SpaceOps 2010 Conference
 <i>Delivering on the Dream</i>
 <i>Hosted by NASA Mars
25 - 30 April 2010, Huntsville, Alabama

AIAA 2010-1951

SOLAR Payload Operations: Achieving Flexibility to Support a Long Term Science Mission

Ségolène Brantschen[1]
Space Applications Services, Belgium

L. De Smet[2]
Space Applications Services, Belgium

Alice Michel[3]
Belgian Institute for Space Aeronomy (IASB/BIRA), Belgium

SOLAR is a European payload installed on the Columbus External Payload Facility (CEPF) and mounted on a Columbus External Payload Adapter (CEPA). This paper first presents the SOLAR payload and mission and then focuses on the progressive achievements of the Belgian User Support and Operations Center (B.USOC) towards adapting its initial operational concept to ensure sustainable support to the SOLAR mission. SOLAR was among the very first Columbus payloads switched on after Columbus installation in February 2008 and continues to perform science as of today. To maximize science return during a foreseen three year mission, the B.USOC had to adapt to the various constraints of real-time operations such as 24/7 on-console staffing, ISS constraints and interaction with Columbus Control Centre. Two major axes of improvement have been followed: first adapting on-console staffing to the various operational modes, and improving the flexibility of SOLAR activities planning.

I. Introduction

Upon decision made by the Manned Space Programme Board in 1998, ESA adopted a decentralised infrastructure for the operation of European payloads on board the ISS, based on the concept of User Support and Operations Centres (USOCs). The B.USOC (Belgian User Support and Operation Center) is a USOC set up by ESA and Belgium. The main role of the centre is to promote space research programmes and flight opportunities to the Belgian scientific community in universities and federal institutes. Subsequently, the B.USOC provides support to scientists concerning the definition, the development and the operation of their experiments.

One of the payloads for which the B.USOC is responsible is the SOLAR external payload. It is dedicated to tracking and observing the Sun and hosts three instruments: SOLSPEC, SOVIM and SOLACES. The payload was launched together with the European Columbus laboratory on the STS-122/1E flight in February 2008, and has been operating since that moment. The SOLAR operations are performed for teams of French, German, Swiss and Belgian scientists from the B.USOC by the Belgian Institute for Space Aeronomy (IASB/BIRA) and Space Applications Services.

---

[1] Operations Engineer, Operations Group, Space Applications Services, Leuvensesteenweg 325, 1932 Zaventem, Belgium, not an AIAA member.
[2] Operations Engineer, Operations Group, Space Applications Services, Leuvensesteenweg 325, 1932 Zaventem, Belgium, not an AIAA member.
[3] B.USOC ISS Operations BIRA Project Manager, IASB, Avenue Circulaire 3, 1180 Bruxelles, Belgium, and not an AIAA member.

II. Presentation of the SOLAR Payload

SOLAR is a European payload installed on the Columbus External Payload Facility (CEPF) and mounted on a Columbus External Payload Adapter (CEPA) developed by Boeing SPACEHAB in the frame of an ESA/NASA barter agreement on the Early ISS Utilisation. Apart from scientific contributions for solar and stellar physics, the knowledge of the solar energy irradiance into the Earth's atmosphere and its variations is of great importance for atmospheric modeling, atmospheric chemistry and climatology.

SOLAR consists of three instruments complementing each other to allow measurements of the solar spectral irradiance throughout virtually the whole electromagnetic spectrum, from 17 nanometers to 100 micrometers, in which 99% of the solar energy is emitted. The scientific instruments are:

1) SOVIM (Solar Variable and Irradiance Monitor) measures irradiance in the near-ultraviolet, visible and thermal regions of the spectrum (200 nanometers - 100 micrometers).
2) SOLSPEC (SOLar SPECtral Irradiance Measurements) covers the 180 nanometer - 3000 nanometer range with high spectral resolution.
3) SOLACES (SOLar Auto-Calibrating Extreme UV/UV Spectrometers) measures the EUV/UV spectral regime (17 nanometers - 220 nanometers) with moderate spectral resolution.

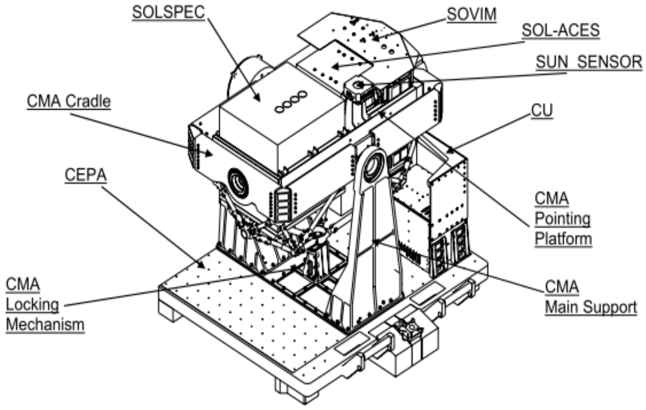

Figure 1. SOLAR Payload Overview.

The SOLAR instruments are mounted on a Coarse Pointing Device (CPD) for Sun pointing and make use of the CPD Common Control and Power Distribution Unit (CU) to get power, to collect, packet and dispatch to ground the Instruments generated telemetry data and to receive the ground issued telecommands and ISS data and timing synchronization. The CPD accommodates the instruments and provides the pointing capability thanks to a two-axis rotating platform and a Sun sensor. The first axis is used to compensate the ISS orbital motion (de-rotation function), while the second axis is used to correct the orbital plane drift and seasonal Sun apparent motion (indexation function). The selected reference position for SOLAR allows the following approximate useful pointing ranges for CPD:

1) around Y axis: ±40 deg for de-rotation from Sunrise (Ram) to Sunset (Wake)
2) around X axis: ± 24 deg for elevation toward outboard (Starboard) and inboard (Port)

The power to SOLAR is provided through two power lines or feeders, coming from different power outlets. One line is used when SOLAR and the instruments are powered off and where consequently the SOLAR platform is free-floating. In this situation, only the survival or stay-alive heaters are powered and are used to keep SOLAR and the instruments above the minimum switch on values. The second power line is used to power on SOLAR and the instruments and to perform the tracking and science measurements. Both, survival and nominal feeders can be active together, or the survival feeder can be active alone.

Figure 2. SOLAR Installation EVA. *(Image courtesy of NASA).*

After successful launch of STS 122, SOLAR has been installed on Columbus on February 15th , 2008. From the moment SOLAR has been powered on, the Operation team had to ensure 24/7 on console duty as per ESA requirement. All activities were performed in accordance with Col-CC (Columbus Control Center) Joint Operations Interface Procedures and with coordination with Col-OC (Columbus Operations Coordinator). After a few weeks of operation, it became clear that the operational constraints followed by Col-CC and based on the operation of Columbus as a system were limiting the SOLAR operations in ensuring sustainable support to this scientific mission – planned at that time for 1.5 year and now extended by 3 years. In view of real-time issues, some adjustments to the operational concepts were made in concert with the Col FCT (Columbus Flight Control Team), ESA and the PIs (principal investigator) to ensure the most effective support for the mission.

III. On Console Presence

The initial team of operators at B.USOC was composed of 3 certified operators and 3 trainee operators who were allowed to cover console during no-commanding shifts and under the responsibility of a certified operator on call. It quickly appeared that a full time console presence with only 6 operators did not leave time for the proper off-line support such as operations planning, operation products update, and contact with scientists or reporting to ESA.

While the first option was to increase the team, hiring and training new operators takes at least 6 months, so a short term solution had to be found. Therefore, the requirement of having an operator on console from the moment the payload is powered was revised in the light of the specific SOLAR operations.

A. Sun Visibility Window

Due to ISS orbital mechanics and due to the mechanical range of the SOLAR Coarse Pointing Device, the Sun is not always observable by SOLAR. The visibility is mainly dependent of the "ISS beta angle", which relates the Sun position with the ISS orbital plane, and which varies slowly over time. In the nominal +XVV+ZLV ISS attitude, SOLAR observations are possible when the beta angle is between -24 ° and +24 °, imposed by the X axis rotation limits. In practice, this leads to so called Sun Visibility Windows lasting typically 10 to 15 days during which SOLAR is tracking the Sun with its instruments continuously active and measuring(see Fig.2). During a Sun Visibility Window the instruments are pointed to the Sun each ISS orbit for about 20 minutes. The duration of the SOLAR day is enforced by the Y axis rotation limits (40° to -40°). So, during a Sun Visibility Window, the X axis variation goes slowly and it takes the complete Sun Visibility Window to go from one extreme position to the other, while the complete rotation around the Y axis occurs every ISS orbit.

From this, it is clear that the ISS attitude influences the Sun Visibility Windows. A Yaw or Roll different from zero will shift the start and end times of the Sun Visibility Window. A good prediction of the ISS attitude is therefore important to be able to properly predict a Sun Visibility Window. Outside the Sun Visibility Windows, SOLAR is not able to track the Sun and only once a week one of the instruments is performing science calibration measurements. During this period, the SOLAR platform stays in its home position, which is ensured by the motor control.

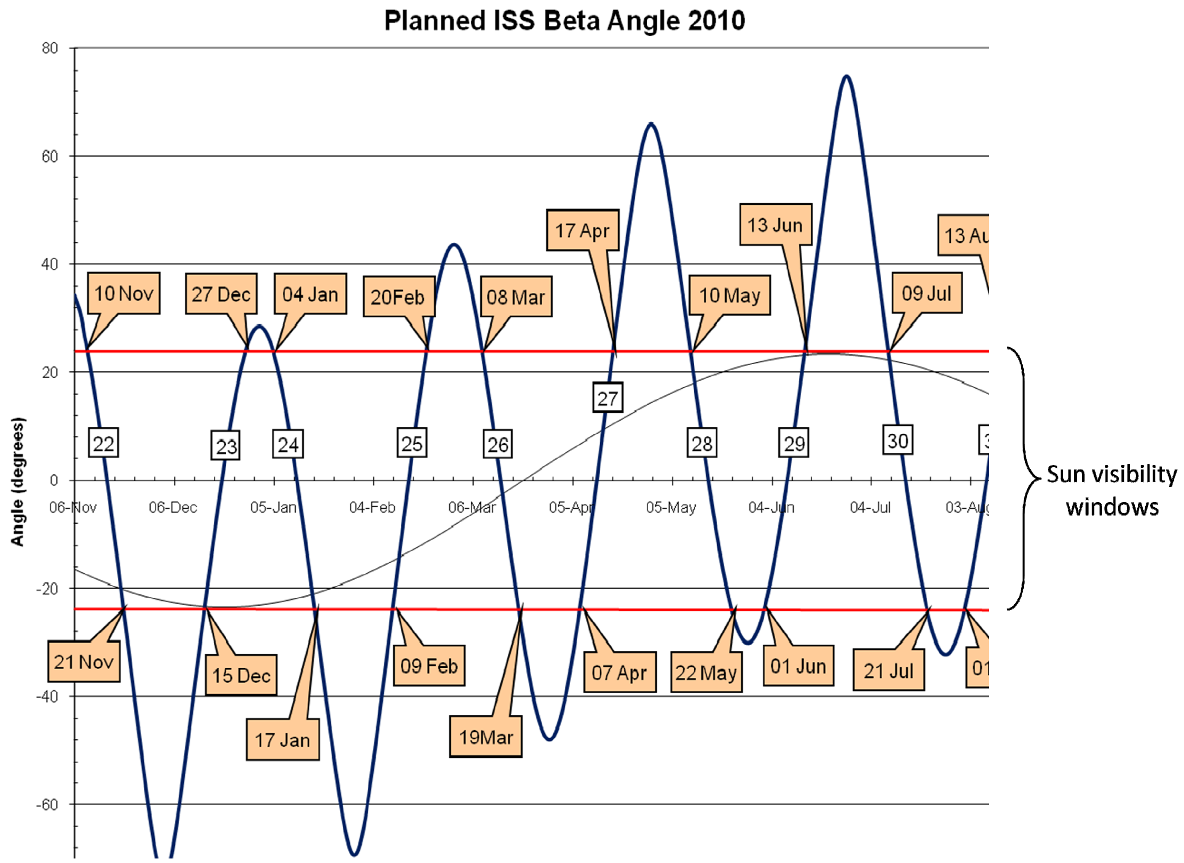

Figure 3. Predicted Sun Visibility Windows early 2010.

B. SOLAR Operational modes

The constraint of being on console 24/7 out of Sun Visibility Windows (with reduced operational activities) and optimizing the on-console coverage during these phases was aimed at. To do so, more refined operational modes typical for SOLAR operations were defined. For each mode the most effective on-console coverage was applied.

1) *SOLAR Science Mode:* in this mode SOLAR is fully powered (both nominal and survival feeders are on) and performs Sun tracking every ISS orbit. In this mode, constant monitoring and regular commanding are required to support science acquisition. Consequently, B.USOC Operator is on console 24/7.
2) *SOLAR Idle Mode:* in this mode, SOLAR is powered on (both nominal and survival feeders as for Science Mode) but the instruments are not performing Sun measurements and the SOLAR CPD platform is kept in its home position and is motor controlled. On console support is then limited to 8 hours per day (including week-ends) and 24/7 on-call with a defined response time of 2 hours to be on console in case of anomalies or unforeseen events.
3) *SOLAR Survival Mode:* SOLAR is only powered by its survival power feeder. In this configuration, the SOLAR computer (CU) and Instruments (SOLACES, SOLSPEC and SOVIM) are powered off, but heated by stay-alive heaters. These heaters are designed to keep all subsystems above their switch-on temperatures. On site support is reduced to office hours with still 24/7 on-call support and a defined response time of 2 hours to be on console in case of anomalies or unforeseen events.

To properly document this new operational concept, several documents were prepared with the support of both ESA Payload Operations Manager and Columbus Flight Control Team:

1) A technical note by ESA defining the different SOLAR modes and related operator support. This note includes also reference information for Col-OC when SOLAR is in Idle Mode and the B.USOC Operator is not on console:

a. An assessment of the known anomalies and corrective actions. Analyzing all anomalies that had occurred from the beginning of the mission, only two of them can potentially happen when SOLAR is in Idle configuration, and none of them require an immediate reaction from the B.USOC Operator.
b. An exhaustive description of H&S telemetry and limits, based on real telemetry (and not only on design phase documentation).
c. An analysis of all the error messages received from SOLAR since the beginning of operations.

2) A dedicated Joint Operations Interfaces Procedure (JOIP) defining the B.USOC Operator and Col-OC interface guidelines. This JOIP describes for example how the B.USOC Operator on-call is alerted of an anomaly or when and how the B.USOC Operator should provide the list of the on call operators when off-console.

To ensure a smooth transition between the different modes of operations, the shift plan is prepared based on the beta angle predictions about 40 days before the start of the month. To take into account ISS attitude changes, a margin of 24-36h is added at both sides of the Sun Visibility Window.

A few weeks before the predicted start of the Sun Visibility Window, the actual ISS attitude predictions become available (from NASA's MCC-H Web ATL) and are entered into a simple thumb rule-based prediction tool, yielding a significantly improved prediction (with an accuracy of a few ISS orbits). Based on this, the science planning can be prepared. Once very close to the start or end of the Sun Visibility Window, the operators have the possibility to track the actual behaviour of SOLAR, enabling predictions to better than two orbits. The reason for this remaining inaccuracy is the instability in the ISS attitude which is sometimes observed.

The SOLAR survival mode could not be used when the new SOLAR operational modes were introduced because although this concept was acceptable to SOLSPEC, SOLACES and the SOLAR platform, it would present a possible threat to SOVIM. SOVIM contains radiometers which can be damaged if left at lower temperature for long periods of time. In addition, the scientists were concerned about potential contamination by condensation that would occur within the instrument in the long run. In the meantime, an internal failure of SOVIM led to loss of the instrument, thus the Survival Mode could be implemented.

IV. Commanding

The second improvement to the operational concept developed by B.USOC in cooperation with Col-CC was the concept of "Real-Time commanding windows" for payloads. When the mission started, payload command activities were divided into scheduled and un-scheduled activities. Scheduled activities are those, which are planned in the OSTP. Any other activities are considered as un-scheduled (e.g. execution of malfunction procedures, saving of equipment/payload in case of anomalies, etc).
Nominal commanding of the payload is thus part of "scheduled activities" and should as such be already reflected in the Weekly Look-Ahead Plan, fixed 2 weeks in advance. Modification in timeline in the near-execution timeframe shall be avoided or minimized (E-7, E-3 and E-1 timeline reviews of the OSTPV timeline - respectively 7, 3 and 1 day prior to execution). A scheduled activity has the following characteristics in OSTPV:

1. It has a start time and a duration
2. It is linked to a PODF via its execution note. In other words, the exact sequence of commands is frozen.

Commanding of SOLAR was only allowed during scheduled activities in OSTPV where the exact time and used PODFs were defined days in advance and available in the execution note of the activity. By operating SOLAR via the Columbus infrastructure for some months, it became clear that this was tailored for Columbus system operations and occasional payload activities, but not taking into account specificities of routine science operations.

A. Science specificities

The specificities of payload science operations are mainly its unpredictability. The activities to be performed for a scientific payload are influenced by a number of factors such as ISS attitude, current scientific results of the experiment and other ISS activities. They cannot all be planned in advance due to the dynamic nature of the experiment. Rigid planning and strict sequences in procedures do not provide the necessary freedom and flexibility to react on scientific results and adapt upcoming activities in view of current results. Planning for such activity should therefore be as flexible as possible whilst still adhering to agreed operational concepts.

In the specific case of SOLAR, the SOLACES instrument is using Command Schedules (CS). A Command Schedule is a dedicated pre-programmed time-ordered sequence of time tagged commands to be sent to the SOLAR instruments or the CPD system. The Command Schedules length is defined by the scientist. Some last for 5 orbits then stop, others last longer than 30 orbits. The scientists have the option to repeat the CS automatically until a command to stop them is sent by ground. Until the CS or sequence of CS to be executed is known, it is not possible to exactly predict when one will stop and commanding will be needed to restart the next one. It is impossible to know two weeks in advance when commanding will be needed either because the sequence of CS is not known or because scientists have specific requests based on latest results. Additionally, waiting for an allocated commanding time slot in OSTPV leads to loss of science.

B. Payload Real-Time commanding window

Flexibility was gained by implementing the "Payload Real-Time commanding window" concept which is now documented in the JOIP. A real-time commanding window for payloads is defined as a payload commanding activity for specific scientific operations, shown in OSTPV, for which the exact execution cannot be defined within the OOS or WLP process. In other words, the activity is not linked to a single operational procedure (Payload Operations Data File, PODF), but to a list of pre-defined PODFs. The actual activities are defined shortly before the activity is scheduled and agreed with Col-FCT via a Columbus Flight Note. The following criteria should be fulfilled for the activity to be eligible for this process:

1) The activity should have no significant impact on the use of Columbus resources. Consequently, activities such as power on or off should appear as distinct activities in the timeline.
2) The activity should only affect the payload itself and not affect other payloads or subsystems. All the commanding and monitoring should be solely under B.USOC responsibility. For example, when uploading a file from Ground to SOLAR via Columbus MMU, Col-OC and COL-DMS are responsible for managing the file on the Columbus MMU, thus, this activity should be clearly defined in the OSTPV to ensure that the resources are available to perform it.

In practice for SOLAR, an activity called SOL-REAL-CMD lasting 24 hours is planned every day of the Sun Visibility Window. It gives the B.USOC operator an immediate access to command SOLAR upon Col-OC and COL-FD go. Two situations can occur:

1) Foreseen command activities: these are known commands to be performed by the B.USOC operator and coordinated with Col-CC a few hours in advance of the Real-Time commanding window.
2) Unforeseen command activities: these are additional unscheduled commands. The reason for this may be due to a request from a scientist based on latest scientific data, or a need for optimization after a change in the applicable constraints.

In both cases the exact sequence of commands as issued is documented in the implementation note of the CFN. The execution of the commanding activities is always coordinated in real-time with Col-OC with the approbation of Col-Flight. The concept was finalized after a trial period of two months for evaluation. Both the Col-FCT and the B.USOC operators acknowledged the benefit in efficiency and flexibility. With the appropriate coordination between all parties, the scientific program becomes more dynamic and responsive as the plan provides flexibility to accommodate real-time science accomplishments.

V. Update of PODFs

The PODFs used for SOLAR were validated on the SOLAR FM some months before the launch. The PODFs were written based on inputs of the payload developer and the scientists and with the SOLAR scientific operation plan in mind. It is clear from the previous chapters that after adapting the science execution to the optimum, the

SOLAR PODFs needed an update. With all the knowledge gained after two years of real-time SOLAR execution, and with the new dynamic operations, the old PODFs are now replaced or updated accordingly.

VI. Conclusion

To ensure execution of science onboard Columbus, it is necessary to consider the specifics of the payload and adapt operational concepts. Where many system and payload activities can indeed be very predictable, the dynamic nature of science must be taken into account. This has been accomplished by involving all actors: B.USOC, PIs, ESA POM, Col-FCT, European Planning Team, by documenting all processes and iterating after trial periods. All these achievements toward a greater flexibility were the result of careful efforts to adapt and fine-tune the operational concept, leading to a more efficient operational concept for the B.USOC, taking into account the specifics of SOLAR while still adhering to agreed operational concepts.

Acknowledgments

The authors thank the European Space Agency (ESA) Directorate of Human Spaceflight (D/HSF) (ESA Exploitation Programme) and the Belgian Science Policy Office (BELSPO) (ESA Prodex and other programmes) for their funding. B.USOC is part of the Services & Operations Division of the Belgian Institute for Space Aeronomy (BISA).

Further the authors thank the ESA Payload Operations Management (ESA-POM), the ESA Mission Science Office (ESA-MSO), the Columbus Control Centre Flight Control Team (Col-CC FCT), the SOLAR Payload Developers, the Science Teams, and the B.USOC Operator team for the good collaboration and support.

Also a special word of thanks to the ESA USOC management and Space Applications Services management for their support and for providing the budget and personnel for the activities.