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

AIAA 2010-2056

Dealing with Operations Constraints for External Payloads on ISS

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Operations constraints can be expected in any mission and are taken into account during mission preparation. However, practical experience needs to be gained to fully assess those constraints in order to align the operation concept accordingly. This paper addresses the operations constraints experienced by the payload operations team while continuously operating external ESA payloads (SOLAR by B.USOC, and EuTEF by Erasmus USOC) on ISS/Columbus for a period of over 1.5 years. Constraints covered by the paper include issues related to the ISS attitude and orbit, availability of the various ISS resources, and various types of events that potentially interfere with payload operations (ISS thruster firings, vehicle (un)dockings, crew EVAs, ISS maintenance and anomalies, and other ISS operations). This is complemented by an overview of the operations products needed for dealing with these constraints in operations, and some practical issues that were experienced. This overview could be helpful to teams planning operations of external payloads on ISS, in order to properly prepare for the kind of constraints and situations they will typically encounter while operating their payload. Several of the constraints also apply to internal payloads, though additional constraints are likely to apply there. The SOLAR operations are performed from the B.USOC by the Belgian Institute for Space Aeronomy (IASB/BIRA) with Belgian company Space Applications Services, whilst EuTEF was operated from the Erasmus USOC located at ESA/ESTEC by Nederlandse Lucht- en Ruimtevaartlaboratorium (NLR) jointly with Space Applications Services, both Centers being under contract of the European Space Agency.

I. Introduction

OPERATIONS constraints can be expected for any payload in any space mission. They are therefore taken into account during payload design and mission preparation to the extent possible. However, practical experience with operations on a specific space platform is useful to be able to fully know and assess those constraints and their consequences, in order to be able to optimize the payload operations concept accordingly.

This paper addresses the operations constraints experienced while continuously operating external ESA payloads (SOLAR by B.USOC, and EuTEF by Erasmus USOC) on ISS/Columbus for a period of over 1.5 years. This overview could be helpful to Payload Developers and teams planning operations of external payloads on ISS, to properly prepare for the kind of constraints and situations they will typically encounter while operating their payload accommodated in the Columbus module. Several of the constraints also apply to internal payloads on Columbus, though additional constraints are likely to apply there.

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The SOLAR[1] external payload 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 Belgian User Support and Operations Centre (B.USOC) located in Brussels, by the Belgian Institute for Space Aeronomy (IASB/BIRA) and Space Applications Services.

EuTEF is a technology demonstration external payload, hosting nine instruments: EXPOSE, TRIBOLAB, PLEGPAY, DEBIE-2, FIPEX, DOSTEL, MEDET, EVC and EuTEMP. It was launched on STS-122/1E in February 2008, and returned on STS-128/17A in September 2009, 1.5 years later. It was operated continuously during that period. The operations were performed from the Erasmus USOC at ESA/ESTEC in Noordwijk, the Netherlands, by Nederlandse Lucht- en Ruimtevaartlaboratorium (NLR) and Space Applications Services.

All operations were performed under ESA contract.

II. Operations Constraints

A. ISS resources

The most obvious set of operational constraints experienced by a payload is that of the resources that are provided to it by the ISS. Not all resources are available permanently, and some need to be shared with other payloads and systems.

1) Electric power

Each Columbus External Platform of the Columbus module is provided with two distinct electric feeders: one for operational power and one for survival power (typically for heaters). Electric power is nominally available continuously. Over the 1.5 years of operations electric power was never lost inadvertently. However, electric power may need to be switched off by Flight Rule as part of installation or maintenance activities on-board. Also, in some circumstances like dockings and undockings, the amount of electric power available is limited, and reduced power consumption or temporary switch-off may be requested. But even though electrical power is generally available, it still needs to be quantified and booked through the activity planning process. Considering this, it is important to know the actual power consumption of the payload in various configurations (including the behavior of the heaters in various thermal conditions), and to properly quantify the thermal clock for the payload when switched off (also considering several initial configurations and thermal conditions). The main external factors influencing the thermal conditions are the ISS attitude and Beta angle (see Section II.B).

2) Ground Commanding

Commands to the ISS and the Columbus module are uplinked via the NASA ground segment and over the S-band, via the TDRS satellites. The availability of the S-band varies, but it is typically available 50-80% of the time. S-band windows typically last 10-50 minutes. Mere availability of the S-band is however not enough to be able to command a payload. First, it is generally not allowed to “command in the blind”, i.e., to send a command without being able to see the result. As the result of commanding a payload is generally only visible in the payload telemetry, which is sent over Ku-band. This means that commanding is generally only possible when both S-band and Ku-band are available. Secondly, commanding is only to be done according to validated ground commanding procedures residing in the PODF (see section III.D.2), at a moment when the execution of this particular procedure is planned through the planning process (which is fixed days in advance). Thirdly, every commanding activity needs to be coordinated in real-time with the Flight Control Team (FCT, in this case at Col-CC), to avoid conflicts with unexpected events not in the planning and to ensure proper situational awareness of the FCT. Finally, if a command is not successful for some reason (even an obvious one), it involves some coordination with the FCT before the command can be resent or corrected. These processes on the other hand create constraints that significantly limit the possibility for implementing a “telescience” operations concept, where the scientist would just freely react upon science telemetry. Though the operator team managed to significantly improve flexibility for the routine science operations, these constraints are extremely important to consider in an early stage of payload design, as they define the level of autonomy of the instrument, and the concept of operational interaction with the payload. Also, besides defining and validating a Mission Database for the payload, a well-prepared set of PODF procedures needs to be available covering most of the commands in the Mission Database, and these PODFs all need to be validated on a payload model before being used. Ways to improve the flexibility of routine operations are the use of on-board scripts, or the negotiation of a “real-time commanding window” [1] where a pre-defined set of PODFs are agreed to be usable with minimal pre-coordination (see section III.D.3).

3) Medium Rate Telemetry

Payload Housekeeping Telemetry packets and Science Telemetry packets are sent to ground over the Ku-band, also via the TDRS satellites. The availability of the Ku-band link is generally slightly less than the S-band, around 40-70%. During the Ku-band outages, the telemetry is recorded on-board on NASA's High-rate Communications Outage Recorder (HCOR), to be replayed to ground when Ku-band is available again. The overall downlink bandwidth available from ISS is currently 150 Mbps, but of course this needs to be shared between all partners and instruments. The bandwidth for the telemetry therefore needs to be booked as part of the planning, but is then available continuously. Occasional loss of telemetry is possible, but experience shows it is limited to less than 1% of the telemetry. When designing the payload operations it is important to realize that the operator will not get all telemetry in real-time, and that telemetry packets that are sent only upon an event might just make it to the telemetry archive but not to the operator's display.

4) High Rate Telemetry and video

Also High Rate Telemetry and video are downlinked via the Ku-band and buffered on the HCOR when the downlink is not available. This resource is however not to be considered as one that is permanently available, as a lot of coordination is needed for booking it and generally only limited windows will be available to a specific payload. The operations concept shall preferably not depend on the immediate and full availability of the high rate telemetry. Ways for predicting and controlling the rates, volumes and timing of the high rate telemetry generation by the payload are essential.

5) File Transfers

File transfers to and from the payload are possible. For technical reasons the file handling for Columbus is however performed by the Col-CC FCT and not by the payload operator. The coordination involved is significant, and generally the files for uplink need to be available at latest 8h before their on-board usage. Also per payload a limited amount of "file transfer positions" is available on the Columbus Mass Memory Unit (MMU), limiting the amount of files that can be transferred at a time. If faster or more flexible data transfers are needed, other concepts of data transfer need to be considered.

6) Microgravity measurements

Since the ISS is a manned spacecraft with a lot of activities going on, the levels of microgravity provided to the payloads vary. Disturbing factors include thruster firings, reboosts, dockings and undockings, astronaut activities, etc. There are microgravity sensors on the ISS, but they are not always active, their use requires substantial coordination, and being located elsewhere they do not accurately reflect the actual microgravity at the payload location. If microgravity is important to the experiment, inclusion of microgravity sensors inside the payload is therefore highly advised. Part of the operations concept should also be what to do in case of significant disturbance of microgravity. If safing of the payload is needed, the safing and resuming shall be simple. Preferably the payload shall be safe when unpowered.

7) Space environment measurements

No space environment measurements are available to payloads. All payloads shall therefore measure the environmental parameters that have an impact on their functioning. Examples are radiation levels, solar illumination, space environment composition, electric potential, etc.

B. ISS attitude/orbit

The ISS attitude and orbit obviously have an impact on external payloads. NASA provides predictions of the ISS attitude and orbital parameters, which allow for proper planning of payload activities a few weeks in advance.

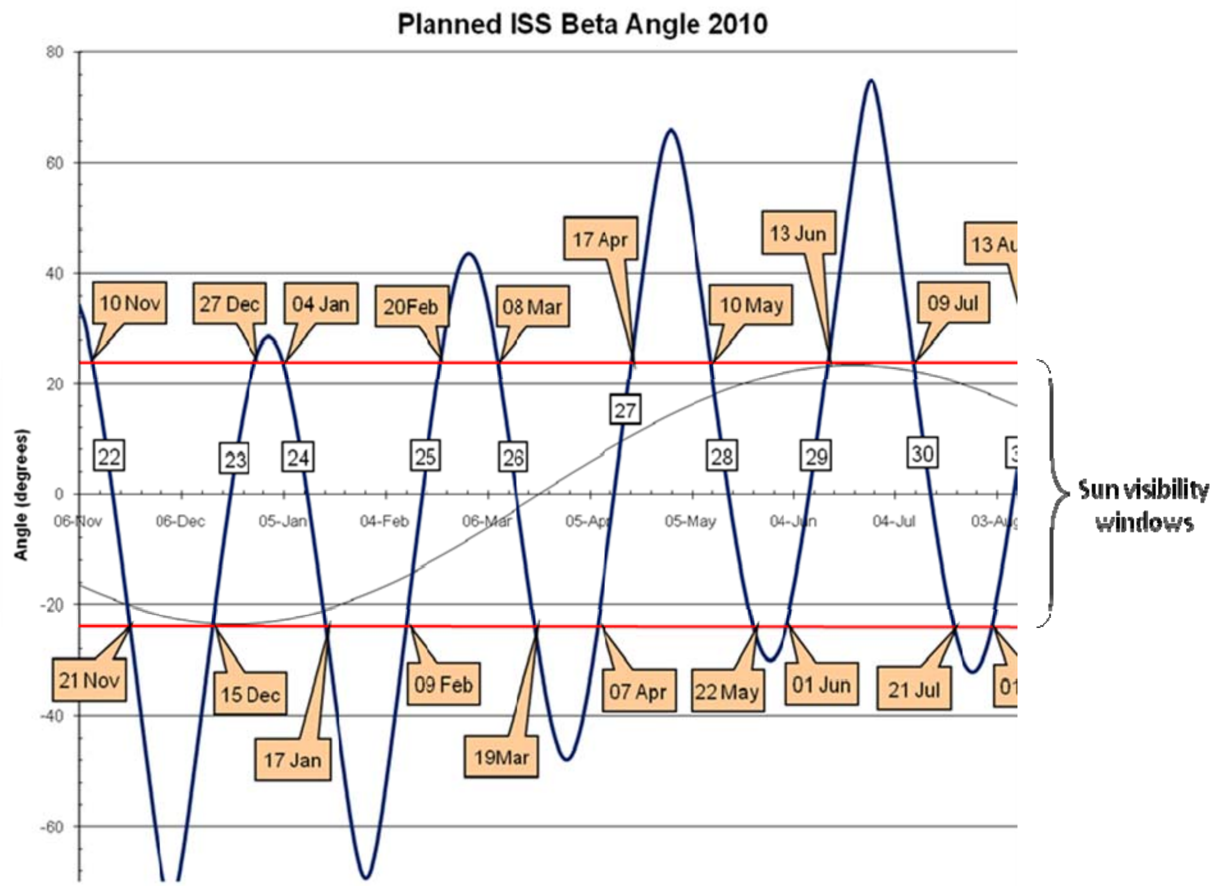

Figure 1. The β-angle, and the corresponding Sun Visibility Windows for the SOLAR payload.

1) Thermal aspects

An external payload's thermal state and behavior are heavily influenced by its illumination by the Sun, which fluctuates significantly. There is of course the "day/night" cycle, but its effect will not be constant: first there is the ISS attitude which is not always the same (e.g., during a Shuttle docking, the complete station is rotated by 180°), and this changes the direction of illumination. Also the angle between the ISS orbital plane and the Sun direction (the β-angle) varies with a roughly bi-monthly and a yearly period (see Figure 1). During some periods, there is even no "night" on ISS: the Sun is always shining on it. A good thermal analysis for various ISS attitudes and β-angles, taking into account possible occultation of the instrument by other ISS elements, is important to provide the payload operator with appropriate background information, especially regarding the thermal clocks in case of power cut and the expected power consumption by the payload heaters.

2) Visibility of observation object

The ISS attitude, orbital position, and β-angle directly impact which part of the sky or Earth is visible and thus observable by the external payload. It is important to check early in the payload design that the resulting constraints are compatible with the science objectives. For the SOLAR payload, for instance, the pointing device can track the Sun over 80° each ISS orbit only when the Sun culmination is not further away than 24° from instrument zenith. In a nominal ZLV +XVV ISS attitude, this translates to β-angle being between –24° and +24°, but when Roll and Yaw are not zero, the period of Sun visibility is shifted in time, and its duration altered. In practice for SOLAR Sun observations are only possible 20 minutes per ISS orbit and this typically only 12 days per month, and the start and end of the Sun visibility period are difficult to predict precisely.

3) South Atlantic Anomaly

Over typically 10 hours per day, the ISS passes through the South Atlantic Anomaly at each orbit, exposing the instruments to higher levels of cosmic radiation. The instrument should be designed such that no manual commanding is needed related to this, as this would make operations too complex.

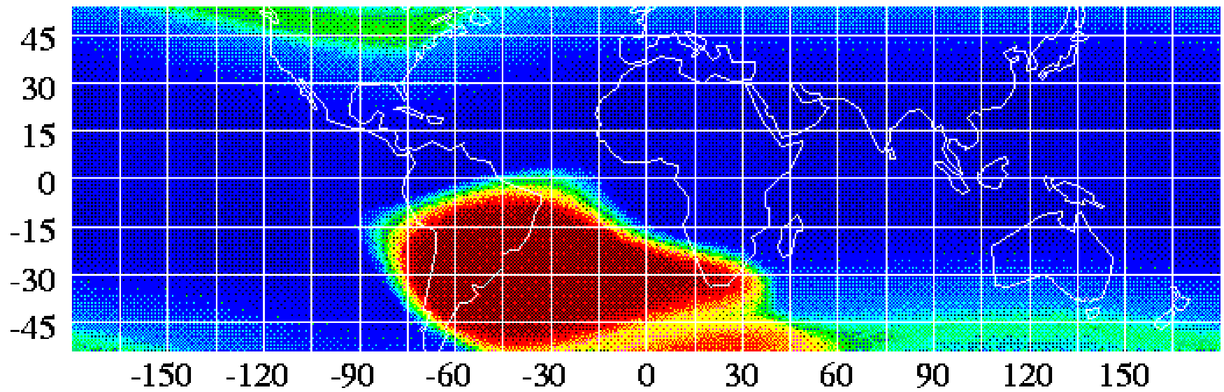

Figure 2. South Atlantic Anomaly as measured by ROSAT. Picture taken from Wikipedia.

C. Interfering events

The ISS is a very dynamic environment, with a lot of planned and unplanned activities and events, possibly impacting the payload operations. Events that typically impact the operations of external payloads include:

1) Thruster firings

Regularly the ISS thrusters or a visiting vehicle's thrusters need to be activated. This can be for a reboost maneuver, for testing a thruster, for changing the ISS attitude, or to execute a Debris Avoidance Maneuver. These events can impact the payload operations in several ways. There is the obvious disturbance of the microgravity, possibly perturbing the measurements or requiring a payload safing. There is also the possible contamination of the instruments with corrosive gasses emanating from the thrusters. Also there is a request to limit the sending of commands during the various activities related to thruster firings. There are a few thruster events per month, and thruster firings are announced at latest 24 hours in advance.

2) Vehicle docking, undocking, and relocation

A lot of vehicle traffic is needed to maintain the ISS operations: the Shuttle, Soyuz, Progress, ATV, HTV and in the future other vehicles visit the ISS, resulting in dockings, undocking and vehicle relocations every few weeks. This vehicle traffic typically goes along with thruster firings and attitude changes. The impact on the payloads is similar to that of thruster firings, but frequently there is also a temporary limitation in the amount of electrical power available. Events related to vehicle traffic are visible in the planning products, but are subject to slips due to launch slips or programmatic decisions.

3) Crew EVA

Once in a while the ISS or Shuttle crew performs Extra Vehicular Activities (EVAs). The impact on external payload operations is mainly driven by safety: if the astronauts have to come close to the instrument, concerns such as touch temperatures, moving parts, gas release and powered items become a problem. In practice this means that a payload needs to be passive or deactivated if a crew member is working in the neighborhood. EVAs also go along with a high need for video downlink, making High Rate and video resources mainly unavailable to payloads during EVAs. EVAs normally happen every few months, but are very frequent during Shuttle docked phases.

4) ISS maintenance and anomalies

Occasionally there is a need for maintenance or there is an anomaly on one of the ISS or ground systems needed for the payload operations. The impact of these is typically a forced power down (rare), a temporary loss of the telemetry and/or telecommanding, or an unrecoverable loss of telemetry data. This happens no more than once every few months.

5) ISS and payload venting

There are many sources of venting and gas releases on the ISS. Most of them do not generate gas concentrations in excess of the concentrations given in the design requirements for ISS payloads. Some of them however do, and it is important to properly analyze their impact on payloads and experiments. Instruments with high voltage could be damaged by corona discharges. Instruments with optics could have the optical surfaces damaged by corrosive gasses or gas deposition. Or it could just be that the measurement is invalidated. When analyzing the effect of venting, the elements to consider are release location and direction, gas composition, and gas concentration. The planning and coordination related to ventings is not centralized. If coordination is needed, a bilateral cooperation needs to be set up between the venting entity and the impacted payload. Agreements are documented in Flight Rules or Payload Regulations.

6) Other operations on ISS

Other crew, system and payload activities on-board can impact payload operations in several ways: obviously and as mentioned before, microgravity disturbance and ventings, but also the prioritization of resources has an impact. Crew time, electric power, high rate telemetry and video are all shared resources which might be assigned to another activity when needed. Proper planning, documentation of the constraints and interactions, and assignment of priorities can help limiting the impact of this.

III. Dealing with the Operations Constraints

D. Operations Products

The way that the various operations constraints are managed within the ISS world is via "Operations Products". Operations Products are documents which define the various aspects of how operations are to be performed. The main types of Operations Products are:

1) Mission Database, Synoptic Displays and Command Stacks

Central to the use of a payload on Columbus is the Mission Database (MDB), a database containing all telemetry, telecommands, and all associated parameters and limits. The validated MDB is used to prepare the payload's synoptic displays and the command stacks, which are used by the payload operators to monitor and control the payload.

2) Operations Procedures

The payload operator can only send commands to a payload following a validated procedure. The procedure is formatted in ODF (Operations Data File) standards, and for Columbus payloads, the ESA Payload ODF (PODF) is published to the whole ISS community through the International Procedure Viewer (IPV). In order for a procedure to be certified for execution, it needs to be reviewed by different parties, validated and distributed via IPV. When authoring PODFs, it is good to remember that the procedure might be needed in a slightly different context, and that all useful commands from the MDB need to find their way in a PODF.

3) Timeline

The timeline preparation for crew and ground controlled activities starts about 6 months before the start of the increment, with the release of the On-Orbit Operations Summary (OOS). By that time all activities that will need to be performed during the increment need to be identified, and a PODF needs to be associated to them. Following further steps and processes for coordination, and transition from the pre-increment timeframe to the execution timeframe, one week before the start of the week of execution, the Weekly Look-ahead Plan (WLP) is released, putting an exact execution time on all activities. At this stage it is still possible to implement a change, but after this point in time it becomes much more difficult to change the integrated Columbus / ISS timeline. The timeline is further reviewed 7, 3 and 1 days before execution, but changes need to be kept minimal and a good rationale at this stage. For SOLAR and EuTEF the flexibility of the implementation of routine operations was improved through a "real-time commanding window": a set of PODFs covering routine science operations was selected, and it was agreed with the FCT that these could be freely executed, if properly documented four hours before the start of the real-time commanding window, following a specific process defined in the Joint Operations Interface Procedures (JOIP).

4) Joint Operations Interface Procedures

Agreements on how the various Control Centers cooperate and interface are documented in Joint Operations Interface Procedures (JOIP). This is also the place were payload-specific agreements are documented, e.g., how to handle the "real-time commanding window".

5) Flight Rules

Flight Rules are ISS element-level operations constraints defined and agreed in advance by all international Partners. They are developed to guarantee crew and vehicle safety, and prevent hardware damage to ISS systems.

6) Payload Regulations

Operations constraints that affect payload integrity are documented in Payload Regulations. They are developed by the involved International Partner responsible for a particular Station Element, like ESA for the Columbus module. These regulations allow payload operations to be conducted in the most efficient and successful way, with minimal adverse interference.

7) Other operations constraints

Operations constraints that affect science outcome are prepared internally among scientists and operators teams. They guarantee scientific requirements formulated by the science team of an experiment.

8) Flight Notes

Flight notes are used in the real-time operations environment to document agreements and temporary changes to operations products.

E. Payload Engineering Support and Payload Anomalies

In case of new anomalies during the operations phase, the related operations are put on hold. An Anomaly Resolution Team (ART) meeting is called (with the operator, the FCT and the Payload Engineering Support (PES)), where the way to proceed is discussed and decided. Trivial and known anomalies may be resolved by the FCT, with later disposition by the ART. If further investigation is needed, an MRB is called by the PES (Payload Developer). If a special activity or procedure is defined by the MRB to be executed on-board, generally a PODF needs to be written and validated before execution. This activity then needs to be planned before it can be executed.

In order to be able to properly support the operations, PES needs to have a good availability during operations (in line with the operator availability and the criticality of the ongoing operations), and needs to have flexible access to the payload telemetry archive.

Typical tasks performed by PES include on-site support to commissioning activities, thermal, mechanical, and venting contamination analyses for various events on-board ISS, and the already described support to payload anomalies.

F. Control Centre staffing

The reality of operations on-board ISS mean that a responsible operator needs to be available whenever the payload is powered, and needs to be in the control room whenever the payload is performing activities. For SOLAR and EuTEF this meant a 24/7 availability (24 hours per day, 7 days a week). At times when the SOLAR payload was powered but idle, part of the 24 hours could be covered on-call.

Experience has shown that while different schemes like 16/7, 8/7, 16/5 or 8/5 on console do mean more flexibility for the operations team to adopt other tasks. This also goes along with a need for higher flexibility to cover occasional events or anomalies outside the covered periods, when on-call. These advantages and disadvantages need to be balanced.

For continuous long term 24/7 operations, our experience shows a team size of 10 persons per position is adequate for a long-term period, to allow for the necessary flexibility in the team.

IV. Conclusions

Dealing with operations constraints defines the way in which a payload is operated and how the ground teams have to organize to support these operations. It is therefore essential to have a good and detailed overview of the kind of operations constraints one has to deal with, in order to better prepare the operations and the team. Even design choices can be made during payload development to allow for easier or more flexible operations. This paper is an attempt to feed back this kind of information from the control room to the payload developers and operations engineers, in order to contribute to improving operations and design of external payloads.

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 we 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 and EuTEF payload developers, the SOLAR and EuTEF Science Teams, and the B.USOC and Erasmus USOC Operator teams for the good collaboration and support.

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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