Space at Surrey: Micro-Mini-Satellites For Affordable Access To Space

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Changing world politics and military emphasis have brought considerable pressure on space agency financial budgets and a shift to increasing commercialisation of space activities. Budgetary pressure, coupled with the rapid advancement of commercial and consumer micro-electronics, has catalysed the use of smaller and more computationally capable satellites as a 'faster, cheaper, better' means of realising space missions - complementary to conventional large satellite systems. Affordable small satellites, however, require a very different approach compared with established space engineering techniques.

ollowing the first space launch in 1957, satellites rapidly grew increasingly large and enormously expensive. Initially, the 'space race' was an effective catalyst for the development of advanced technology as the super-powers strove to outdo each other and gain the advantageous 'high ground' of space - irrespective of budget. However, as costs escalated and timescales lengthened with satellites generally taking many years to mature from concept to useful orbital operation, this process limited access to space to only a relatively few nations or international agencies.

Changing world politics and military emphasis in the last decade has brought about a quiet revolution in space. Pressure on space agency financial budgets has increasingly meant that fewer (and bigger) satellites have been commissioned and new ideas, technologies and scientific experiments have found it difficult to gain timely access to space.

The staggering developments in micro-electronics, stimulated increasingly by the consumer market rather than military requirements, and the dramatic pace of consumer product development, caused space technology often to lag considerably behind that now taken for granted on Earth. The combination of reducing budgets for space and increasing capability of low-power micro-electronics have enabled a new breed of highly capable 'smaller, faster, cheaper' satellites to realise many space missions - complementing the conventional large satellite systems still necessary for large-scale space science and communications services to small terminals. Indeed, in the field of commercial satellite communications, numerous constellations of small satellites have been proposed and are being built to provide a range of global services to hand-held terminals either for real-time voice or non-real-time data.

However, whether a particular satellite is 'large' or 'small' depends somewhat upon viewpoint. For instance the 'small' satellites for the Iridium mobile communications system weigh in at over 600 kg each – whereas those for Health-Net email network are a mere 50kg! In view of this potential for confusion, the classification shown in *table I* has become widely adopted.

Although there have been many examples of large, small and even mini-satellites, however it is only relatively recently that capable micro-satellites have shown that it is possible to execute both civil and military missions very effectively, rapidly, and

Table I. Classification of satellites by size.

Class	*Mass (kg)*	*Cost ($M)*
Large satellite	> 1000	>100
Small satellite	500 -1000	30 – 100
Mini-satellite	100 – 500	7 – 20
Micro-satellite	10 – 100	2 – 4
Nano-satellite	1 – 10	0.2 – 1
Pico-satellite	<1	<0.2

at low cost and risk, for the following applications:

- Specialised Communications Services and Research;
- Earth Observation and Remote Sensing;
- Small-Scale Space Science;
- Technology Demonstration/Verification;
- Education and Training.

Surrey microsatellites

The University of Surrey has pioneered microsatellite technologies since beginning its UoSAT programme in 1978. From very modest experimental beginnings, its space-related research, post-graduate teaching and international commercial activities are now housed within a purpose-built Surrey Space Centre (*figure 1*) - with over 150 academic and professional staff and postgraduate research students. The objectives of the Centre's programmes are:

- to research cost-effective small satellite techniques;
- to demonstrate the capabilities of micro/minisatellites;
- to catalyse commercial use of micro/minisatellites;
- to promote space education and training.

Over the last decade, Surrey has established an international reputation as pioneers of innovative small satellites in a uniquely combined academic research teaching and commercial environment.

Surreys' first experimental microsatellites (UoSAT-1 and 2) were launched free-of-charge as 'piggy-back' payloads through a collaborative arrangement with NASA on DELTA rockets in 1981 and 1984 respectively. Since then, a further eleven low cost yet sophisticated microsatellites have been placed in low Earth orbit using Ariane, Tsyklon and Zenit launchers for a variety of international customers and carrying a wide range of payloads (*table II* and *figure 2*).

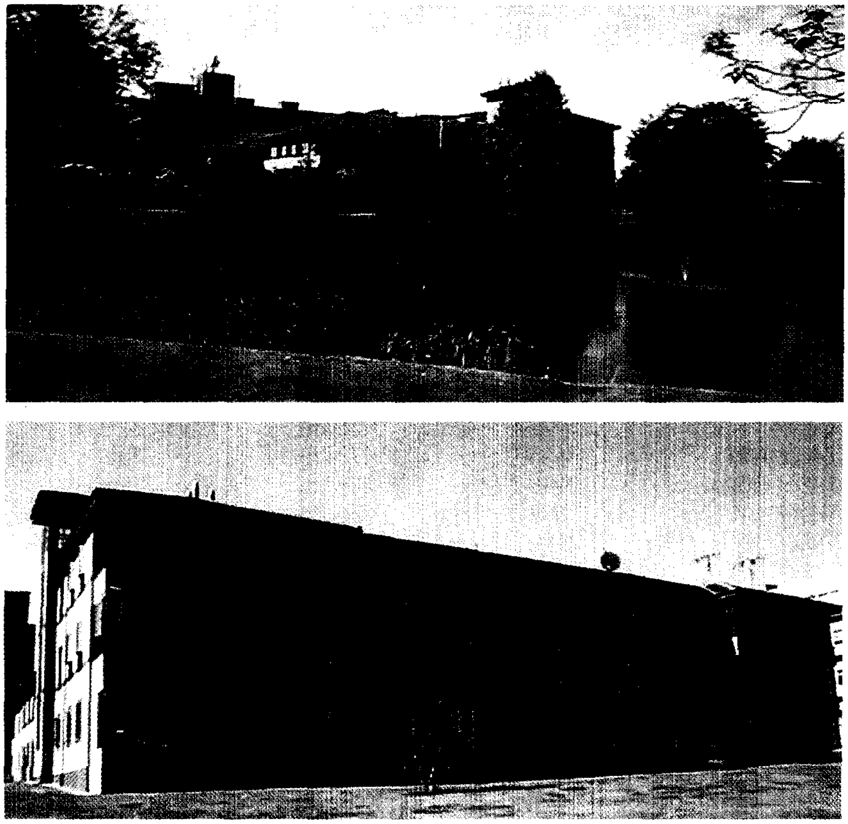


Figure 1. *The Surrey Space Centre and SSTL facilities.*

Surrey's new 315kg minisatellite UoSAT-12 was launched from the Baikonur Cosmodrome during April 1999 and four new microsatellites for Malaysia, China, France and USAF are currently being prepared for launch in 1999 and 2000.

UoSAT-1 and 2 originally both used a rather conventional structure - a framework 'skeleton' onto which were mounted module boxes containing the various electronic subsystems and payloads with a complex 3-dimensional inter-connecting wiring harness (*figure 3*).

Following UoSAT-1 and UoSAT-2 (in 1984), the need to accommodate a variety of payload customers within a standard (ASAP) launcher envelope (400 x 400 x 600mm and 50kg), coupled with increased demands on packing density, electro-magnetic compatibility, economy of manufacture and ease of integration, catalysed the development at Surrey during 1986 of a novel modular design of multi-mission microsatellite platform. This modular microsatellite platform has been used successfully on seventeen missions, each with different payload requirements, and allowing the spacecraft to proceed from order-to-orbit in typically 10-12 months!.

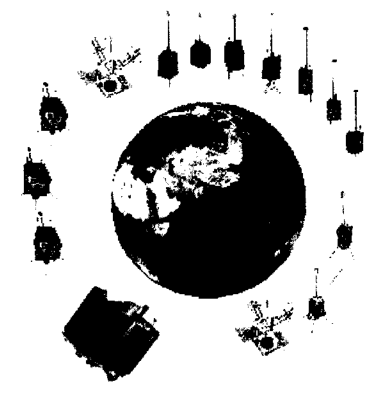


Figure 2. *Surrey micro and minisatellite missions in LEO.*

Table II. University of Surrey Microsatellite Missions.

Microsatellite	*Launch*	*Orbit*	*Customer*	*Payloads*
UoSAT-1	1984-D	560 km	UoS	Research
UoSAT-2	1984-D	700 km	UoS	S and F, EO, rad
UoSAT-3	1990-A	900 km	UoS	S and F
UoSAT-4	1990-A	900 km	UoS/ESA	Technology
UoSAT-5	1991-A	900 km	SatelLife	S and F, EO, rad
S80/T	1992-A	1330 km	CNES	LEO comms
KitSat-1	1992-A	1330 km	Korea	S and F, EO, rad
KitSat-2*	1993-A	900 km	Korea	S and F, EO, rad
PoSAT-1	1993-A	900 km	Portugal	S and F, EO, rad
HealthSat-2	1993-A	900 km	SatelLife	S and F
Cerise	1995-A	735 km	CNES	Military
FASat-Alfa	1995-T	873 km	Chile	S and F, EO
FASat-Bravo	1998-Z	835 km	Chile	S and F, EO
Thai-Phutt	1998-Z	835 km	Thailand	S and F, EO
UoSAT-12	1999-S	650 km	SSTL and Singapore	EO, Comms
TiungSAT-1	1999-Z	1020 km	Malaysia	EO, Comms
Clementine	1999-A	735 km	CNES	Military
SNAP-1	2000-S	650 km	SSTL	Technology
Tsinghua-1	2000-S	750 km	PR China	EO, Comms
PicoSAT	2000-?	650 km	USAF	Military

* built in Korea using SSTL platform and KAIST payload. D=Delta; A= Ariane; T=Tsyklon; Z=Zenit; S=SS18/Dnepr; LM=Long March.

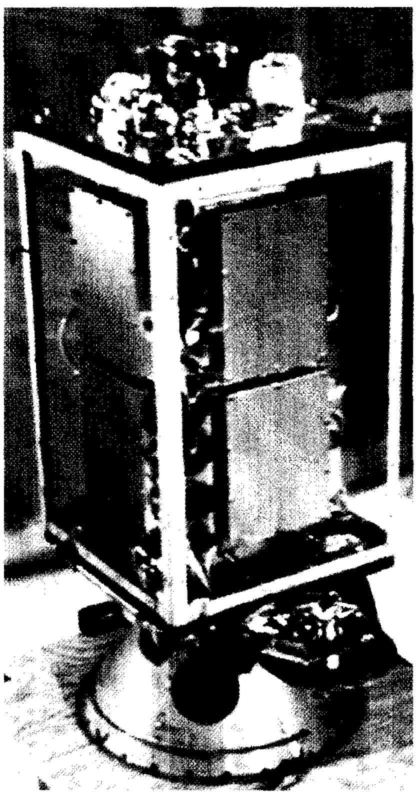


Figure 3. *UoSAT-1 microsatellite (70kg, 1981).*

The modular configuration

The SSTL modular microsatellite (*figure 4*) has no 'skeleton' but rather a series of identical outline machined module boxes stacked one on top of the other to form a body onto which solar panels and instruments may be mounted.

Each module box, houses the various microsatellite subsystems - eg. batteries, power conditioning, on-board data handling, communications and attitude control. Payloads are housed either in similar modules or on top of the platform alongside antennas and attitude sensors as appropriate.

Electronically, the microsatellite uses modern, sophisticated, but not necessarily space-proven, electronic circuits to provide a high degree of capability. These are underpinned by space-proven subsystems - resulting in a layered architecture that achieves high performance with operational redundancy by using alternative technologies rather than by simple duplication (*figure 5*).

Communications and Earth observation payloads require an Earth-pointing platform and so the microsatellite is maintained to within 0.3° of nadir by employing a combination of gravity-gradient stabilisation (using a 6-metre boom) and closed-loop active damping using electromagnets operated by the on-board computer. Attitude determination is provided by Sun, geomagnetic field sensors, and star field cameras, whilst orbital position is determined autonomously to with ±50 metres by an on-board GPS receiver. Electrical power is generated by four body-mounted GaAs solar array panels, each generating ~35W, and is stored in a 7Ah NiCd rechargeable battery (*figure 6*).

Communications are supported by VHF uplinks and UHF downlinks, using fully error-protected AX.25 packet link protocols operating at 9.6 to 76.8 kbps, and are capable of transferring several hundred kBytes of data to brief-case sized communications terminals.

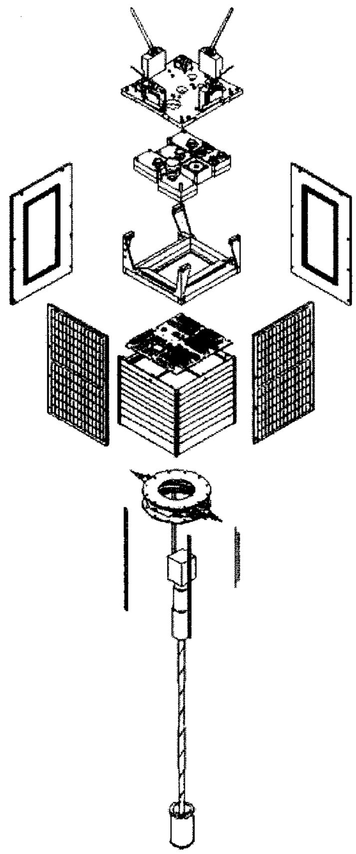


Figure 4. 'Exploded' view of SSTL microsatellite structure.

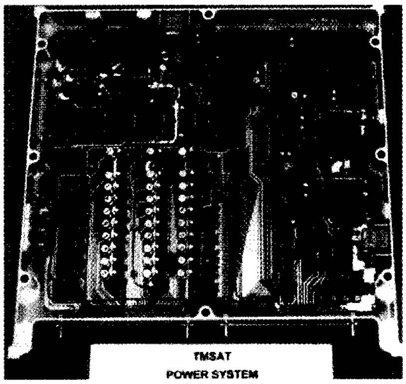
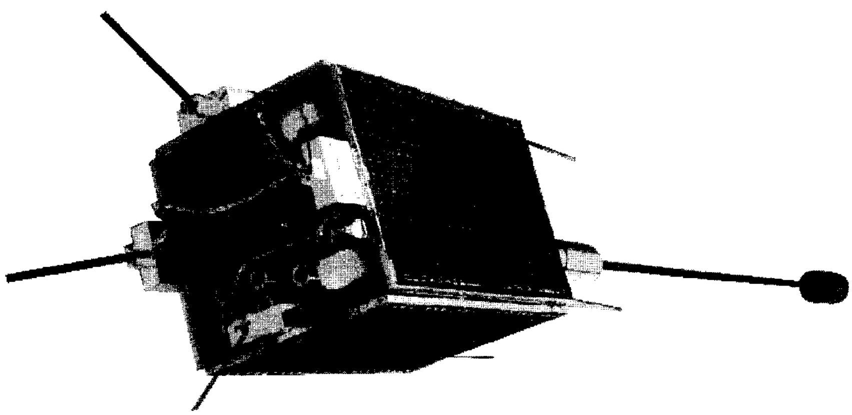


Figure 5. Typical SSTL microsatellite module.

On-Board Data Handling

It is the On-Board Data Handling (OBDH) system that is the key to the sophisticated capability of the microsatellite. At the heart of the OBDH system is a 80C386 On-Board Computer, which runs a 500 kByte real-time multi-tasking operating system with a 128 MByte solid-state CMOS RAMDISK. In addition, there is a secondary 80C186 OBC with 16 MByte SRAM, two 20 MHz T805 Transputers with 4 MBytes SRAM, and a dozen other microcontrollers. A primary feature of the OBDH philosophy is that all the software on-board the microsatellite is loaded after launch and can be upgraded and reloaded by the Control Groundstation at will thereafter. Normally, the satellite is operated via the primary OBC-386 and the real-time multi-tasking operating system. All telecommand instructions are formulated into a 'diary' at the groundstation and then transferred to the satellite OBC for execution either immediately or, more usually, at some future time. Telemetry from on-board platform systems and payloads is similarly gathered by the OBC-386 and either transmitted immediately and/or stored in the RAMDISK whilst the satellite is out of range of the Control Station. The OBC's also operate the attitude control systems according to control algorithms that take input from the various attitude sensors and then act accordingly. Thus it is this OBDH environment that allows such a tiny microsatellite to operate in a highly complex, flexible and sophisticated manner, enabling fully automatic and autonomous control of the satellites systems and payloads.

The latest SSTL microsatellite platforms (*figure 7*) have enhanced subsystems supporting the following major new features for greatly increased performance and payload capacity. The first version of the enhanced



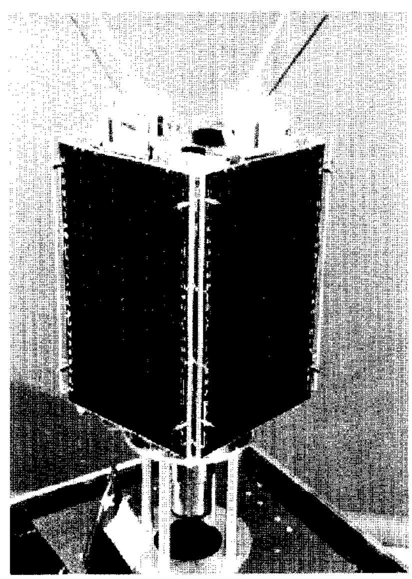


Figure 6. Microsatellite configuration.

microsatellite platform was used on the FASat-A mission for Chile launched into LEO by a Ukrainian TSYKLON launcher in 1995 and has since been further developed and used on the new FASat-Bravo, Thai-Puht, Tiung-Sat-1 (*figure 6*), PICOSat and now Tsinghua-1 missions providing:

- distributed telemetry/ telecommand for easy expansion;
- 5 MIPS (386) OBC + 256 MB RAMDISK;
- 1 Mbps on-board LAN;
- autonomous GPS navigation (50m);
- attitude determination (0.005°);
- 0.25° rms nadir pointing pitch/roll axes, 2° yaw;
- 128 kbps BPSK downlinks.

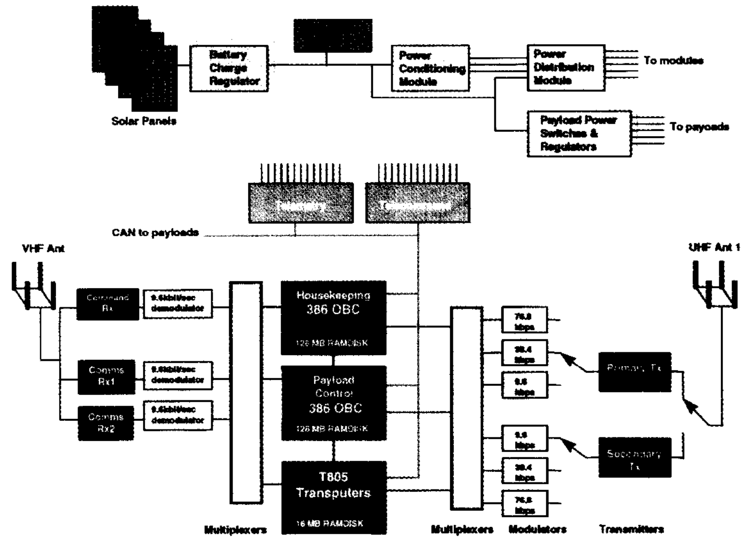


Figure 7. SSTL microsatellite platform systems.

Applications of micro/minisatellites

The early UoSAT missions demonstrated the potential capabilities of microsatellites and generated considerable interest in applications such as digital store-and-forward file transfer and in-orbit technology verification, however wider applications such as space science and Earth observation were slow to develop. Emerging space nations, however, were quick to recognise the benefits of entering the space-faring community with an affordable, low-risk 'first step' via an extremely inexpensive yet realistic micro-satellite programme. The need to handle this growing interest, to catalyse wider industrial and commercial applications, and to generate regular income to sustain a research activity in satellite engineering at the University of Surrey without dependence on government funding, stimulated the formation in 1985 of a University company - Surrey Satellite Technology Ltd (SSTL). SSTL provides a formal mechanism to handle the transfer of small satellite technologies from the University's academic research laboratories into industry in a professional manner via commercial contracts. Since UoSAT-5, all the Surrey microsatellites have been designed and built for individual commercial customers. The income generated by SSTL is then re-invested to support the academic activities of the Surrey Space Centre, which has now become the European 'centre of excellence' in satellite engineering research, teaching and applications. The range of applications of microsatellites can be demonstrated by reviewing recent examples of payloads carried by the UoSAT/SSTL microsatellite platform.

LEO communications

Various constellations of small satellites in LEO (Low Earth Orbit) have been proposed to provide world-wide communications using only hand-held portable terminals (*figure 8*); these broadly fall into two main categories:

- real-time voice/data services (eg. Iridium, Globalstar);
- non-real-time data transfer (eg. Orbcom, HealthNet).

The close proximity of the satellites in LEO to the user and the consequent reduction in transmission loss and delay time appear attractive when compared to traditional communications satellites in a distant geostationary orbit - holding out the promise of less expensive ground terminals and regional frequency reuse. The communications characteristics associated with a LEO constellation pose, however, quite different and demanding problems, such as varying communications path and links, high

Figure 8. SSTL LEO microsatellite communications in Antarctica.

Doppler shifts, and hand-over from satellite to satellite.

Currently, there is only one small LEO satellite service in full operation (HealthNet) which employs a 'constellation' of just two microsatellites, HealthSat-1 and 2, both built by SSTL for the network operator, SatelLife (USA). HealthNet, and the services waiting to be implemented (e.g. TemiSat, OrbComm, VITASat, GEMStar) use narrowband VHF/UHF frequencies recently allocated to the 'little-LEO' services to provide digital data store-and-forward "email" capabilities for use with small, low-power user ground terminals that can be located in remote regions where existing the telecommunications infra-structure is inadequate or non-existent.

These VHF/UHF frequency allocations exhibit such deleterious effects as multi-path propagation and, in particular, man-made co-channel interference which can very significantly reduce the performance that can be achieved in practice by the satellite communications system compared to that expected from a simple theoretical model. A thorough understanding of the real LEO communications environment at VHF and UHF is therefore necessary in order to select optimum modulation and coding schemes. Several SSTL satellites microsatellites carry a Digital Signal Processing Experiment (DSPE) which has been designed to provide a sophisticated in-orbit test bed for research into optimising communications links with satellites in LEO. The DSPE comprises a TMS320C25 and a TMS320C30 with data interfaces to the spacecraft communications sub-systems - enabling it to replace the hardware onboard modems with an in-orbit, re-programmable modem. The DSPE is being used in a research programme to evaluate adaptive communications links - continuously optimising modulation/demodulation techniques, data rates and coding schemes.

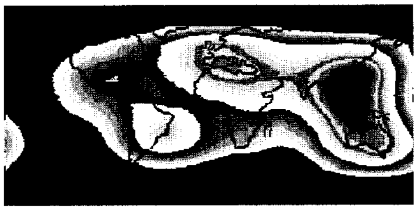


Figure 9. *LEO VHF interference environment.*

The interference characteristics of the VHF LEO frequency allocations have been measured using an experimental communications payloads on the S80/T and HealthSat-2 microsatellite missions (*figure 9*). In conjunction with a mobile groundstation, S80/T has measured the VHF spectrum 'noise' and interfering signals to evaluate the use of VHF frequencies for a full-scale LEO communications service (S80). S80/T was completed by SSTL for the Centre National d'Etudes Spatiales (France), from proposal to launch, within 12 months!

Space science

Microsatellites can offer a very quick turn-around and inexpensive means of exploring well-focused, small-scale science objectives (e.g. monitoring the space radiation environment, updating the international geomagnetic reference field, etc.) or providing an early proof-of-concept prior to the development of large-scale instrumentation in a fully complementary manner to expensive, long-gestation, large-scale space science missions. SSTL missions have demonstrated that it is possible to progress from concept through to launch and orbital operation within 12 months and within a budget of £2-3M. This not only yields early scientific data but also provides opportunities for young scientists and engineers to gain 'real-life' experience of satellite and payload engineering (an invaluable experience for later large-scale missions) and to be able to initiate a programme of research, propose and build an instrument, and retrieve orbital data for analysis and presentation for a thesis within a normal period of post-graduate study.

Figure 10. *LEO radiation environment from PoSAT-1.*

UoSAT-3 and 5, KITSAT-1 and 2 and PoSAT-1 (*figure 10*) provide examples of the use of a microsatellite platform for collaborative space science research between the University of Surrey, the UK Defence Research Agency, UK AEA, the UK Science and Engineering Research Council, KAIST and Portugal.

A 'Cosmic Ray Effects and Dosimetry' (CREDO) payload monitors the

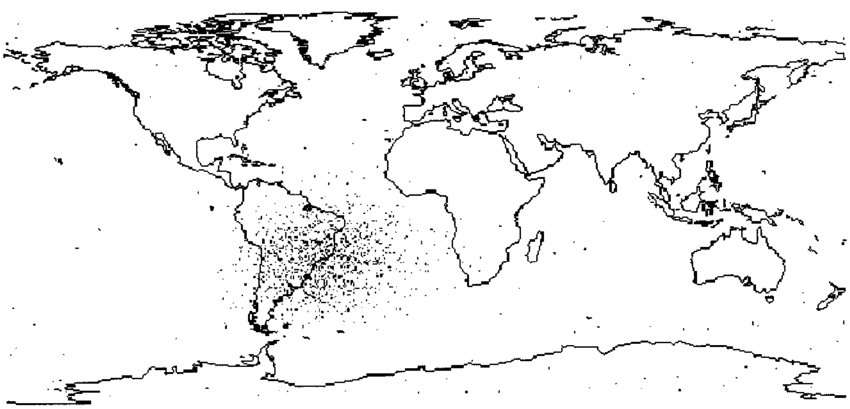


Figure 11. *LEO radiation effects - SEU's on PoSAT-1.*

near-Earth radiation environment (*figure 11*) and provides an important opportunity to validate ground-based numerical models with flight data yielding simultaneous measurements of the radiation environment and its effects upon on-board systems (especially SEUs (Single Event Upset) in VLSI devices).

Earth observation

Conventional Earth observation and remote sensing satellite missions are extremely costly - typically in excess of £150M each - and thus there are relatively few such missions and the resulting data, whilst impressive, is correspondingly expensive. The development of high-density two-dimensional semi-conductor Charge-Coupled Device optical detectors, coupled with low-power consumption yet computationally powerful microprocessors, presents a new opportunity for remote sensing using inexpensive small satellites.

UoSAT-1 and 2 both carried the first experimental 2D-CCD Earth imaging cameras which lead to the development of the CCD Earth Imaging System on-board UoSAT-5, intended to demonstrate the potential of inexpensive, rapid-response microsatellite missions to support remote sensing applications. Clearly, the limited mass, volume, attitude stability and optics that can be achieved with a tiny microsatellite means that a different approach must be taken to produce worthwhile Earth observation. For these reasons, SSTL employs electronic cameras with 2-dimensional CCD arrays to gather imagery from its microsatellites. Because cameras capture whole images in a single snap-shot, they preserve scene geometry and are therefore immune to the residual attitude drift experienced on microsatellites.

The Earth Imaging System (EIS) on-board the microsatellites comprise 1024 × 1024 pixel area CCD digitised to 256 levels of grey. The digitised data is stored within a CMOS RAM which is accessed by two Transputers to allow the image data to be processed to enhance quality and compressed to reduce storage and transmission requirements. The EIS data is transferred via the microsatellite's local area network to the 80C186/386 on-board computers and stored as files within the 32-128 Mbyte RAM DISK for later transmission to ground - some 60 images can be stored within the RAM DISK at any one time. The EIS is commanded to collect an image of a particular area of the Earth's surface by the on-board computer which operates a multi-tasking, real-time operating system responsible for the automatic operation of the microsatellite mission.

Ground controllers select a sequence of images of areas of interest anywhere on the Earth's surface and, checking the time and position of the microsatellite using an on-board GPS receiver and orbital model, instruct the on-board computer to collect the images according to a 'diary' that is loaded periodically in advance to the microsatellite.

The PoSAT-1 microsatellite carries two independent cameras providing a wide-field ground resolutions of 2km for meteorological imaging and a narrow-field ground resolution of 200 metres for environmental monitoring, with 650 nm (±40nm) optical filters providing good separation of arid/vegetation and land/sea boundaries and disaster warning: see *figure 12*.

Figure 12. *NIR meteorological images of Honduras and Northern Europe (PoSAT-1).*

The latest generation of small Earth observation satellites using the SSTL platform, such as Thai-Puht support EIS cameras yielding better than 90-metre ground sampling distance with 3 spectral bands providing multi-spectral image data in LANDSAT-compatible bands (*figure 13*).

The Tsinghua-1 microsatellite for launch in 2000 will provide 35 m 4-band multi-spectral imaging with the capability of ±15° (± 200 km) off-nadir imaging coverage upon demand.

In-orbit technology verification

Microsatellites also provide an attractive and low-cost means of demonstrating, verifying and evaluating new technologies or services rapidly in a realistic orbital environment and within acceptable risks prior to a commitment to a full-scale, expensive mission.

UoSAT-based microsatellites have supported a wide range of such in-orbit technology demonstrations, covering:

- new solar cell technologies;
- modern VLSI devices in space radiation;
- demonstration of advanced communications;
- 'pilot' demonstrations of new communications.


Figure 13. Image of Sydney, Australia from Thai-Puht microsatellite.

For example, satellites depend upon the performance of solar cell arrays for the production of primary power to support on-board housekeeping systems and payloads. Knowledge of the long-term behaviour of different types of cells in the radiation environment experienced in orbit is, therefore, essential. The continuing development of solar cell technology, based upon a variety of materials and different process techniques, yields a range of candidate cells potentially suitable for satellite missions.

Unfortunately, ground-based, short-term radiation susceptance testing does not necessarily yield accurate data on the eventual in-orbit performance of the different cells and hence there is a real need for evaluation in an extended realistic orbital environment. UoSAT-5 carries a Solar Cell Technology Experiment (SCTE) designed to evaluate the performance of a range of 27 samples of GaAs, Si and InP solar cells and from a variety of manufacturers. When the sun passes directly overhead of the panel mounted on the body of the microsatellite, the monitoring electronics are triggered automatically and measure typically 100 current/voltage points for each cell sample. These data are then sent in a burst to the microsatellite's on-board computer, together with associated temperature and radiation dose data, for storage prior to transmission later to ground. SCTE measurements are taken repeatedly immediately after launch, when the radiation degradation is most rapid, and then at increasing intervals thereafter.

Military applications

The demands of a military-style satellite procurement and the cost-effective approach to microsatellite engineering might, at first sight, appear incompatible! However, whilst retaining the essential characteristics of low cost and rapid response, a military version of the SSTL microsatellite platform with deployable solar panels has been developed to support various military payloads. The main differences between the 'commercial' and 'military' versions of the platform is in the specification of components and, particularly, in the amount of paperwork that traces hardware and procedures. An optimum trade-off between the constraints of a military programme and economy has been sought which results in an increase factor for cost and timescale of approximately 1.5 when compared to the 'commercial' procurement process.

The first use of the SSTL military microsatellite platform was on the CERISE mission designed and built for the French MoD and launched a 700km low Earth orbit by Ariane in July 1995 (*figure 14*). After a year of perfect operations, Cerise made history as the first operational satellite to be struck by a piece of space debris (rocket fragment) which severed its stabilisation boom. However, due to the flexibility of the microsatellite systems, SSTL engineers were able to re-stabilise Cerise by uploading new attitude control algorithms and return it to operations.

A second microsatellite for the French MoD is now being completed (Clementine) for launch into LEO in 1999 and a microsatellite (PICOsat) is being built for the USAF FCT programme (*figure 15*).

The Geostationary Transfer Orbit (GTO) provides a good opportunity to study

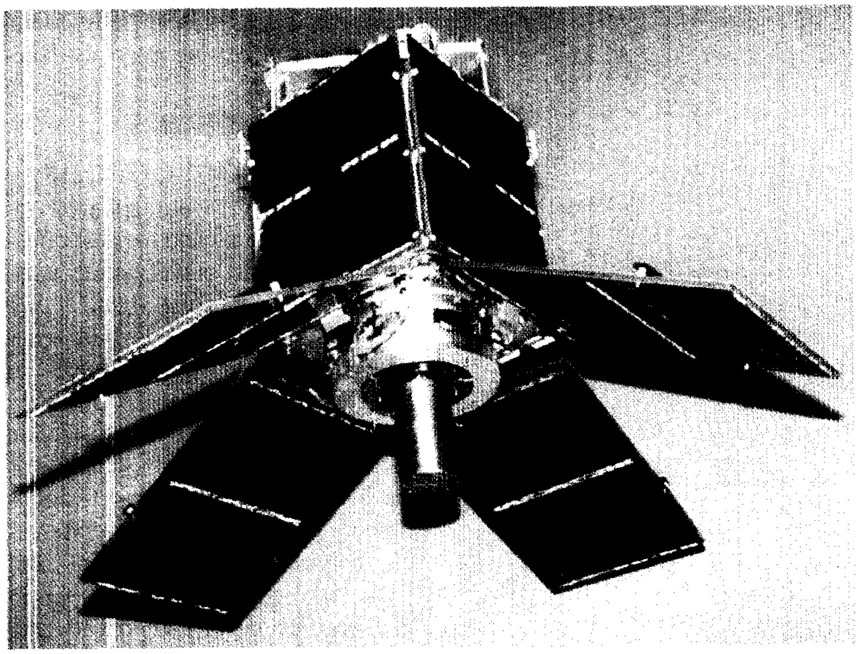


Figure 14. Cerise microsatellite.

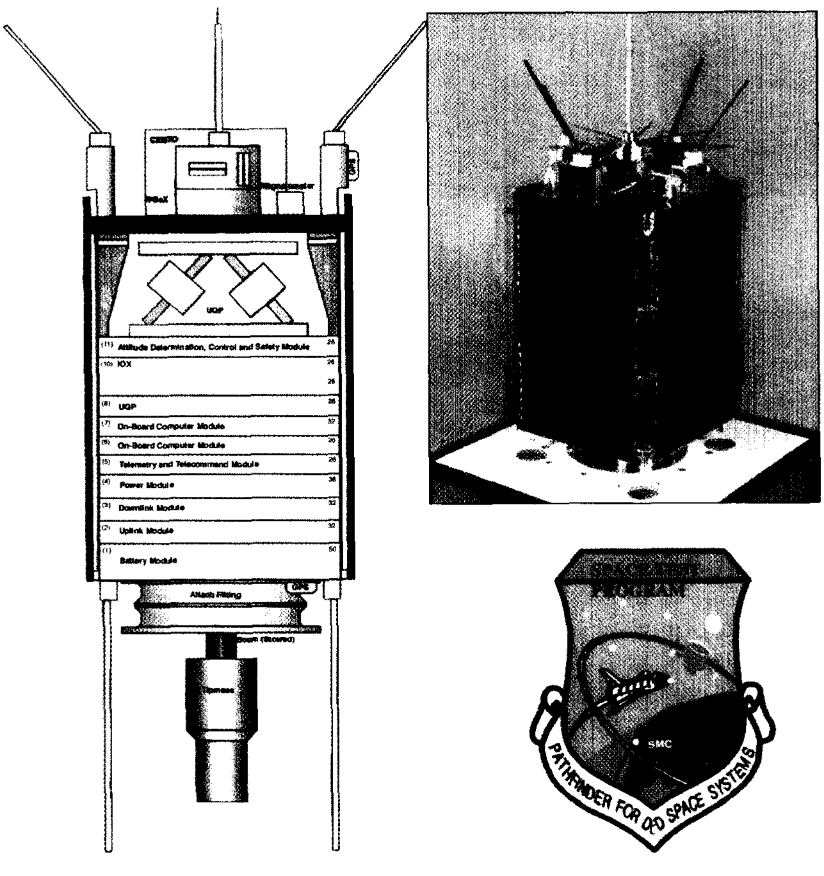


Figure 15. USAF space test programme PICOSat.

the effects of a severe radiation environment on satellite components - especially solar cells and VLSI components. Surrey has provided platform sub-systems and payloads to the UK Defence Research Agency (DRA - Farnborough) for their two Space Technology Research Vehicle (STRV-1) microsatellites which were launched into GTO in early 1994. STRV-1a and b carry a range of in-orbit technology demonstration payloads - particularly to study the effects of the space radiation environment on military satellite components.

Know-how transfer and training using microsatellites

Although microsatellites are physically very small, they are nevertheless complex and exhibit virtually all the characteristics of a large satellite - but in a microcosm. This makes them particularly suitable as a focus for the education and training of scientists and engineers by providing a means for direct, hands-on experience of all stages and aspects (both technical and managerial) of a real satellite mission - from design, construction, test and launch through to orbital operation.

The very low cost, rapid timescale and manageable proportions makes this approach very attractive to emerging space nations who wish to develop and establish a national expertise in space technology through an affordable small satellite programme. Each know-how transfer and training (KHTT) programme is carefully structured according to the specific requirements or circumstances of the country or organisation concerned, but the first phase typically comprises:

- Academic Education (MSc, PhD degrees);
- Hands-On Training (seconded to SSTL);
- Groundstation (installed in country);

- Microsatellites (1st at SSTL, 2nd in country);
- Know-How Transfer (satellite design licence.

Six highly successful international know-how transfer programmes have been completed by Surrey and SSTL (*figure 16*) with two programmes under way and a new programme with PR China just starting; these are summerised in *table III.*

A total of 70 engineers have been trained through these in-depth KHTT programmes at Surrey – a further 320 students from countries world wide have graduated from the MSc course in Satellite Communications Engineering unrelated to these KHTT programmes.

Once developing space nations have mastered microsatellite technology, the minisatellite provides a logical next step in the development of an increasingly capable national space infrastructure (*figure 17*).

Surrey Space Club

As each of these international know-how transfer and training programmes has been based around an SSTL microsatellite, the participating organisations share a common experience with Surrey; a common spacecraft design heritage; common spacecraft-groundstations; and common communications protocols. After returning to their home country, each organisation has commenced its own national space activities and research projects. In order to be able to share new ideas, discuss common interests, and work together to achieve common space goals, the "Surrey Space Club" has been formed as a regular forum for this 'commonwealth' of developing space nations to meet and learn from each other - thus to:

- Share satellite resources - there are 8 Surrey-designed microsatellites currently in operation in orbit from partners;

Table III. SSTL know-how transfer and training programmes.

Country	*Dates*	*Satellites*
Pakistan	1985-89	BADR-1
South Africa	1989-91	UoSAT-3/4/5
South Korea	1990-94	KITSat-1/2
Portugal	1993-94	PoSAT-1
Chile	1995-97	FASat-Alfa/Bravo
Thailand	1995-98	TMSAT-1
Singapore	1995-99	Merlion payload
Malaysia	1996-98	TiungSAT-1
China	1998-99	Tsinghua-1

- Gain greater access time to spacecraft in orbit through coordinated and shared access to the network of 9 Surrey-based groundstations around the world;
- Exchange new ideas on small satellites research and development;
- Build small satellite constellations together (e.g. the Disaster Network of EO Microsatellites);
- Co-ordinate low cost launch opportunities for members;
- Help new members maintain the momentum of a long term national space programme;
- Contribute to planetary exploration by international co-operation (e.g. Surrey's Lunar Mission 2001).

It is believed that all the members will derive great benefit through closer collaboration via the "Surrey Space Club" whilst at the same time, importantly, maintaining their own clear independence.

The first forum of the "Surrey Space Club" was during the visit of Queen Elizabeth to Surrey in December 1998 when she opened the new Surrey Space Centre building and presented SSTL with the Queen's Award for Technological Achievement (*figure 18*).

All past (and future!) Surrey technology transfer partners are welcome to join this unique opportunity for international co-operation.

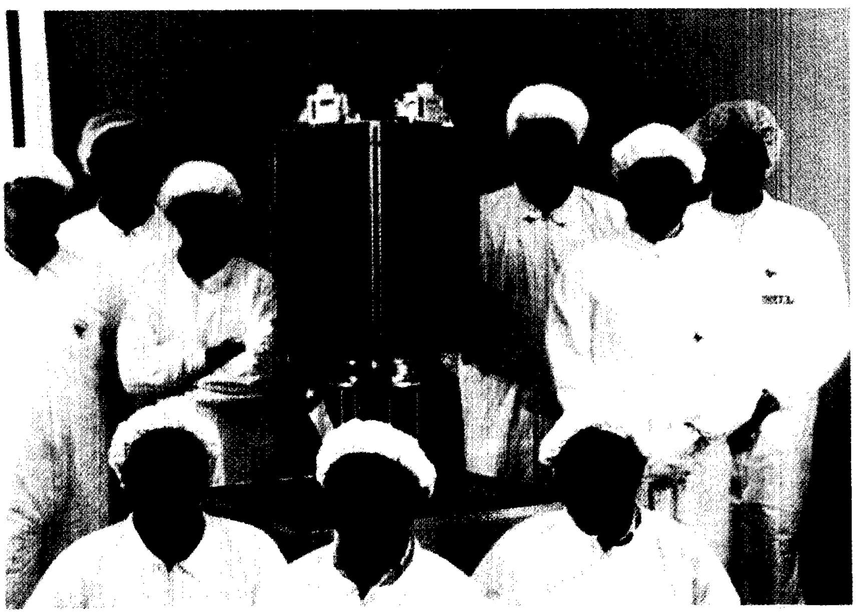


Figure 16. *Know-how transfer to Chile with FASat-Alpha/Bravo.*

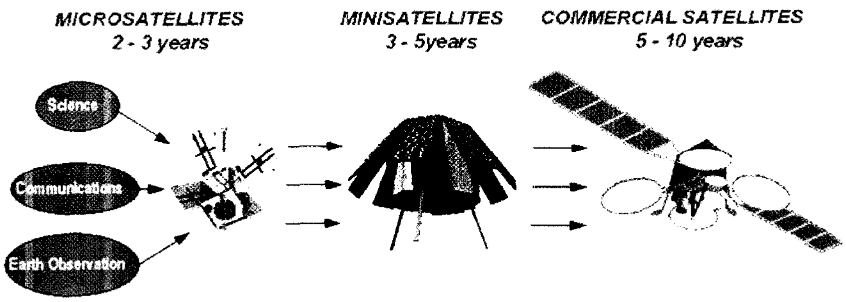


Figure 17. *From microsatellites to commercial satellites via minisatellites.*

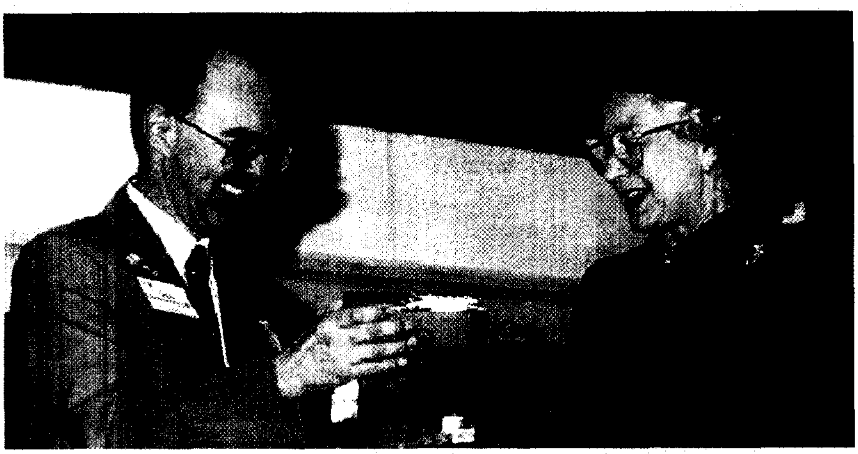


Figure 18. *Queen Elizabeth presents award for Technological Achievement*

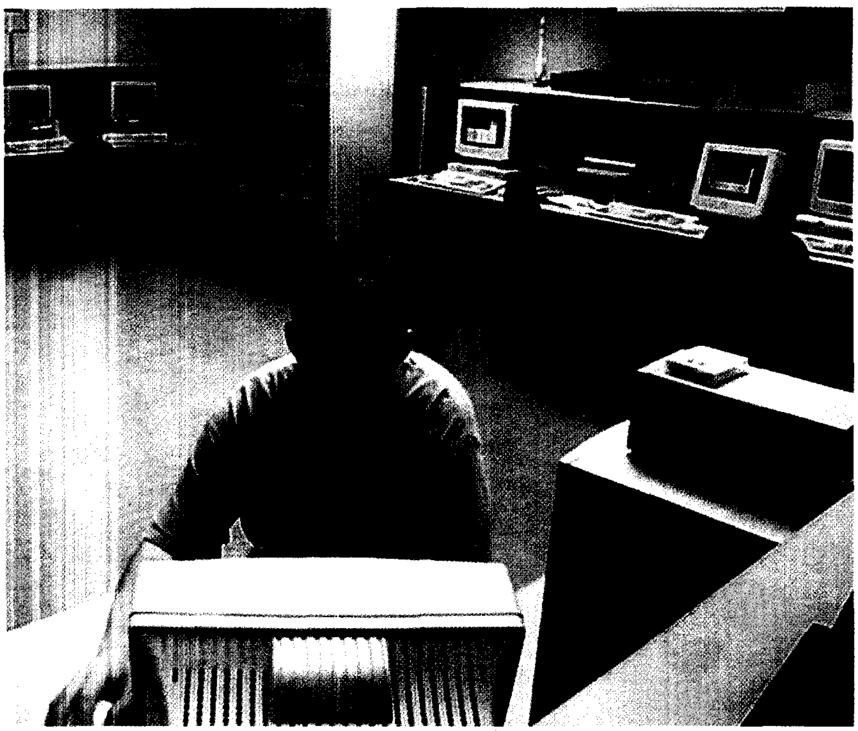


Figure 19. *New SSTL Mission Control Centre at Surrey.*

Microsatellite groundstations

Compact and low-cost mission control groundstations have been developed by SSTL to operate the microsatellites once in orbit. These groundstations are based on PCs and are highly automated - interacting autonomously with the microsatellite in orbit -to reduce manpower requirements and to increase reliability.

The SSTL Mission Control Centre at Surrey (*figure 19*) operates eleven microsatellites in LEO with just a single operator.

SSTL has installed nine such groundstations for KHTT partners and other customers worldwide (*figure 20*).

SSTL minisatellites

In response to growing payload demands for power, volume and mass - but still within a small-scale financial budget - UoSAT and SSTL are developing an enhanced, modular, multi-mission minisatellite platform capable of supporting missions up to 400 kg.

The SSTL minisatellite platform has been designed according to similar cost-effective principles that have proved so successful on the UoSAT/SSTL microsatellites - resulting in a basic platform cost of £4-5M and compatible with a range of affordable launch options - on Ariane, CIS, Chinese and US (Pegasus) launchers to meet a variety of mission objectives and capable of operating in different orbits. Its primary features are:

- 400 kg total mass;
- 150 kg payload capacity;
- 1.2m diameter, 1m height;
- 3-axis, 0.1 degree, attitude control;
- GPS autonomous orbit and attitude determination;
- 1 Mbps L/S-band communications links;
- On-board propulsion for orbit manœuvres;
- cold gas thrusters for attitude control;
- 300 watts orbit average power, 1 kW peak power.

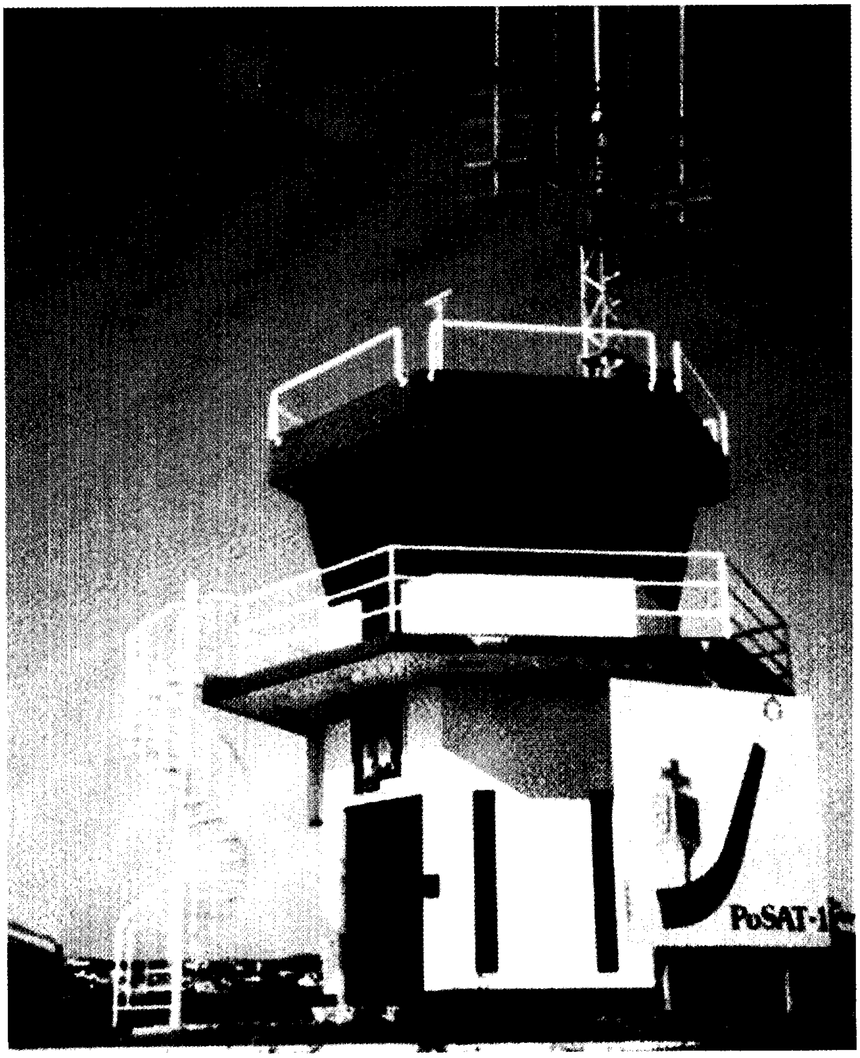


Figure 20. *SSTL groundstation in Portugal for PoSAT-1.*

UoSAT-12 minisatellite

UoSAT-12 demonstrates the capability of this minisatellite platform (*figure 21*). Three-axis control is provided by a combination of magnetorquers, momentum wheels and cold gas N_2) thrusters - whilst an experimental electric N_2O 'resisto-jet' thruster will provide orbit trimming and maintenance demonstrations for future network constellations. UoSAT-12 was launched successfully by a converted SS18 ICBM (Dnepr) launcher into LEO in April 1999.

The UoSAT-12 minisatellite carries 35-metre resolution multispectral and 8-m panchromatic CCD Earth came-

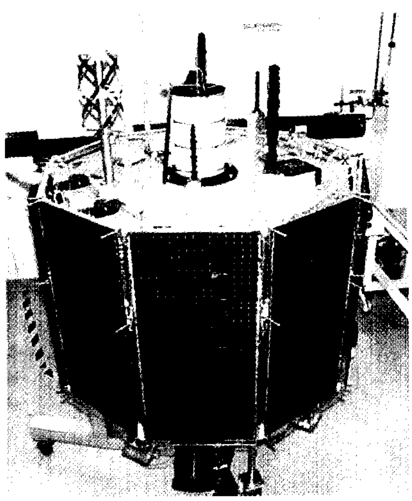
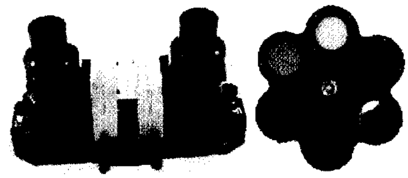


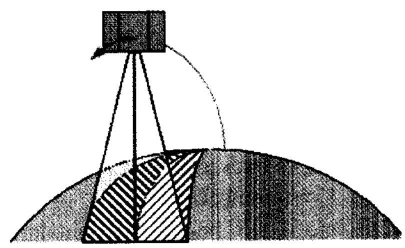
Figure 21. *UoSAT-12 minisatellite at SSTL prior to launch.*

8-m panchromatic CCD Earth came-ras (*figures 22* and *23*).

Sophisticated frequency-agile VHF/UHF and L/S-band DSP regenerative transponders will provide both real-time and store-and-forward communications to small terminals.

The SSTL minisatellite platform can be used to support a range of other missions, such as a light-weight SAR (*figure 24*).





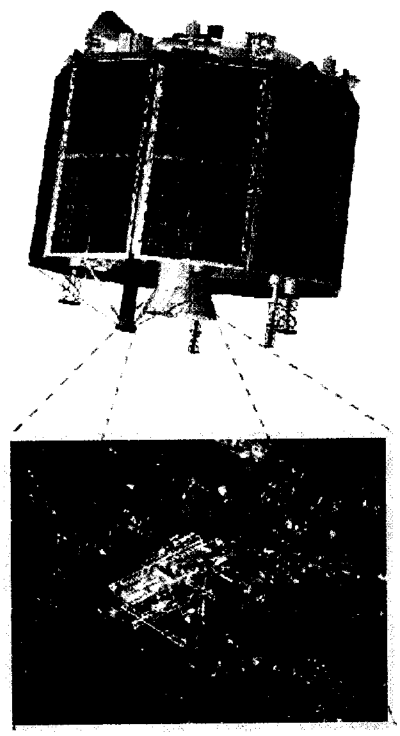


Figure 22. *UoSAT-12 multispectral image (32m) of Detroit.*

New SSTL 'enhanced microsatellite'

A new SSTL 100 kg 'enhanced microsatellite' (*figure 25*), based on the proven flight heritage of the 50 kg microsatellites, supports missions requiring larger payloads at low cost. The 600 × 600 × 500 mm bus structure accommodates larger solar panels, and provides flexible internal and external payload accommodation. Nevertheless, this bus fits comfortably on low-cost secondary payload carriers such as the new Ariane-V ASAP.

Four body-mounted GaAs solar panels provide 38 W average power. A full 3-axis attitude control system allows payloads to be pointed at any terrestrial or celestial target with an accuracy better than 0.2°. A network of onboard computers and embedded controllers automates all telemetry and telecommand, communications, payload control and data management functions. Communications links in the VHF and UHF bands use standard packet protocols to provide connection to the mission control centre and to any remote communications or data-collection terminals. A 1 Mbit/s S-band downlink provides high-speed communications for the remote sensing payload, using international standard CCSDS ground/space link techniques.

The SSTL enhanced-microsatellite can carry 5 CCD remote sensing cameras providing 3-band multispectral imaging with 50 metres ground resolution and panchromatic imaging with 20 metres ground resolution; and a panchromatic or colour-mosaic wide area meteorological imager with 1 km ground resolution.

A clear payload volume measuring approximately 300 x 300 x 200 mm is available on the Earth-pointing facet of the satellite, and additional volume is available within the space frame. Payloads up to 30 kg mass can be accommodated in the Enhanced Small Satellite.

Figure 23. *UoSAT-12 Panchromatic (10m) image of Los Angeles.*

Nanosatellites!

A tiny, highly integrated, 2 kg 'nanosatellite' SNAP-1 is being built as a research project at Surrey for launch in 1999 and intended as an 'inspector' satellite to image the 'mother' minisatellite and launch vehicle (*figure 26*). Future applications for the nanosatellite are for remote inspection of satellites, the international space station and monitoring of deployments systems in orbit, and carrying small space science

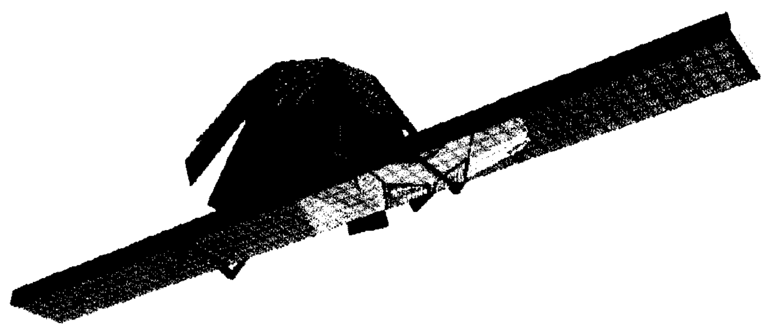


Figure 24. *SSTL minisatellite SAR configuration.*

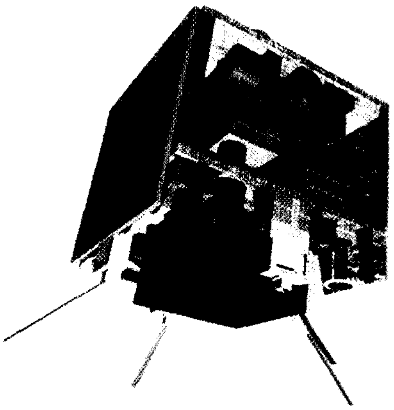


Figure 25. SSTL 100kg enhanced microsatellite configuration.

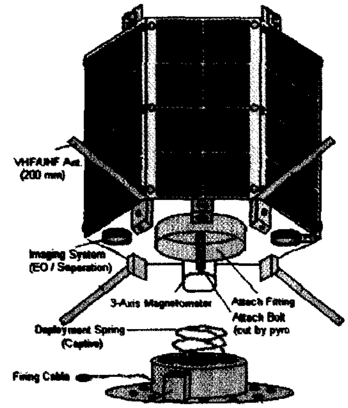


Figure 26. Surrey SNAP-1 nanosatellite.

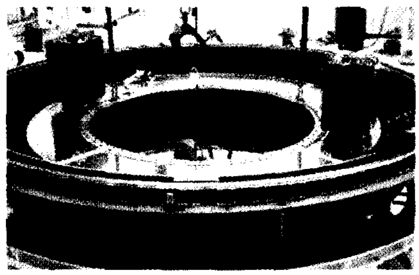


Figure 27. ASAP with SSTL microsatellites (KitSat-1 and S80/T).

instruments requiring measurements with spatial diversity.

Low cost launches

However, a sustained, commercial, low-cost small satellite programme must also be matched by correspondingly inexpensive and regular access to orbit through formal launch service contracts - as it makes little sense to construct sophisticated yet inexpensive microsatellites if the launch costs remain prohibitively high. Early microsatellites were launched virtually for free on a 'favour' basis by the US and USSR, but these launch opportunities were infrequent and unpredictable. The breakthrough came in 1988 when Arianespace developed the Ariane Structure for Auxiliary Payloads (ASAP) specifically to provide, for the first time, regular and affordable launch opportunities for 50 kg microsatellites into both LEO and GTO on a commercial basis *(figure 27)*.

To date, some 18 microsatellites have been launched via the ASAP but, whilst it has been key to catalysing microsatellites world-wide, Ariane alone cannot now provide the number of launch opportunities into LEO needed to meet the burgeoning growth of small satellites. and so alternative, inexpensive launch options from the CIS (on Tsyklon, Zenit, and Cosmos) are now increasingly being used for micro/minisatellites.

Within the last few years, the large stockpiles of ICBMs in the CIS have become available for use as small launchers through the demilitarilisation programme (e.g. SS-18/Dnepr; SS-19/Rockot; SS-25/START). SSTL co-operated with ISC Kosmotras (Moscow) to convert the SS18 ICBM into the first Dnepr small satellite launcher for the successful launch of the UoSAT-12 minisatellite from a silo at Baikonur in April 1999 (*figure 28*).

Project management

Solving the technical challenges associated with the design, construction, test and operation of a microsatellite is less than half of the story - in parallel with the technical considerations of the mission, effective project management is crucial to the realisation of a successful low-cost, sophisticated small satellite project.

Affordable small satellites require a very different approach to management as well as technology if cost, performance and delivery targets are to be met. Several attempts at taking a traditional aerospace organisation to produce such satellites have failed because of the rigidity of management structure and 'mind-set'. Small teams (25 persons), working in close proximity with good communications, with well-informed and responsive management, are essential.

These characteristics are best found in small companies or research teams rather than large aerospace organisations, who may find it difficult to adopt or modify procedures necessary to produce affordable small satellites using staff and structures that are designed for conventional aerospace projects. The main ingredients for a successful small satellite project can be summarised as:

- highly innovative technical staff;
- small, motivated teams;
- personal responsibility for work rigour and quality;
- good team communications, close physical proximity;
- well-defined mission objectives and constraints;
- knowledgeable use of volume, modern components;
- layered, failure-resilient system architecture;
- thorough burn-in;
- technically-competent project management;
- short timescale (prevents escalation of objectives!).

Summary and conclusions

The University of Surrey embarked upon the design of its first experimental microsatellite in 1978 and UoSAT-1 was launched by NASA in 1981 - since then a further eleven low cost yet highly sophisticated microsatellites have been built and launched into low Earth orbit. The UoSAT/SSTL missions have demonstrated that microsatellites can play a useful role in supporting specialised communications, Earth observation, small-scale space science, and in-orbit technology verification missions.

Whilst obviously limited in payload mass, volume and power, but with very real and attractive advantages in terms of cost and response time, microsatellites offer a complementary role to traditional 'large' satellites by providing an alternative 'gap-filler' for affordable quick-response or exploratory missions for both civil and military objectives. Developing space nations have used rapid and inexpensive microsatellite projects to act as the focus for effective technology transfer and an affordable first step into orbit. A further 2 microsatellite missions were launched by SSTL in 1998 and a new minisatellite are scheduled in 1999. Four more microsatellites and a nanosatellite will be launched in 1999-2000.

Building upon its success with microsatellites, Surrey is now building an affordable, modular (400 kg) minisatellite capable supporting more demanding payloads - but still within a cost of ~£5M (€ 8 M)- in order to stimulate further use of small satellites to complement large space programmes. Surrey has established itself firmly as the international centre of excellence in academic research, teaching and commercial applications of small satellites.

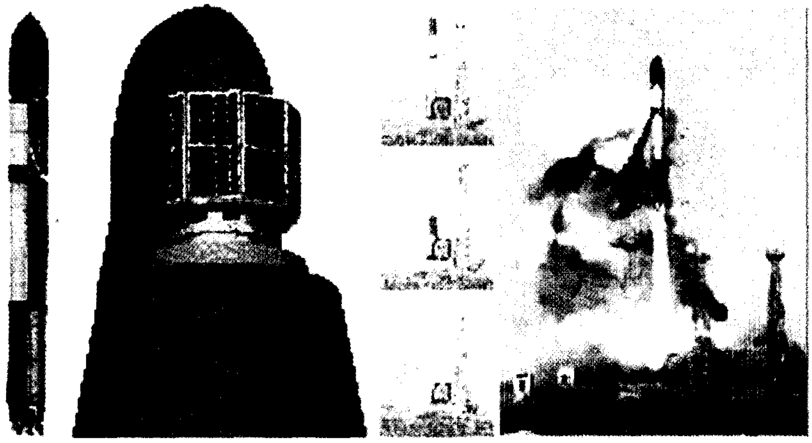


Figure 28. *UoSAT-12 minisatellite on SS18/Dnepr launcher April 1999.*

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