PRISMA Mission Control: Transferring Satellite Control Between Organisations

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The PRISMA in-orbit test-bed was launched in June 2010 to demonstrate strategies and technologies for formation flying and rendezvous. OHB Sweden is the prime contractor for the project which is funded by the Swedish National Space Board (SNSB) with support from DLR, CNES, and DTU. Mission operations are carried out from OHB Sweden's purpose built control-room in Solna, Sweden, using the company's own GNC and platform experts to conduct the mission. As an experimental technology demonstrator a large number of in-orbit experiments were initially planned, with desires exceeding the constraints of available funding. In an effort to extend the use of the satellites and enable more experiments DLR/GSOC offered to temporarily operate the satellites from their control center in Oberpfaffenhofen, Germany, for a period of five months. Control of the spacecraft was transferred to GSOC in March, 2011, after a training period of several months. A number of experiments were executed, including GSOC's own formation flying and autonomous orbit keeping, SSC ECAPS's green propulsion and several different OHB Sweden experiments. Handover back to OHB Sweden was then performed in August the same year, from where the mission continues to be run. Transferring control of a satellite project from one organization to another, including new operational personnel and a new control room, posed a great challenge to both parties. This paper describes the mission concept, the background for the transfer, implementation of a mirrored control room and the process of transferring knowledge from the design and operations team of OHB Sweden to the GSOC operations team.

I. Introduction

Formation flying and rendezvous has been identified as key enabling technologies in several advanced disciplines involving scientific applications or on-orbit servicing and assembly.[1,2,3,4] Applications include distributed satellite systems for enhanced remote sensing performance, for planetary science, astronomy, the assembly of large structures on-orbit as well as re-supply or repair of orbital platforms. For all these applications, there is a need to implement on-board guidance, navigation, and control (GNC) with a high degree of autonomy. This aspect motivated Swedish National Space Board (SNSB) and OHB Sweden (OHB-SE) to initiate the development of the PRISMA mission in 2004.[5,6] Potential participants were invited by the prime to contribute to the mission with different key technologies and to also implement self-defined experiments sharing mission time and resources. The resulting mission consisted of several hardware and software experiments involving new technologies for propulsion, vision based sensors, GPS and other RF-based navigation, as well as GNC-algorithms. OHB-SE as well as German Aerospace Center (DLR/GSOC) and the French Space Agency (CNES) have developed their own GNC software for the execution of a series of closed loop orbit control experiments.

The PRISMA mission demonstrates technologies related to Formation Flying and Rendezvous in space. OHB Sweden is the prime contractor for the mission which is funded by the SNSB. Further support to the mission is provided by the DLR/GSOC, CNES, and the Technical university of Denmark (DTU). PRISMA consists of two spacecraft: Mango and Tango and is in a sun-synchronous orbit at an altitude of 750 km, 06:00 local time of ascending node (LTAN). Launch of the clamped together satellites occurred on June 15, 2010 and Tango was

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separated from Mango on August 11 the same year. The nominal mission was completed by the end of August, 2011. Figure 1 shows the PRISMA satellites in the clean room as they are for shipping to the launch site.

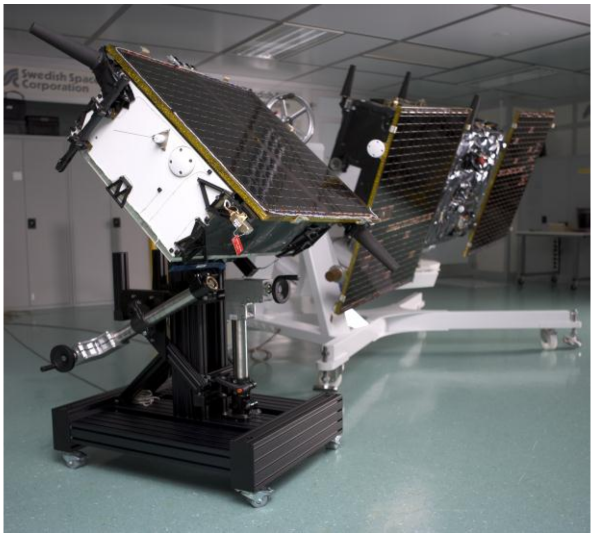

Figure 1. The PRISMA satellites ready for launch

II. Mission Concept

A. Operations Concept early adaptation

The mission operations concept of the PRISMA mission has seen several iterations over the years. Up to the finalisation of the extended mission it has taken three different shapes, with two major events impacting the operations concept. In the first and original configuration, which was never utilized, the operations concept of the Odin mission[7] was adopted which utilizes two control centers divided between Esrange/Kiruna and Stockholm/Solna. The responsibilities at Esrange was the antenna ground station and operator control center (OCC), where all telecommands were sent from a position very close to the antenna. This was supposed to remove the need for a redundant communication link to Esrange. The remaining functions, e.g. overall mission control, procedure planning, validation and simulation, were under the responsibility of Stockholm/Solna in the mission control center (MCC). See figure 2, left.

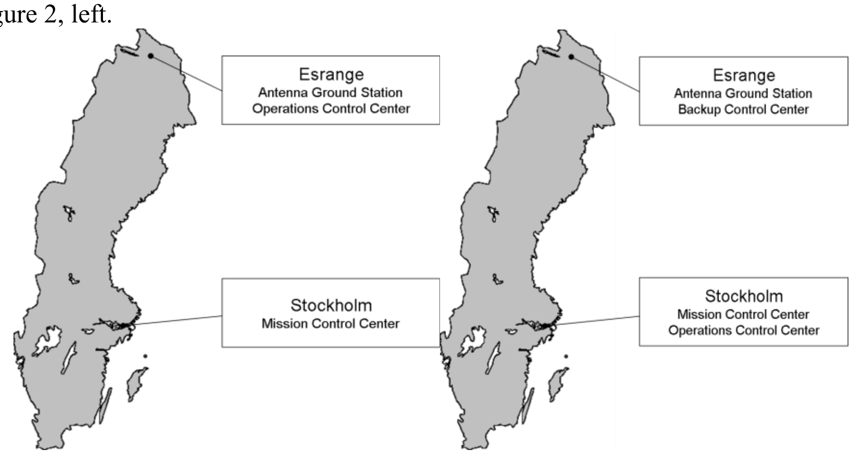

Figure 2: First iterations of operational concept

The first major event affecting the operations concept was the cost involved to implement the OCC at Esrange, staffing it would require hiring additional personnel when at the same time the financial situation of the world had led to available resources in Solna. It was then decided to move the OCC function from Esrange to Solna, and to have full TM and TC capability from both Esrange and Solna, but to downscale the Esrange OCC control room to a back-up control center to be used only during periods of substantial link disturbance. The operation concept then included the possibility to move the personnel from Solna to Esrange in such a situation. Some minor maintenance of the backup control center at Esrange was performed, although it has never been used to send commands to the actual spacecraft in orbit[8]. Figure 2, right, shows the second operational concept.

Moving the operator function to Solna had the advantage that no new staff was needed and all personnel in the operations team were already experts of different parts of the spacecraft and/or ground segment as they had been part of the PRISMA development team. On the other hand, since the orbit of PRISMA in combination with the use of the Esrange ground station resulted in night time operations, the staff in Solna found it hard to adapt to the nightly activities which the personell at Esrange is very accustomed to from previous missions.

Further into the development of the operational concept additional issues required another change of the operations concept and GSOC' involvement was discussed to preserve Swedish resources. (see chapter 3).

With the operational concept in place having full TM and TC capability in Solna, the Misson Control Center was built based on the OHB-Sweden developed ground system RAMSES.[9]

B. Ground segment and mission tools

A key part of mission operations is of course the ground system itself. For the PRISMA mission this has been the RAMSES (Rocket and Multi-Satellite EMCS Software) suite, developed by OHB Sweden in parallel with the satellites. RAMSES is a fully CCSDS PUS[10] compatible TMTC system, running on the Microsoft Windows platform. It is a modular system that is easily configured to suit a wide range of applications; for tests on subsystem level in early project stages or as a full-fledged control system during spacecraft integration and test as well as in the mission operations phase. The software was developed specifically with the PRISMA mission in mind, but was designed to be compatible with any PUS based platform. As such it has also been used for sounding rockets[11] and in a select number of other projects by OHB-SE.

Integral to the RAMSES concept is the deployment of stand-alone applications, communicating with each other over a dedicated local area network. The software suite provides all the TM/TC components necessary for controlling the spacecraft, such as TM displays, script execution, telemetry and telecommand logging, alarm and event monitoring and more. It provides a modern graphical user interface, allowing quick familiarization with operations and ease of configuration. Further, the choice of utilizing the Windows platform gives the system a high degree of portability.

RAMSES was used throughout the entire development phase of PRISMA, from early software testing through the integration and test of the complete system. This led to the entire operations team being intimately familiar with the software, allowing more time to be spent on learning the space segment during the operational preparations.

C. Mission Preparations

The ground system was further expanded with a set of mission specific tools developed in MATLAB. These tools are a suite of applications for specialized functions that were not available in the version of the RAMSES ground segment used for PRISMA. Each tool was developed to fill the need for either the entire operations team or a few members only, and was in most occasions compiled into an executable file. Some tools, which were inherited from other missions, were in a format not suitable for compilation and these tools had to stay uncompiled, due to the amount of time needed to convert them into compilable versions. Other tools contain the entire onboard running software, and to not loose execution performance, they too had to stay uncompiled. This suite of tools, or part of it, was deployed onto the computers in the control room and on the team members personal computers, depending on what needs each control room position or team member had. However, the uncompiled tools were not as easy to distribute, and instead, they were deployed onto specific computers located in the control room.

While developing the spacecraft, a hardware in the loop-simulator was also developed offering the availability of an on-ground-flying satellite. This simulation environment, called the OpsSim, and is centred around the spacecraft simulator, SatSim.[12]. This is a Matlab/Simulink real-time simulator, developed by OHB Sweden to facilitate hardware-in-the-loop testing, able to mimic most on-board units, as well as the space environment itself. Figure 3 shows a schematic of the Solna mission control center.

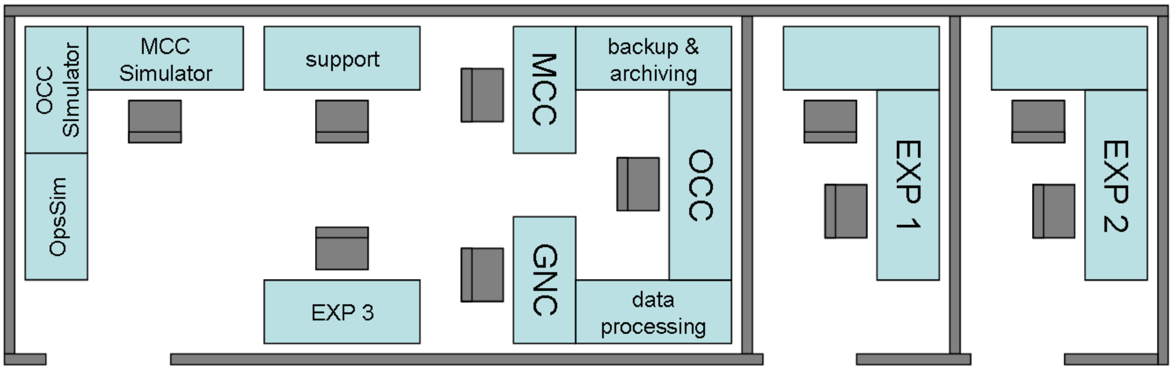

Figure 3: Solna MCC Overview

D. Flight Procedures

The flight procedures used in the PRISMA mission are divided in three different categories; functional procedures (FUN), platform commanding procedures (CMD) and experiment controlling programmes (PRG). The functional procedures are documents describing how to perform a certain operational task and do not send commands to the spacecraft directly, instead calling the commanding procedures. The platform commanding procedures are used to maintain the platform in a daily manner by pre-launch validated procedures, whilst the experiment controlling programmes are dynamic procedures created by the experimenters to implement a piece of the timeline as an onboard experiment, and are validated shortly before the experiment execution time. This is done in several layers, starting with the experimenter writing an experiment definition file in XML format, which is then translated to the RAMSES procedure language PLUTO.[13] The procedure is validated in a faster than real-time software based simulator, which is running the actual onboard software and the experiment output from the simulator is validated by inspection by both the operations team and the experimenter. The PLUTO translation of the experiment is then uploaded to the OpsSim hardware simulator for spacecraft acceptance validation, before upload and execution by the actual spacecraft.

The downloaded resulting telemetry from each experiment is automatically processed by the PRISMA ground segment to produce a high level data pack which is sent to a central repository at the Parallel Data Center (PDC) at the Swedish Royal Institute of Technology in Stockholm. Also the raw telemetry from the spacecraft is sent to PDC.

E. OHB mission preparations and team training

Detailed mission preparation started roughly one year prior to the actual launch of the satellites with the establishment of the core operations team. The early priority of the core team was to develop and test the library of functional flight procedures describing the processes involved of performing different tasks with the satellites and detailing the commissioning phase of the mission. As the original plan was to operate the mission as an internal project an early decision was made not to write a dedicated operations manual, instead relying on these functional flight procedures to cover the same content. Together with the experience from the development phase of the team this was envisaged to be sufficient and a good way to allocate resources.

The team was eventually expanded to include the operators and the team training was started in earnest. Training was almost exclusively performed through mission simulations, both against the actual flight model and against the operational simulator to provide the team with sufficient experience in preparation for the actual mission. Key to these simulations was the use of the high-fidelity simulator, used throughout the development of the satellites in various configurations

Repeated simulations of different mission phases allowed the team's confidence in processes, procedures and the space segment itself to quickly grow, with simulation complexity increasing throughout the training campaign. A large factor in the rapid training of the team was due to the curiosity and sense of responsibility of the members themselves. Subteams were naturally formed, with each (flight directors, GNC experts and operators) providing further detailing the operational processes and sharing the gained knowledge with the rest of the team.

The simulations were from an early stage focused on simulating actual passages, with no data being available between them. This led to the team being aware of the pace of operations from the start and the establishment ofroutines for checking the satellite state from mass memory dumps and limited real-time telemetry, which were vital to the execution of the mission.

Most mission phases were rehearsed to a greater or lesser extent, including the sometimes very different requirements of the experiments. While most experiments focused on utilizing the large degree of on-board autonomy others were very much planned to be executed in open-loop, requiring a greater deal of training and simulation. This was especially true of SSC ECAPS' HPGP experiment, entailing the in-orbit testing of a new type of propulsion system. These experiments were executed in real-time during passages and consisted of large amounts of thruster pulses, requiring close communication between everyone present in the control room and a focus on the need of rapid response times when called for by the experimenter.

III. Transferring mission control

As mentioned above, the operational concept was to change once more during the project, and again the background was financial. Different factors during the development phase indicated the need to substantially de-scope the mission timeline, or by other means find funding to be able to execute it. As DLR/GSOC was already a partner in the project, and also wanted to collect experience of close formation flying as rendezvous and proximity operations in view of the upcoming DEOS mission, the solution to handover the entire PRISMA operations to DLR/GSOC in Oberpfaffenhofen for a period of a few months was proposed and eventually accepted.

At the time of the handover decision, no one could embrace the full width of the manoeuvre to shift operations control not only from one country to another, but also from a small operations organisation based on project experienced spacecraft experts to a professional organisation based on team members used to formal satellite deliveries including training and sufficient spacecraft and operations related documentation.. At this stage the PRISMA launch was only months away, and the preparation workload increased dramatically.

Moving the operations from Solna to Oberpfaffenhofen meant expanding the current operations concept to have not only the nominal MCC in Solna and the backup control center in Kiruna, but to also have a second nominal mission control center in Germany. In addition to this, two new links needed to be established; one between GSOC and Esrange for telemetry and telecommands and one between Oberpfaffenhofen and Solna for access to the OpsSim environment. The latter was needed as the OpsSim environment was not possible to move, but was still used in an essential step of the experiment programme validation chain and therefore had to be accessed from the German control center.

This new operations concept gave the opportunity to include several more antenna ground stations already linked to GSOC, especially the DLR Station station Weilheim but also the remotely located antenna in Inuvik/Canada.. Figure 4 shows the complete operations concept that was used during the execution of the PRISMA mission.

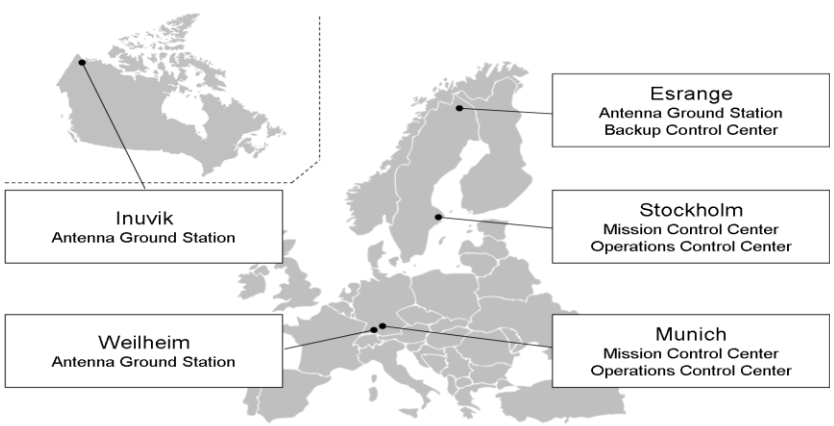

Figure 4: Control centers and ground stations at handover

IV. Preparing a second MCC

Due to the tight project schedule and the limited resources, the main approach for implementation of an additional mission control center for PRISMA in Germany was the installation of a clone of the Swedish ground system in combination with the use of established elements of GSOC's multi-mission environment. Both aspects ensured an acceptable implementation effort and high levels of control center's compatibility and mission operations safety. The main work for the implementation concentrated on the topics control room and equipment and network & ground stations.

A. Control room & equipment

For the PRISMA mission, eight consoles within one of GSOC's multi-mission control rooms were allocated providing the needed workspace for both the flight operations team and the scientists who were supporting their experiments. The control room layout is visualized in Fig. 5. The main elements of the mission control system were provided by the RAMSES system whose installation on PCs at each console was straight forward. According to the standard approach for safe mission operations, two different LANs were implemented. The flight operations were run from the so-called OPS LAN, whilst all other tasks (i.e. email, web, office applications) were available on the so-called Office LAN. The latter was also used for the simulations with SatSim, which was accessed remotely via internet. Secured copy processes allowed copying of data between both LANs.

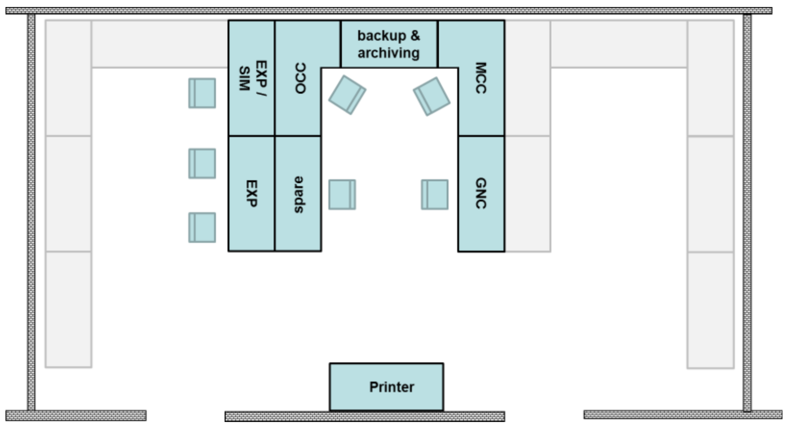

Figure 5: PRISMA workspace in the multi-mission control room 9 at GSOC

B. Network & ground stations

For the flight operations, GSOC's ground station concept based on using its ground station in Weilheim, Germany and the station of the German Remote Sensing Data center of DLR in Inuvik Canada plus the station of the Swedish Space Cooperation in Kiruna. The concept provided full flexibility and the option to run the flight operations during office hours.

At the start of GSOC's involvement in the mission operations, the Swedish network concept foresaw a direct and exclusive connection of the Kiruna antenna with the control center in Solna. This isolated application seemed to be incompatible with the multi-mission environment at GSOC because it did not allow running PRISMA among other missions and it also prohibited the use of other ground stations. Therefore, some changes of the Swedish network were done in order to allow connection of the Kiruna station to both MCCs, Solna and Oberpfaffenhofen.

First tests with Kiruna showed periodic telemetry outages which were caused by heavy traffic on the connection between GSOC and Solna which was also used by other customers. A dedicated line was rented for the period of GSOC operations to avoid these network problems. The connection between Oberpfaffenhofen to GSOC's antennas in Weilheim, shared with other missions at GSOC, was extended to ensure no delay of the PRISMA telemetry.

The implementation of the ground stations for PRISMA was performed in parallel to the other preparations starting with Kiruna and Weilheim and later for Inuvik. For the verification of GSOC's uplink capability before handover to Germany, some test passes were performed in close coordination with the Swedish flight operations where test commanding was performed via all three stations.

C. Additional preparations

Beyond these main elements some already existing tools and mechanisms of GSOC's multi-mission environment were configures and used for the PRISMA flight operations. One of these tools was an Ops Web comprising operational functions for activity planning and reporting, anomaly and recommendations handling as well as links to documentation and useful information. The most relevant functions were also available for external users which allowed processing of anomaly reports and recommendations by both engineers at GSOC and specialists in Solna.

For data processing and archiving, a combined approach was followed. During Germany's operations, GSOC performed the archiving of the raw telemetry data and its provision to the project data storage PDC. The post-processing was still done by the MCC in Solna.

V. Knowledge transfer

A. Tools and processes used

The decision to start preparing for a handover of operations to GSOC was taken only a few months prior to the launch of the satellites, with the OHB-SE operations team deep in their own preparations and simulations. This made it very difficult to prepare dedicated training to the GSOC team and the lack of an operations manual made the prospect of transferring control of the satellites seem all the more difficult. To solve this potentially major problem members of the GSOC team were embedded with the OHB-SE operations team. In the very start as observers only, allowing OHB to complete the final training sessions in the weeks leading up to launch while GSOC observed and read up on the flight procedures and other documentation available. This initial period of "self-study" forced the GSOC team to be more active in their information gathering, collecting questions for the OHB-SE satellite experts to answer in-between simulations.

Many of the operational tools developed by OHB Sweden could be provided to GSOC and GSOC staff could be trained in using them during their attendance in Solna. But some functionality still needed to be implemented by GSOC:

- Orbit determination,
- Two-line element (TLE) computation and command generation,
- PassScheduler which supported the planning and scheduling of ground station passages,
- PassageList which generated the setup file for the corresponding display tool PassageClock by OHB-SE,
- ExperimentPlanning was developed for better planning and overview during experiments, and
- Several monitoring tools for the status and conditions of each single spacecraft and the formation.

After launch and initial commissioning primarily the operators of OHB-SE took the lead in training the GSOC personnel on the use of the RAMSES system, having GSOC being co-operators during passages, observing and asking questions as opportunity allowed. As additional time went by the roles were reversed, with GSOC taking the role of operator, supported by OHB-SE personnel. This allowed a safe method of performing on-console training, using the actual satellite without jeopardizing the execution of the mission.

Eventually the GSOC operators (primarily consisting of those planned to take the role of flight directors during actual GSOC operations) could take over all the responsibilities of the operators, completely replacing the need for OHB-SE's own operators. This put GSOC right in the middle of operations, a prime position to learn more of both the ground system and the space segment. As the nominal mission settled into a semblance of routine more time could be provided by the OHB-SE experts to further answer questions and help establish procedures for operations.

The German personnel learned to operate the ground system applications, executed procedures and actions during the passes by directly doing it. They were also involved in the planning and pass preparation process of the Swedish flight director. This provided the essential insight into the flight operations planning and preparation. The GSOC GNC specialists were also working together with their Swedish counterparts in planning, preparation and evaluation of the experiments. As the date for mission handover was approaching the next step for the GSOC personnel was taken, conducting entire passages from the flight director seat, usually with an additional GSOC operator on-site, under the supervision of OHB Sweden.

Altogether, this approach required a lot of travelling but improved the cooperation of both teams. Finally, all GSOC flight operations team members had practical flight experience with PRISMA at the time of handover.

B. Remote simulations

A key element for the knowledge transfer from Solna to GSOC was the availability of the hybrid OpsSim simulator, which allowed the GSOC personnel to test their facility and to simulate and train the handling of the satellites. The Simulator located at the Solna MCC could be accesses remotely from GSOC and therefore could be used by both teams for their preparations and trainings. For the German simulations, the OpsSim was configured by the specialists in Solna for the corresponding scenario (epoch of simulation, start-up formation, loaded board software etc.) and then accessed remotely via a VPN tunnel for transfer of telemetry to GSOC and telecommands from GSOC. This opportunity was fundamental for gaining experience and knowledge about the satellites behaviour during future experiments and resulted in a successful operation at GSOC.

C. GSOC internal team training

In parallel to the on-the-job activities in Solna, the GSOC team performed cross trainings and class room lessons to spread the knowledge about the satellites, the mission operations and the experiments through the team. These activities were completed with simulations accessing the SatSim simulator in Solna and a rehearsal prior to the handover. Main topics of the training activities were the execution of the routine flight operations, performance of special experiment tasks and detection and handling of contingency situations (e.g. no telemetry situations, safe mode occurrences, reconfiguration issues, etc.).

Another relevant aspect of the internal team training was to get familiar with the specific GSOC environment. This also comprised the instruction of operators of GSOC's multi-mission team which had the responsibility to do the OCC (PRISMA operator) duty. These personnel could not be trained in Sweden and were therefore trained by experienced engineers, who had operated PRISMA in Solna.

The GSOC team created some at hand documents and reference lists. Handbooks about the satellites and the GNC system were created by collecting information about the satellites and operations received during the training in Solna. Furthermore, OHB-SE tool descriptions and VPN tunnel establishment were documented. Cross-reference lists of the flight procedures and its command parameters were generated. All generated documentation built an effective support for the internal team training and also allowed quick access to needed information during the real flight operations.

D. Flight Procedure update- and delivery procedure

The set of pre-launch validated flight control procedures created at OHB-Sweden are under strict version control and were important to transfer to GSOC without loosing their validity. Therefore, a flight procedure update- and delivery process was established to ensure updates were made to the OHB-SE repository, and that the updates were flight qualified by the pre-launched established process.

The update- and delivery process always started with a request for an update, either by GSOC or OHB-Sweden. The update, if approved, was implemented and flight qualified by OHB--SE experts and then the entire set of flight procedures were extracted from the repository and delivered to GOSC, to completely overwrite the previously delivered set of flight procedures. There were a few exceptions to this process, such as the procedures that needed to be generated every day e.g. passage scheduling procedures. Instead of establishing a complicated procedure for daily transfers of procedures the GSOC developed tools for generating them had their output flight qualified by OHB Sweden

E. PRG-procedure validation process

In parallel to the set of flight control procedures, the experiment programmes used to implement pieces of the timeline also needed to be transferred to GSOC. Since these procedures are validated close to the experiment execution time they are simulated on the faster-than-real-time simulator, which could not be moved to GSOC. Instead, the validation chain for the experiment programmes was split up, leaving the first steps of translating the XML descriptions into PLUTO and running them on the simulator in Sweden, and the final steps of spacecraft upload tests and experiment readiness reviews to be performed from Germany.

VI. Handover and Re-handover

A. Basic handover concept

The handover of the control of a space flight mission from one control center to the other is a complex process, which needs to be prepared well in order to ensure a smooth and safe handover of the responsibilities. With the handover, detailed information about the mission, status of the space segment (e.g. latest information about the formation, loaded time-tagged commands, etc.) and configuration data of the ground system components (e.g. data bases, flight procedures, etc.) needs to be exchanged. Typically, the handover process starts several months before the handover day by generating a corresponding handover plan. This plan defines who is doing what and how are the responsibilities for the corresponding topics. For PRISMA, this plan gave a detailed timing of all activities and also comprised all relevant information (so-called handover data packages) needed to get exchanged between the control centers.

A set of handover criteria were defined which needed to be fulfilled. One basic criterion was the completion of the MCC implementation and the training of the personnel in Oberpfaffenhofen. This was demonstrated on time in an operational readiness review. Another aspect was the availability of an emergency procedure for the GSOC team in case of anomalies with the ground or the space segment. This procedure comprises step-by-step orders for first aid activities and for informing of the teams including on-call numbers. It was also agreed that the MCC Solna stayed in hot-standby for three days and that two Swedish specialists were present at GSOC during the first days of German flight operations for on-site support. For the following time, an on call support was arranged.

Another important aspect was the coordination of the data archiving and post-processing. Some weeks before the handover, GSOC was still working on the telemetry data gap issue and so it was arranged that Solna should keep on doing both the telemetry raw data archiving and the data post-processing. Thus, GSOC needed to start their operations using Kiruna passes only for the first days.

B. Detailed handover activities and timeline

The timing of the handover activities for PRISMA is shown in the table 1 below. The final handover preparations started 14 days before handover with the official announcement of the handover day. The first handover data package comprising database information, a mid-term experiment and activity plan and an agreed handover timeline was provided 4 days before the handover.

The PRISMA handover from Solna to GSOC was planned for the 14.03.2011 between two passes. The Solna team completed their activities on the early afternoon and provided a second data package with the latest information about the satellites, status of subsystems (modes, configurations, etc.), loaded time-tagged TCs, latest TM parameter warnings and latest procedure updates. GSOC was already monitoring the telemetry at this time. In a following teleconference, the content of the handover data was discussed and the handover was formally agreement by both parties. The upcoming pass in the afternoon at around 18:45 was operated by GSOC whilst the Solna MCC was in standby monitoring the activities. The first command activities went fine so the handover was stated as completed after the pass in another phone call.

After performance of the first two weeks of operations by GSOC, the telemetry reception quality by GSOC could be stated as good so the responsibility of the raw data archiving changed from Solna to GSOC. From this time on, Weilheim station passes could be used and Inuvik passes were available by end of April 2011. As agreed before, the processing of higher level products remained in Solna during the entire GSOC operations period.

Step	Time	Activity
0	2 months before H/O	Preparation of handover plan and procedure
1	H/O – 2 weeks	Handover date/time announcement
2	H/O – 4 days	Preparatory handover teleconference Both parties agreed procedure and timeline Handover data package 1 was provided
3	H/O – 2 days	Coordination of Kiruna scheduling and uplink access
4	Last pass before H/O	Last Solna operations GSOC monitoring TM Handover data package 2 provided after pass
5	Handover	Handover teleconference Discussion of data package 2 Space segment and GSOC stated green for H/O Handover execution confirmed by both parties
6	First pass after H/O	Satellites operated successfully by GSOC via Kiruna Solna monitoring TM Start of on-site support by Solna specialists at GSOC Start of Solna stand-by phase
7	H/O + 1 day	Start of experiment operations
8	H/O + 3 days	End of Solna stand-by phase
9	H/O + 1 week	End of Solna specialists on-site support Start of on-call support by Solna specialists

Table 1. Handover timeline

C. Handover lessons learned and re-handover

After completion of the handover, a report was generated, which also contained some lessons learned. One was that the booking of Kiruna station passes was not properly arranged. The station was mainly running in automated mode and always needed booking updates with the complete list of all passes. But when GSOC sent their booking request some days before, they accidentally deleted the previous bookings of Solna. This could be fixed quickly the day before handover but the procedure was updated regarding the re-handover.

Another lesson learned was that the schedule on the handover day was very tight. There was only little time for the handover data package provision and for the implementation of the latest configurations into GSOC's system. Due to a glitch in the conference system, the handover telecon was performed in a hurry, which didn't cause any problem since no anomalies occurred. But for the re-handover the timing was improved.

Taking the experiences of the handover to GSOC into account, the re-handover plan was created correspondingly. This time, the plan did not foresee a hot stand-by phase of GSOC after the re-handover and also no on-site support was needed because the mission went back to the home control center and sufficient personnel was available in Solna.

Finally the re-handover took place on August 23rd 2011. The preparation of the re-handover including data package exchange etc. was executed as before, but with some more time between the last contacts of GSOC and the first activities of Solna. After two successful passes, Solna confirmed completion of the re-handover and GSOC was released.

VII. Experimenter experience OHB vs. GSOC

After the handover of the PRISMA operations to GSOC, the Solna staff became an experimenting team and a remote support team, while all other functions and platform maintenance were transferred to GSOC. With the implementation of the Weilheim and Inuvik ground stations, the GSOC had full flexibility to plan the active flight operations and thus the experiment activities could be executed during daytimes. This improved the availability of remote support to both the GSOC operations team and the experimenters from the support team in Solna, which was working only during daytime.

In the same way the Swedish GNC-experts had interfaced the experimenters before the handover, GSOC's GNC-experts continued this function after the handover. They were in contact with the experimenter from the preparation and final planning through the experiment validation until the experiment's execution. The first validation of the prepared experiments were performed by Solna engineers by reason that the corresponding software simulator (GNC simulator) could not be provided to GSOC and thus needed to be run in Solna. However, the resulting TM from the GNC simulator was distributed via PDC to GSOC and the experimenters in the same way as before the handover. For the monitoring of the experiments and the GNC related functions of the satellites, on the one hand the GSOC GNC team could use OpsTools provided from Solna, on the other hand also tools developed by GSOC were used to support the experiment operations, e.g. the ExperimentPlanning for scheduling and further monitoring applications.

Prior to each experiment execution phase, an experiment readiness review ERR was conducted via phone, where Solna and GSOC engineers discussed the upcoming experiment together with the experimenter. Topics of the review were general aspects of the experiment, entry conditions, activities and their scheduling in context with the available station contacts, needed flight procedures and their validation, expected satellite behaviour and corresponding telemetry, special measures in case of anomalies as well as safety and experiment abortion actions. A corresponding experiment plan was finalized which built the backbone for the detailed passage activity planning.

The baseline concept for conducting the flight operations included the personal presence of the experimenter during the ground station contacts at the MCC, but also cases where the experimenter was connected via phone only during passages could be conducted successfully. In these cases live (real-time) telemetry was not available for the experimenter so the serving GNC engineer at GSOC reported the relevant information verbally by phone and discussed the situation and next steps with the experimenter.

Experimenters attending the execution of their experiments at GSOC basically found working conditions comparable to the environment in Solna. One difference at GSOC was that they could not connect their Laptops directly to the real-time telemetry data stream due to the network safety rules at GSOC, but dedicated workstations were available at their consoles providing the real-time telemetry and access to the recorded (offline) data archive was possible via a public LAN. Another aspect was that telemetry raw data were available on the data archive PDC with a delay of up to 20min after the pass, thus post-processing products were provided later than during operations at Solna. As described before at GSOC the OPS-LAN and Office-LAN are strictly separated, consequently dump data arriving from the ground station in the OPS-LAN needed to be transferred to the Office-LAN first and is followed by the upload to the PDC. Since both transfers were triggered automatically every 5 minutes and the transfers itself taking up to five minutes due to the huge amount of data and internal virus checker in worst case the delay summed up to 20 minutes.

According to the experimenters both aspects did not have big disadvantages effects on the operations. The main disadvantage experienced during operations at GSOC was caused by the fact that the XML files prepared and provided by the experimenters had to be translated into PLUTO files for commanding. The corresponding translation tool was not available at GSOC due to the need to preserve configuration management between the two control centers, thus a loop over an automatic translation job in Solna was necessary and took some time, which made it very hard to react on spontaneous change requests by the experimenters which was previously possible during Solna operations with direct access to the master configuration.

With the availability of the ground stations in Weilheim, Kiruna and Inuvik, it was also possible to run operations with consecutive station visibilities and a cumulative contact time of up to 30 minutes. This was not explicitly required by the experiments but was conducted some times as an additional experiment to measure the outage of telemetry and command links during the change from one station to the next.

VIII. Conclusion

The successful completion of all the experiments originally planned prior to launch would most certainly never have been possible without the temporary transfer of operations to Germany. In this manner the handover has been a large contributor to the overall accomplishments of the PRISMA mission, but additional to this has been the great opportunity for co-operation and learning for both of the operational teams. The OHB-SE team has greatly benefited from the vast operational experience of GSOC in spacecraft operations, while the German team has gained valuable knowledge on the operation of formation flying satellites.

IX. References

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