PRISMA – AN AUTONOMOUS FORMATION FLYING MISSION

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ABSTRACT

PRISMA is an ongoing satellite project comprising two satellites. The project constitutes an in-orbit test bed for Guidance, Navigation and Control (GNC) algorithms and sensors for advanced closed-loop formation flying and rendezvous. The satellites will be launched in a low earth orbit and carry out a series of maneuvering experiments and sensor experiments during a mission time of 8-10 months. Autonomous formation flying in decimeter precision will be demonstrated using relative GPS and Formation Flying RF metrology instruments. Vision based methods using a modified star camera will demonstrate autonomous homing and rendezvous from hundreds of kilometers down to close proximity. Proximity operations based on GPS or optical information shall be demonstrated all the way down to almost physical contact.
A new environmentally friendly, non-toxic chemical propulsion system as well as a new MEMS micro-thruster system will be flight demonstrated.

1. INTRODUCTION

There are a number of planned missions and mission concepts that request several satellites in various modes of cooperation. This may be interferometer missions like Darwin, on-orbit inspection and service missions like CX-OLEV, or automated rendezvous missions like Mars Sample and Return. This in turn needs developments within critical technologies such as guidance, navigation and control (GNC) and sensor technology.
In Europe, several organizations have made plans for entering the multi-satellite and formation flying discipline, but until quite recent, there has been no real project planned.
Recognizing the need for a forceful initiative, the Swedish National Space Board (SNSB) and Swedish Space Corporation (SSC) created the PRISMA mission. PRISMA is a combination of a Formation Flying (FF) and Rendezvous (RV) technology test bed, and a technology flight for several subsystems under development by SSC and other Swedish industries. The FF and RV part of the mission would utilize and further develop the Guidance, Navigation and Control (GNC) competence at SSC.
In order to create a strong and internationally competitive project, several European industries were invited to join the project, contributing with sensor technology and GNC competence.
The project was formed in early 2005, when the following main contributors could be registered:

- German Aerospace Center (DLR), contributing with a GPS navigation system including GPS H/W
- Alcatel Space, later replaced by CNES, contributing with the Formation Flying RF sensor (FFRF)
- Danish Technical University (DTU), contributing with a Vision Based System (VBS).

Together with motor technology experiments from two subsidiary companies to SSC, ECAPS and Nanospace, a core mission was formed.

2. MISSION GOALS

2.1. Primary goals

The primary goals are technology demonstrations and maneuver experiments containing GNC and sensor technology for a family of future missions where RV and /or FF must be utilized. The demonstrations are:

- Autonomous Formation Flying based on a GPS system and a Formation Flying RF sensor system
- Homing and Rendezvous based on VBS only
- Proximity Operations, based on GPS and VBS
- Final Approach and Recede Operations, based on VBS only

These experiments contain the flight demonstration of the GPS system, the FFRF sensor system and the VBS system as such.

2.2. Secondary goals

The mission also has a set of drivers originating from the Swedish national space program where different developments in platform technology have been undertaken. These are:

- Flight demonstration of the High Performance Green Propellant (HPGP) 1-N thrusters
- Flight demonstration of the Micropropulsion System cold gas thrusters
- Further development of the Data Handling System and Power Distribution System
- Model based Onboard Software development methods using Matlab/Simulink and autocode generation methods.
- PUS and CCSDS compatible Ground Support Equipment.

3. MISSION OVERVIEW

The mission consists of two spacecraft. One is called MAIN and is a 3-axis stabilized, highly maneuverable spacecraft of about 150 kg. The other spacecraft is called TARGET and has no orbit maneuvering capability but will act as a passive but intelligent target for many of the maneuvering experiments of the Main spacecraft.
The two S/C will be launched clamped together to a sun-synchronous dawn-dusk orbit of about 700 km altitude.
Once in orbit, a check-out phase will start with the two S/C clamped together. Various sensor, actuator and motor systems will be commissioned during a few weeks. After the commissioning phase, the satellites will be separated and the real experiment phase will start. The experiments will be detailed in section 5.2.
The mission is designed for a very short and intensive campaign. The baseline mission time is only 8-10 months, during which the experiments will be run as a continuous sequence.

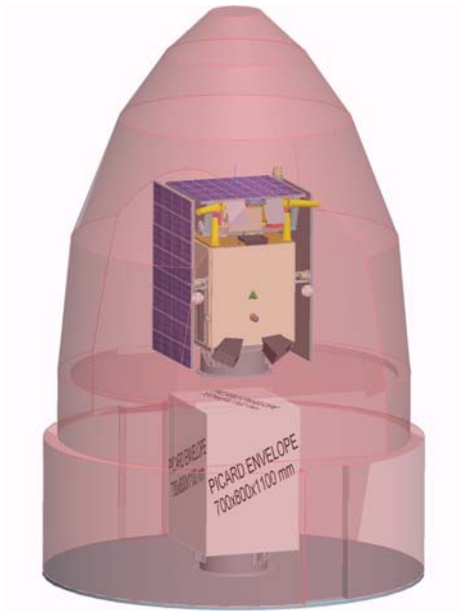


Figure 1: PRISMA stack at launch

The mission will be controlled from a Mission Control Centre located at SSC in Solna, with an executive operations centre and antennas located as SSC base Esrange in the north of Sweden. The satellites make around 14 orbits per day, of which 10 can be seen from Kiruna with an average contact time of 8 minutes each.

3.1. Launch configuration

The baseline launcher is a Dnepr launch vehicle from Baikonour, where PRISMA will be secondary payload. The launch configuration is depicted in *Figure 1* under the Dnepr fairing.
In the launch configuration, the TARGET S/C is clamped to the MAIN upper face via a small separation system. The complete stack weighs 200 kg and the dimensions are roughly 800x800x1300 mm.

3.2. Nominal flight configuration

The orbit geometry is such that the sun vector is essentially normal to the orbit plane. In a nominal flight configuration, the MAIN is located along-track and behind the TARGET as depicted in *Figure 2*. From this basic relative position, the MAIN will assume different positions, attitudes of motion profiles relative to the TARGET according to the specific experiment to be performed.

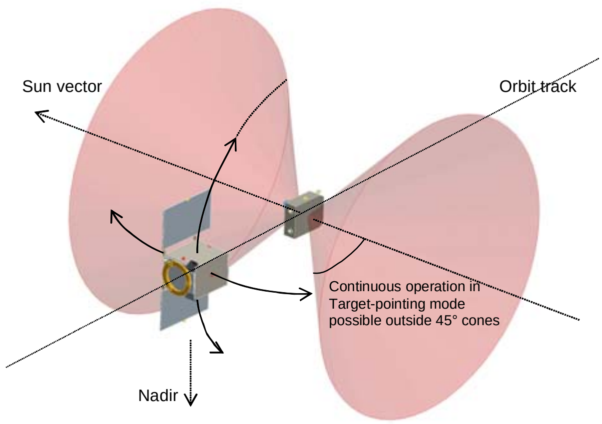


Figure 2: PRISMA in flight configuration

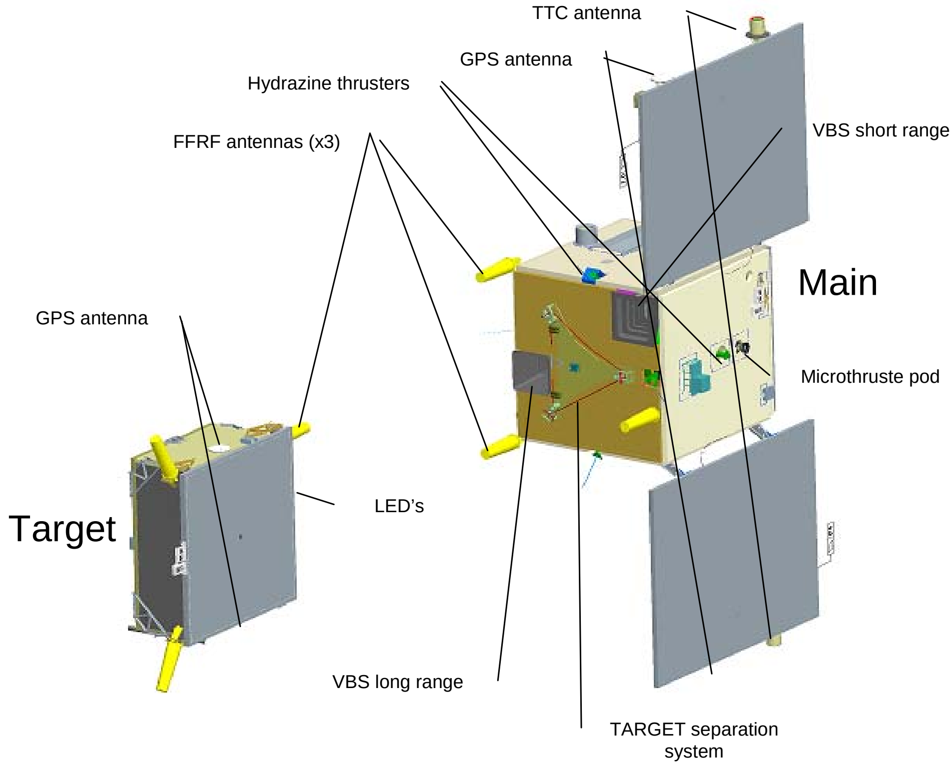


Figure 3: Main and Target layout in flight configuration

4. SPACECRAFT DESIGN AND ARCHITECTURE

4.1. MAIN layout

The layout of the MAIN S/C is shown in *Figure 3*. The structure is a box made by standard aluminum honeycomb panels. An extra vertical panel inside the S/C carries most of the propulsion components as seen in Figure 6.
Two solar panels of in total two m^2 cell area are deployed after separation from the launch vehicle, and locked in a fix position.
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 free view toward the TARGET in the nominal flight configuration. Also the geometry is arranged for a good antenna pattern for the FFRF instrument antennas.

4.2. Target layout

The TARGET is an aluminum honeycomb panel box with one side consisting of the body mounted solar array. The TARGET is clamped to the MAIN upper part during launch via a small separation system developed by SSC for previous projects.
TARGET is equipped with infrared LED's for creating the "cooperative mode" for the VBS experiments.

4.3. S/C architecture and subsystems

An overview of the MAIN S/C architecture is shown in *Figure 4*. The whole architecture is built with redundancy such that all functions essential for more than one experiment are single failure tolerant, while single experiments are not.
The TARGET architecture is similar, however with the exception of ground communication units, the propulsion, and many of the sensors and actuators for the GNC system.

4.3.1. Data handling and OBSW

The core of the Data Handling System (DHS) on both S/C is a LEON 3 32-bit fault tolerant processor implemented in an Actel FPGA. Also TM/TC functions are implemented in FPGA's. 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 Matlab and Simulink which is then autocoded using Real Time Workshop. The methods used greatly simplify the implementation of e.g. the GNC software which also is developed in Matlab/Simulink.

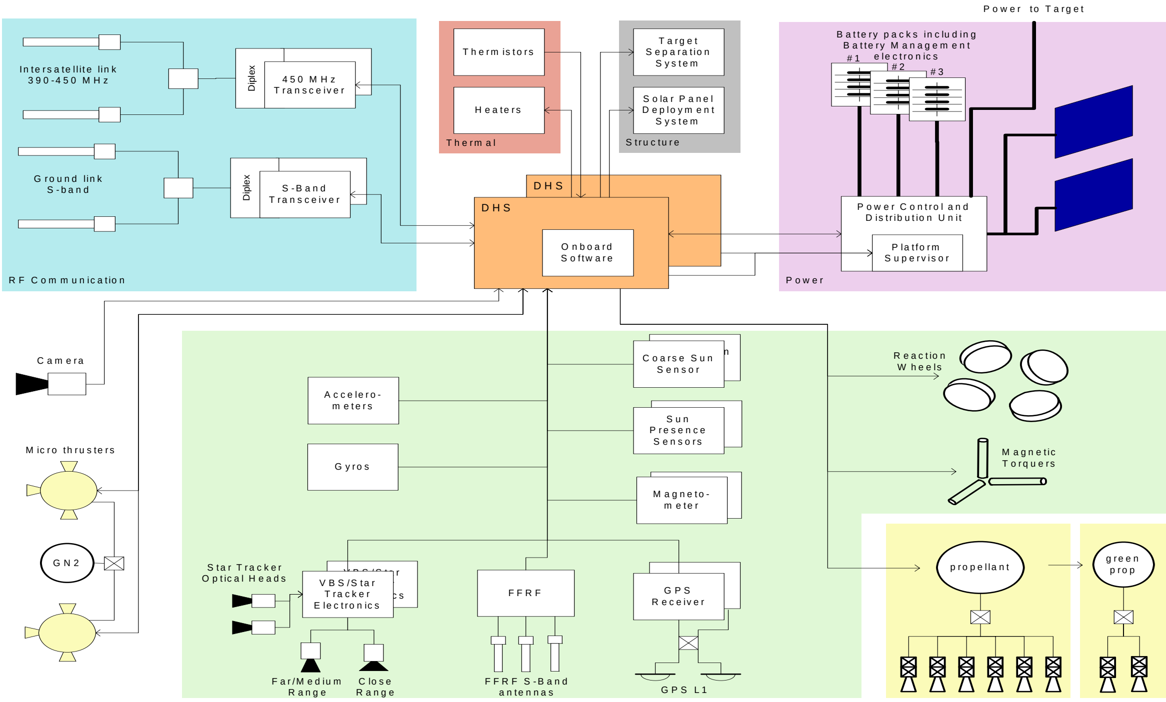


Figure 4: PRISMA MAIN block diagram

4.3.2. Communication

The ground communicates only with the MAIN S/C. This is done via an S-band link with 2 simultaneously active antennas located on the solar panels. The downlink capacity is 1 Mbps.
The communication to and from TARGET is arranged via a 450 MHz Inter Satellite Link (ISL) with 9.6 kbps capacity in both direction. This link shall be operational in the range of 0.5 m to 10 km.

4.3.3. GNC

The MAIN spacecraft is 3-axis attitude controlled. The attitude control system is based on reaction wheels with magnetic momentum management. The system uses two star tracker camera heads in combination with five rate gyros for primary attitude estimation. Sun presence sensors, medium accuracy sun sensors and magnetometers are also used.

The orbit control of the main spacecraft is different depending on the experiment phase. The GPS based navigation will be fundamental as a back-up in all phases. Five accelerometers are also used for navigation input.
In the other experiments, the orbit control will be based on the VBS as well as the FFRF. The
orbit control experiments are described in more detail in section 5.2.

The attitude control on the TARGET spacecraft is based on pure magnetic actuation in combination with sun presence sensors, medium accuracy sun sensors and magnetometers.

SSC is responsible for the complete GNC software development. DLR contributes with the GPS navigation function which is used also in the SSC experiments. DLR and CNES also contribute with guidance and navigation software for their own open and closed loop experiments.
The mode architecture of the MAIN GNC system is depicted in *Figure 5*.
Basically, there is one mode for each formation flying experiment with the addition of a Safe Mode. The Safe Mode ensures spacecraft power (attitude) safety as well as safe orbit control (i.e. collision avoidance).
The mode architecture is selected such that the

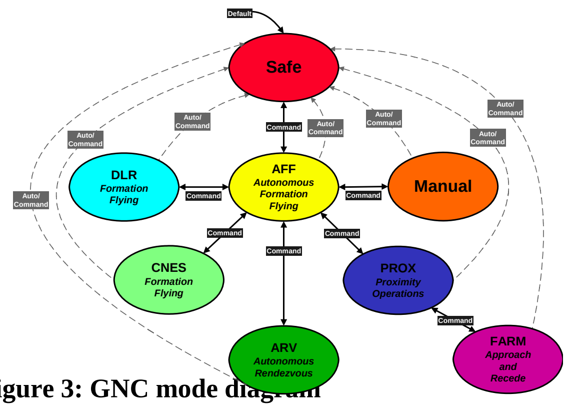


Figure 3: GNC mode diagram

Figure 5: GNC modes diagram

Autonomous Formation Flying (AFF) experiment mode is the central mode from which all other modes are accessed (see further discussion below).

4.3.4. Power system

The MAIN power system consists of a power conditioning unit giving 28V regulated power, the solar array with 400 W from triple junction Gallium arsenide cells, and 3 Lithium Ion battery packs. The system is dimensioned such that the MAIN shall be able to support full operation during eclipse season, also with the solar array panels turned away 45 deg from the sun.
The TARGET power system is similar, but with nominally 100 W power from the solar array.

4.3.5. Propulsion

The PRISMA MAIN has three propulsion systems

- the nominal Hydrazine system with 6 1-N motors
- the HPGP experimental system with two 1-N motors
- the experimental microthruster cold-gas system

The motor systems are depicted in Figure 6

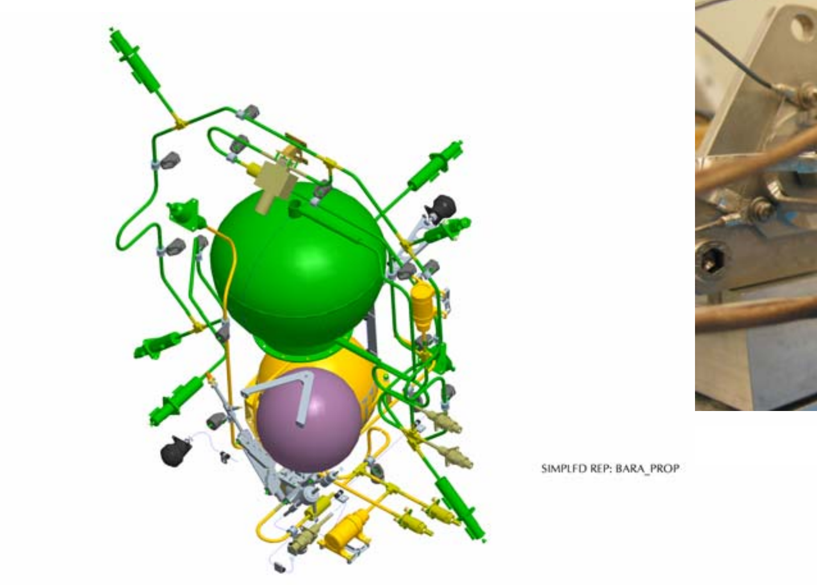
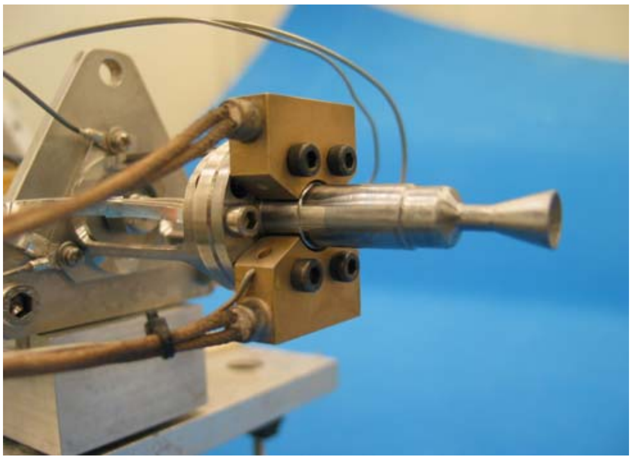


Figure 6: PRISMA three motor systems

The Main propulsion system consists of six 1-N thrusters directed towards the MAIN S/C Centre of Gravity (COG), giving torque-free translational capability. The propellant tank contains 11 kg of usable fuel and gives approximately 110 m/s delta-V over the mission. Firing times will range from 0.1s (requested typically at autonomous formation flying and proximity operations) up to steady state burns up to 2 minutes.
The Hydrazine system has been designed by Swedish Space Corporation, based on procured components from mainly US suppliers.

The High Performance Green Propellant (HPGP) motor experiment is a new propulsion system introducing environmentally friendly, non-toxic ADN-based fuel which theoretically gives 10% better impulse and 30% higher density than hydrazine. The actual development tests have been ongoing for several years, and have now demonstrated 20,000 pulses and several kg fuel throughput in ground tests. The performance has proved to be better than hydrazine in all modes of operation.
The HPGP propulsion system has two 1 N thruster, also directed towards COG. The system provides redundancy to the main hydrazine system if any nominal thruster should fail. The propellant tank contains 5.6 kg of usable fuel and gives approximately 60 m/s delta-V over the mission
The development, involving the propellant itself and a compatible 1-N thruster and catalyst bed, is driven by ECAPS, a subsidiary company to SSC, and has been supported by ESA for several years.



The Micropropulsion system is based on MEMS-technology (Micro-ElectroMechanical Systems) and is under development by NanoSpace, a subsidiary of SSC, on contracts from ESA and the Swedish national space board.
The micropropulsion system shall be capable of delivering accurate thrust ranging from tenths of micro-Newtons up to a milli-Newtons. Such a system would

be a potential candidate for future missions where extremely low and accurate thrust is requested, such as Darwin, Gaia, Xeus, Proba-3, Simbol-X and others.
The key component is the thruster module containing a silicon wafer stack with four complete rocket engines with integrated flow control valves, filters, and heaters. Extremely small internal heaters inside the thrust chamber increase the performance of the system in terms of specific impulse. The propellant is Nitrogen. The four thrusters are orthogonally distributed in the equator plane of the golf ball sized thruster module.

The thrust will be too low for PRISMA to actually utilize in the fairly disturbed LEO orbit it is in. However, the functionality and performance of the thruster system will be flight demonstrated during the mission, mainly via estimating the velocity increments via the GPS system and the Precise Orbit Determination functionality.

5. GNC EXPERIMENTS

5.1. Overview

The GNC manoeuvring experiments consists of SSC, DLR, CNES, and DTU experiments. These include closed loop orbit control of the MAIN spacecraft.

The different experiments will be distributed over the mission length in a sequence with increasing level of complexity, ensuring early harvest results for all parties in the beginning of the mission.

SSC is responsible for the overall experiment planning and design, and has designed experiment sequences in all experiment sets. DLR and CNES each has dedicated autonomous formation flying experiments based on their respective sensor system contributions; the GPS and FFRF systems. Both have dedicated software embedded in the GNC core software created by SSC. DTU supports all VBS-based experiments with the highly sophisticated functionality of the VBS camera system. All these are described separately in the sections below.

5.2. GNC experiments under SSC responsibility

The SSC GNC experiments to be carried out can be sorted into four different groups:

1. Autonomous Formation Flying (AFF) – Passive formation flying based on GPS.
2. Homing and Rendezvous – Autonomous rendezvous based on VBS
3. Proximity Operations – 3D proximity precision forced motion based on GPS and/or VBS.
4. Final Approach and Recede – Very close VBS based operation.

The different experiments are summarized in
Table 1 where also typical relative distances are given.

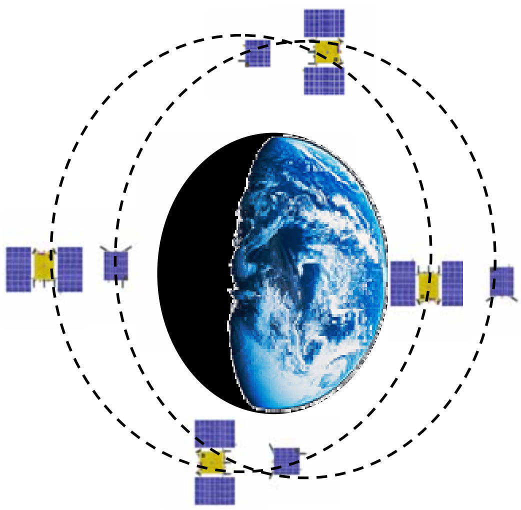
Table 1

Experiment	Distance range (m)	Sensor
Autonomous Formation Flying	20 – 5000	GPS
Homing and Rendezvous	10 – 100 000	VBS
Proximity Operations	5 – 100	VBS and/or GPS
Final Approach and Recede	0 – 5	VBS

These four experiments are selected because they highlight different important aspects of formation flying and each of the experiments is based on one or several model scenarios.
The experiments are described in more detail in the following sections as well as in [1].

5.2.1. Autonomous Formation Flying

The Autonomous Formation Flying (AFF) experiment concerns passive relative orbits. Such orbits make use of the slightly different orbits of the two spacecraft to create a natural periodic motion. The resulting orbit is in this way passive and the only control required is to maintain the orbit counter-acting external disturbances, such as solar pressure, aerodynamic drag and gravitational irregularities.
The orbit control is based on relative GPS with navigation data provided by the navigation filter supplied by DLR.
The model missions for the AFF are situations occurring in On-Orbit Assembly and Inspection, passive apertures, and loose formations.



Several different in-plane as well as out-of-plane orbits will be part of this experiment. The different orbits will also be applied at different distances.

As shown in Figure 5, the AFF Mode is the central mode in the mode architecture. The reason is that the AFF orbit control is considered to be the most robust of the different experiments. It is also considered to be the simplest mode in terms of operations. For these reasons, the mode will be used as a parking mode while preparing the other experiments. The AFF is illustrated with Figure 8.

5.2.2. Homing and rendezvous

The Homing and Rendezvous experiment consists of complete autonomous approach and rendezvous based on the VBS.
The different phases are - the autonomous location of the TARGET spacecraft, orbit phasing, intermediate transfer and in the end, the final approach to the TARGET spacecraft through a predetermined approach corridor. All of these steps are designed to be automatic but with possibilities for commanded escape.
The typical model mission for this experiment is a Mars Sample Return Mission but servicing in geosynchronous orbit as well as assembly in escape orbit are also relevant model scenarios.
The experiment is executed for several cases with Rbar and Vbar final approach directions.
For each execution of an experiment, the MAIN spacecraft is placed in a specific relative orbit by ground command after which the autonomy is enabled.

5.2.3. Proximity operations

The 3D Proximity Operations experiment consists of forced trajectories in the close proximity of the TARGET spacecraft.
The navigation takes place in a network of flight-paths defined about a virtual structure defined around the TARGET spacecraft as illustrated with *Figure*9.

Typical model missions are On-Orbit Servicing, Inspection, and Assembly.
The proximity operation experiment has two different branches. The first is based on relative GPS where the navigation is retrieved from the DLR navigation filter.

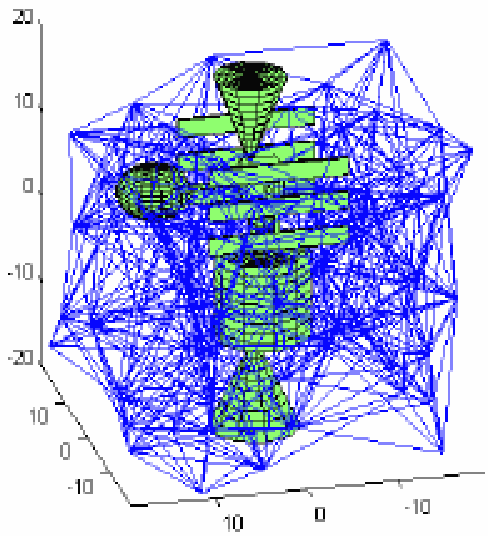


Figure 9: Flight paths around virtual structure

The second is VBS-based where the navigation is made using the VBS. The VBS can operate with a cooperative TARGET equipped with an LED pattern but also with a non-cooperative TARGET where there are no aids for the VBS other than the geometry of the TARGET itself. In these operational phases, the VBS delivers both the relative distance and the relative attitude to the TARGET spacecraft.
The controller used in the proximity operations experiment is based on a non-linear model predictive control law [2].

5.2.4. Final approach and recede

The Final Approach and Recede experiment is a natural continuation from the proximity operations. Based on VBS measurements, the MAIN spacecraft approaches the TARGET along a predefined approach corridor down to an as close as possible distance.
With the help of two dedicated LED patterns on TARGET in combination with the use of two camera head units, the VBS will deliver highly accurate distance measurements as well as relative attitude determination.
The typical model mission for this experiment is a delivery point in an On-Orbit Assembly mission or an inspection point in an On-Orbit Inspection scenario.

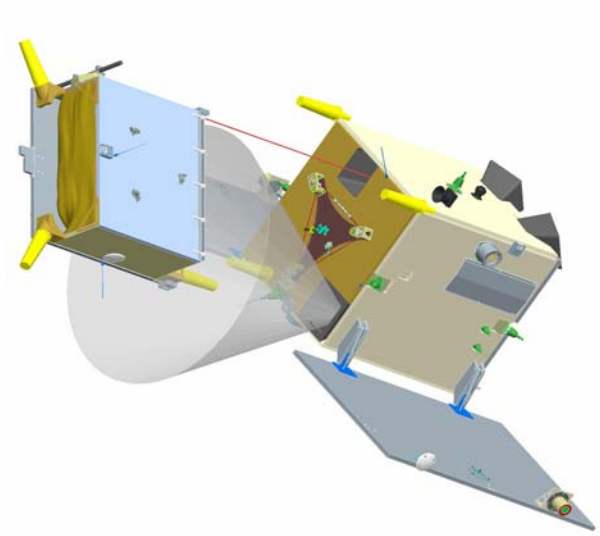


Figure 10: Final approach configuration

5.3. AFF using DLR's GPS-based GNC System

5.3.1. GPS Hardware

The MAIN and the TARGET spacecraft will, for redundancy purposes, each carry two independent GPS receivers that are operated in a cold configuration. Increased flexibility for handling non-zenith pointing attitudes is provided by two GPS antennas on each spacecraft, which are selected by an onboard algorithm for optimum GPS coverage or may, alternatively, be set by ground command.

In accord with the envisaged application, the high-grade miniature Phoenix receiver [4] has been adopted for the PRISMA mission. Phoenix is a twelve channel single-frequency GPS receiver based on a commercial-off-the-shelf hardware platform and qualified by DLR for use in low Earth orbit (LEO). It offers single-frequency Coarse/Acquisition (C/A) code and carrier tracking and can be aided with a priori trajectory information to safely acquire GPS signals under high dynamic conditions. Upon tracking, Phoenix outputs a One-Pulse-Per-Second (1PPS) signal which is applied for the onboard time synchronization. Particularly important for formation flying missions is Phoenix's feature to align the message time tags to integer GPS seconds which facilitates the differential processing of raw GPS data in the subsequent navigation filter.

The receiver is built around the GP4020 baseband processor of Zarlink, which combines the correlator, a microcontroller core with a 32 bit ARM7TDMI microprocessor and several peripheral functions in a single package. Phoenix provides a code tracking accuracy of better than 0.5 m and a carrier-phase accuracy of better than 1 mm at 45 dB-Hz. With a mass of the receiver board of 20 gr, a size of 70 x 47 x 15 mm and a power consumption of 0.85 W at begin of life, the receiver is particularly suited for small satellite missions like PRISMA.

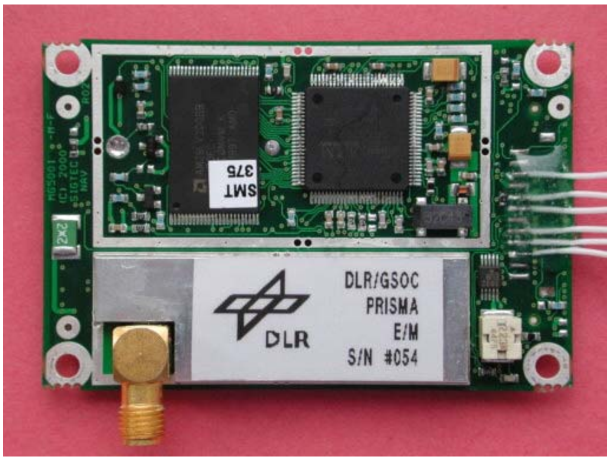


Figure 11: *Phoenix GPS receiver board*

5.3.2. GPS-based GNC Software System

The GPS-based GNC software on MAIN contributes both to the Basic Software (BSW) in terms of GPS sensor message processing as well as to the Application Software (ASW) see *Figure* 12. The latter encapsulates all top-level guidance, navigation and control applications. The GPS interface (GIF) handles GPS raw data formats and ephemerides, and performs data sampling as well as coarse editing of MAIN and TARGET GPS data prior to the GPS-based orbit determination (GOD). For an efficient software implementation, the architecture comprises two cores: the ORB core which is executed every 30 s and the GNC core, executed once per second to clearly separate the computational intensive GPS-based orbit determination from functions with low computational burden. The GPS-based orbit prediction (GOP) function evaluates the orbit, provided by the orbit determination function, at a 1 Hz rate and accounts for orbit manoeuvres which have not been taken into account already by GOD. It outputs MAIN and TARGET orbit states as well as associated quality indicators which are used by other onboard GNC functions as well as by the autonomous formation control (AFC) function implementing the guidance and control algorithms for formation acquisition and control.

GOD implements a reduced-dynamic orbit determination which accounts for the complex gravity field of the Earth (complete to order and degree 20), third body accelerations from the Sun and the Moon, as well as atmospheric drag and solar radiation pressure. Any deficiency in the assumed force model is absorbed in an empirical acceleration vector defined in a co-moving frame. A symmetric filter design has been chosen which adjusts the absolute states of both spacecraft. The relative spacecraft state is simply computed by differencing the absolute states. In this

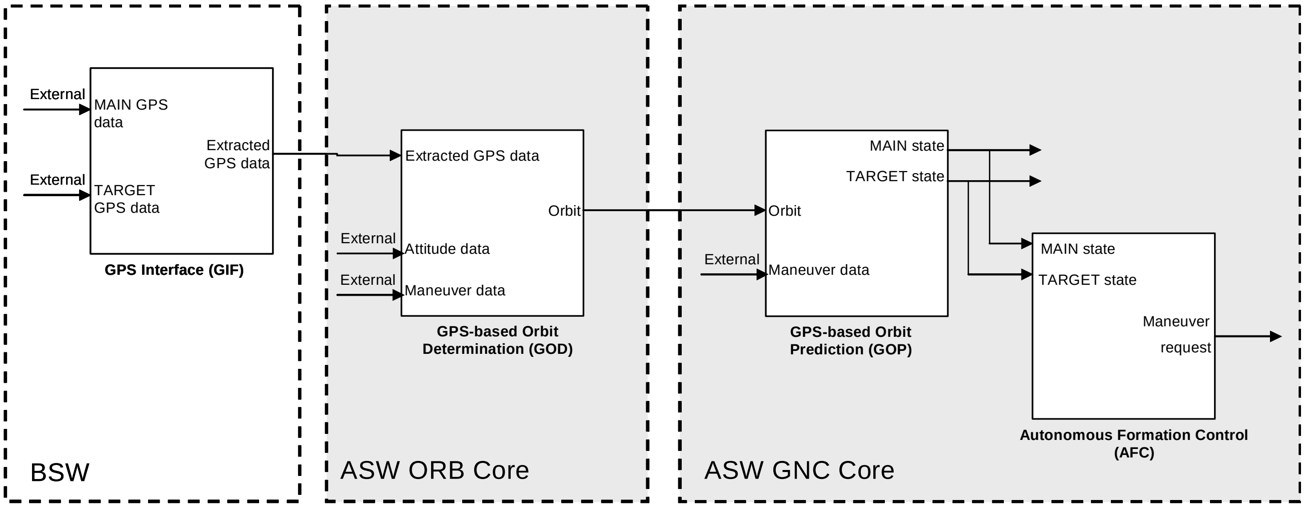


Figure 12: Schematic GPS-based GNC software architecture

way, no explicit model for the relative motion is required and the interdependency of absolute and relative dynamics is fully exploited. For absolute state estimation, an ionosphere-free combination of pseudorange and L1 carrier-phase measurements is applied while a precise relative state is implicitly determined from single-difference carrier phase measurements.

5.3.3. GPS-based AFF

Based on the sole use of GPS as navigation sensor, the Spaceborne Autonomous Formation Flying Experiment (SAFE) will be conducted to demonstrate a fully autonomous, robust and precise formation flying of spacecraft. To this end, a fuel-optimized guidance and control algorithm will be employed at typical spacecraft distances of 100 to 2000 m, which is representative of future bi-static radar satellite formation flying missions.
The guidance concept applies the eccentricity-/inclination vector separation (D'Amico et al. 2006) which avoids collision hazard from along-track position uncertainties through the proper separation of the two spacecraft in radial and cross-track direction. A deterministic impulsive feedback control is applied for formation keeping which is, through its low computational burden, ideally suited for an onboard implementation. SAFE will exploit the versatility and generality of the relative eccentricity/inclination vector control in order to acquire and maintain safe close formation flying configurations in complete autonomy over long time intervals (weeks). For control window sizes of 5 m, 7 m and 20 m in the relative inclination, eccentricity and mean argument of latitude, respectively, and in the presence of realistic sensor and actuator performances typically six orbit maneuvers are executed per day requiring an overall daily delta-v budget of about 0.04 m/s.

5.4. CNES contribution and the FFRF instrument

As partner on the PRISMA mission, CNES delivers the Formation Flying Radio Frequency (FFRF) subsystem, an RF metrology package which is baseline as first stage metrology sensor for all future European FF missions, such as the CNES' SIMBOL-X and ESA's DARWIN and XEUS. The FFRF subsystem development, of which feasibility studies were made under ESA TRP funding, is currently in phase C/D, with Alcatel Alenia Space France (AAS-F) as prime contractor.

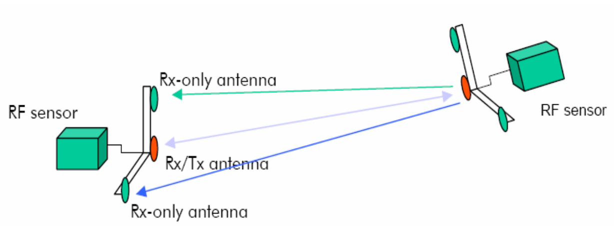


Figure13: Two-satellite FFRF S/S configuration

5.4.1. The FFRF subsystem

The FFRF subsystem is in charge of the coarse relative positioning of 2 to 4 satellites. It produces relative position, velocity and line-of-sight (LOS) as inputs to GNC subsystem for which it provides coarse metrology measurements. As the first element in the FF metrology system chain, the FFRF sensor ensures initial good relative navigation accuracy for the subsequent optical metrology subsystems (coarse optical lateral metrology, fine optical metrology, and fine longitudinal metrology).

The FFRF subsystem consists of one FFRF terminal and up to 4 sets of antennas on each satellite in a constellation. On PRISMA, MAIN is equipped with a triplet (1 Rx/Tx master and 2 Rx slaves) and TARGET is fitted with 3 single Rx/Tx antennas for omni directional coverage. The antennas are manufactured by SAAB Ericsson Space.

The terminal operates by dual frequency in S-band, and multi-satellite signal exchange is managed by TDMA. Ranging and angular measurements are extracted from received signals and are used for computing relative position (1 cm accuracy), velocity and LOS (1° accuracy). In addition to providing relative navigation measurements, the FFRF subsystem also provides time bias synchronization between the satellite clocks as well as an inter satellite link (ISL) as auxiliary functionality (12 kbit/s or 4 kbit/s bitrate).

A detailed description of the FFRF subsystem can be found in [6].

5.4.2. The FFIORD experiment

FFIORD stands for Formation Flying In-Orbit Ranging Demonstration, and is the official name of the CNES experiments within the framework of the PRISMA mission. The main objectives of this demonstration are twofold:

- Open loop: Validate the FFRF subsystem on ground and in orbit
- Closed loop: Test the control loop and the on-board algorithms necessary for maintaining 2 satellites autonomously in close formation by using as input the data from the FFRF sub-system.

The objective of the FFRF sensor validation is to make the instrument operate in a high variety of conditions, in order to:

- validate the initialization procedure
- determinate the measurement limits
- verify performances over the whole measurement domain (range < 15 km   v <0.5 m/s,   dq/dt < 5°/s)

The closed loop formation flying experiment will be run by CNES and will put the PRISMA satellites through a number of formation configurations and manoeuvres which will be executed autonomously by the CNES OBSW module during the RF Based Formation Flying experimental set. The objective is to put the FFRF sensor and GNC algorithms to the test in scenarios that are as close as possible to realistic future FF missions. The experiment will last approximately 17 days, and has been divided into 6 separate experimental objectives (EO), which will be executed in parallel or sequentially according to the nature of each EO:

1. Relative navigation
2. Station-keeping at different distances and offset positions from the orbit track (VBAR)
3. Translation manoeuvres in plane and cross track
4. Football orbit keeping
5. Collision avoidance (auto. transfer on Football orbit in 1 or 2 manoeuvres)
6. Deployment phase

A detailed description of the CNES participation on PRISMA can be found in [7]

5.5. DTU contribution and the VBS system

DTU has developed the microASC, a fully autonomous miniature stellar reference instrument, for use onboard spacecrafts as an attitude reference sensor [8]. The microASC is designed for highly flexible configurations and can host from 1 to 4 camera head units (CHU), located at suitable places and directions on a spacecraft, such that a fully redundant blinding free attitude sensor configuration can be achieved. The instrument is shown in Fig. 14.

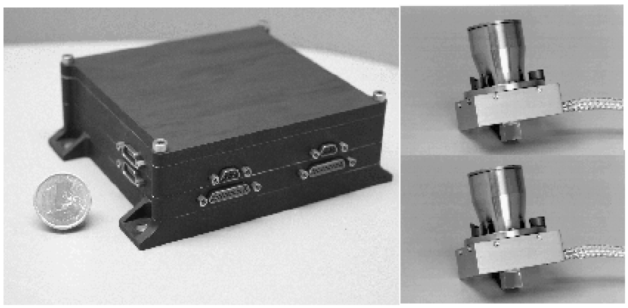


Figure 14: Redundant microASC shown with two CHUs

Onboard PRISMA two CHUs are used as standard attitude reference sensors, with their pointing directions such that simultaneous blinding by Sun, Earth and the Target SC is avoided during the complex fly-around maneuvers.
The third port on the microASC is also equipped with a standard CHU. This CHU is however pointed in the forward direction, such that the target SC can be in its field of view for most mission phases.
The fourth port is equipped with a CHU with a modified focal length, iris and electronic shutter, so as to enable operations at high light conditions at close range.

The VBS data processing is performed in the microASC, which is made possible by its huge spare processing power for its standard operation. The basic SW has four different modes of operation, entered based upon the actual configuration of the target and chaser.

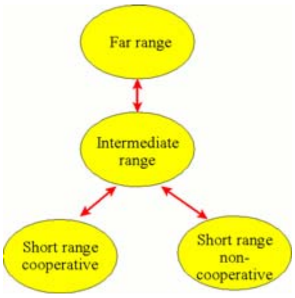


Figure 15: Operational modes of the VBS

From Fig. 15 it is seen that the central mode is the intermediate mode that branches to a far range mode and two short range modes depending on the state of the target SC. The switching between the modes are fully autonomous, but may be forced by ground command in critical maneuvers.

The far range mode is entered whenever both stars and the target SC is detectable in the FOV, the intermediate range when the target is to bright to allow for star detection and the short range mode when features of the target in the FOV is discernible.

The non-cooperative short range mode operation principle is based on a 3D model database of the target stored in the microASC. This model contains information on target features, their relative distances and location. Features of the target image obtained using natural illumination from Sun and Earth albedo, is matched to the database model, whereby both relative position and pose information extraction is possible.

The cooperative mode operates in a similar fashion, however instead of relying on natural illumination LEDs on the target, arranged in specific patterns, are used to generate feature points in the image. To ensure a sufficient contrast ratio to the natural illumination background, the VBS cameras and LEDs are operated in synchronous pulse mode.

Table 2 summarizes the instrument modes, their approximate operational ranges and the information generated.

Table 2

Mode	Range	Position	Pose
Far range	1000km-500m	Inertial, pointing only	-
Intermediate range	2km-30m	Relative, pointing only	-
Short range non-cooperative	200m-2m	Relative, pointing and distance	3 DOF
Short range non-cooperative	200m-20cm	Relative, pointing and distance	3 DOF

6. SUMMARY AND CONCLUSIONS

PRISMA is a technology demonstration mission that includes several advanced technology demonstrations in different disciplines, ranging from advanced guidance and control algorithms to new developments of sensors and propulsion systems. The PRISMA mission may therefore be a stepping stone for several future small multi-satellite mission.

In summary, PRISMA will demonstrate

- Autonomous Formation Flying
- Autonomous Proximity Operations
- Vision Based rendezvous sensor
- Test flight of Darwin RF sensor
- Test flight of Green Propellant propulsion system
- Test flight of a MEMS-based micropropulsion system

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