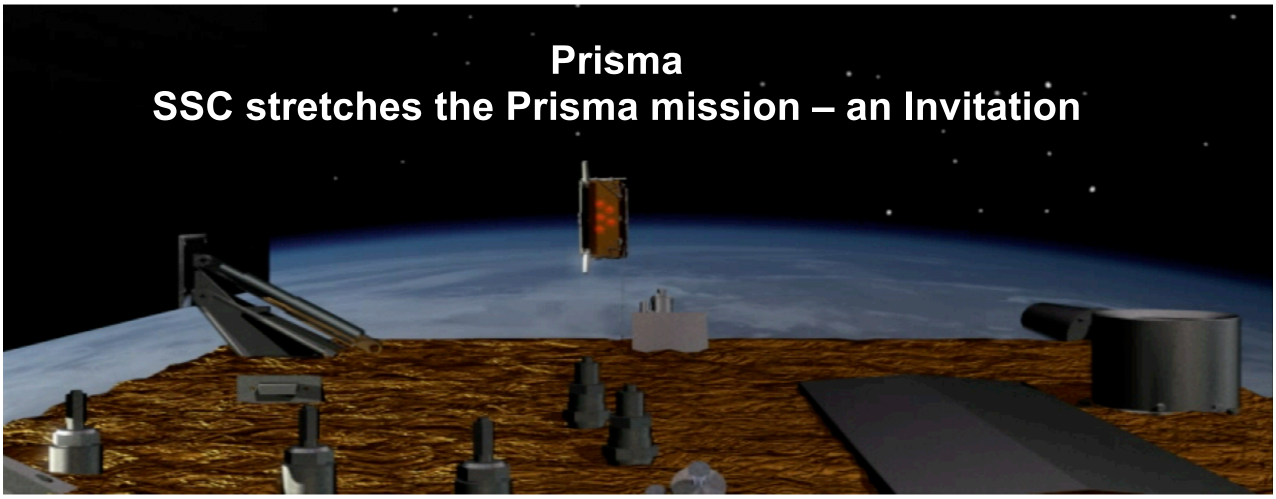


CONTENTS

1 – INVITATION TO USER EXPERIMENT AND PRISMA-COPIES

The Background

The Swedish Space Corporation (SSC) has developed the Prisma system, Prototype Research Instruments and Space Mission technology Advancement, to demonstrate critical technologies for enabling various types of proximity operations: rendezvous, sustained formation flying, collision avoidance, etc. Prisma consists of two space vehicles, an agile Mango and a passive Tango that plays the role of a translationally passive resident space object (RSO). Launched as a single Combine on June 15, 2010, the system is now commissioned and well into the Nominal mission. The partners/Experimenters in the current ongoing Basic mission are: DLR, CNES and DTU. Since their separation on August 10, Mango and Tango have been continuously involved in technology demonstrations, with the two units playing different roles as the Experiments proceed. Both Prisma units are 3-axis stabilized spacecraft, and Mango has monopropellant thrusters. Navigation-wise the Prisma system carries multiple sensors for space situational awareness. These include: A differential GPS system for inter-satellite distances exceeding a few meters. A visual based sensor (VBS) system identifies the RSO (Tango) at distances up to several hundreds of kilometres, and tracks the position and/or pose of the target down to as close as 0.1 meters.

The Invitation 1 – User Experiments

At the end of the Nominal mission, anticipated to be in the spring or summer of 2011, it is expected that the Mango spacecraft will have 50+ m/s of ΔV remaining. Swedish Space Corporation (SSC) has a TAA in place with Princeton Satellite Systems (PSS) covering the areas of formation flying (FF), rendezvous and docking (RVD) and related guidance, navigation and control. The two companies are now looking to further develop and leverage the Prisma capabilities, primarily in the U.S. space market. To this end, Swedish Space Corporation (SSC), in conjunction with Princeton Satellite Systems (PSS), has started to offer civilian and military organizations in the United States the opportunity to use Prisma for their own flight experiments. This offer is now expanded and the invitation is opened also to non-U.S. entities. SSC is now actively seeking User Experiments with Prisma that involve both short term, commercial-based ventures, as well as longer-term commitments and cooperation based on a joint and mutual interest.

The Invitation 2 – Prisma Copies Tailored for the User

SSC is also capable of building copies of Prisma for U.S. and non-US organizations. These could be follow-ons to the experiments suggested above. This would allow rapid advances in on-orbit technology through the use of a flight-tested spacecraft. TRL raising and risk reduction are potential possibilities. Purchased Prisma spacecraft could be loaded with customer flight software and host new sensors. New spacecraft would be available within about 18 months (assuming a rebuild of current design). SSC can provide interfaces to most standard launch vehicles.

Examples of User Experiments

The purpose and objective of a particular user experiment is completely up to the customer to define. Given the unique capabilities of the Prisma spacecraft, the experiment domain can involve one or more of the following areas: formation flying, rendezvous & docking, proximity operations, on-orbit servicing, and on-orbit assembly. While these represent the key functions that Prisma can support, the User Experiment is not restricted to this domain. Single S/C experiments and "no-ΔV"-experiments are of course equally possible to establish. User-Experiments could in principle involve changes in the flight software via additions of custom S/W modules, although user-specific and tailored attitude/orbit maneuvers that are conducted within the existing system capabilities involve a lower effort and can be completed faster.

Example of areas for User Experiments:

- All-onboard experiments
- ground supported experiments,
- sensor data processing for situational awareness,
- autonomous operation formation flying and relative orbit maneuvers,
- automated check out and planning,
- Inspection, servicing, repair and 3D proximity operations,
- the experiment could use ΔV – or not
- could use both S/C – or use only Mango – or use only Tango,
- could focus on GNC algorithms – any combination of Guidance, Navigation, and Control,
- etc.

For any of the above listed areas, the purpose of the experiment could range from a full Proof of Concept to a more simple "fiddling around, gathering data" type of experiment. The objective could range from "training/education" to "TRL raising and risk reduction" of GNC flight software components. Below are a few examples of different approaches for the implementation of the Experiment:

- **Time slots with tailored maneuvers** - customers provide desired maneuvers (translational + rotational) which are executed by the Prisma operations team on the flying Prisma. This option is the fastest path to flight testing. Customer ground software can also be integrated into the Prisma ground support system to produce an automated ground loop.
- **User S/W** – User software, e.g. Planning, GNC, autonomy related S/W, etc, is integrated into the overall onboard S/W of the flying Prisma. This software can be used to control the spacecraft. The telemetry data is collected and provided to the customer for evaluation. SSC and PSS would provide the support for integration of the user software.
- **Prisma Testbed** - This option includes a complete Prisma spacecraft. The Prisma retains its flight processor and the original set of GNC proximity operations functionality thus providing a flight-tested backup to the customer's software. In addition, on top of the nominal avionics, the system will/can be equipped with an electronics bay for the customer's own flight computer and interfaces to the customer's own sensors. Multiple customers can share the same flight computer if desired. The operations can be done by SSC or by the customer themselves, in the latter case a full RAMSES control station will be part of the delivery.
- **Prisma Testbed with Pre-Loaded Flight** Computer - This option includes the complete Prisma spacecraft plus a complete flight computer system based on the PowerPC 750 processor equipped with its own attitude and orbit control software. The customer can add their own software to this flight computer with support from the Prisma team.

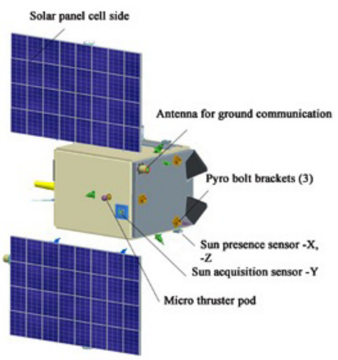
Guidelines to an Experiment

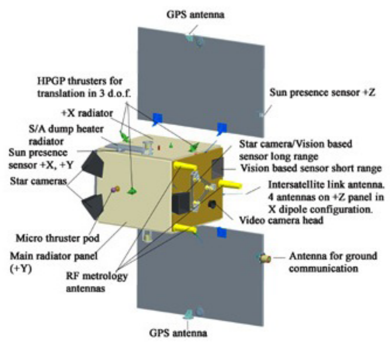
The purpose of this whitepaper is to provide the necessary background information and the guidelines necessary for a potential User to conceive, to setup and to approach SSC/PSS in order to discuss a possible User Experiment on Prisma. The paper describes the existing GNC capabilities of the system and it describes the general work flow of the integration process itself. The description is taken to a level where the major components and features in the Process - incorporation, integration, interaction, contractual, pricing principles, etc. - become visible.

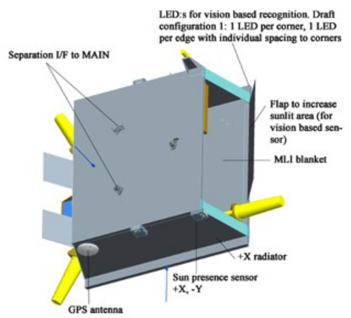
The whitepaper is meant to provide a starting point for the discussions, since each idea and experiment will be unique unto itself,. Accordingly, each experiment will require a unique process when it comes to its detailed incorporation and integration into the mission and into the system. The whitepaper can therefore serve as a necessary guide for building other experiments.

2 – PRISMA - GENERAL SPECIFICATIONS

The figures below show the main layout of the two Prisma spacecraft – Mango and Tango, outlining also the major spacecraft GNC components. Mango: The structure is a box made by standard aluminum honeycomb panels. Two body-fixed 1 m^2 solar panels are deployed after separation from the launch vehicle. The power system is over-sized to allow Prox Ops in arbitrary geometry domains, with approach vectors relative to the RSO for extended periods of time. The upper part of the S/C is configured such that the VBS cameras, one with long range and one with short range focus, have a clean view toward the RSO in the nominal flight configuration. Tango has an aluminum honeycomb panel box with one side consisting of the body mounted solar array. The Tango is clamped to the Mango upper part during the launch via a small separation system developed by SSC for previous projects. Tango is equipped with 2 sets of infrared LEDs for creating the cooperative mode of the VBS related experiments, one global omni-coverage set and one local set, with precise sub centimeter precision, for final approach / recede experiments in a narrow approach zone.







3 - PRISMA – GNC SPECIFICATIONS

The core of the Avionics System on both spacecraft is a LEON 3 32-bit fault tolerant processor implemented in an Actel FPGA. Also TM/TC functions are implemented in FPGAs. The processor communicates with a 1 GB mass memory and the TM/TC functions via a SpaceWire bus, while the communication to the platform units electronics is based on the CAN bus. The Onboard Software (OBSW) application layer is to a large extent built in a MATLAB / Simulink (Mathworks) based environment where the source code is autocoded using Real Time Workshop/Embedded Coder. The development environment and methods used greatly simplify the implementation of the GNC software which of course also is developed in MATLAB / Simulink.

The Prisma testbed comes with a flight proven set of GNC capabilities – translational and rotational control - for various types of proximity operations:

- GPS based and VBS based Rendezvous,
- sustained formation flying, GPS based and VBS based
- Proximity Operations, GPS based and VBS based
- T-periodic relative motion for a variety of geometries,

- safe orbit guidance and collision avoidance.
- Etc

These GNC capabilities provide the conceptual and functional platform from which User experiments can be defined and implemented.

4 – INCORPORATION & INTEGRATION OF A USER EXPERIMENT

The Main Steps - Table

The main steps in the process to incorporate and integrate a User Experiment are summarized in the table below. Some of the steps are elaborated in more detail in the subsection below. In the table there is a Who-column, which indicates where the effort/responsibility will lie. In the table, with "SSC" shall be understood a mix of SSC and PSS efforts, the mix will depends on who is the customer and what is the nature of the experiment.

Step	Description	Event / Milestone	Who
1	User shapes his idea and generates the first Outline of the experiment		User
2	SSC/PSS concludes if the experiment is feasible or not	Feasible or not	SSC
3	SSC makes a first assessment of the integration approach		SSC
4	SSC generates a preliminary Proposal	Preliminary Proposal	SSC
5	Customer evaluates the proposal		User
6	SSC + Customer together, details the setup and the contract,		SSC+User in dialogue
7	Contract is signed,	Contract, Kick Off:	SSC+User
8	Experiment is incorporated and integrated into the system		SSC+User in dialogue
9	Experiment / Testbed Interface Review	Milestone 1:	SSC + User
10	Integration Readiness Review	Milestone 2:	SSC + User
11	Flight Components Acceptance Review	Milestone 3:	SSC + User
12	Configuration of the onboard system, software patches,		SSC
13	Experiment reaches status = Ready for Execution	Milestone 4:	SSC + User
14	Experiment is performed		SSC + User
15	Experiment success declared	Milestone 5:	SSC + User
16	Exploitation of results		
17	Publications of results		

The Main Steps – An Elaboration

The starting point for a potential customer of a User Experiment is this **whitepaper - Stretching the Prisma mission – an Invitation**. The paper is intended to give the potential customer the initial information and guidelines necessary for him to find out if the Prisma Testbed is **of interest at all** for realizing his idea. The User shapes the idea and generates a first outline - a **Short Facts & Description** - of the experiment. In the annex an example of the Short Facts & Description structure is presented.

The User approaches SSC with the idea and proposal in a form - the Short Facts & Description - where a **quick feasibility assessment** can be made by SSC/PSS. Based on the Short Fact & Description, SSC/PSS examines if the proposed Experiment is possible, given the available capabilities and flexibility within the Prisma system. This assessment involves a minor clarifying **dialogue between SSC/PSS and User**, i.e. a dialogue and information exchange enough to ensure correct understanding of the essential and main User needs and expectations.

SSC/PSS Concludes if the proposed Experiment is feasible or not.

If the idea is deemed feasible and if SSC/PSS believes that an interesting deal can be setup with the User, SSC makes a first assessment and identifies the integration approach that, for this particular experiment, will give the **leanest and smallest impact integration**. If other approaches are of interest to the customer, SSC is of course willing to discuss other principles for the integration.

SSC generates a **preliminary Proposal** based on the "leanest and smallest impact" integration, describing the principles and architecture for the incorporation, the integration, the schedule, the exploitation of data and the programmatics, including the principles for the pricing

After receiving the proposal, the customer **evaluates the proposal,** and concludes if the possibility/ies identified by SSC are acceptable or not. SSC and Customer then collaborate to **detail the work plan and the contract** and the Contract is **signed**,

SSC/PSS **incorporates and integrates the experiment**. The incorporation and integration involves **five (5) major steps and associated contractual Milestones** with a mix of "Cost Reimbursements" and "Fixed Price" payment components.

The work will from time to time **involve significant interaction between SSC/PSS and the Customer**. The level of interaction will depend heavily on the nature of the experiment. Our (SSC & PSS) interface and integration work would take two/three persons full time and will be priced at a Cost Reimbursement basis. For the integration work we charge about 140Euro per hour, the amount of integration work would obviously depend on the amount and complexity of the functionality and software that is to be integrated. An estimate plus some margin of this effort will be included in the contract.

The **SSC support** during the definition, setup, planning, implementation, execution and evaluation phases will be "sufficient" for full integration of the Experiment into the mission, into the system, **the SSC support will be "sufficient" but it will be at a "no-nonsense" and "best effort basis".**

Milestone 0: The **Kick Off**, the principles and architecture for the functional integration is defined already at the level of Proposal & Contract elaboration. Contract signature and kickoff involves a Kick Off payment. The size of the kick off payment will depend on the nature, the risk, and the effort of the particular experiment but will typically involve about 20% of the total amount.

Milestone 1: Definition and design of the functional, operational and sequential interfaces. This effort will be an iterative and partly incremental process, where the necessary details will present themselves as the definition and design of the experiments and of the adaptations on the existing system, progresses. A formal review - **Experiment / Testbed Interface Review** - concludes that the interfaces now satisfy the customer needs. The effort reaching the Milestone 1 is based on a Fixed firm price, typically this amounts to about 20% of the total amount.

Milestone 2: Any new User Experiment is expected to consist of a mix of sequential events and activities – related to both the onboard system and to the ground station. It could involve procedures and software, it could use the existing components, could need modifications and/or it could require entirely new system components. Some of these components could be Customer Furnished Items, i.e. components that would be the actual "test object" or the "experiment object of interest". These components are obviously developed by the customer himself. On the SSC side the incorporation and integration work involves adapting the existing system and making room for the new stuff. The integration involves all dimensions: functional, operational, procedural and sequential integration. The integration is done in two steps. The milestone 2 deals with the first step. It consists of integration tests at SSC based on an all soft Matlab/Simulink verification/simulation. The integration tests will typically consist of a series of operational scenarios (test cases) that exercises and captures the behaviour of the user experiment in general and in particular captures the behaviour of the user components within the Prisma system, i.e. performance is not the main issue at this stage. A formal review - **Functional Integration Readiness review** - concludes that the user experiment is sound and doable and that the associated user components (and the adaptations of the existing system) are now ready for the final implementation and final integration into the flight system. The effort reaching the Milestone 2 is based on two parts – one part is based on a Fixed Firm price, and a second part is based on a Cost Reimbursement, see above.

Milestone 3: Before being uploaded on the spacecraft, the system configuration corresponding to the Experiment setup will go through a Flight Code Acceptance Test, where all flight code and flight procedures are validated and approved. This test involves verification/simulation with flight representative computer/processor and commanding systems in the loop. A formal review – **Flight Components Acceptance Review** - concludes that the flight system it OK and ready to be configured for the experiment. This step involves in particular, but is not limited to, the validation of code modifications, additions and patches that could be associated with the experiment. The effort reaching the Milestone 3 is based on two parts – one part is based on a Fixed Firm price, and a second part is based on a Cost Reimbursement, see above.

Milestone 4: The Experiment would be phased into the overall mission timeline, such to ensure an efficient use of the overall system and project resources. Once in orbit, the experiment will be **given a nominal timeslot** for the flight configuration, setup, execution, possible repetition, evaluation and experiment completion. The time unit for the allocated time slot is weeks, i.e. the shortest timeslot for an experiment is one (1) week. A formal review – **Execution Readiness Review** - concludes that the experiment is ready for execution. The effort reaching the Milestone 4 is based on three parts, one based on the expected ΔV consumption (a 2 cm/sec experiment obviously cheaper than a 2 m/s experiment), a second part based on a Cost Reimbursement for the antenna and operator costs, the nominal rate is 18 kEuro per day. In case of longer periods of needed "inactiveness", we could opt for a leaner antenna and operator usage, typically 10 kEuro/day. The third part is a Cost Reimbursement for the SSC support regarding the Mission Control and the Flight Dynamics tasks.

Milestone 5: **Experiment success.** The successful execution of the Experiment would obviously depend on other test-bed performances and capabilities at the stage of the time slot for the Experiment of concern. Should the system "fail to deliver" nobody is to blame. Since the "experiment success" is continuously at risk, a certain percentage (e.g. 15%) of the total contract sum will be kept until a formal review concludes that the experiment has been successfully completed. If the system fails to deliver, this final 15% sum is cancelled.

Exploitation of results & Publications –In principle, SSC advocates for openness and transparency and would seek to present Experiment results through publications or media exposure. However, the exploitation of any Experiment results is up to the discretion of the User, and will be determined during the proposal/contract phase of the process.

5 – PRESENTING THE EXPERIMENT - SHORT FACTS & DESCRIPTION

The Format and an Example

The starting point for a potential customer of a User Experiment is the whitepaper - **Stretching the Prisma Mission – an Invitation**, the paper is intended to give the potential customer the initial information and guidelines necessary for him to find out if the Prisma Testbed is **of interest at all** for realizing his idea. The initial task for a customer is to **shape his idea and generate a first outline - a Short Facts & Description** - of the experiment. This document will be the input that will form the basis for the feasibility assessment done by SSC – does SSC have something to offer the customer or not?

The table below presents one useful format regarding the content and structure of the Short Facts & Description input document. For illustration purposes, the third column in the table provides example content for an Experiment that a User would supply.

SHORT FACTS & DESCRIPTION

The experiment will obviously need a lot of things. But if focusing on the core, on the essence, on what constitutes the core of experiment success at the end, then the following defines pretty much intentions and expectations of the intended Experiment.

Item	What	For this Experiment (an Example)
Which Unit is needed	Both S/C or Mango only or Tango only and/or Other	Mango only
Use dV or not	use or not,	Yes
Estimated dV	How much ΔV is expected to be needed by the Experiment	A lot, approximately 25 m/s
Prime sensor systems	The primary needs of my Experiment involve one or several of the following. If "other" please elaborate. - GPS absolute, - GPS relative, - VBS long range, - VBS short range, - Star Cameras, - Rate sensors, - accelerometers, - Outreach & PR telescope/Camera, - Artificially degraded and/or reshaping sensor (one or several of the above) data, thus mimicking other sensor H/W - other	The core of my experiment circles about: GPS absolute & VBS long+Short & Outreach & PR telescope/Camera
Translational maneuvers – min range	Shortest ISD (inter-spacecraft distance)	20 m
Translational maneuvers – max range	Largest ISD	1000s of kms
Translational maneuvers –	Max relative velocity	N/A

max relative velocities		
Translational maneuvers – fine/coarse continuous or static	The core of my experiment deals with coarse or fine accuracy continuous motion or with static holdings	N/A
Translational maneuvers - duration	Duration of the experiment, from Let-Go of the Experiment to completion of the Experiment	8 month
Translational maneuvers - repetitions	Repetitions are involved, how many	no repetition, only one long go
Requirements or not regarding the Ground track and the GS visibility	For addressing the core of my experiment, do I have any requirements regarding the Ground track and regarding the GS visibility requirement ?	No
Regarding the GNC algorithms – new SW or not	For addressing the core of my experiment: I need a complete new GNC SW / need some of my own / can use the existing Prisma GNC	Existing Prisma
Regarding possible own GNC algorithms – in the loop	For addressing the core of my experiment: I need to be in the control loop in real time / my SW must run in real time but in parallel (off line) with the nominal Prisma GNC I need to be in the control loop in real time but via ground station / can be off line and perform on ground post-processing I have no custom GNC software in the Experiment	No custom GNC S/W
Regarding possible own GNC algorithms - the scope	My custom GNC algorithms involve one or several of the following (Y/N): - Attitude/rate estimation, - Attitude/rate shaping, - Attitude/rate control, - Orbit determination / Navigation, - Translational shaping, - Translational control, - Other	N/A No custom GNC S/W
Other	Other short facts and pieces of information that is deemed useful for SSC/PSS in order for an initial feasibility assessment of the proposed Experiment	I need to be active in an intermittent mode, 2 days of action, then passive for 4 month, only low frequency monitoring, then once again active for one week, this process is repeated for the two target RSOs I have in mind
Narrative description	A narrative description of the needed, of the foreseen, of the expected sequence of events and activities when the Experiment is being executed. Typically 1-3 pages, with possibly illustrating drawings and numbers. Suggestion of approach – envisage, once in orbit, from the moment of Let-Go of the Experiment to the completion of the Experiment, describe what – functionally, operationally and sequentially, you would like to see take place.	With Mango, visit two neighboring (wrt inclination and semi major axis) RSOs, one by one. I need to align the Mango orbit with the RSO one, to make a rendezvous with and to approach to about 20 m ISD, take a picture in sunlit conditions and then move to the second RSO, the bulk of aligning the orbit planes is via, including two initial/end orbit maneuvers, the natural relative orbit plane drift, the alignment

		burns and coarse rendezvous is done using the GPS Absolute system together with the coarse NORAD TLEs for the RSOs, the fine OD of the RSO and the final rendezvous and approach of the RSO is done using the VBS sensor systems, it is assumed that the existing Prisma rendezvous and final approach capabilities are sufficient for my needs.
Experiment success	Define what would constitute success at the end of the experiment. Typically 2 to 5 sentences. Suggestion of approach – Envisage that the Experiment has been completed. What key results would you need in order to state that the Experiment has been successful or not?	If I have "captured" at least one of the RSOs with a couple of good images with the Outreach Camera, I consider the experiment as successful.

FOR MORE INFORMATION

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