PRISMA

Demonstration mission for advanced rendezvous and formation flying technologies and sensors

PRISMA is a technology mission for demonstrating formation flying and rendezvous technologies, developed by Swedish Space Corporation. The project is funded by the Swedish National Space Board, and supported by in-kind contributions from the German Aerospace Centre (DLR), CNES and the Danish Technical University. The primary goals are to perform Guidance, Navigation and Control demonstrations and sensor technology experiments for a family of future missions where rendezvous and formation flying are a necessary prerequisite.

The GNC demonstrations are: Autonomous Formation Flying, Homing and Rendezvous, Proximity Operations and Final Approach and Recede Operations. The sensor technologies are GPS, RF metrology and star tracker based vision sensor. A high level of autonomy shall be implemented. The mission consists for two spacecraft, an advanced and highly manoeuvrable 140 kg satellite, and a simplified 40 kg spacecraft without manoeuvrability. Both shall be launched together on a Dnepr Launch vehicle as secondary payload into a sun-synchronous orbit at around 700 km altitude. The launch is scheduled for second half of 2008. The operations will be conducted from the Swedish ground station at Esrange in northern Sweden. The mission lifetime is approximately 8 months.

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BACKGROUND

Several future space missions planned in Europe and elsewhere (Darwin and other types of observation missions, missions within the Aurora program such as Mars Sample Return, In Orbit Servicing type mission such as ConeXpress) will require advancements in the fields of several disciplines such as autonomous formation flying, automated rendezvous and in-orbit servicing. These disciplines in turn need developments within critical technologies such as guidance, navigation and control (GNC) and sensor technology. However, in Europe no precursor or other technical demonstrator mission is currently planned for this purpose.

Swedish National Space Board (SNSB) and Swedish Space Corporation (SSC) has therefore taken the initiative to create the PRISMA mission, a formation flying (FF) and rendezvous (RV) technology test bed which, in combination with national interests in demonstrating platform technology developments, shall fill parts of the need for flight demonstration.

European companies with sensors and instruments in need for flight demonstration have been invited to contribute to the mission with in kind contributions of flight instruments and software (S/W) developments. The initiative started end 2004 and was very successful. DLR, Alcatel Alenia and Danish Technical University (DTU) responded positively, and in April 2005 the mission requirements had been established. Later in 2005, the French space agency, CNES, has entered by supporting the Alcatel Alenia part of the project.

MISSIONS GOALS

Primary goals

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

- GNC manoeuvring experiments with high level of autonomy containing: Autonomous Formation Flying, Homing and Rendezvous, Proximity Operations and Final Approach and Recede Operation. The experiments are run mainly by SSC with important contributions from DLR.
- GPS-based navigation system experiment from DLR, which shall evaluate real-time differential GPS as sensor for autonomous formation flying
- Vision Based Sensor (VBS) based on a star camera, to be evaluated as a multi-range range tracking and RVD sensor.
- A demonstration flight test of the Formation Flying Radio Frequency meteorology package (FFRF) considered for Darwin.

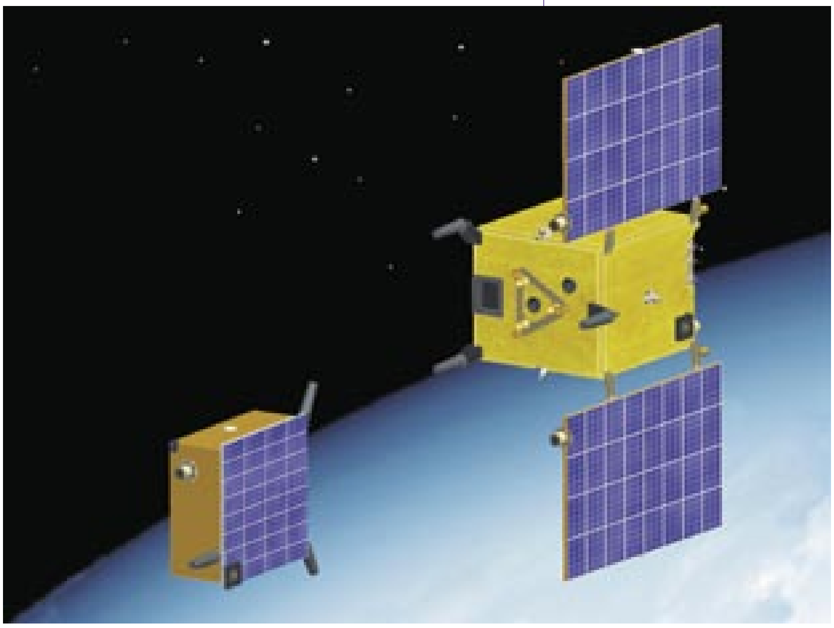
Secondary goals

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

- The High Performance Green Propellant (HPGP) 1-N motor system developed by jointly by SSC, Volvo Aero and FOI (Swedish defence research organisation). This is an ESA-supported development of a non-toxic propulsion system with equal performance as Hydrazine
- Further development of core functions of the System Unit flown in the Smart-1 mission (developed by SSC) and the Power distribution and battery handling units flown in the Smart-1 mission (developed by Omnisys in Gothenburg).
- New Onboard Software development, where the utilization of Matlab/Simulink and autocode generation (successfully employed on Smart-1 application cores) are developed to envelope the whole Data Handling layer
- Development of a PUS and CCSDS compatible Ground Support Equipment both for test and operations, with a flexible infrastructure supporting multi-satellite operations.
- The Micro System Technology cold gas thrusters under development by Nanospace AB.

MISSION DESIGN

The mission consists of two spacecraft, one advanced and highly manoeuvrable called MAIN and one smaller and without manoeuvrability called TARGET. The satellites are launched clamped together to a sun-synchronous circular orbit at approximately 700 km altitude. The local time of ascending node is 06.00 or 18.00, which makes the orbit plane fairly close to perpendicular to the sun vector during the whole mission. This fact facilitates the satellite design w.r.t. power generation, e.g. no rotating solar panels are required. A launch reservation agreement is already signed with Kosmotras for a launch vehicle as a secondary payload to the CNES satellite Picard.

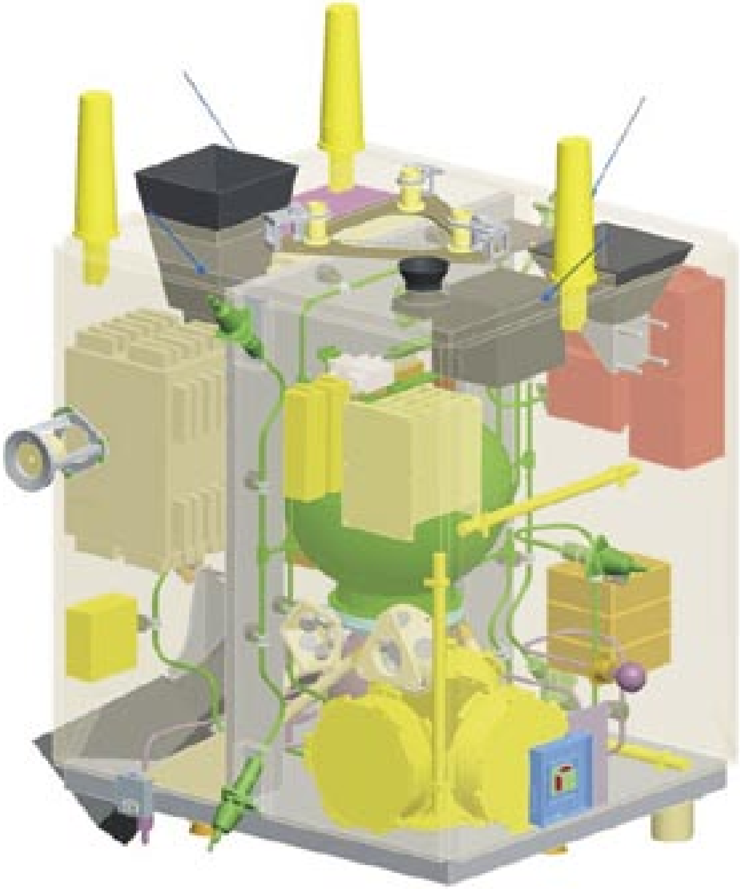


A nominal flight configuration - the MAIN "looks at" the TARGET with its antenna and sensors. Figure: SSC

The two spacecraft have fundamentally different roles in the mission. The TARGET has no orbit control capability but follows the trajectory in which it is injected. The MAIN has full translational capability, and will perform a series of manoeuvre experiments around the TARGET on both close and long range using the different sensors provided. The MAIN has a nominal sensor side on the "upper" face of the S/C body (see figure 5), equipped with the optical VBS sensor camera heads and the FFRF instrument antennas. In most cases, the MAIN will be located alongtrack w.r.t. the TARGET S/C, such that the MAIN can "look at" the TARGET maintaining the solar panels directed towards the sun in the chosen dawn-dusk orbit.

The backbone navigation sensor is based on GPS receivers on both satellites. The TARGET communicates its position to the MAIN via an intersatellite link, and the relative position and velocity can be calculated in real time with centimetre accuracy. The GPS system, giving even higher accuracy after on-ground post processing, will be used to verify other sensor systems performance. The MAIN is a fully 3-axis stabilized S/C with 6 thrusters arranged to give torque-free translational capability in all directions. The MAIN S/C performs all autonomous manoeuvres and maintains communication to ground.

In contrast, the TARGET has course 3-axis stabilization by means of magnetic control only, but contains no delta-V capability at all. It acts like a visible target for the MAIN, and communicates its position and status to the MAIN via a 450 MHz



The main structure.
Figure: SSC

intersatellite link. The TARGET also contains one FFRF unit which communicates the corresponding unit on the MAIN.

The S/C masses are approximately 140 kg for the MAIN and 40 kg for the TARGET. They are launched clamped together such that the first mission phase will be a joint operation of the 2 satellites where critical systems can be checked out. Also, during the motor systems check-our in the clamped phase, some delta-V will be spent on making the orbit slightly eccentric, since the GNC experiments are aiming at demonstrating functionality also in an arbitrary orbit, not only for circular orbits.

After separation and start-up of the TARGET, the MAIN will start with an experiment series as given by the experiment schedule. The mission lifetime is planned to 8 months, which is the estimated duration in order to demonstrate all experiment functions. The mission will be controlled via the SSC control station Esrange in the northern part of Sweden. However, much of the mission planning will be made at SSC's technical centre in Stockholm.

EXPERIMENTS

GNC Experiments

The GNC manoeuvring experiments will mainly be run by SSC, with important contributions from DLR but also from DTU and CNES. The experiments can be divided in the following four categories:

1. Autonomous formation flying
2. Homing and Rendez-Vous
3. Proximity Operations
4. Final Approach/Recede Manoeuvres

These are described briefly below. A high level of onboard autonomy will be implemented. The experiments will be developed further in close collaboration with the sensor experiments and demonstrations. They will in the practical mission be mixed with the other experiments and conducted in a sequence optimized for fuel consumption, time and operational complexity.

Autonomous Formation Flying

This experiment set aims at demonstrating initialization, reconfiguration and autonomous control of time-periodic motions. This may be used in e.g. future passive aperture missions, orbit servicing or for coarse formation control.

The experiment shall demonstrate that the MAIN can autonomously establish and maintain a fix time-periodic relative distance to the TARGET on typically decimetre level of control, counteracting gravitional, drag and other disturbance forces with a minimum of fuel consumption and with no ground intervention. The relative distances may vary between typically 30 m to several hundred meters. The demonstration shall be valid for eccentric orbits as well as circular orbits. The GPS system is the cornerstone sensor in this experiment. The GPS receivers are delivered by DLR, who also runs the spaceborne autonomous formation flying experiment (SAFE). The GPS and the SAFE are further described in a separate paragraph. Also the Formation Flying Radio Frequency (FFRF) metrology instrument delivered by Alcatel Alenia may be tested in closed loop as a demonstration of course formation flying and anti-collision algorithms as a precursor for the Darwin mission.

Homing and Rendezvous

This experiment set aims at demonstrating long range tracking and rendezvous capability by optical sensors, typically to be used in missions where GPS systems are not available. This may be servicing missions in geosynchronous orbits, Mars Sample Return, and others.

The Vision Based Sensor (VBS) shall be used in order to identify the TARGET as a non-stellar object at distances up to 500 km, and to track the TARGET down to very close range, typically 10 meters during a sequence of autonomously scheduled approach manoeuvres.

Areas to investigate are among others the degree of cooperativeness needed of the TARGET S/C (the TARGET will be equipped with swichable light diodes), the division of functionality between on-board S/W and ground control centre etc.

Proximity Operations and Final Approach/Recede Manoeuvres

The 3-dimensional Proximity Operations experiment set includes the Final Approach and Recede experiments where Main will navigate as close as possible to TARGET, preliminary to within only a few meter range. The guidance algorithms on the MAIN S/C will autonomously generate trajectories to traverse between various holding points in the TARGET body frame while avoiding no-fly zones. Approach and recede corridors will be defined between some of the holding points and the TARGET.

The model missions are On-Orbit Servicing, On-Orbit Inspection, and On-Orbit Assembly in both near-earth scenarios and beyond. The 3-Dimensional Proximity Operations will use both GPS and the vision based sensor. The Final Approach and Recede experiments will use the vision based sensor and potentially a complementary camera sensor for the final meters.

The TARGET will be configured to a cooperative target in terms of visible markers and/or light diodes, and non-cooperative using no lights and with varying attitude and rates.

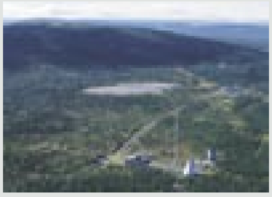
The mission geometry and the dawn-dusk orbit allows to manoeuvre around the TARGET without power constraints within the zones depicted in figure 2, however shorter periods (<30 minutes) may be supported by battery power only.

SENSORS AND ACTUATOR EXPERIMENTS

GPS-based navigation and SAFE

DLR has assumed responsibility for providing a GPS-based onboard navigation system offering precise absolute and relative orbit information in

Swedish Space Corporation



At its engineering centre in Solna, Stockholm, SSC develops satellites, subsystems and experiments for sounding rockets as well as airborne systems for maritime surveillance. Sounding rockets and high-altitude balloons are launched from Esrange, SSC's facility near Kiruna. The satellite ground stations at Esrange provide data reception, TT&C and mission control services. Satellite communication services are also performed at SSC's facility Stockholm Teleport. SSC has around 300 employees.

SSC owns the German company LSE AG, which provides engineering and satellite operations services. SSC is also a part-owner of NSAB, which distributes television and offers other telecommunication services on its Sirius satellites, of ECAPS, which develops and manufactures green propulsion systems and of NanoSpace, which develops microsystems for space applications.

Since SSC was established by the government in 1972, the company has provided the main technical expert services needed to coordinate, implement and execute both national and international activities. The Swedish national programmes have formed the core of SSC's activities, providing the basis for SSC's development into a competent internationa- business partner for space projects.

Esrange Launch Site

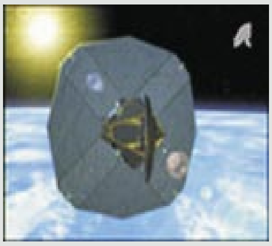
In 1961, the first rocket to be launched into space from Sweden took off, and five years later, Sweden's own rocket base for space research, Esrange, was founded.

Esrange, near Kiruna is an international centre for peaceful exploration of space. The customer includes individual scientists within space-related disciplines, and international space organisations such as ESA, CNES, DLR, JAXA and NASA.

Satellite Operations

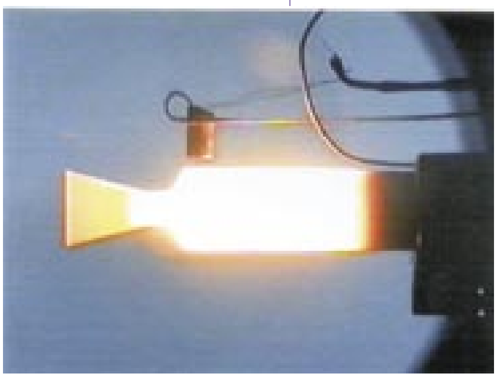
SSC's Satellite Operations Division provides support to operators of various types of satellites, covering operations from satellite launch phase and onward. The Division operates own and client assets in Sweden and provides services world-wide through PrioraNet.

Space Systems



The Space Systems Division, located at SSC's space engineering center in Solna, Sweden designs and builds systems and subsystems for space research and other space projects and provides flight services on sounding rockets.

real-time. For redundancy and coverage purposes, each satellite will carry two independent GPS systems. Increased flexibility for handling non-zenith pointing attitudes is provided by two GPS antennas, selectable by ground command. The Phoenix GPS receivers to be flown on PRISMA are twelve channel single-frequency receivers based on a commercial-off-the-shelf hardware platform and qualified by DLR for use in low Earth orbit.



HPGP thrusters during firing test. Photo: SSC

The onboard navigation system on the MAIN satellite will process local GPS measurements and raw code and carrier phase measurements transmitted from the TARGET by the intersatellite radio link. A sophisticated Kalman filter will be employed for a dynamic modelling of the absolute orbits of both spacecraft, comprising the complex Earth's gravity field, atmospheric drag and empirical accelerations. Real-time position accuracies of 2 m for the absolute and better than 0.5 m for the relative navigation are expected. Post-processing will provide absolute accuracy of better than 0.5 m, and relative positions with centimetre accuracy.

In addition to the GPS-based navigation system, DLR will contribute to the PRISMA mission the Spaceborne Autonomous Formation Flying Experiment (SAFE). SAFE complements other PRISMA experiment sets with the objective to demonstrate a fully autonomous, robust and precise formation flying of spacecraft. Formations flying at typical distances of 100 to 2000 m is foreseen, which is representative of future bistatic radar satellite formation flying missions.

Microthruster pod with 4 thrusters along the "equator". Photo: SSC

Vision Based Sensor (VBS)

The VBS experiments will be run jointly by Danish technical University (DTU) and SSC. The DTU star camera, used in several space missions, has the capability to track non-stellar objects and report the direction in global direction vectors. This capability shall be developed such that MAIN S/C can find the TARGET S/C from several hundred kilometres and deliver sufficient data in order to precisely determine the TARGET S/C orbit (either on-board or on ground). The sensor shall also be used as an image recognitions sensor for shorter range and pose information of the TARGET.

The functionalities mentioned shall be developed in the PRISMA mission in order to explore the possibility to use the star camera as future low-cost multi-functional tracking sensor. Especially important is to evaluate the sensor performance in different lighting conditions and backgrounds.

In the PRISMA mission, a dedicated VBS star camera head, identical to the standard camera head, will be implemented, beside the two redundant heads used for ordinary star camera functions. Probably, also a 4:th head will be implemented for covering short range (0-10 m) to the TARGET, where the standard camera optics cannot focus. All four camera heads will be connected to the micro-ASC (Advanced Stellar Compass9 recently developed by DTU. The micro-ASC is fully redundant and can handle four camera heads in any crosstrapping configuration.

Formation Flying RF sensor (FFRF)

The FFRF experiment will be run by CNES and Alcatel Alenia Space. The sensor development is currently driven by the formation flying mission Darwin, where it will be used as a coarse formation flying sensor for formation establishment down to centimetre level, and collision avoidance. A breadboard has been developed on ESA contract.

The sensor is located on each S/C in the formation and works with a dual frequency S-band communication and a set of nominally seven antennae on each S/C. The position and direction to the neighbouring units are calculated by means of measurements of pseudo-ranges and carrier phase measurements for ranging, and single difference of carrier phase measurements for direction. The system shall have a dynamic range between 100 m to 30 km. The experiment on PRISMA shall focus on validating the sensor performance in acquisition time, stability and accuracy at different ranges and dynamic conditions. A flight test is especially important w.r.t. multipath phenomena.

The implementation on PRISMA is simplified compared to the Darwin baseline, with only three antennae on MAIN and TARGET respectively, restricted to hemispherical coverage.

The FFRF sensor may also be used to test advanced GNC functions in closed loop intended for the future Darwin mission, and which is in the interest of ESA to investigate due to difficulties to test on ground. This may be coarse formation flying and anti-collision algorithms with the FFRF instrument in closed loop with the GNC system.

High Performance Green Propulsion

SSC and Volvo Aero have formed a subsidiary company called ECAPS, for the development of an environmentally friendly and non-toxic chemical propulsion system called High Performance Green Propulsion (HPGP). The development is supported by ESA. The system shall provide performance equally or better than monopropellant hydrazine, but cancel all the disadvantages and costs implied by the highly toxic and hazardous hydrazine.

At present, extensive testing has been performed on a 1-N engineering model motor.

This motor system shall be flight demonstrated on the PRISMA mission. The implementation consists of 6 1-N thrusters located on the MAIN S/C, such that torque-free motion can be created in all directions. A propellant tank containing 12 kg fuel gives approximately 110 m/s delta-V over the mission.

The system shall demonstrate performance by both steady state burns up to 30 seconds, down to minimum impulse bits of 0.1 Ns (requested typically at autonomous formation flying and proximity operations).

Since PRISMA mission relies heavily on the performance of the motor system, it is essential that the system show reliable results before flight.

Micropropulsion cold-gas thrusters

Nanospace, a spin-off company from the Uppsala University, partly owned by SSC develops micro-technology cold-gas thrusters, capable of delivering continuous thrust levels between 10 microNewton to 1 milliNewton.

The thrusters are manufactured in MEMS technology in stacked silicon wafers with integrated thruster valves and thrust feedback measurement system. The stack contains 4 orthogonally located thrusters. This is integrated in the thrusters pod depicted in the figure 4. The pod has approximately the size of a golf-ball.

The main advantage over conventional motor systems in the very low and disturbance free thrust, an the thrust feedback control which enables a continuous throttling between minimum and maximum thrust without discrete impulse bits. The development is supported by ESA.

The implementation on PRISMA is to have 2 thruster pods located such that all thrusters can be fired. The performance of the thrusters system will be measured by means of disabling the attitude control loop of the MAIN S/C and register the attitude motion caused by the thrusters.

The system will however not be included in the PRISMA GNC design, since the development is not sufficiently mature. The motor system is thus to be regarded as an experiment only.

Layout

The MAIN S/C layout is depicted in figure 5. It is based on a bow shape of approximately 700x700x1000 mm sides. The body has 2 deployable solar panels of in total 2 m². The nominal sensor side on the "top" face contains the VBS camera heads and the 3 FFRF antennas.

The separation system to the TARGET is also located on the top face, the sensor side, for accommodation reasons on the launcher.

The propulsion system, the HPGP motor system, contains 6 1N thrusters directed towards the COG of the S/C, where the 12 kg tank is located. The potential misalignment of the thrusters can be cancelled by the reaction wheel torque.

The locations of the thrusters are chosen such that there are no thrusters in the rendezvous direction.

The micropropulsion thruster pods are located on the bottom deck and are oriented such that the 4 thrusters on each of the 2 pods can be operated. The system is not intended to give delta-V to the MAIN S/C, but the location does not rule out the possibility.

The TARGET S/C is a smaller box with one bodymounted solar panel of approximately 0.5 m², see figure 6. All equipment is located on the bottom floor, which also acts as a radiator in the nominal sun-oriented flight configuration.

Both MAIN and TARGET are equipped with GPS receivers as described earlier.

The antennas are configured such that in nominal flight configuration, both active antennas are zenith pointing such that both S/C receivers will "see" the same GPS satellites, enabling differential GPS techniques for relative GPS calculation. This means that the MAIN GPS antennas are located on the solar panel edges.

Prisma in launch configuation. Figure: SSC

Accommodation on launcher

The PRISMA in launch configurations is preliminary located on the upper floor of the Dnepr Space Head Module, whit the CNES satellite Picard located below.

PROJECT PLANNING AND SCHEDULE

The project schedule is directed towards launch in second half of 2008. The project has to now focused on the PDR in mid November. From there, detailed design and procurement will commence.