61st International Astronautical Congress, Prague, CZ.

IAC-10-A2.7.2

RESULTS AND EXPERIENCES FROM THE SODI-IVIDIL EXPERIMENT ON THE ISS

A. Rodríguez
Spanish User Support and Operations Centre (E-USOC), Spain arodriguez@eusoc.upm.es

J. Rodríguez, A. Laverón-Simavilla[*], V. Lapuerta[t]

E-USOC is the Spanish User Support and Operations Centre, one of the ten similar centres distributed at different locations in Europe. These centres perform the operations of experiments on-board the Columbus Module, the main contribution from the European Space Agency (ESA) to the International Space Station (ISS).

By the end of year 2008 E-USOC started to work on a new endeavour. The preparation of the necessary products to operate the first of three experiments to take place on the Selectable Optical Diagnostics Instrument (SODI) payload: the IVIDIL experiment (acronym for Influence of VIbrations on DIffusion of Liquids). SODI is a payload built by the European industry that after being launched on 28th August 2009 by Shuttle Discovery was mounted inside NASA's Microgravity Science GloveBox (MSG), at ESA's Columbus Module. The basic principle of SODI design is to have a modular instrument equipped with various optical diagnostics, such as Mach-Zehnder Interferometry, Particle Image Velocimetry and Near Field Scattering.

The SODI-IVIDIL experiment studies the influence of controlled vibration stimulus (slow shaking) on diffusion in liquids in the absence of convection induced by the gravity field. Researchers plan to characterize the spectral influence of g-jitter to increase the understanding of the kinetic mechanisms influencing diffusion effects in the presence of vibrations, therefore allowing for more successful science to be operated onboard ISS.

IVIDIL was installed by Frank de Winne (ESA) and Robert Thirsk (CSA) on September 23rd, 2009. E-USOC began operations on this payload on October the 1st. From E-USOC, in a 16h/5d basis, operators have monitored and controlled the payload. A total of 57 scientific runs were successfully performed, generating 82439 scientific images and telemetry logs for around 1070 hours of experiment. On January 28th 2010, Soichi Noguchi (JAXA) deinstalled IVIDIL, successfully concluding a particularly demanding mission, where close coordination with the MSG team at NASA's Payload Operations Interface Center (POIC) was needed.

This paper will present a brief summary of the principles of the IVIDIL experiment, as well as the characteristics of the SODI payload and its interfaces with the ground equipment. Also, the work done by E-USOC in terms of preparation of procedures, displays, and setting up of the ground environment will be exposed. To conclude with outcomes of the mission, as well as lessons learned and conclusions.

I. E-USOC ROLE IN COLUMBUS OPERATIONS

The Columbus Laboratory was successfully launched on the 7th of February 2008 on Space Shuttle Atlantis. Once this module was attached to the International Space Station, the first European laboratory for long term experiments on microgravity became a reality, being the biggest contribution from ESA to the ISS.

The Columbus module hosts several International Standard Payload Racks (ISPRs) dedicated to the research on different scientific fields. One of these racks is the Microgravity Science GloveBox, owned and operated by NASA, which accommodated and provided the necessary resources to the SODI-IVIDIL experiment, one of E-USOC's latest missions.

For the preparation and execution of the operations of the different experiments carried out on board Columbus, ESA adopted a decentralized approach based on User Support and Operations Centres (USOCs). These centres are distributed over different ESA countries in Europe. The diverse payloads and the manifold experiments taking place on them are assigned to the USOCs, based on their areas of expertise. As per this concept, the Spanish User Support and Operations Centre (E-USOC) acts on behalf of ESA as responsible of the IVIDIL experiment. Located in Madrid, Spain, it provides an interface between the scientific community –real users of the facilities on board the Columbus laboratory- and the ISS: The scientific data from IVIDIL is downlinked from Columbus on orbit to ground and distributed to E-USOC via NASA's Payload Operations Interface Center (POIC), responsible for the operation of MSG. In a similar manner, commands are sent to the facility, following the inverse path.

[*]Spanish User Support and Operations Centre, Spain {jrodriguez, alaveron}@eusoc.upm.es
[t]Universidad Politécnica de Madrid, Spain mariavictoria.lapuerta@upm.es

II. THE SODI-IVIDIL EXPERIMENT

The SODI instrument is a project funded by ESA which, with its modular design, provides optical diagnostics for fluid samples of different nature. The IVIDIL experiment, in particular, aims at the study of the influence of vibration on the diffusion phenomena in liquids in the absence of gravity. Binary mixtures of water and isopropyl alcohol, in different concentrations, are used as experimental samples. Two cell arrays were developed, each containing a primary cell with an experimental sample and a companion cell for reference measurements. The cell arrays are equipped with Peltier elements that allow establishing a controlled thermal gradient in the cells, thus originating the diffusion phenomena. A shaking mechanism provides the required vibration to the cell arrays, while SODI optics perform simultaneous Mach-Zehnder interferometry and digital holography observations in the primary and companion cells, respectively.

The experiment allows control over three scientific parameters:

1) Temperature gradient in the cells
2) Vibration amplitude
3) Vibration frequency

Different combinations of these parameters are scanned in experimental runs following a pre-defined schema, summing up a total of 41 runs (39 x 18.5 hours and 2 x 33.5 hours). Telemetry from the experiment is sent to ground in real-time and recorded on-orbit by the SODI instrument, together with the scientific images taken by the optics.

The Microgravity Science GloveBox, hosting the SODI-IVIDIL hardware, provides the experiment with the necessary power, cooling and data interfaces. Being the IVIDIL experiment very sensitive to external vibrations, accelerometers installed inside MSG are used to acquire data on microgravity disturbances in parallel to the science runs.

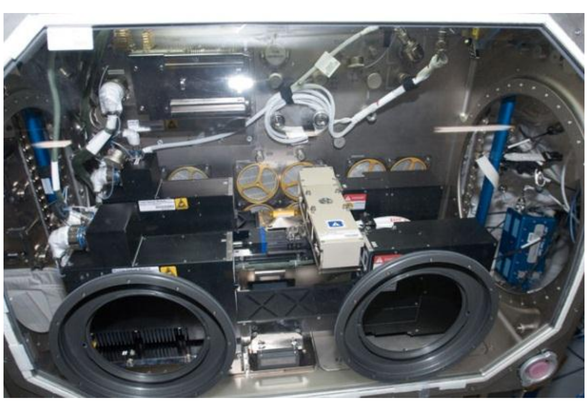

Fig. 1: SODI-IVIDIL hardware in MSG.

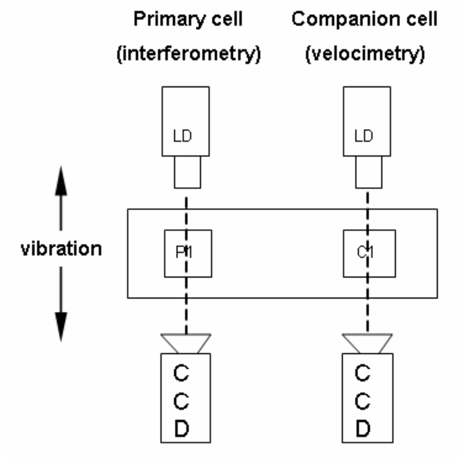

Fig. 2: IVIDIL cell array, composed of a primary cell and a companion cell.

Two main scientific teams participate in the project, led by Valentina Shevtsova, from ULB-MRC, in Belgium, and Ziad Saghir, from Ryerson University, in Canada.

III. OPERATIONS CONCEPT

An operations concept was developed at E-USOC for the SODI-IVIDIL experiment, with the main goal of fitting the scientific requirements into the operational constraints of the ISS environment, and specifically of the MSG, taking into account the resources allocated to the mission.

Being crew time one of the most valuable resources on the ISS, crew intervention for IVIDIL was minimized, and only required for the purely mechanical activities. Once crew had installed the SODI-IVIDIL hardware in MSG, science operations were to be conducted by the E-USOC ground operators, using displays to monitor and command the experiment.

IVIDIL experiment runs need to be performed according to a pre-defined scientific timeline: specific heating, diffusion and vibration times are imposed, and need to be repeated consistently over the different runs. Due to the non-continuous signal coverage from the ISS, it is not possible to achieve this purely by sending commands from ground, making this type of experiment very suited for script based execution. Thus, scripts are developed which, when run by the SODI software on-orbit, automatically conduct the experimental runs. The ground operators command the start of the relevant script and monitor its execution by means of ground displays. Some flexibility and control capabilities are implemented in the following ways:

- Modifications to the scientific parameters are possible by uplinking a modified script file to the SODI file system on-orbit.

- Executing a specific part of the script code allows adapting the order in which the experimental runs are performed, without requiring the modification of the script file.

Additionally to the real-time telemetry received from the experiment, a subset of the scientific images stored by the SODI instrument on-orbit are downlinked during the execution of the runs, which allows a quick assessment of the experiment progress and possible needed changes (e.g. scripts modifications), both from a scientific and engineering point of view. The image files are retrieved from the SODI file system and transferred to MSG by the E-USOC operators; then the MSG operations team at POIC downlinks the files, and once they are on ground distributes them to E-USOC. Thus, an effective coordination is required between the E-USOC and MSG teams for these downlink operations.

The flash disks in which SODI stores the IVIDIL scientific data (images and telemetry log files) would be returned to ground as the primary way to deliver the complete experiment data to the science team. One of the main EUSOC tasks is to provide the science team with reliable and consistent data. These data products would consist of:

- Telemetry reports, containing complete records of the status on all the parameters needed to be studied by the science team (temperature reading from the cells, vibration amplitude and frequency, optics parameters…). The telemetry timestamps would be used to match each scientific image with the corresponding values.
- Scientific images, timestamped and grouped by runs with its correspondent MD5 checksum.
- Microgravity vibration data from the ISS sensors. These data would be retrieved from the NASA repositories and distributed to the science team, giving them information on the microgravity levels and possible disturbances on-orbit during the execution of the runs.
- IVIDIL Plans/Schedules. Information on start time of the activities, estimated duration, etc. in order to increase the scientists' awareness on the on-going operations.

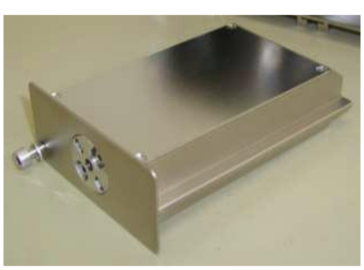

Fig. 3: SODI flash disk unit.

IV. OPERATIONS PREPARATION

The operations concept described in the previous section was used as the baseline upon which all operations products, on-orbit activities planning and overall operations setup were developed at E-USOC. The activities performed are summarized hereafter:

a) Coordination and iteration with the scientific team, making sure all requirements and experimental constraints are properly understood and implemented. The main outcome of these iterations is an experiment execution plan which integrates the sequence of runs to be performed into an operations calendar, detailing which runs are performed each day, which sets of scientific parameters are used and the downlink/backup strategy.

b) Coordinate with POIC planners to schedule the necessary on-orbit activities to be carried out for the execution of the experiment and define the resources needed for them.

c) Coordinate with POIC for the development of crew procedures.

d) Development of procedures for ground command operations.

e) Validation of these procedures with the Engineering Model: check their feasibility, execution time, verify the payload telemetry and telecommand database…

f) Support ESA Safety in the review and implementation of safety aspects related to the SODI-IVIDIL hardware and its operations, i.e. identification and control of all possible hazards both for the on board crew and for the hardware.

g) Development of displays for E-USOC operators' use, to command and monitor the execution of the experiment and verification of its concurrence with the payload telemetry and telecommand database.

h) Provide each scientific team with a User Home Base (UHB). This includes the setup of the needed communication links and tools (e.g. displays) that allow them to follow the on-board operations from their premises.

i) Provide the Payload Developer with a User Home Base (UHB) to give remote engineering support for SODI-IVIDIL during the operations.

j) Ground Segment verification tests, validating E-USOC ground segment tools and interfaces with external entities (POIC, UHBs…).

k) Development of procedures for the operational interfaces between the different teams.

l) Ground operators training and simulations.

m) Execution of an Experiment Sequence Test: an end-to-end test was performed using the SODI-IVIDIL Flight Model and the MSG Engineering Model to verify that the integrated operational setup (operational and technical interfaces, systems, tools…) were ready and adequate to support the operations.

V. OPERATIONS EXECUTION

The SODI-IVIDIL hardware installation in MSG was completed successfully by Frank de Winne (ESA) and Robert Thirsk (CSA) on September 23rd, 2009. On October the 1st SODI was activated and E-USOC performed with success a checkout activity verifying that all SODI-IVIDIL systems were working as expected. Starting on October the 5th, the IVIDIL experiment operations were conducted from E-USOC, completing with success a total of 57 scientific runs in two blocks, one for each cell array, until the SODI-IVIDIL hardware was removed by Soichi Noguchi (JAXA) on January 28th 2010.

The final experiment duration was much longer than initially expected, for several reasons:

Resources limitations

Resources constraints implied that, on specific periods, either the MSG microgravity sensors, or the complete MSG rack could not be powered. Although nothing could be done in the latter case, the need for microgravity measurements was revised by the science team, relaxing the requirement for those runs which were less sensitive to external disturbances, thus minimizing as much as possible the impact of these limitations in the experiment plan.

ISS maneuvers

Due to the sensitivity of the IVIDIL experiment to microgravity disturbances, runs were not scheduled during events like ISS thruster firings (e.g. for reboost operations), docking and undocking of visiting vehicles, debris avoidance maneuvers, etc. Scheduling changes in these events had an impact in the experiment plan. In the worst case, unexpected events led to the interruption of the on-going run, which had to be repeated from the start later on.

System malfunctions

SODI system malfunctions appeared on occasions, affecting the on-going experimental run. The consequent troubleshooting time and the repetition of the affected run caused delays in the overall experiment plan.

Scientific value

Given the very good scientific results reported by the science team after the nominal experimental runs, more runs were added to the plan, some with new parameters and some repeated from previous runs for statistical purposes. In total, 57 runs were performed (41 were initially foreseen).

In order to adapt to these changes in the plan, the experiment scripts had to be modified by E-USOC on several occasions during the experiment operations. Each of these changes implied script development activities on ground, validation with the Engineering Model, files verification by the MSG team and the processing of the request to uplink the new files to the ISS. A very successful coordination was performed between the different teams (ESA, E-USOC, POIC, science team, payload developer) in order to prevent these processes from interfering and delaying the on-orbit operations.

The two SODI flash disk units used for the IVIDIL experiment were returned to ground, and the science data processed by E-USOC and successfully delivered to the science team in April 2010.

Number of runs	Total recorded images	Total recorded data (MB)	Images downlinked in near real-time
57	82439	164878	15815

Table 1: SODI-IVIDIL experiment data summary.

VI. MISSION OUTCOMES

Since the SODI-IVIDIL experiment was installed in MSG in September 2009, and until its removal in January 2010, 57 runs were performed with success for a total experiment duration of around 1070 hours, generating 165 GB of good quality scientific images.

From a scientific standpoint, the initial objectives of the experiment were fully accomplished, and the experimental program extended by almost 50%. Very positive feedback has been received from the science team on the data gathered during the experiment operations.

From an operational point of view, the mission is also considered by E-USOC as a great achievement and a very valuable experience: the complex mission environment, involving numerous teams with different responsibilities on NASA and ESA side, required the proper level of coordination, both during the experiment preparation and execution. As an example, even though some technical problems were present on occasions during real-time operations, they did not prevent the continuation of the experiment, and the teams worked hard in finding solutions or work-arounds to all of them.

The following lessons learned can be highlighted:

A. Crew Activities

The level of real-time support and feedback offered by some of the crew members who participated in SODI activities helped importantly in increasing the level of awareness of the ground operators, allowing them to quickly understand issues whenever they appeared, and to provide the necessary feedback. This included:

- Regular reporting on activity progress and status.
- Reporting on stowage information which differs from the original stowage plan.
- Use of imagery to support the activity: digital pictures, live video.

B. Automated operations

The use of scripts was almost the only feasible way to comply with the scientific requirements of the IVIDIL experiment. Additionally, risks were kept to the minimum when the scripts were running autonomously, and issues mostly appeared during the commanding periods before their execution. However, such a level of automation can also introduce heavy workloads and possible delays when changes are required, even if they are not significant (e.g. changes in the values of the scientific parameters). This should be taken into account when developing the payload software, the scripts and the procedures and tools to use them, so that the necessary flexibility is allowed without introducing significant risks.

C. Teams coordination and support

Having a good coordination and support to and from the payload developer and the science team is vital for being able to deal with issues in real-time with very little or no impact on the on-orbit operations. In this regard, having the two teams providing on-site support at E-USOC during the first days of operations, and proper and regular reporting from E-USOC (on a daily basis), proved to be invaluable for the awareness and involvement of all the teams during on board operations.

VII. CONCLUSION

The SODI-IVIDIL experiment was installed in MSG by the ISS crew in September 2009, and until its removal in January 2010, more than 1000 hours of experiment were performed, completing 57 runs and delivering 165 GB of data for the science team. Preparing and executing this experiment on board Columbus was a challenging mission, only possible with a good cooperation and coordination between all the multiples entities involved in the process, with different responsibilities and aims. The scientific achievements in this case surpassed the expectations, both in terms of quantity and quality of the data, and thus this mission is considered an important success and an invaluable operational experience for the E-USOC team.

The second SODI experiment, called COLLOID, will be uploaded to the ISS with the Progress 39P flight, and will be conducted by E-USOC starting on September 14th 2010.

ACKNOWLEDGMENTS

The authors would like to thank the Centro para el Desarrollo Tecnológico Industrial (CDTI) (The Centre for the Development of Industrial Technology) for the opportunity to work on projects such as the one described in this paper.

REFERENCES

[1] Baseline Definition Document (BDD) for User Operations and Support Centres, PLOPSESABDD-001-100, Issue1, rev2, 12 December 2001.

[2] IVIDIL Experiment Scientific Requirements, SCI-ESA-HME-ESR-IVIDIL, Issue 2, Rev0, 11 February 2007.