Science Mission Scenarios Using “PalmSat” Pico-Satellite Technologies

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Outline

- Background
- SNAP-1 Experience
- PalmSat’s Design Philosophy
- PalmSat’s Configuration
- Payloads
- Conclusions

PalmSat
Background

1981-91

UoSAT
Micro-satellites
50-65 kg

2000

SNAP
Nano-satellite
6.5 kg

~$1M ticket price
~10X mass reduction
Greater capability

2005

PalmSat
Pico-satellite
~ 1 kg
Background

- “CubeSat” concept has shown that ~1 kg satellites are an effective tool for space engineering education.

- Advances in COTS microelectronics and MEMS are making such satellites increasingly attractive as low-cost demonstrators of new technologies and techniques.

- Building upon our experience with SNAP, Surrey’s “PalmSat” is intended to meet both these objectives.
SNAP-1 Experience

- **SNAP-1** – UK’s First Nano-Satellite.
  - 1995 challenge: “design a soccer-ball sized spacecraft”!
  - SNAP-1 design begun in earnest in October 1999, delivered May 2000, launched 28\textsuperscript{th} June 2000.
  - Designed and constructed by SSC staff and students, and SSTL engineers. Funded by SSTL as internal R&D Project.
  - **Design-to-orbit – 9 months; cost \( \leq \$1M \).**

Dr. Craig Underwood, SNAP-1’s Chief Architect and Co-Project Manager

Jerome Salvignol, Project Manager
Ed Stevens, AIT Manager

Dr. Guy Richardson, SNAP-1’s Chief Mechanical Engineer
SNAP-1 Experience

- SNAP-1 Key Design Principles
  - Keep it simple, make it modular, use COTS.
  - Keep the number of harness interconnections small – use a standard power and CDHS interface (CAN Bus)
  - Use a standard mechanical interface (Eurocard 160 x 100 mm sized modules).
SNAP-1 Experience

SNAP-1 AIT & EVT – Spring 2000
SNAP-1 Experience

Rapid Off-The-Shelf Nano-Satellite Core

SNAP-1 Modular Configuration

SNAP Modules at the USAF Academy
These form the core of FalconSAT-2
SNAP-1 Experience

Pre-Flight: Tsinghua-1 and SNAP-1 Mounted on the Nadezhda COSPAS-SARSAT Satellite

Launch June 28th 2000, Plesetsk
SNAP-1 Experience

- **SNAP-1 Orbital Manoeuvres**
  - 18/8/00: SNAP-1 ~2 km below Tsinghua-1 – manoeuvres start.
  - 50 mN butane CGT fired ~4 times per day (~10 cm/s ΔV per day) under OBC control, with ADCS stabilisation and on-board GPS positioning.
  - 30 days later, SNAP-1 ~1 km above Tsinghua-1.
  - After separating by more than 15,000 km, SNAP-1 had manoeuvered to within ~2,000 km of Tsinghua-1 by 18/3/01.

SNAP-1 and Tsinghua-1 Semi-Major Axis History
Obtained from On-Board GPS: June 2000 – March 2001
PalmSat's design is as the result of a series of UG/PG student projects carried out since 2000 (6-8 per year).

We apply SNAP's modular COTS design philosophy – albeit with “credit-card” (90 mm x 55 mm) sized modules.

PalmSats will be launched *en-masse* in “swarm”-type missions, where many satellites (10’s or 100’s) are deployed to synthesise some mission function – e.g. multipoint sensing for Earth observation or space science.

Such missions require cooperation between the vehicles, hence autonomous attitude and orbit control, and inter-satellite link technology will be essential.

The first mission will demonstrate these technologies in a remote inspection/rendezvous/formation flying scenario.
PalmSat’s “Housekeeping” block comprises 7 modules:
- Power System
- On-Board Computer
- UHF Uplink/Downlink Transceiver and Modem
- VHF Uplink Receiver and Modem (optional)
- Attitude Control System (Magnetorquer Rods – Pitch-Axis MW)
- Attitude Determination System (tri-axial Magnetometer – Sun-Sensors)
- GPS Receiver

PalmSat’s “Payload” block will comprise (in the first instance):
- CMOS Cameras (Pair for Remote Inspection)
- 2.4 GHz ISM Band Inter-Satellite Link.

The payload interface will be CAN data in/out (2 wires), regulated +5V (or +3.3V), raw battery voltage (≈6-8V) and ground.

An Orbit Control System will be attached to the base.
Each rectangular facet is approximately 10 cm × 6 cm, and each can support two 4 cm x 4 cm cells per face, giving 12 body-mounted cells and 24 deployed panel-mounted cells.

The body-mounted cells act as passive thermal control surfaces – as do the hexagonal end-facets, which support the antennae and payload cameras.

The walls are 2mm thick aluminium alloy to provide radiation shielding.

Internally there is a stack of credit-card modules linked by a flexi-rigid harness under the top facet.
Power System

- 18 panels of triple-junction solar cells give ~ 210 mA each at 4.2 V under load.
- Input power ~ 1.7W – 5.2W depending upon attitude. Average ~ 4W in sunlight.
- Boost regulator BCR steps internal voltage up to charge the ~6-8V battery.
- 5 Cell advanced NiCd battery (as flown on SNAP-1) gives ~8.4 Whr in 120g package. Good for 8-10 thousand cycles.
- Buck regulator PDM provides switched, over-current protected +3.3V or +5.0V lines to sub-systems as required.
- Further boost regulators are used for high voltage systems (e.g. the transmitters ~ 12V).
On-Board Data Handling

- PIC family chosen: simple, low cost, low power, good interface support (USART, SPI/I²C, CAN). Watchdog timers and PWM/ADC etc.
- 18F8680 has 64K program memory with full CAN 2.0B support for payload interface.
- USART connects to uplink/downlink for simple asynchronous packet communications at 9600 bps.
- Basic operating code stored in serial EEPROM with FRAM used for telemetry data storage.
- Power system controller allows “back-door” control over the spacecraft.

Palmsat OBDH Packets:
TTC, Payload Data and Program Code

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2nd Prototype PalmSat OBC
Communications

- Uplink and downlink use amateur radio packet links at 9600 bps.
- Prototype VHF receiver and UHF transceiver built by students based on COTS technology (VEC-1002K 2m-band receiver, Tekk KS-960 70cm-band transceiver).
- Devices can be modified for spaceflight.
- Half-duplex operation possible with transceiver alone, but the extra receiver allows full duplex operations - preferred.
- Dual-band antenna and VHF/UHF diplexer modelled, built and tested on a full-size PalmSat RF-equivalent model ("Tin-Sat").
Students have developed a miniature 3-axis magnetometer based on the Honeywell HMC2003 magneto-resistive sensor. This is the primary attitude sensor.

Miniature Sun-sensors based on CMOS photodiode arrays are also in development. This provides extra input to the attitude Kalman filter.

Students have developed a three-axis magnetorquer rod control system similar to that used in SNAP-1. This is the baseline control system.

A ultra-miniature pitch-axis momentum wheel with MEMS gyro sensing is also in development which can give PalmSat a $2^\circ$ s$^{-1}$ slew capability, with $0.5^\circ$ pointing precision.
• Although SNAP-1 already carries a credit-card-sized GPS receiver for orbit determination, SSTL have continued to develop the system.

• The resulting SGR-05U receiver is based upon a commercial MG5001 OEM GPS board manufactured by Sigtec.

• The SGR-05U has the following specifications:
  - Dimensions: 70 x 45 x 10 mm
  - Mass: 20 g
  - Operation Temperature: 0°C to +50°C
  - Power Supply: 0.5-0.8 W at 5 V
  - ±15 m position accuracy on-orbit
  - Cold-Start TTFF 10 minutes.

• SNAP-1 used a patch antenna for its GPS system, however, for PalmSat, a miniature antenna solution has been derived from Sarantel’s PowerHelix antenna range.
The SNAP-1 propulsion system used small solenoid valves manufactured by Polyflex Aerospace in the UK, to vent butane as its propellant.

The Lee Products Extended Performance Solenoid Valve (EPSV), which is ~6mm diameter x 33mm long, has a mass of less than 6g with an average draw power of 0.75W, is suitable for PalmSat.

This is the basis for an ultra-miniature propulsion system, based on water as a propellant. Just 8 g of water would give ~3 ms\(^{-1}\) \(\Delta V\) to PalmSat.

SSTL have already successfully test-fired an experimental version of this thruster in orbit on the UK-DMC micro-satellite.
Payloads

- **Remote Inspection Cameras**
  - 640 x 480 pixel CMOS Camera.
  - 2 Mbytes of image storage memory.
  - Two imagers are flown:
    - Medium Distance Camera: 25 mm focal length, f/4, 11° x 8.2° FoV
    - Short Distance Camera: 2.9 mm focal length, f/2, 79° x 63° FoV
  - PhD research is in progress in using such a system to determine the relative pose and range of a target spacecraft.

- **Multi-Spectral Imager**
  - Radiometric imaging sensors, based on CMOS technology.
  - An 8-spectral band prototype has been developed as part of the NigeriaSat program.
  - Applications include ocean colour sensing, and meteorological scale imaging at low GSD (100~200m).
• **Inter-Satellite Link**
  - PalmSat-1’s other payload is expected to be a COTS 2.4 GHz ISM-band data transceiver, to be used for inter-satellite link experiments.
  - A 200 mW output RF power device from Aerocomm is currently under study.
  - This has a mass of 20g, a power consumption of 2W in transmission mode and 575 mW in receive mode.
  - It can support 115 kbps links over 3 km and 9600 bps over 10 km.

Aerocomm 2.4 GHz Transceiver
Payloads

- **Thermal-IR Camera**
  - A 320 x 240 pixel array imager using uncooled microbolometer technology sensitive to the 8-12 µm band (LWIR).
    - NETD: in the range 0.4 - 0.8 K
    - Minimum detectable fire area: ~25m x 25m
    - GSD: ~260 - 500 m
  - The current imager has a mass of 1-3 kg (including optics); power consumption is ~2W. Further miniaturisation may enable this to fit on a future PalmSat.
  - It has application to forest-fire and volcanic plume detection, as well as potential application to sea-surface temperature monitoring and meteorological temperature mapping.
  - A swarm of PalmSats could provide a cost effective way of providing a continuous “fire-watch” from orbit.
• **Near-UV Radiometer**
  - The Ozone Mapping Detector (OMAD) instrument was flown on the FASAT-Bravo micro-satellite.
  - The payload comprised four UV sensitive PIN-diodes each viewing an area of 150 km x 150 km, and set to narrow wavelength bands at 289 nm, 313 nm, 334 nm and 380 nm.
  - Data from this instrument were used to primarily to recover *global total ozone* data, although it does also have application to monitoring *aerosols* in the stratosphere.
  - The OMAD payload mass (including structure) is ~200g and the power requirement is 500 mW. The data-rate is ~64 kbyte per day.
  - This instrument could therefore be easily adapted to fit PalmSat.
• Ionising Radiation Detection
  - CEDEX detects protons and heavy ions >30 MeV energy.
  - This payload flies on the TiungSAT micro-satellite, and has a mass (including mechanical housing) of 600g, and a power consumption of ~2W. The data rate is up to ~200 kbytes per day.
  - It is capable of detecting up to 200,000 particle hits per second in a 3cm x 3cm PIN diode detector/particle telescope and it records the pulse height spectrum for a LET range of 64 to 8400 MeV cm² g⁻¹.
  - A swarm of PalmSats could be used to investigate the Van Allen belts, and solar particle event phenomena in some detail.
Conclusions

- Advances in miniaturised electronics and MEMS technology enable pico-satellites to become important tools in the scientific exploration of the Earth and its environments - especially when used in swarms.

- Swarms will require sophisticated technology to enable the appropriate level of cooperation between the vehicles in the swarm.

- The University of Surrey’s PalmSat pico-satellite is being developed to support such an endeavour, with the first launch expected in 2005-7.

- Already, the PalmSat programme has enabled many students to gain practical “hands-on” experience of spacecraft engineering, as well as to contribute towards the development of a sophisticated pico-satellite platform.

- As with the SNAP nano-satellite programme before it, the PalmSat programme shows the benefit of collaboration between academics, students and engineers, working in a “real-world” environment.
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