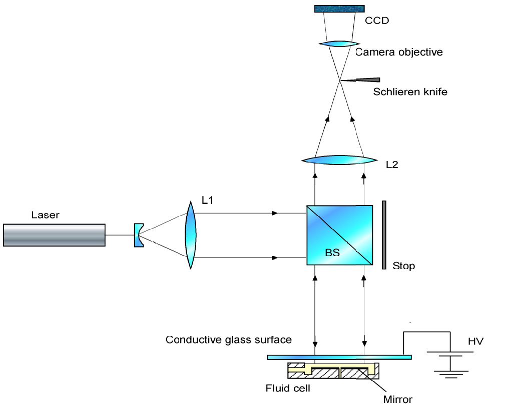

Figure 6 – Sketch of the Shlieren/shadowgraphy setup available in FSL. The Shlieren knife can be removed to perform shadowgraphy. The Fluid cell sketched in the drawing is that of the previous figure.

ESA DECENTRALISED PAYLOAD OPERATIONS CONCEPT

For the phase of routine operations of European Space Agency (ESA) payloads on the ISS, the user support and payload operations infrastructure makes use of a decentralised architecture (Figure 5).
Payload operations on the ISS will comprise the operation of the Microgravity Facilities for Columbus (MFC) (i.e. BIOLAB, FSL, MSL, EPM) and the European Drawer Rack (EDR), as well as the operation of externally mounted payloads.
The decentralized approach to ESA operations on ISS relays at least on the following three main points **[2]**:

- Nationally funded User Support and Operations Centres (USOCs) exist and have offered to be involved in the ESA payload operations activities.
- More than a hundred Principal Investigators (PIs) with their respective scientific group are expected to be involved in a single mission increment with a typical duration of three months of in-flight operations.
- The payload operations onboard are continuous and are mainly characterized by the operations of ESA facilities.

The most important building blocks of this decentralized organization are the Columbus Control Center (COL-CC) and the USOCs.

Columbus Control Centre (COL-CC)

The Columbus Control Centre (COL-CC), located at DLR/GSOC, Oberpfaffenhofen, Germany, will provide the necessary co-ordination functions for conduct of payload operations on the ISS **[3]**.
It is the job of teams located at the Col-CC to collect, co-ordinate and consolidate inputs from the payload operations teams with respect to real-time and near-real time activities.
The Col-CC provides a point of contact to the partner's operations centres **MCC-H** (Mission Control Center – Houston), **POIC** (Payload Operations Integration Centre), **MCC-M** (Mission Control Centre – Moscow) for issues affecting the whole ESA payload complement. For other issues related to the ESA payloads located on the ISS the Col-CC co-ordinates responses with the operations management personnel.
During operations execution the Col-CC will be the unique responsible for the Columbus Module, while for what concerns the payloads it will be in charge of monitoring and co-ordination of operations for the ESA payload complement on the ISS, and of communications co-ordination, which includes the communications between the flight crew and European users and the communication network management between the ground centres (e.g. USOCs).

User Support and Operations Centres (USOCs)

The USOCs play an important role in linking the science user community to the ISS utilisation. With decentralised USOCs it is ensured that focal points for the preparation and the conduct of ESA payload operations are created which are both very close to the payload operations on-board ISS and the scientific user groups **[3]**. The centres will be outfitted with a set of ESA provided standard services. This includes the implementation of communications capabilities and the provision of Engineering Models (EMs) and Science Reference Models (SRMs).
Depending on the scope of the task assigned to a USOC, it will be a Facility Responsible Center (FRC) or a Facility

Support Center (FSC): The FRCs will have sufficient knowledge of the functionality of the facilities allocated to them, that they can operate the payload in flight. The FRCs will be primarily responsible for operating their payload rack at system level. If specific knowledge and particular interest in a subsystem exists in a country other than the country where the FRC is located, or if a sub-system of a facility is contributed by a member state that is not the FRC country, then a center of that country can be associated with the FRC as an FSC. An FSC will operate a facility at sub-rack level.
ESCs will be evoked for the operations preparation and flight operation execution of individual experiments contained in the facility.

ISS European Ground Segment and Ground Communication Network

The ESA provided ground communication system comprises four main aspects with the following major services:

- The Wide Area Network Services (IGS-WAN) are based on VPN (Virtual Private Network) technology and include ESA relays located at international partner sites, IGS access nodes in Europe and data transport services, such as data voice and video for Columbus, Automated Transfer Vehicle (ATV) as well as for any other European ISS utilisation within the US Lab or the Russian Lab. The IGS provides the communications infrastructure connecting the user centres for operations. The IGS includes management of the network to ensure proper end-to-end communications for the various centres.
- The Data Services System (DaSS) represents a uniform interface to European users for the exchange of telemetry and telecommand, based as far as possible on CCSDS standards. It provides telemetry (raw and processed) distribution, user command handling services, as well as a de-multiplexing service at the Columbus CCSDS Gateways at the international partner sites.
- The Voice Conferencing System (VoCS) provides access to any operational voice loops as well as to A/G and S/G loops. VoCS offers storage, archiving and retrieval of selected voice loops. Col-CC provides keysets for USOCs and for a limited number of UHBs
- The Video Distribution and Conferencing System (ViDS) supports the reception and distribution of ISS video to the USOCs via the IGS network. Users can retrieve video data from the Col-CC via file download / IP (Internet Protocol) streaming. Video conferencing services are offered for all ground segment sites.

The main technical interfaces for all User Support centres will be implemented via the physical connection to the ESA IGS-network. This implementation will allow connection between all Sites, which are provided with an IGS-node for the purpose of communications and data exchange.
The IGS forms a private network using Telecommunications Provider furnished communications networks (ATM and ISDN services, in conjunction with ESA-provided IGS Nodes, which are installed at each participating facility). The IGS nodes provide communications termination, routing and management facilities.

The Figure 5 gives an overview of the IGS and the relationship between IGS nodes, MSM-GS centres and the IGS network **[4]**.

The HR-TM follows a different route to the USOC(s). Also the HR-TM comes down via the HOSC and is also de-multiplexed by the DaSS equipment at the HOSC. However the full data recovery to CCSDS packets and Image packets is no longer performed on the HOSC. The end-to-end implementation approach provides the use of common technology at all sides minimising the requirements for network and service management and for maintenance.
The European operations infrastructure, with its communications network, data services and management and co-ordination functions will provide services for all European payloads on the ISS, irrespective of their location. This objective is summarised in the following two basic requirements:

- All payloads will use the ESA ground communication system (IGS)
- All ESA payloads on the ISS will use the Data Services System (DaSS)

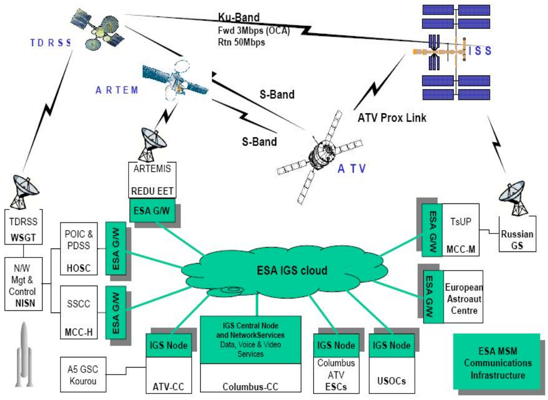

Figure 7 Overview of the ISS ground segment.

OPERATION PREPARATION FOR INCREMENT 16

The FSL operations preparation concerns the development of all the products needed to correctly operate the facility and to correctly interact with the other entities involved in the COLUMBUS operations, as well as the staffing of a trained team for the on console operations.

Operational Products:
The operations products fall in four different categories.

FSL operations:

- Payload Operations Data File (PODF)
- Experiment Procedure (EP)

MARS has managed the development and the validation of the PODF products that presently are in their final version according the ESA/NASA process. Moreover MARS is supporting the EP testing and validation phase (whose development is under the GEOFLOW PD responsibility)

Operations Safety:

- Operations Hazard Control Matrix (OHCM)
- Hazardous Command

MARS is responsible for the Operations Safety for FSL. In this role MARS has developed and maintains the OHCM and has supported the identification of the FSL hazardous commands.

Interaction the other entities

- COL CC Joint Operations Interface Procedures (JOIP)
- MARS/FSC/ESC Joint Operations Interface Procedures
- Flight Rules (FR)/Payload Regulations (PR)

MARS has supported the development of the COL-CC JOIP, presently under review for the final publication, and is working to the definition of analogues procedures for the interactions with the E-USOC, ALTEC and the CSA. The document is presently under work and it will be finalised for the end of October. One FR and four PR have been identified for FSL discussed and approved in dedicated review sessions managed by COL CC.

Activities Planning

- FSL/Experiment Activities Planning

MARS supports the development of the Columbus activities timeline for the I16. Presently the final OOS has been finalised by EPT on the basis of the so-called Planning Requests provided by MARS planners. The process leading to the development of the WLP and subsequently of the OSTP has started.

On console operators team
The real time operations are managed with three teams that allow the coverage of up to 24 hours per day. Each team is composed of

- Operation Leader (OPS Lead)
- Science Coordinator/System Support (SCICO)
- Ground controller (GC)

MARS has supported this process from the definition of a training plan, to the participation to the JMST. Two Ops lead are presently certified for the I16 Operations. The third Ops Lead will be certified in October. All the other team members are already to operate as GC or SCICO.

CONCLUSIONS

The FSL represents, for what described above, one of the most sophisticated space facility ever developed. a number of scientists, from all over the world can perform experiments, sending commands and receiving data directly in their laboratories., thanks to FSL modular philosophy and the decentralized approach to operations.

It will be possible, through this approach, to maximize as much as possible the scientific results expected by the Fluid Science scientific community.
Currently the FSL ground segment is ready to support the FSL Operation during the commissioning phase and the subsequent first experimental activity on GeoFlow.
The process to achieve Certificate of Flight Readiness is initiated and will be complete with the final Operations Readiness Review in middle November.
Ops leads and supporting personnel are finalizing in few weeks the on-console certification process, and all the ops products are a the end of their validation process.
A new era of science opportunities will start on December 6th.

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