Hands-on Activities in Education

European students, taking part in an ESA Microgravity Research Campaign, are seen here floating in 'zero g' during a parabolic flight in an Airbus A300 aircraft

Motivating Young Europeans for a Future in Space

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The purpose of ESA's Education Office is to motivate young people to study science and technology and, in particular, to ensure a qualified workforce for ESA and the European space sector in the future.

Introduction

The Education Office supports student 'hands-on' activities including the design, development, integration, testing, launching and operations of small satellites such as CubeSats and CanSats, and the provision of payloads on satellites, sounding rockets, stratospheric balloons and parabolic flights. Many thousands of European students have taken part in the various projects facilitated by the Education Office in the 10 years of its existence (1998–2008).

History

The ESA Education Office was set up in 1998 by René Oosterlinck, then Head of Legal Affairs, Procedures, Rules and Organisational Matters, with former ESA astronaut Wubbo Ockels as its Head. Since September 2007, the office

The Express satellite is launched on 27 October 2005 by a Cosmos rocket from Plesetsk in Russia

has been headed by Francesco Emma. The office now has three units: the Policy and Coordination Unit, the Education Projects Activities Unit and the European Space Astronomy Centre (ESAC) unit located at Villafranca near Madrid. The latter is integrated within the ESAC Communication & Education Office.

For many years, concerns have been voiced in Europe about the growing indifference of students towards scientific and technology disciplines. During the Lisbon conference in 2000, the European Council devised a strategy to help reduce the scarcity of human capital in the European Science, Engineering and Technology (SET) domain.

The Education Office, while serving the general needs of Europe, particularly focuses its efforts in increasing the skills and knowledge of youngsters with regard to space. The overall strategy is to target students aged between 6 and 28 years. Its hands-on activities, involving both suborbital experiments and satellite projects, offer practical experience to undergraduate and postgraduate university students.

Student Educational Satellites

A number of small satellites have been, or are being, developed with the support of the ESA Education Office.

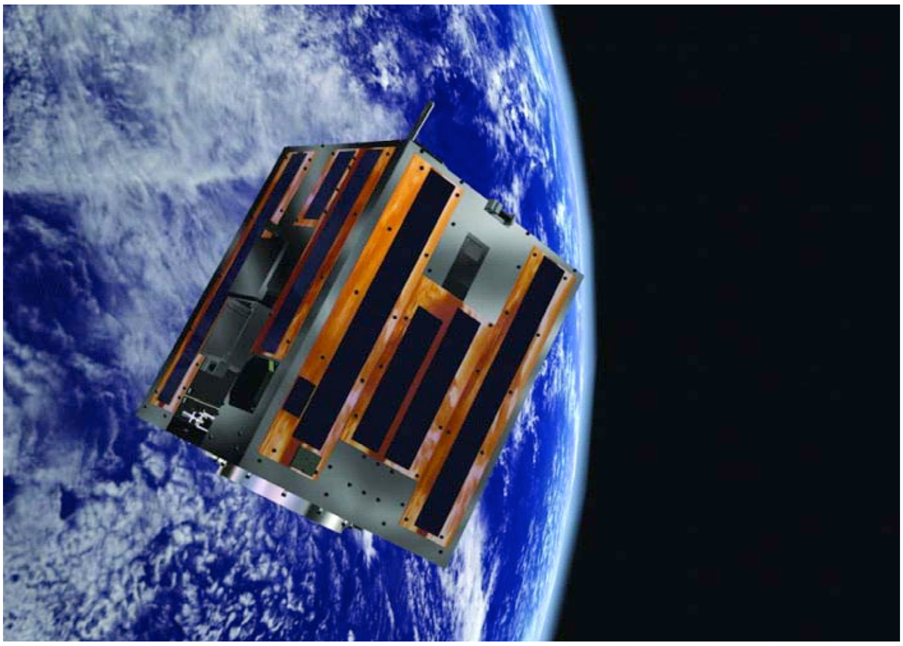
Express

Express was a box-shaped (60 x 60 x 70 cm) microsatellite with a launch mass of 62 kg, including as passengers three 'picosatellites' (CubeSats) of 1 kg each and their associated deployment system. Express was built entirely by student teams, taking in only 18 months from start to launch. The Education Office provided networking facilities that:

– enabled the student teams to exchange information and discuss technical issues, solutions and schedule;
– identified a suitable launch opportunity and covered the launch cost;
– provided technical and management coordination;
– organised and sponsored regular

workshops at ESTEC where the student teams agreed on their interfaces and could get advice from experts;
– managed the integration and testing of the satellite including the provision of the test facilities; and
– managed the launch campaign.

Express was launched on 27 October 2005 by a Cosmos rocket from the Plesetsk Cosmodrome in northern Russia into a Sun-synchronous, circular orbit at 686 km altitude. Unfortunately, due to a failure in the electrical power subsystem, the satellite batteries could not be recharged and the satellite shut down after 12.5 hours of normal operation. Nevertheless, in many respects, Express was a success. Of the 19 subsystems, 12 operated successfully, five could not be tested because the mission ended prematurely, and only two failed. Valuable lessons were learned during the development, integration, testing and operational phases of the project, with the malfunction itself being the most valuable lesson. The media impact was enormous, with an estimated 100 million viewers watching the launch of Express on TV.


Artist's impression of Express in orbit

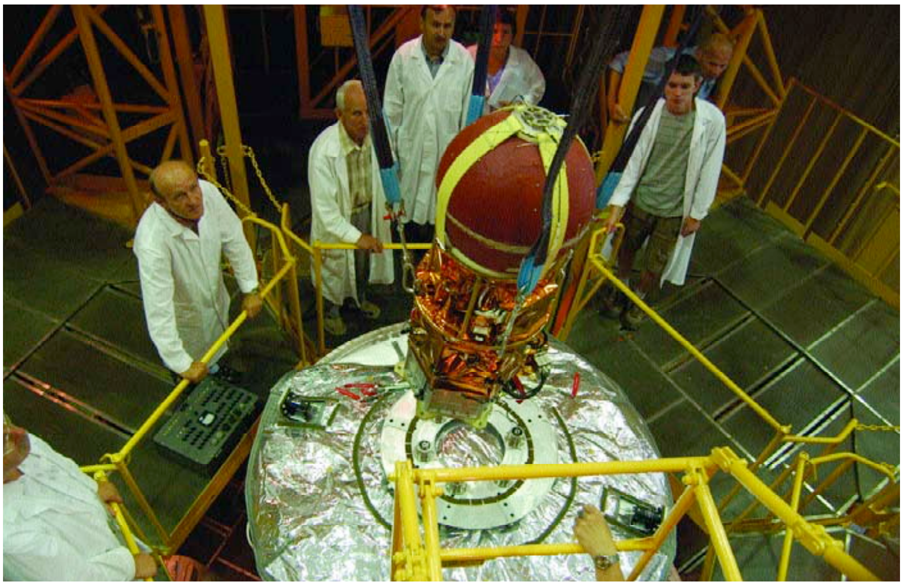
European Student Earth Orbiter (ESEO)

ESEO is a 110 kg microsatellite currently due for launch into a geostationary transfer orbit (GTO) as an auxiliary payload in 2011. To achieve its mission objectives, ESEO will carry a narrow-angle camera for taking images of Earth. Four charged particle detectors measure the total radiation dose received at different locations outside and inside the satellite, a Langmuir probe on a 40 cm deployable pole measures the instantaneous radiation, and a series of dedicated memory chips indicate the effects of radiation on the satellite's electronics. ESEO will also test technologies in orbit, for example, thin film solar cells mounted on deployable solar panels, a reaction wheel, a thrust vector system with a carbon-fibre nozzle, and a star tracker developed by students that will be space-qualified for later use on the European Student Moon Orbiter (ESMO).

The box-shaped (70 x 70 x 80 cm) satellite has four deployable, Sun-tracking solar panels. The attitude determination system comprises two Sun sensors, a three-axis magnetometer, a three-axis gyroscope and a star tracker. The attitude control system comprises a single-axis reaction wheel, four nitrogen cold-gas attitude thrusters and a main thruster for orbit control. This main thruster is used at the end of the mission for lowering the perigee in order to ensure reentry due to atmospheric drag within 25 years, thus complying with the European space debris Code of Conduct. Mission lifetime is not expected to exceed one month, considering the harsh energetic particle environment in the radiation belts in GTO and the fact that student teams can generally only afford commercial-off-the-shelf electronic components.

Making final adjustments to the Express student satellite at ESTEC, The Netherlands, in September 2005

A low Earth orbit (LEO) mission is currently being considered as an alternative to the baseline GTO option because of the reduced launch cost. Should this be retained the deployable solar arrays, the main thruster and most of the nitrogen would not be needed. This, together with a few additional minor savings, would result in a reduced launch mass of 80 kg. A launch on the VERTA 1 qualification flight (VERTA is the Vega Research and Technology Accompaniment programme) into a Sun-synchronous, circular orbit at 700 km altitude is



Top, Russian technicians lower YES2 onto the Foton-M3 spacecraft using a roof-mounted crane at the Baikonur Cosmodrome in Kazakhstan. Above, Foton-M3 is then placed inside the Soyuz rocket fairing, seen here alongside the Soyuz booster inside the Integration Building at Baikonur in September 2007

currently being explored, along with commercial launch opportunities.

The ESEO project Phase-B2 (consolidation of preliminary design) is due to begin in September 2008 and for the first time it will be implemented with a prime contractor to perform the system engineering, and coordinate and guide the subsystem work of the students. The current GTO orbit will be compared, during the Invitation-to-Tender process, with a possible LEO mission.

European Student Moon Orbiter (ESMO)

ESMO is a mini-satellite mission to be designed, developed, built, tested and operated by students. Its objectives are to prepare the next generation of lunar explorers, image the Moon from lunar orbit for public outreach, and conduct niche science/technology experiments related to future lunar exploration. Some 300 students from 29 universities in 12 countries are currently participating in the project.

In order to achieve these objectives, a miniaturised payload would perform measurements in lunar orbit over a six-month period. The core payload is a 2.5 kg narrow angle camera for optical imaging of specific locations on the lunar surface upon request from schools, and a 9 kg subsatellite, called Lunette, for global gravity field mapping via accurate ranging of the subsatellite from the main spacecraft. Lunette would be deployed in a near-circular polar orbit at 100 km altitude. Possible alternative scientific payloads under definition are a biological experiment to characterise the effects of the lunar environment on living cells, and a passive microwave radiometer to measure the temperature of the lunar regolith a few metres below the surface.

The box-shaped (85 x 85 x 62 cm) ESMO mini-satellite has a launch mass of 250 kg. Electrical power (110 W) is provided by body-mounted gallium arsenide solar cells. The attitude and control system comprises two star trackers, four Sun sensors, two Inertial Measurement Units, four reaction wheels and eight cold-gas thrusters. Downlink (8 kb/s Moon-Earth) and uplink (4 kb/s Earth-Moon) communications are in the S-band. The ground stations at Malindi (10 m dish), Weilheim (15 or 30 m) and ESAC (15 m) will be used during the mission, supplemented by additional coverage from Perth and Kourou in the early GTO phase.

ESMO will be launched into GTO from Kourou in 2012, flying as a secondary payload by using the Ariane Structure for Auxiliary Payloads (ASAP) adapter on Ariane-5 or Soyuz. Over a period of three months, an on-board liquid bipropellant propulsion system will be used to transfer the spacecraft from GTO to its operational lunar orbit via the Sun-Earth L1 Lagrange point.

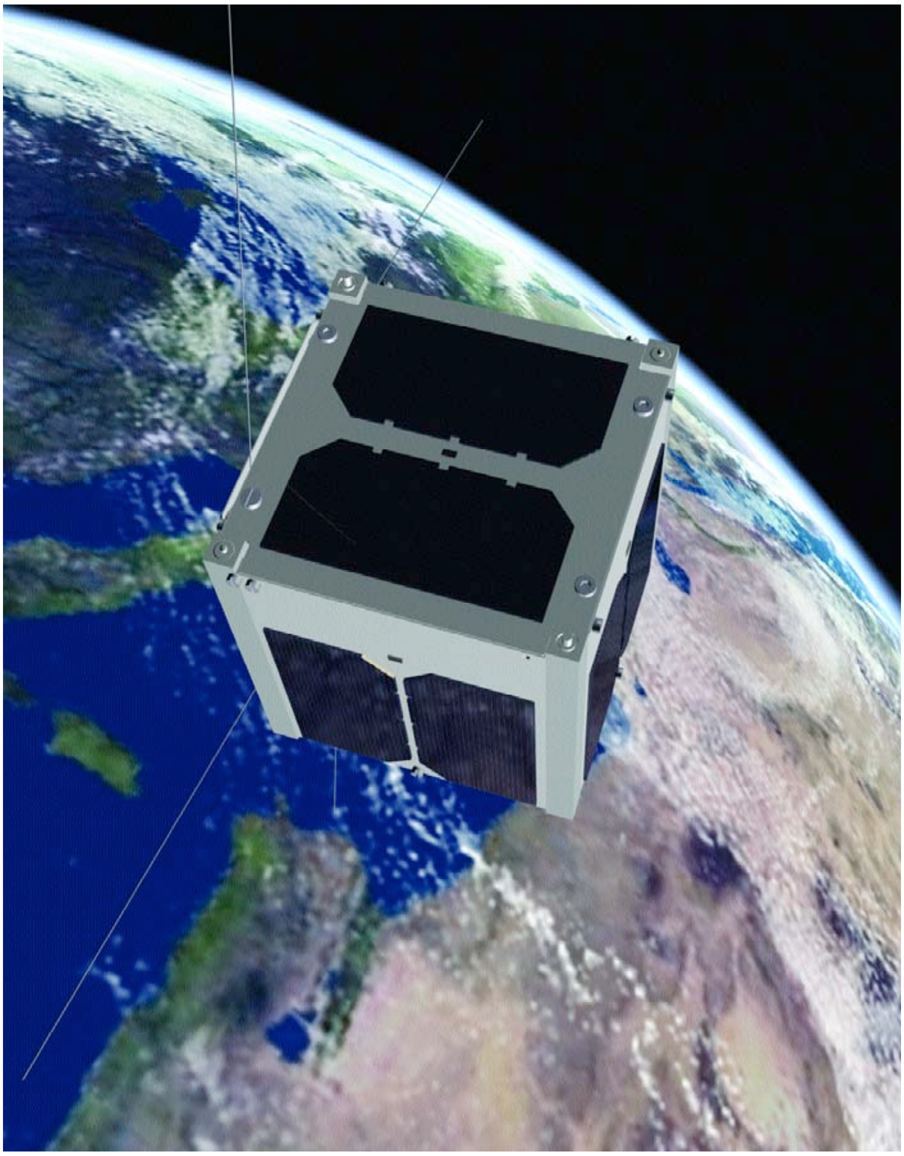
The project successfully completed a one-year Phase-A Feasibility Study and passed its Phase-A Review at a workshop in ESTEC in December 2007. The ESMO Phase-B/C/D/E1 contract is due to start at the beginning of 2009, following the same contractual set-up established for ESEO.

Second Young Engineers' Satellite (YES-2)

YES-2 was one student experiment on board a Russian Foton-M3 spherical capsule. The Foton carried a microgravity payload of 600 kg, provided mostly by research institutes and European industry under the management of the Directorate of Human Spaceflight (D/HSF). YES2 had the objective of demonstrating the 'Space Mail' concept for the first time, by returning a capsule (with payload) safely to Earth using a tether-assisted, deorbiting manoeuvre instead of a conventional retro-rocket propulsion system.

YES2 was built and tested by university students from all over Europe under the supervision of the Education Office and the industrial prime contractor Delta-Utec. The flight hardware installed on top of Foton-M3 had three components:

– the Foton-located YES2 Deployer (FLOYD), 21.7 kg, accommodating a 31.7 km-long, 0.5 mm-thick, non-conductive tether;
– the Mechanical and data Acquisition and Support System (MASS), 7.9kg;
– Fotino, a small spherical capsule (5.6 kg, diameter 40 cm), equipped with a heat shield to survive reentry. Inside Fotino there were thermocouples, thermistors, pressure sensors, accelerometers, gyroscopes, and a magnetometer to measure relevant physical parameters during reentry, a GPS receiver to determine its location, a parachute to ensure a soft landing and an ARGOS beacon to locate Fotino on the ground after landing. As there was no telemetry from Fotino to FLOYD or to the ground, so all data was stored on board Fotino and only be retrieved if Fotino was found after landing.



Artist's impression of a Cubesat in orbit

Foton-M3 was launched on 14 September 2007 by a Soyuz launcher from Baikonur. YES2 tether deployment started on 25 September. During the operation of YES2, the summary telemetry data obtained from Foton-M3 through the Russian ground station network indicated that the tether only partially deployed to a total length of 8.5 km. Subsequent thorough analysis of raw telemetry data showed instead that the tether was fully deployed. USSTRATCOM radar tracking data and Foton-M3 accelerometer data confirmed this result which was initially not evident because of a failure in the optical detectors sensing the deployment of the tether. This failure also caused a release of the Fotino capsule with a higher than planned speed acting against the direction of orbital motion. This caused the Fotino capsule to reenter the atmosphere at slightly steeper angle than planned. It has been

Used in the REXUS programme, the Improved Orion M112 is an unguided solid-propellant single-stage rocket, launched from Kiruna in Sweden

estimated that Fotino may have landed about 800 km short of the expected landing area, perhaps in the Aral Sea, which could explain the failure of the ARGOS beacon to send a signal acknowledging the landing.

The hands-on educational objectives of the project exceeded expectations. Some 450 students participated in the YES2 project from over 50 universities throughout the project lifecycle with about 120 students from five university centres of excellence involved in the later build and test phases of the engineering and flight models, when the implementation approached that of ESA space project standards.

Due to its innovative nature and large student involvement, the experiment received a high level of public outreach in various media, including TV, internet, newspapers and magazines in Europe and internationally. This was well complemented by a comprehensive, regularly updated project mini-website on the ESA Education web portal and a more informal student website. Amateur observers in Alaska and Antarctica also attempted to image the tether in orbit, but unfortunately local weather conditions prevented these efforts.

CubeSats

A CubeSat is a fully operable picosatellite for educational purposes which measures 10 x 10 x 10 cm, weighs up to 1 kg and uses Commercial Off-The-Shelf electronic components. The CubeSat standard was defined in 1999 by Stanford University and California Polytechnic State University. CubeSats can be built for €50 000–€100 000, plus €25 000–€50 000 for the launch. This price, compared to larger satellites and their associated higher launch costs, has made CubeSats a viable option for universities across the world.

Apart from the standard satellite subsystems (power, telecommunications, attitude determination and control, on-board data handling and storage) most CubeSats carry one or two scientific instruments or a technology demonstration payload. The telecommunications power is of course very limited and so CubeSats can only have a reasonable downlink data rate (9.6 kb/s) up to about 800 km orbital altitude.

On 28 May 2007, René Oosterlinck (then ESA Director of Legal Affairs and External Relations) and Antonio Fabrizi (Director of Launchers) signed an agreement to include an educational payload on the maiden flight of Vega, ESA's new small launch vehicle which is currently under development. This educational payload consists of nine CubeSats with two back-up CubeSats that can replace the primary satellites should they not be ready in time.

To support the selection of the CubeSats for Vega, a workshop was organised by the Education Office on 22–24 January 2008. The workshop at ESTEC was the first of its kind at a European level and brought together almost all of the European CubeSat teams for the first time. There are now 35 teams developing CubeSats in ESA Member States and Cooperating States.

The BEXUS balloon gondola sitting on its transport vehicle with the stratospheric balloon in the background. The balloon has a total volume of 10 000 m3 and grows to a diameter of 40 m when the maximum altitude is reached

Global Educational Network for Satellite Operations (GENSO)

As a complementary hands-on activity to CubeSats, GENSO is a planned network of over 100 small ground stations that is intended to provide global, near-continuous coverage of educational satellites in LEO. The network is being implemented under the auspices of the International Space Education Board (ISEB) with CNES, CSA, ESA, JAXA and NASA as member space agencies.

At present, a university typically builds a small satellite (e.g. a CubeSat) and launches it into low Earth orbit. It also builds, or already has available, a ground station to track the satellite and facilitate uplink/downlink telecommunications.

The period of a low Earth orbit is typically about 90 minutes, but the duration of a satellite pass over the ground station is very short and varies from approximately 10 minutes in the best case to no coverage at all for most of the orbits. When supporting only one satellite project, the ground station is not in operation 97% of the time. This is highly inefficient and often, despite on-board data storage capability, a limiting factor in mission return.

Moreover, there are sometimes mission critical operations requiring uninterrupted coverage for several hours. In the worst-case scenario, if there is an on-board emergency, there is no immediate access to the satellite. However, the situation would dramatically improve if the satellite could be tracked by other ground stations along its ground track.

During a workshop at the University of Aalborg in November 2007, a successful proof of concept was demonstrated when an Authentication Server in Austria was connected to the Ground Station Server (GSS) and the Mission Control Client (MCC) applications installed on the Aalborg ground station. Japanese and American hardware drivers were configured to control the ground station hardware, and telemetry was received from four student satellites – the passes were scheduled, the satellites tracked from horizon to horizon, the radio set and corrected for Doppler, and data decoded.

Since then, the GSS application has been installed in three further ground stations in the UK, California and Japan to run tests for tracking satellites and automatically scheduling passes. A GENSO detailed design review will take place at ESTEC in September 2008, closing out the Alpha software development phase. Thereafter, the Beta Phase will begin, involving a number of tests at some 20 ground stations during 2009, and ending with the Critical Design Review in September 2009. GENSO is expected to be fully operational by mid-2010.

Other Hands-on Projects

Rocket/Balloon Experiments for University Students (REXUS/BEXUS)

REXUS and BEXUS are five-year programmes providing Swedish and German university students with the opportunity to launch educational experiments on sounding rockets and stratospheric balloons. Three cycles are envisaged during these programmes, each beginning with a Call for Experiment Proposals and ending with

Operated by Novespace, ESA uses the Airbus A300 'Zero-G' for its parabolic flight campaigns (Novespace)

the launches. A cycle comprises two rocket launches and two balloon launches. All launches are managed by Eurolaunch and take place from Esrange, near Kiruna, in northern Sweden. On each launch, half of the payload resources are available to Swedish students, the other half to German students. The flights are funded by the Swedish National Space Board (SNSB) and the Deutsches Zentrum für Luft- und Raumfahrt (DLR).

For their share of the payloads, SNSB has decided to invite students from all ESA Member States to participate in the REXUS and BEXUS campaigns. To this end, SNSB has asked the ESA Education Office to make European-wide announcements for the two annual opportunities, select the experiments, manage the interface between the selected experiment teams from European universities and SNSB and Eurolaunch/Esrange, and cover the expenses of European students to attend all of the associated activities (workshops, training week, reviews and launch campaign).

In the REXUS campaign, a spin-stabilised, solid-propellant, single-stage rocket with an 'Improved Orion' motor is used, reaching an altitude of 90–100 km. The total available mass for student experiments is about 30 kg. BEXUS uses a 12SF helium balloon from Zodiac (France), which can carry a student experiment mass of 40 kg to a ceiling of 35 km. The floating phase at ceiling altitudes can last up to four hours. The first REXUS and BEXUS flights with eight European student experiments selected by the Education Office will take place in March 2009 and October 2008, respectively.

Stratospheric Platform Experiment (STRAPLEX)

STRAPLEX is a collaboration between the University of Porto and ESA which began in 2005. It involves balloons that are launched from Évora in Portugal and can reach an altitude of 34 km with a payload mass of 4.5 kg. Since the end of 2005, four qualification flights have been successfully completed. The last one of these, on 2 May 2008, included for the first time a lightweight (0.5 kg) transponder. On 22 October 2006, two experiments – a radiation measurement system from the University of Valencia and an accelerometer from a Dutch school – were flown successfully and STRAPLEX is now fully operational. For this year's campaign, six experiments were selected, two from universities in Spain and Portugal, which will be flown at the end of July, and four from high schools in the UK, Belgium and Sweden (2), which will be flown in September.

Student parabolic flight experiments: Fly Your Thesis!

Parabolic flights were proposed by ESA to foster university student interest in microgravity research all over Europe. The Student Parabolic Flight Campaign (SPFC) was the first hands-on activity offered by ESA, staring in 1994. The last full ESA student campaign was held in 2006.

After 2006, the whole ESA Parabolic Flight programme was subject to a thorough review, and several managerial and safety recommendations were made for future campaigns. Following these recommendations and specific interactions between the ESA Education Office and the Directorate of Human Spaceflight, a new programme concept called 'Fly Your Thesis! An Astronaut experience' has been agreed for 2008/2009. The following aspects are especially emphasised:

- Academic: the experiment work must be an integral part of the student's syllabus. This can be through a Master thesis, a PhD thesis, a research programme or any form of project supported by the applicant's university.
- Scientific: the quality of the scientific proposals will be reviewed by a high-level Board panel, including experts from ESA and ELGRA (the European Low Gravity Research Association).
- Outreach: the ESA Education Office, in close coordination with the ESA Communication and Knowledge Department, will stress the outreach/communication aspects to foster interest in Europe for science, ESA activities and microgravity research.

A new call for student experiments has been launched in June 2008, for a preliminary selection of about 20 university teams in September 2008. These will come from all over Europe and consist typically of two to four students, together with an endorsing professor, appointed as the Experiment Principal Coordinator.

These teams will work on a detailed microgravity scientific experiment proposal, with the support of an ELGRA mentor. The teams will present their projects to a Review Board through a dedicated workshop at ESTEC in December 2008. This Board will then select the best three or four teams that will eventually fly their thesis in 2009. ESA is also assessing the possibility for all preliminary selected teams to visit the ESA European Astronaut Centre facilities in Germany.

The final three/four teams will design and build their experiment rack in the first half of 2009, assisted by qualified professionals and their ELGRA mentor. The cost of the manufacture will be partly supported by the ESA Education Office. The experiments will then be fully integrated within ESA's 51st Microgravity Research Campaign (MRC) for two weeks in fall 2009 in Bordeaux, France. Here, they will experience three flights, each of 30 parabolas, one parabola lasting 20 seconds. This will allow the selected teams to be in contact with experienced professional scientific teams from across Europe.

It is also intended that some of the best teams not finally selected for the flights will be invited to perform some microgravity research using ESA's microgravity and hypergravity facilities (e.g. the Large Diameter Centrifuge) at ESTEC. This is currently under assessment and considered an important complementary aspect of the new programme.

CanSats

A CanSat is a 'satellite' accommodated within the volume and shape of a regular soft drink can. The CanSat concept was introduced in 1998 by Professor Robert Twiggs from Stanford University. Just like a real satellite, a CanSat consists of a 'bus' and a payload. The bus comprises the structure (the aluminium soft drink can, antenna, circuit board), power (battery), telecommunications (transmitter), on-board computer and the recovery system (parachute). The payload may consist of sensors for measuring accelerations, the ambient air temperature, pressure and humidity, a differential GPS, a camera (pictures or video), attitude determination sensors or a mini-rover.

A CanSat is launched by an amateur rocket to an altitude of 500–4000 m. After release from the rocket at apogee, a parachute or parafoil opens and 5–20 minutes later the CanSat makes a soft landing. The drop time, during which it transmits telemetry, is comparable to the horizon-to-horizon pass of a satellite in low Earth orbit. Their advantages are that they can be built at very low cost, typically under €1000 and can be proposed, designed, built, tested and launched in six to nine months.

The building of a CanSat usually involves participation in a competition for university and high school students. Such competitions are organised regularly in different parts of the world. The competitions are in two categories: the standard CanSats (370 g) and the 'Open Class' (over 1 kg), which often includes a mini-rover. In Europe, CanSat competitions are being held in The Netherlands, France and Spain. The Education Office has organised some CanSat activities in the past and has been requested to organise a European-wide competition.

Conclusions

Up to 10 000 European students have been involved in the various hands-on activities announced, managed and funded by the ESA Education Office. They have been able to visit ESTEC and participate in workshops, project reviews, integration and test campaigns. They have prepared the required documentation according to semi-professional standards and participated in communication and outreach activities. They have benefited from the support by ESTEC staff on these projects and from discussions with these experts. Throughout all these processes they have met fellow students from other European countries, learned how to work successfully as a team, and established valuable contacts at ESTEC and in the space industry. Several hundred Masters and PhD theses have resulted from these projects, and the active involvement in one of the projects of the Education Office has often been the first step towards a successful career in space.

A typical 'Cansat' (Univ. of Wurzburg)