PRISMA Mission Extension: Adapting Mission Operations to New and Changing Mission Objectives

N. Ahlgren[1], T. Karlsson[2], R. Larsson[3], R. Noteborn[4]
OHB Sweden AB, P.O. Box 1064, SE-171 22 Solna, Sweden

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. In early September of 2011, 15 months after launch, all primary mission objectives of the PRISMA formation flying satellites had been achieved and mission success was declared. Since a significant amount of delta-V capability still remained an open call for new experiments was issued, inviting both old and new experimenters to use the capabilities of the formation. Several interested parties took the opportunity to perform their own experiments with an existing platform, each coming with new mission objectives not previously planned to be flown on the PRISMA satellites. Some of these experiments were close to what had already been achieved within the nominal mission, but some included new ways of using the formation not envisioned by the spacecraft designers. The new experiments span from data collection in specific relative orbits, with a separation from a few meters to several kilometers, to entirely new modules within the on-board software. Changing from a pre-planned technology demonstration mission to operating a commercial resource required adaptation of the original operational concept, taking into account the different levels of experience of the customers and managing the satellites between experiments. This paper describes how these new mission objectives were integrated in operations and how a sometimes very short turn-around between initial concept and experiment execution was implemented with the aid of well established validation processes, high degrees of on-board autonomy and a flexible 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 SNSB and 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 DLR/GSOC and 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 (OHB-SE) is the prime contractor for the mission which is funded by the Swedish National Space Board (SNSB).Further supported to the mission is provided by the German Aerospace Center (DLR/GSOC), the French Space Agency (CNES), and the Technical university of Denmark (DTU). PRISMA consists of two spacecraft: Mango and Tango. The orbit is a sunsynchronous 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 separated from Mango on August 11 the same year. The nominal mission was completed by the end of August, 2011. Figure 1 shows the

[1] Space Systems Engineer, Spacecraft Department, niklas.ahlgren@ohb-sweden.se
[2] AOCS Engineer, AOCS and Software Department, thomas.karlsson@ohb-sweden.se
[3] AOCS Engineer, AOCS and Software Department, robin.larsson@ohb-sweden.se
[4] Senior AOCS Engineer, AOCS and Software Department, ron.noteborn@ohb-sweden.se

PRISMA satellites in the clean room as they are ready for shipping to the launch site.

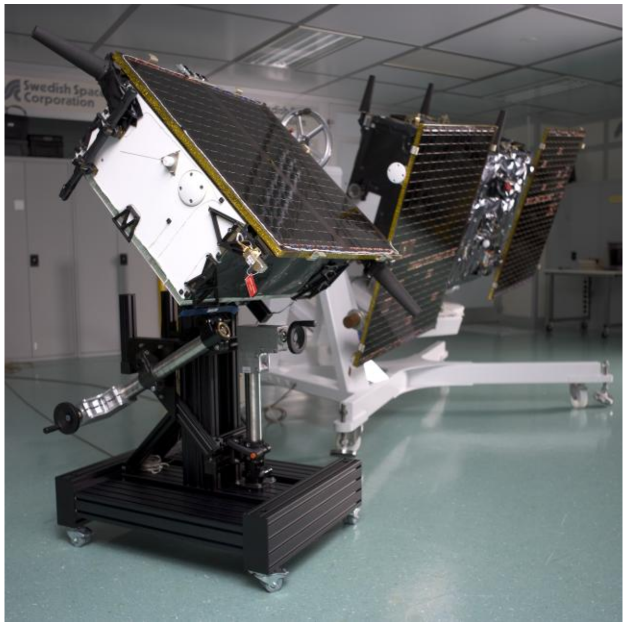

Figure 1: The PRISMA satellites ready for launch

II. Mission Concept

A. Mission development

A key ingredient in the mission concept was the early involvement of the different experiment teams. As several of these contributed to different parts of the software development, both for their own experiments and to navigation and interfaces used by the platform as a whole, close cooperation between the development team and the experimenters was vital for the overall development of the on-board software (OBSW).

This cooperation took several forms, e.g. workshops and exchange of interface control documents. It also included early input from the experimenters to the development of the operational concept. The knowledge of both internal and external experimenters of their planned operations to a large degree defined the needs and constraints of operations.

Part way into the project a dedicated Experimenter Advisory Board was established, consisting of representatives from each major experiment team. The role of this team was to both monitor the development of the operational concept and the mission as a whole and to act as a sort of peer review for the different experiments themselves.

Such close cooperation lead to a natural sharing of information, with knowledge of the platform itself becoming large among the experimenters. Some of the experimenters even used the spacecraft modes developed by others as a baseline for validation of their instrumentation and initial commissioning of their navigation and control software modules.

With experiment definition and refinement being spread over the entire development phase of the mission all the concepts of operations were clear for the core experimenters well in advance of the actual execution of their experiments. This lead to well developed processes and effective communication during the execution itself.

B. Experiment validation

One of the largest contributions to the success of the nominal mission was the use of an extensive validation and simulation process, the basis of which was established already during the system level testing of the satellites.

Core to this process was a well defined format for exchanging detailed experiment time-lines and actual command sequences. This was done through the development of a dedicated XML format, which could be readily translated into both simulation input and actual command procedures for upload to the spacecraft itself.

These XML documents, named experiment programmes (PRG), were developed by the experimenters themselves and then delivered to the operations team for validation. This validation was performed in stages using the OHB-SE developed Satellite Simulator (SatSim[7]), a high fidelity simulator capable of simulating both the space environment and the satellites themselves.

SatSim was developed in a modular fashion, allowing it to be used throughout the entire development phase of the mission. At it's most "lightweight" it consists of a pure GNC simulator, known as GNCViewer, which is a Matlab/Simulink module capable of faster than real-time simulations. The next step up is a hardware in the loop simulator, based on XPcTarget, capable of communicating over the satellite CAN bus with the onboard computer, listening in on all commanding and able to simulate all platform and most experiment units in real-time. This version was used during the OBSW development and also for operational simulations of the mission.

The final configuration of SatSim was used during the system test phase of the satellites. Here the configuration was very close to the OBSW development environment, though fewer units were simulated, instead using the actual flight hardware, with external stimulators driven by SatSim.

Once an experimenter had prepared a PRG it was delivered to the operations team for validation. This was primarily done using the GNCViewer version of the simulator, with the result being provided back to the experimenter for review in an iterative process. As the PRG converged to a more stable version to be actually executed in orbit the XML would be translated to an operational command script in the PLUTO[8] language. This result would then be uploaded to the operational simulator for command verification and a procedure integrity check.

After the experiment had passed this final validation step an Experiment Readiness Review (ERR) was held between the operations team and the experimenter to establish the final go ahead for execution. This ERR was usually held only days before the execution of the experiment and also served to establish consensus on the initial conditions and non-experiment commanding needed during the execution. The entire process from experiment development to execution can be seen in Figure 2

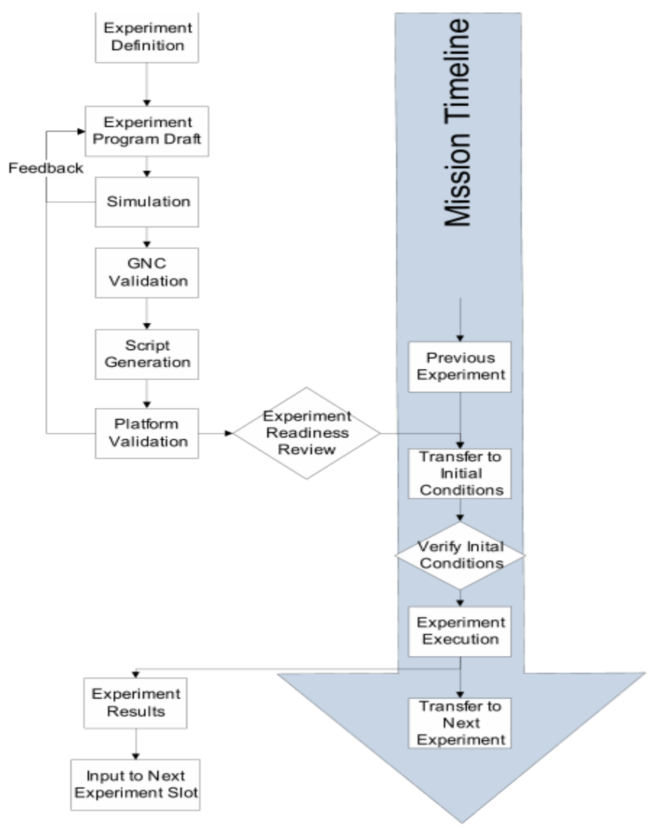

Figure 2: Experiment preparation and execution process

III. Completion of Nominal Mission

A. Brief mission summary

The nominal mission consisted of the activities and experiments foreseen before launch and were completed a few months later than initially anticipated, in August 2011. It was divided into three phases; LEOP & Commissioning, Early Harvest and Basic Mission, where the Basic Mission was divided into two when it was decided to handover a part of it to be operated from GSOC[9]. The resulting phases then became:

- LEOP & Commissioning
- Early Harvest
- Basic Mission
  - Nominal Mission
  - GSOC Operations

Table 1 shows a breakdown of the phases before the extended mission.

Phase	Experimenter	Type of experiment	Relative distance
LEOP & Commissioning	N/A	N/A	N/A (mated)
	SSC Ecaps	The very first firings	N/A (mated)
	DLR	GPS Calibration	N/A (mated)
Early Harvest	OHB-Sweden	Autonomous formation flying (First closed loop experiments)	0m-3km
	Nanospace	Micro Thruster Firings	1km-3km
	DLR	Autonomous formation keeping	1km-10km
Basic Mission - Nominal Mission	OHB-Sweden	Autonomous formation flying (Maintaining and reconfiguring of relative orbits)	10km-10m
	OHB-Sweden	Autonomous proximity operations, (GPS & Vision based),	30m-2m
	OHB-Sweden	Autonomous Rendezvous (Vision based)	40km-50m
	CNES	RF based autonomous formation flight	10km-20m
	DLR	Autonomous formation keeping	5km-50m
	SSC Ecaps	Green Propulsion flight demonstration	N/A
Basic Mission - GSOC Operations	OHB-Sweden	Autonomous formation flying (completion of experiments)	30km-10m
	OHB-Sweden	Autonomous proximity operations (completion of experiments)	30m-1m
	DLR	Autonomous Orbit keeping	50km-4km
	SSC Ecaps	Green Propulsion flight demonstration	N/A

Table 1: Overview of nominal mission

Many challenging experiments in the field of autonomous formation flying were performed during the Basic

Mission and most were repeated with increased level of difficulty and demands on accuracy. For example, several proximity experiments were performed based on all three relative sensors systems and for the Vision Based Sensor (VBS) an accuracy of sub centimetre level was achieved[10].

B. Decision to open platform to external customers

In the end of the nominal mission it became clear that a certain amount of dV capability would remain in the spacecraft even after the completion of all planned experiments, which gave rise to the idea to invite new experimenters to benefit from the PRISMA platform. This was proposed to SNSB, who approved continued use of the platform by external customers but without additional government funding, meaning all future experiments had to be financed in a self contained manner. The continuation of the mission could thus offer valuable research and development data regarding formation flying to organisations able to provide the funding necessary, and it was decided to open the platform to external customers.

This additional phase starting after the nominal mission was named the PRISMA Mission Extension and an open call for new experiments was announced to give those interested the possibility to become a partner in the mission. Immediately following the announcement two of the experienced partners and two brand new clients took the opportunity to perform additional experiments. The experienced partners were CNES and DLR, who had already performed experiments on the platform and were well aware of experiment definition procedures and validation. The new customers were the Slovenian Centre of Excellence for Space Sciences and Technologies (Space-SI) and GMV. These four experimenters have, at the time of writing this article, successfully completed their various experiments and other organisations have shown interest to become partners in the extended Prisma mission.

IV. Extended Mission Concept Adaptation

A. Preparation flexibility for new customers

Changing from a mostly internal project and close cooperation with international partners to offering an experiment platform as a commercial resource placed new requirements on the processes involved in both experimenter relations and operations themselves.

While some of the clients were, in fact, returning partners wishing to expand on their initial findings and perform new experiments others had no previous involvement in the project and were as such completely new to the process of going from experiment definition through its execution. This meant that the involvement of the operations team had to come much earlier in the process, if not in time, than before. The new experimenters would need aid in understanding the capabilities and limitations of the PRISMA satellites and how to define the experiments themselves.

Disregarding the experienced returning partners the process of preparing the experiments had to start already before contract signature with initial feasibility studies of what the customers wanted to perform using the formation. This study would be iterated a few times between OHB Sweden and the clients until a set of test cases could be defined which would cover the needs of the customer. These test cases would then serve as the basis of contract negotiations, eventually leading to an agreement to perform the experiment.

The often short time between final signature and actual start of in-orbit experiments meant that the operations team had to be very flexible, allowing for much later input than what was previously the case during the nominal mission.

B. Extended mission time-line

Driving the planning of the time-line for the first extended experiments was the planned use of the CNES developed FFRF terminals. Both the extended CNES experiment and the GMV experiment planned to make extensive use of the instrument. This requirement stood against the need to have the Tango FFRF terminal completely switched off during eclipses due to power constraints existing from before the launch of the satellites.

As such the experiment schedule needed to have all of the first experiments finished by the start of the eclipse season in mid November of 2011. With a four week CNES experiment and one week each for the others, not including preparations and handover of operations from GSOC in early August the schedule needed to become quite compact, with very little time between the experiment campaigns.

Discussions about the scope of the DLR experiment were not started until later, meaning a substantial gap in experiments occurred over the 2011-2012 eclipse season. During this period operational activity was significantly ramped down, awaiting the start of further experiments.

Figure 3 shows the mission time-line for the extended phase, with the eclipse season defining the start of the idle period, and how the first three experiments were finalised before it.

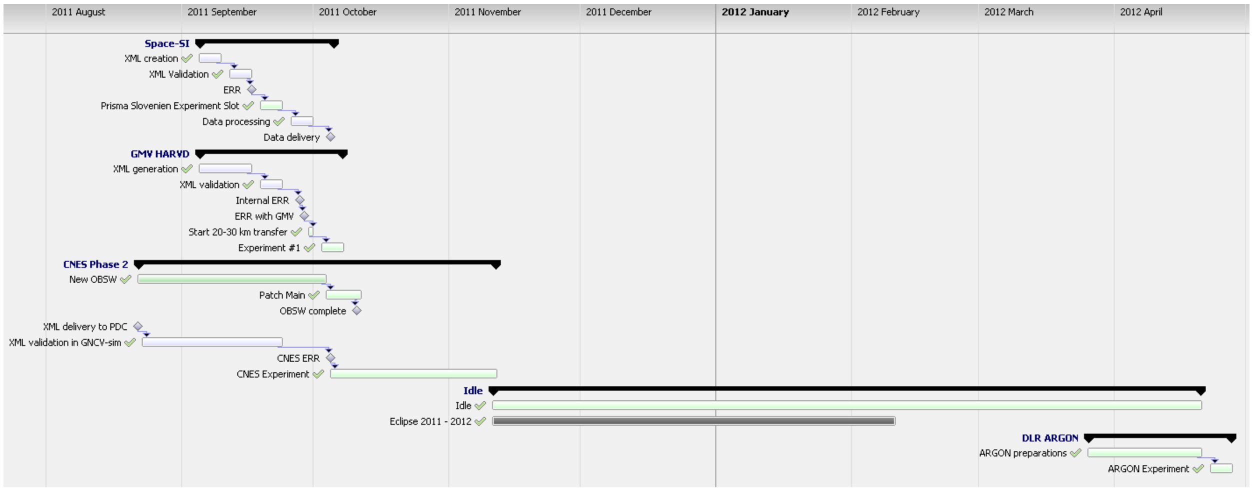

Figure 3: Overview of the extended Prisma Mission

C. Establishment of experimenter support teams

For the new partners not experienced in the experiment definition and validation processes, dedicated teams from OHB-Sweden were set up to take the initiative for the experiment development together with the new partner. These joint workgroups turned out to be very efficient since the experienced operations team members could discuss and transform the new partners' ideas into experiment defining XML very easily.

Several of the experimenters came with new and novel ways of utilizing the satellites. One of the new partners, Space-Si, came up with the idea to take a series of pictures of a landmark on the ground with a feature of the Tango spacecraft, e.g. one of the antennas, lined up with it. This meant a forced relative motion that also took both the earth rotation into account and the absolute attitude of the Mango spacecraft, which required a new tool to be developed. This experiment set was successfully implemented and repeated several times for different landmarks of the earth with different weather conditions. Other experiments included both using the entire formation for data collection for additional on-ground processing as well as only using the Mango spacecraft for attitude experiments. In general, only one week was required to transform the new customer's ideas into XML programmes.

After the XML creation they were to be validated by simulations, and normally iterated with the experimenter for review. But since the experienced operation team members were already involved in the development of the XML's, the validation could be performed without involving the new customer since the experiment objectives and requirements were already well known to the support team performing the validation.

D. Experiment requiring on board software update

CNES, who had performed experiments in different timeslots throughout the whole nominal mission, decided to return in the extended mission and performed a four and a half week mixed experiment. During these weeks three different experiment types were interlaced, resulting in a different objective each day according to a predefined scheme.

One of the new experiments involved an update to the on-board software, since the vision based sensor (VBS) was used as relative sensor in the CNES based navigation, instead of the FFRF terminal that was the baseline sensor when developing the CNES navigation. This was possible because the two different sensor systems output essentially the same information, but still the on-board software needed to be adapted to route VBS information to the CNES navigation library, plus some signal processing.

The software update increased the complexity for the experiment preparations, and a two month period was allocated for CNES to modify their navigation library and deliver it to OHB-Sweden. Another six weeks were then allocated for integration and testing of the new OBSW, before uploading and application on board PRISMA in orbit.

During the integration and testing phase of the new OBSW a logical flag error was found and a new delivery of the navigation library was necessary from CNES. This new delivery meant a full OBSW rebuild and integration and test sequence was initiated at a very late stage, but the planning contained enough margins to accommodate this. The rebuild passed the testing successfully and was uploaded to the spacecraft in time for the execution of the experiment.

The PRISMA operations team working on the on-board software update was not the same as was working with the XML creation and validation, so two teams were working in parallel to establish the initial conditions required for the start of the experiment, which was completed successfully.

E. Passage planning and telemetry rate adaptation

As the mission changed character to a more commercial format the need to manage ground passages in an effective way became necessary. During the time between the client experiments the satellites were placed in a safe relative orbit and as such were in need of less active monitoring. The number of passages scheduled with the ground station could thus be brought down significantly, from the nominal full 10-11 passages/day to as low as 1 or 2, depending on the current needs for platform related maintenance.

To allow the ground station additional flexibility when scheduling these few needed passages two general passage types were defined: Campaign and Standard. The Campaign passages are given higher priority in scheduling as they are used during the actual experiments, usually with customers on-site in the control-room. Depending on the nature of the experiment itself the number of Campaign passages can be between 6-11, where the on-board data-generation rate and thus the telemetry budget defined the required amount of downlink time needed.

Between the experiments the Standard passage designation is used, usually scheduled as one of the first long passages of the afternoon to coincide with normal office hours. This passage designation entails a slightly lower priority in scheduling by the ground station, and as such can be shifted up to a few orbits in case of antenna conflicts.

In order to enable this reduction of downlink time while still maintaining the safety of the satellites a new telemetry configuration was developed, which ensured that all vital data could be sent to ground during the available contacts. This was used to great effect between experiments and allowed for a safe way of monitoring the start of the satellites' second eclipse period in November of 2011.

Once the confidence in the platform during the eclipse season had been established the number of passages was further reduced to just one per day. Confidence in the high degree of on-board autonomy meant that less active monitoring was needed, with the satellites handling formation keeping on their own without the need for ground control intervention. This reduction in the number of passages was possible due to the use of separate partitions in the Mango satellite's mass memory for ordinary and essential data. While the ordinary partition is designed to hold all on-board generated telemetry, including external units, the essential only stores a sub-sampling of the most vital telemetry which would be needed to monitor the platform and formation, giving a quickly downloadable overview of the satellites' status since the last ground contact.

The change to priority based passage scheduling has significantly helped keeping the costs of maintaining the satellites operational down, thus further extending their lifetime and giving more experimenters the opportunity to utilize the unique PRISMA platform.

F. Additional Internal ERR

With more of the detailed experiment definition in the responsibility of the operations team and less time between experiment concept and execution the need for better internal processes in the operations team quickly became apparent. While the process of iterating experiment validation results remained much the same the actual development of the XML fell to the GNC experts of the team itself. To spare the customers from the sometimes detailed configuration discussions an additional, internal, ERR was established to iron out any remaining issues regarding spacecraft configuration and initial conditions. This led to the ERR with the customer running much more smoothly and being more in the form of a final briefing as to the status of the experiment preparations and an opportunity for the experimenters to ask more operational questions to the team. The added bonus was of course also a significantly better prepared operations team, where internal communication was much improved from the original mission concept.

G. Post Experiment Data delivery

All original partners in the nominal mission had full access to the combined mission archive of telemetry through joint data-sharing and non-disclosure agreements. This meant that the same route of data-delivery was not possible to use for the new commercial clients and other ways of delivering data had to be employed.

At the time of the contract signature for new customers in the extended mission, a sub-set of the telemetry to be delivered to the experimenter after each experiment was agreed as a part of the contract. This was a new and additional step in the post-processing chain that had not been needed before, and was developed in advance of the start of the extended mission. In addition, each experimenter also got a MATLAB tool, called GNC-Viewer, which can open and view any post-processed telemetry. This tool was developed before the launch of PRISMA and as it proved to be very powerful for analysis, it has been extensively used during the mission. To be able to offer the same capability to external customers, the tool has been provided in compiled form to them as part of the data delivery.

To be able to extract the sub-set of the telemetry from the raw archive, an additional and manual step was added to the post-processing chain. This was also achieved by a MATLAB tool in which one specifies the telemetry to be extracted for a certain period of time. The tool then filters out the specified data into structs in MATLAB format, ready to be delivered and opened by the customer in the GNC-Viewer.

V. Mission execution

A. Use of Ecaps experiment as test run for streamlined operations

After mission operations were handed back to OHB Sweden in August of 2011 very little of the original mission experiments remained. Chief among them was about 10 days of SSC Ecaps' HPGP experiment wrap-up. As the experiment itself mostly consisted of repeated thruster pulses very similar to the earlier HPGP experiments it was decided to test the new "streamlined" operational concept during its execution.

An internal experiment support team was established and aided the experiment preparations with the needed orbit simulations and procedure finalizations. As both operational team and the experimenter were very familiar with the activities to be performed the ERR could be held very informally and the experiment could start merely one week after preparations started.

Execution of the experiment was also held in a very minimalistic manner, utilizing only two members of the operations team for the entire duration. The need for a dedicated operator was deemed unnecessary and the fact that the nature of the experiment needed less in terms of direct GNC monitoring led to the GNC expert doubling as operator during the passages.

While this unavoidably led to long days (and nights) for those involved the knowledge that operations now were executed in a campaign-based format instead of the previous continuous stream of experiments ensured that the personal impact on the team could be kept low.

As the experiment's nature only allowed it to be carried out in real-time during manned contacts only 5-6 passages per day were used for the experiment. The remaining possible contacts were cancelled to test the newly developed low TM-rate configuration, proving that it was sufficient to safely monitor the satellites.

The successful completion of the HPGP experiment showed that the changed minimalistic operational concept was well prepared to handle the arrival of the first external customers

B. Summary of external experiments

During the extended phase of the PRISMA mission, seven additional experimenters have performed experiments, whereof two were entirely new. Since each experimenter had very different types of experiments, very different demands were put on the preparations and the operations teams. Table 2 gives a detailed view of the extended mission phase.

Experimenter	Type of experiment	Updated OBSW	Relative distance
SSC Ecaps	Individual thruster firings for characterisation of new propellant	No	N/A
OHB-Sweden	VBS based proximity operations	Yes	2 m – 20 m
Space-SI[11]	Simulated radar interferometry remote sensing	No	200 m
	Simulated distributed instrument remote	No	5 m

	sensing		
	Attitude determination of an uncooperative object	No	5 m
	PR imaging of Slovenia and international targets	No	15 m – 20 m
	Third object tracking and observation	No	N/A
GMV	Station keeping, forced V-bar approaches, fly around	No	10 m – 20 km
CNES	FFRF to VBS transitions	Yes	20 m
	VBS based medium range rendezvous	Yes	20 m – 10 km
	Attitude measurements	No	N/A
Swedish Institute of Space Physics	Data collection of MEMS based shutter mechanism	No	N/A
DLR	Ground in the loop VBS based rendezvous	No	1 km – 30 km

Table 2: Summary of extended mission

All experiments in the extended mission were performed successfully, although a few of them lead to an FDIR triggering and had to be rerun. As it turned out, the most difficult one to execute was the Mango attitude measurement during the CNES experiment slot. This was unexpected since the validation simulations indicated very stable execution, but the real life experiments resulted in degraded GPS navigation performance due to fast attitude rotations and corresponding GPS antenna switches. Eventually, the GPS navigation became so poor the FDIR declared the situation too unsafe to maintain, and a switch to the platform safe mode was triggered, resulting in aborted experiment and GPS antenna stable and sun pointing attitude. Re-running the experiment with updated settings led to a successful performance.

C. Experimenter involvement in operations

All customers were invited to participate in the actual execution of their experiments at mission control in Solna, which everyone has done, at least to a some degree, up to this point in time. An experiment control centre has been available for use by all visitors, providing both office space and access to real-time telemetry during satellite contacts. Having the experimenters present in, or near, the control-room also facilitated greater communication during operations, allowing for quick discussions and adjustments of the experiments themselves as needed.

At one occasion during the very long CNES experiment slot, the experimenters very confident the operations team would mange without them for one of the weeks, and the experiment was monitored from CNES facilities in Toulouse by sharing one ground system monitor via Skype. This method was considered safe from a network perspective since the monitoring computer was sitting on an isolated network in the PRISMA control room, and was only able to receive telemetry. With this solution, the CNES experimenters could overlook the continuation of the experiment without them being present in the control room.

D. Operations flexibility

During many of the experiments, but especially for the inexperienced experimenters, high flexibility from the operations team was demanded based on experimenter input. Usually, each experiment filled up a slot starting at the first passage after the non-visible period in the afternoon to the next first passage after the non-visible period the day after. In this fashion, the 24 hour slots could be re-arranged based on certain demands of the experimenter, for example weather conditions when taking ground images or other constraints to be fulfilled before an experiment starts. This was accommodated by having parallel programmes in on-board time tagged queues containing commands relative to their respective release time. Then, depending on weather condition (or similar), the experimenter could at the very end of a shift request release of the most appropriate queue for the following day.

VI. Conclusion

Extending the PRISMA mission by offering access to the platform to other organizations has proved to be a successful but challenging task. However, using the same personnel during the PRISMA development as in the operations increased the flexibility within the team to adapt to new experiment requirements in a very short time. This resulted in a successful experiment time-line between the re-handover of the satellites to OHB-Sweden in August 2011 and the start of the eclipse season in November 2011; a period which included the completion of several remaining experiments, three new experimenters and one complete software update to the Mango spacecraft.

The extended mission required numerous adaptations of the operations concept and also to the tools used for operating the satellite, all of which was successfully completed within the time of each new task. Most remarkable might be the change to operate the satellite in experimental mode with an operations team of only two people, covering only eight hours each day, but also the reduced telemetry strategy to sacrifice on board resolution in favor of reduced downlink requirements, and hence costs, in the non-experimental phase.

The new experimenters provided new experiment ideas to the mission and Figure 4 shows five concatenated images taken during one of the Space-SI experiments, where Mango is positioned into a controlled formation on top of Tango while capturing images of the earth.

To reach new experimenters for the extended PRISMA mission an open call was issued which is still open and valid since the end of the extended mission is not yet determined.

Figure 4: Tango spacecraft captured from Mango when flying in a controlled nadir formation (Image courtesy of Space-SI)

VII. References

[1] S. D'Amico, J.-S. Ardaens, S. De Florio, and O. Montenbruck, "Autonomous Formation Flying - TanDEM-X, PRISMA and Beyond." *5th International Workshop on Satellite Constellations & Formation Flying*, Evpatoria, Ukraine, July 2-4, 2008.

[2] G. Krieger, I. Hajnsek, K. P. Papathanassiou, M. Younis, and A. Moreira, "Interferometric Synthetic Aperture Radar (SAR) Missions Employing Formation Flying." *Proceedings of the IEEE*, May 2010, Vol. 98, No. 5 (2010).

[3] J. Bristow, D. Folta, and K. Hartman, "A Formation Flying Technology Vision." *AIAA Space Conf.*, Long Beach, CA, 2000, AIAA Paper No. 2000-5194.

[4] D. Reintsema, J. Thaeter, A. Rathke, W. Naumann, P. Rank, and J. Sommer, "DEOS – The German Robotics Approach to Secure and De-Orbit Malfunctioned Satellites from Low Earth Orbits." *i-SAIRAS 2010*, August 29-September 1, 2010, Sapporo.

[5] S. Berge, B. Jakobsson, P. Bodin, A. Edfors, and S. Persson, "Rendezvous and Formation Flying Experiments within the PRISMA In-Orbit Testbed." *ESA GNCS 2005*, Louthraki, Greece, October 17-20, 2005.

[6] S. Persson, B. Jacobsson, and E. Gill, "Prisma - Demonstration Mission for Advanced Rendezvous, Formation Flying Technologies and Sensors." *56th International Astronautical Congress*, Fukuoka, Japan, October 17-21 2005, IAC-05-B5.6.B.07.

[7] M. Nylund, T. Karlsson, P. Bodin, C. Chasset, R. Larsson, R. Noteborn, "SATSIM an Advanced Real-Time Multi Satellite Simulator Handling GPS in Closed-Loop Tests", *SFFMT2011 4th International Conference on Spacecraft Formation Flying Missions & Technologies*, Montréal, Canada.

[8] ECSS-E-ST-70-32C: "Test & operations procedure language", 31 July 2008.

[9] T. Karlsson, R. Faller, N. Ahlgren, B. Schlepp, "PRISMA Mission Control: Transferring Satellite Control Between Organisations", *SpaceOps 2012*, Stockholm, Sweden.

[10] P. Bodin, R. Noteborn, R. Larsson, T. Karlsson, S. D'Amico, J. S. Ardaens, M. Delpech, J.-C. Berges, "The Prisma Formation Flying Demonstrator: Overview and Conclusions from the Nominal Mission", *35th Annual AAS Guidance and Control Conference*, Breckenridge, Colorado.

[11] D. Matko et. all., "SPACE-SI Formation Flying Experiments on Prisma Satellites", *Proceedings of the 4S Symposium*, Portorož, Slovenia, 2012.