BACKGROUND

The Fluid Science Laboratory (FSL) - developed by Thales Alenia Space Italia (TAS-I) under ESA Contract - is a multi-user facility for conducting fluid physics research in microgravity conditions on-board the ESA Columbus Module at the International Space Station.

The Telespazio Science Systems & Applications Department is one of the European User Support and Operation Centers (USOCs), named as MARS USOC, and it has the role of the FSL Responsible Center.

The MARS USOC co-ordinates the operations of FSL, availing the engineering support of TAS-I Turin (which relies on the ALTEC Centre for most ground data communications services.

This paper reports on the operations carried out from ISS increment 24 to 30, to support the GEOFLOW experiment, with considerations on how operations are planned and then executed on a 24/5 days basis, on the FSL data generation and handling on board, on the interaction with the Spanish USOC, and how data are eventually downlinked to ground for further science processing and analysis.

The microgravity measurements - performed by the MVIS and MMA accelerometers installed inside FSL - supported the scientific operations, MVIS being also used as FSL active vibration isolation system.

The paper describes the lessons learnt over the relatively long operations support period and provides recommendations on how to enhance the overall FSL scientific throughput for future on-orbit activities.

I. THE FSL SYSTEM

The FSL facility is a multi-purpose modular facility designed for conducting fluid science experiments in space. It consists of different modules and equipment functionally and operationally integrated into one International Standard Payload Rack (ISPR). The FSL distributes ISPR utilities and specific locally generated services to the host fluid physics experiments and retransmits images, science data and housekeeping data for on board and ground processing.

Each experiment is hosted inside a dedicated cartridge, called Experiment Container (EC), designed and implemented under the Principal Investigators’ (PI) responsibility in order to be accommodated on orbit into the FSL Central Experiment Module (CEM) and to be operated in the Columbus pressurized environment via the FSL provided facilities.

Adequate conditioning and routing of the Columbus resources are implemented in order to support the following main FSL system functions: power conversion and distribution; communication and data processing, including data recording and playback; facility commanding and monitoring from ground and flight operator; tele science via ground centers; facility thermal control and fire detection; experiment stimuli diagnostics, resources and interfaces.

In order to allow the execution of a wide range of experiments, proper stimuli and optical diagnostics are provided by means of a set of interfaces and resources in a well-defined area inside the FSL volume for the accommodation of individual EC.
The Experiment Container (EC) is the real core of the facility, containing the fluid cell and all the ancillary equipment related to the experiment itself.

This part is completely experiment dependent; it is conceived by the scientist to include all the hardware and software to support the specific experimental features. The EC is hosted inside, and supported by, in the lower left part of the FSL module, the Central Experiment Module Lower (CEML), providing all the needed interfaces to the EC, and supporting part of the FSL optical equipment and microgravity measurement. The CEML is part of the Facility Core Equipment (FCE).

The CEML drawer contains the Experiment Container with its functional interfaces (power, data, cooling) and provides a feed through panel for the EC interface connections in addition to a variety of diagnostics systems:

- laser and white light sources for background and sheet illumination (with suitable optical systems and moving prisms to create two perpendicular movable light sheets in the EC),
- CCD cameras
- tilt able mirror assemblies
- Microgravity Measurement Assembly (MMA).

II. FSL MAIN ACHIEVEMENTS DURING LAST TWO YEARS

GEOFLOW-II

The core of the GEOFLOW-II experiment may be seen as a miniaturised representation of the Earth. Silicone oil is held between two concentric spheres, which rotate around a common axis. A high voltage difference between the spheres creates a force field which plays the role of gravity and – by holding the inner sphere at a higher temperature - creates an Earth-like temperature gradient from inside to outside.

Understanding the flow of the silicone oil under different conditions is of importance to scientific areas such as the flow in the atmosphere, the oceans and the movement of Earth's mantle on a global scale, as well as other astrophysical and geophysical features. Results from GEOFLOW are also useful for making improvements in a variety of engineering applications, such as spherical gyroscopes and bearings, centrifugal pumps and high-performance heat exchangers.

The scientific data for all the experiment runs have been down linked to the Columbus Control Centre and forwarded to the responsible User Support and Operations Centres, in Italy (MARS) and Spain (E-USOC), and to the science team.

FIRST CAMPAIGN

The ESA Astronaut Paolo Nespoli installed GEOFLOW-II experiment container in the FSL CEM Lower on March, 19th 2011.

![Paolo Nespoli during the installation of GEOFLOW Experiment Container on March, 19th 2011.](image1)

Fig. 2: Paolo Nespoli during the installation of GEOFLOW Experiment Container on March, 19th 2011.
hours basis from Monday to Friday. A typical GEOFLOW run was based on changing the temperature difference between two rotating spheres, or on changing the rotation speed of one of the two spheres being the temperature difference fixed. The applied electrical field was instead unchanged.

The scientific campaign had to be halted in mid July 2011 due to equipment problems. At that stage, however, 25 scientific runs had been successfully completed and about 100 GBytes of image data generated.

THE VMU HYBRID CONFIGURATION

The ISS Astronaut Satoshi Furukawa performed the exchange of the VMU Hard disks successfully on Sept, 6th 2011. The VMU SW was upgraded too in order to manage the higher capacity of the hard disks.

In order to check the upgraded VMU, MARS performed completely from ground (full remote control test) a 5 days test that was named as “VMU Hybrid Configuration Test”. The VMU hybrid configuration was indeed the beginning of a new operations concept for the FSL and was considered as the road map for all the other experiments to follow. To verify the upgraded Video Management Unit, a test plan was prepared based on a GEOFLOW experiment procedure in order to stress the higher capacity hard disks. The size of the two disks was upgraded to 146 GBytes each, whereas the digital tape recorder was kept unchanged. Being the tape recorder not useful for operations, MARS decided not to use the data backup functionality, but only to downlink via HRDL all data (image and acceleration data) once each scientific campaign planned in microgravity has filled the overall size (288GB) of the hard disks. Both images and MMA data have been recorded on VMU HDDs during the hybrid configuration test. Both data were then downlinked to Earth and stored in the MARS ground segment archive. The post-processing analysis indicated no data corruption. About 105 Gigabytes of data were successfully downlinked via HRDL @10Mbps since DOY 255/2011. The MVIS acceleration data acquisition system was also activated in order to additionally challenge the VMU functionality.

With over 89 hours of continuous operations, the hybrid configuration test was completed and considered as a full success. A check of the GEOFLOW-II experiment container functionality was performed some days later and FSL was next declared ready to restart GEOFLOW-II campaign.

The opportunity to use the MVIS, instead of MMA, to monitor the accelerations and the vibrations generated while performing the scientific runs was assessed though comparison with the NASA SAMS Sensor.

SAMS sensor F08 was also installed on ODM Front panel and the acceleration data were acquired in parallel with the acquisition of MVIS accelerometers. The data qualitatively resulted in good agreement. The MVIS sensor was next decided to be used as microgravity data measurement system, Thanks to the CSA (Canadian Space Agency) support, as responsible for the MVIS technology. Before downlink MARS must transfer the MVIS data from MVIS to VMU via rt/rt protocol. This approach affected the operational effort, but it was considered feasible to carry out an additional GEOFLOW-II campaign.

GEOFLOW SECOND CAMPAIGN

The GEOFLOW-II scientific runs restarted on Sept, 20th, 2011 with MVIS configured to acquire data at 750Hz. That rate was driven by the GEOFLOW-II
requirement to collect microgravity data in the range between 0 and 300 Hz.

MARS and the Spanish USOC were able to perform further 38 scientific runs, generating about 650 GBytes of images and about 30 GBytes of MVIS data. The GEOFLOW-II scientific campaign was completed when the last set of GEOFLOW set points were accomplished on May, 7th 2012.

GEOFLOW-II was running in total from March, 19th 2011 until May, 23rd 2012. The total science run time was about 1300 hours (the baseline requirement was ~650 h mandatory runs + 650 h as nice to have). A significant amount of data (some 984 Gbytes) was generated and stored on the VMU.

On the bases of the good results obtained during the described GEOFLOW-II campaign, a set of additional runs was requested by the GEOFLOW science team, to complement and expand the GEOFLOW II research campaign. Their execution is currently foreseen to start on December 2012 for some additional 7 weeks of on orbit operations, during Increment 34. The same EC already integrated in FSL will be used, the only difference being the application of different central force field accelerations, changing the rate of picture acquisition and applying different temperature gradients.

The Increment 36 foresees the integration of a new EC in FSL, namely the ESA FASES experiment.

The FASES project studies the stability of the emulsions, and aims at reducing the gap between the physical chemistry of the droplets interface to the collective properties of an emulsion, which are now only qualitatively known. In particular, the additives (particles and surfactant) in emulsions to improve stability can hardly be studied on ground because of the gravity affecting the physical properties.

The FSL is currently undergoing specific hardware and software enhancements in order to eliminate few operational glitches and even further increase the system flexibility.

### III. OUTLOOK ON FSL FUTURE UTILIZATION

The FSL is one of the most sophisticated and complex space facilities ever developed. Based on multi-user capabilities, integrating very sensitive optical diagnostics, hosting the exchangeable largest experiment containers ever designed, the FSL represents the leading edge of the European technology in space. The possibility to totally control it from ground significantly contributes to expand and enhance the on-board crew time usage options.

The FSL on-orbit activities are proceeding as planned, by effectively securing the FSL scientific performances.

### IV. CONCLUSIONS

The FSL on-orbit activities are proceeding as planned, by effectively securing the FSL scientific performances.

#### II.II References

None