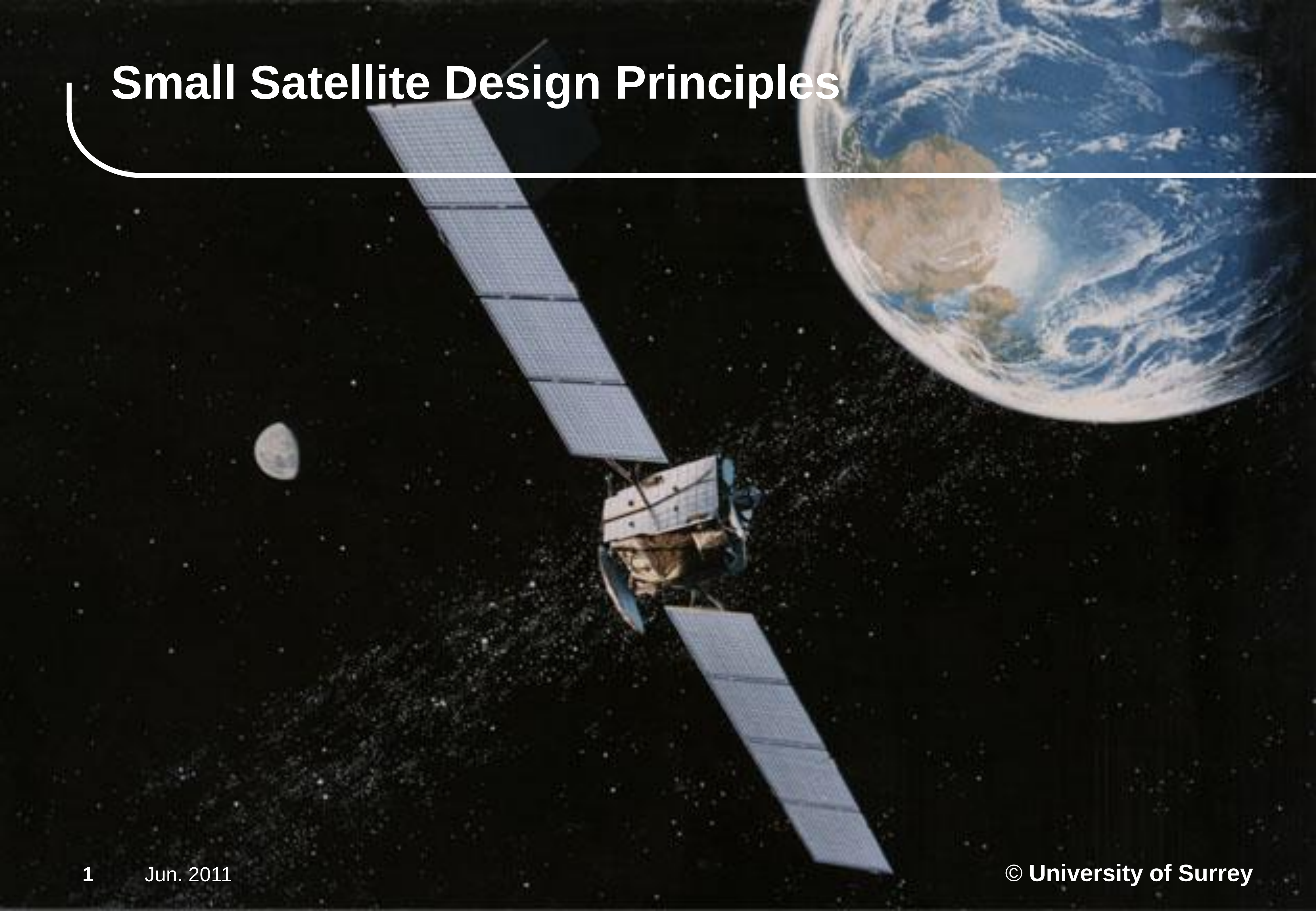
# Small Satellite Design Principles



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# Introduction

## Background

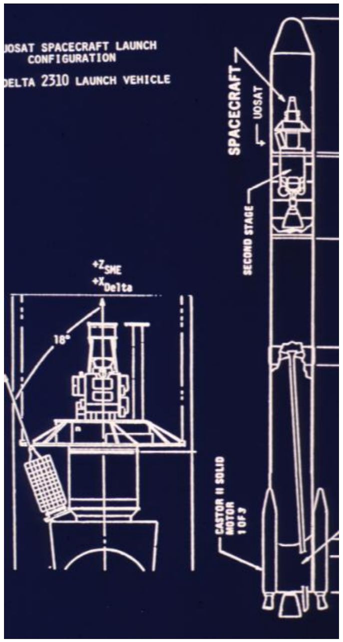
Early satellites were necessarily small, however, the need for ever-larger, more capable and more complex satellites lead to a natural growth in satellite mass.

This trend was first limited by launcher capability, but then by finance and technological infrastructure.

Space nations required a highly developed technological base with huge investment.

This lead to closed markets in space, limited to a few nations - an exclusive club of space 'haves' with enormous military and economic advantages over the space 'have-nots'.

# Introduction



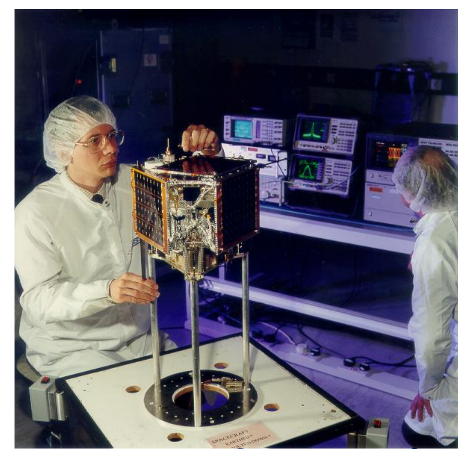

In the 1970's, advances in VLSI lead to the possibility of sophisticated functions being built into highly mass, volume and power constrained satellites.

This in turn lead to dramatic cost-reductions in satellite programmes -as demonstrated by the pioneering OSCAR satellites of the amateur radio community.

The new era in small, sophisticated satellites was ushered in with the launch of UoSAT-OSCAR-9 (1981).

The 1990's have seen a resurgence in interest in small satellites - both by emerging and existing space nations :-

*"Smaller, Faster, Cheaper"!*

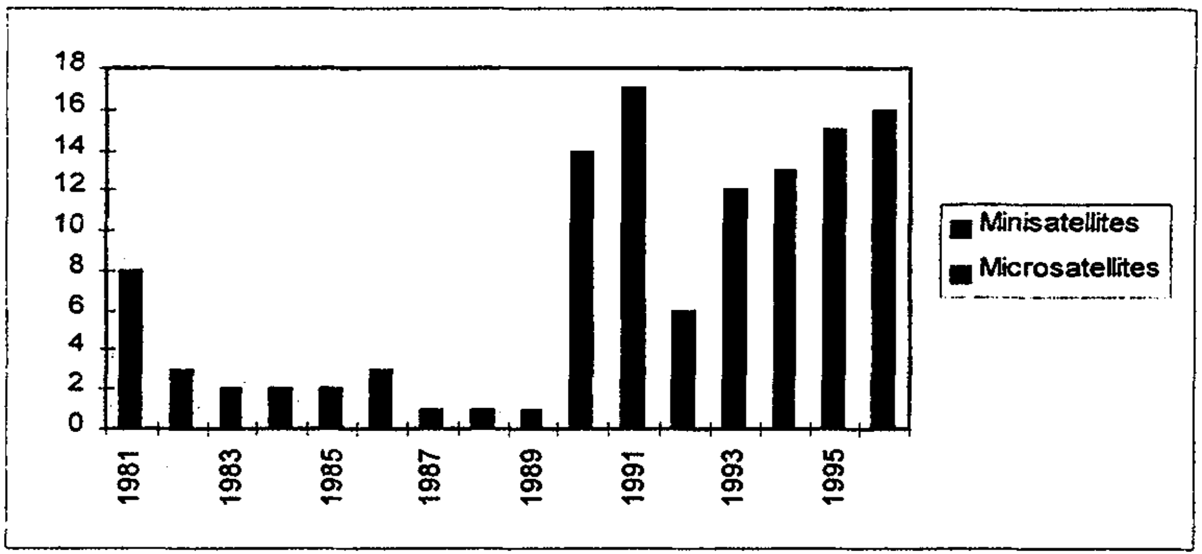


# Introduction

## Satellite Classification [SWEE92]

| | | |
|---|---|---|
| • Large | > 1000 kg | |
| • Small | 500 -1000 kg | |
| • Minisatellite | 100 -500 kg | } |
| • Microsatellite | 10 -100 kg | } - *LightSats = 'small' in this context* |
| • Nanosatellite | 1 -10 kg | } |

## Growth of Small Satellite Missions [SSHP97]



# Small Satellites

**"Cost Effective" versus "Low Cost"**

The terms "cost effective" and "low cost" are not synonymous. Many traditional space missions may be very cost effective and yet still too expensive for nations to afford.

Small satellites can reduce this cost barrier -e.g. it is not unreasonable to plan a microsatellite mission (ground-segment included) within a budget of $3-4M.

But <u>beware</u> - not all small satellite missions are inexpensive - the costs depend crucially on the engineering and management philosophies which are applied.

*"Affordable Access to Space"!*

# Small Satellites

## Microsatellite Costs

| Non-Amateur Microsatellite Costs | | | |
|---|---|---|---|
| ***Satellite*** | ***Mass*** | ***Cost*** *(Small Satellite Cost Model)* | ***Actual Cost*** *(FY95)* |
| **Øersted** | **60 kg** | **$3.8M** | **$18.4M** |
| **RADCAL** | **92 kg** | **$7.8M** | **$16.6M** |
| **ORBCOMM** | **33 kg** | **$2.7M** | **$15.1M** |
| **PoSAT -1** | **49 kg** | **$3.2M** | **$2.1M** |
| *Source: Wertz & Larson, Reducing Space Mission Cost, Microcosm, 1996* | | | |

# Small Satellites

## Breakdown of Satellite Platform Costs

**(Based upon UoSAT -3 & -4 June 1988- January 1990)**

| UoSAT -3 & -4 Pre-launch Budget | | |
|---|---|---|
| | *Direct Costs** | *% of Budget* |
| Salaries | £ 175,000 | 39.1 % |
| Components | £ 190,000 | 42.5 % |
| Test Facilities | £ 32,000 | 7.2 % |
| Travel, Shipping | £ 25,000 | 5.6 % |
| Additional Items | £ 25,000 | 5.6 % |
| Total | £ 447,000 | |
| ** Does not include payload costs, costs of buildings and services, or University overheads (40%)* | | |
| *Source: Evans (Ed.), Satellite Communication Systems 2nd Ed., IEE. 1991* | | |

Launch cost £50,000, Insurance £75,000,
Total Cost: £ 572,000 FY89

# Small Satellites

## Typical (Low-Cost) Microsatellite Budget

| Microsatellite Programme Budget | | |
|---|---|---|
| | *US $ (FY95)* | *% of Budget* |
| Satellite | $ 2,250,000 | 62.5 % |
| Launch | $ 750,000 | 20.8 % |
| Insurance | $ 450,000 | 12.5 % |
| Control Station | $ 75,000 | 2.1 % |
| Operations (1 year) | $ 75,000 | 2.1 % |
| Total | $ 3,600,000 | |
| *Source: Boden & Larson, Cost-Effective Space Mission Operations, McGraw-Hill,1996* | | |

# Small Satellites

## Schedules

Low cost small spacecraft programmes have tight schedules – a typical design-to-orbit period being 12-18 months.
(UoSAT -2 was 6 months!)

Work back from launch:

- launch campaign (1 month)
- integration and environmental testing (2 months)
- flight model assembly / testing (3 months)
- breadboard / engineering model (4 months)
- mission planning / design (2 months)

There is little room for contingency, yet critical milestones must be met:

- procure long lead items at an early stage!
- staff must be well motivated to put in the hours needed.

# Small Satellites

## Resources

Even a small satellite programme needs substantial resources:

- staff (typically ~30-40)
- flight assembly clean room (at least ~36 $m^2$)
- spacecraft integration clean room (optional)
- optics assembly clean room (optional)
- thermal cycling chamber (testing at least at module level)
- software lab / CAD office (ECAD / MCAD / flight software)
- hardware development labs (RF, power, OBDH, sensors)
- mechanical workshop
- flight component store (environment controlled)
- meeting / presentation room
- offices / administration
- access to thermal vacuum/ vibration/ EMC testing facilities

# Small Satellites

## Microsatellite Teams

Working on short timescales and within tight budgets requires teamwork.

Correctly forming, training and organising this team is the key to a successful low-cost small satellite mission.

Contrary to popular belief, using low paid 'student' labour is <u>not</u> cost-effective -using a few highly skilled, highly motivated and conscientious engineers is the best way to achieve low-cost.

*Its the people who are the key 'technology' for low cost small satellite missions!*

# Small Satellites

## Training

To build a practical and useful spacecraft, mission operators and end users must be part of the team.

Team members (even those experienced in the traditional space industry) must be trained specifically for small satellite missions.

Although specialists must be on the team, all team members must receive general training in order that mission operators, bus and payload engineers, and end-users can trade ideas to achieve low cost.

Cross-discipline training is essential, and is practical given the small team size. Swapping roles between missions allows experience to be built up quickly.

# Small Satellites

## Organisation & Management

Simply assembling an experienced team is not sufficient to ensure success.

Mission managers must organise the team effectively and manage it correctly.

The key principles are:

- the free flow of information amongst team members
- flexibility at all stages of the mission
- minimisation of bureaucracy
- be objective driven -not procedure driven

*The manager is part of the team and the team shares the same goal - a successful mission!*

# Small Satellites

## Communication

To capitalise of the training and insight of each engineer, all team members need to be accessible

Regular project meetings and modern computer aids
(e-mail, work groups, LANs) provide the formal communication mechanisms - however this is a small part of the information flow.

A successful team will achieve the best costs, time-scales and mission returns through informal daily discussions.

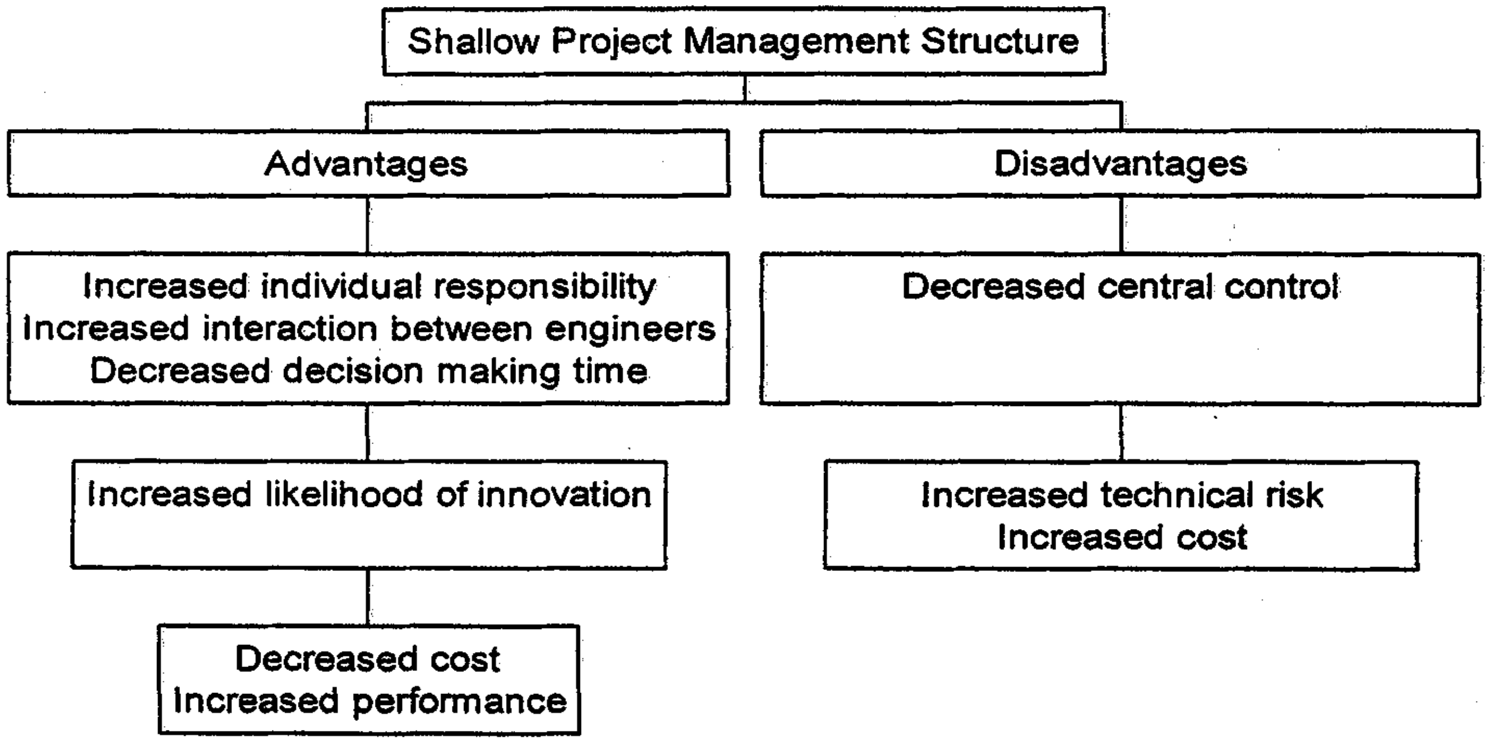
The mission manager must facilitate such informal links through a shallow management structure.

Co-location of the team is a particular benefit.

# Small Satellites

## Communication

### Consequences of Shallow Management Structure



# Small Satellites

## Flexibility

Defining and developing a mission in as little as 12 months does not allow for the certainties associated with the thorough analysis and design possible for longer missions.

The team must retain flexibility throughout the mission in order to cope with late-breaking difficulties, and to exploit opportunities that arise.

Each mission component will have its own requirements for design and interface freezes.

In general these should be left as late as possible, particularly with regard to software and the operations plan.

# Small Satellites

## Standards, PA/QA

Low cost space missions must substitute the initiative and skills of a well-trained team for rigid and comprehensive standards.

We can't reject standards arbitrarily, but should trade off the costs and benefits in each area:

- communications (ESA/NASA TT&C, AX.25?)
- parts procurement (Class-S, MIL-STD, COTS?)
- level of testing, documentation, PA/QA

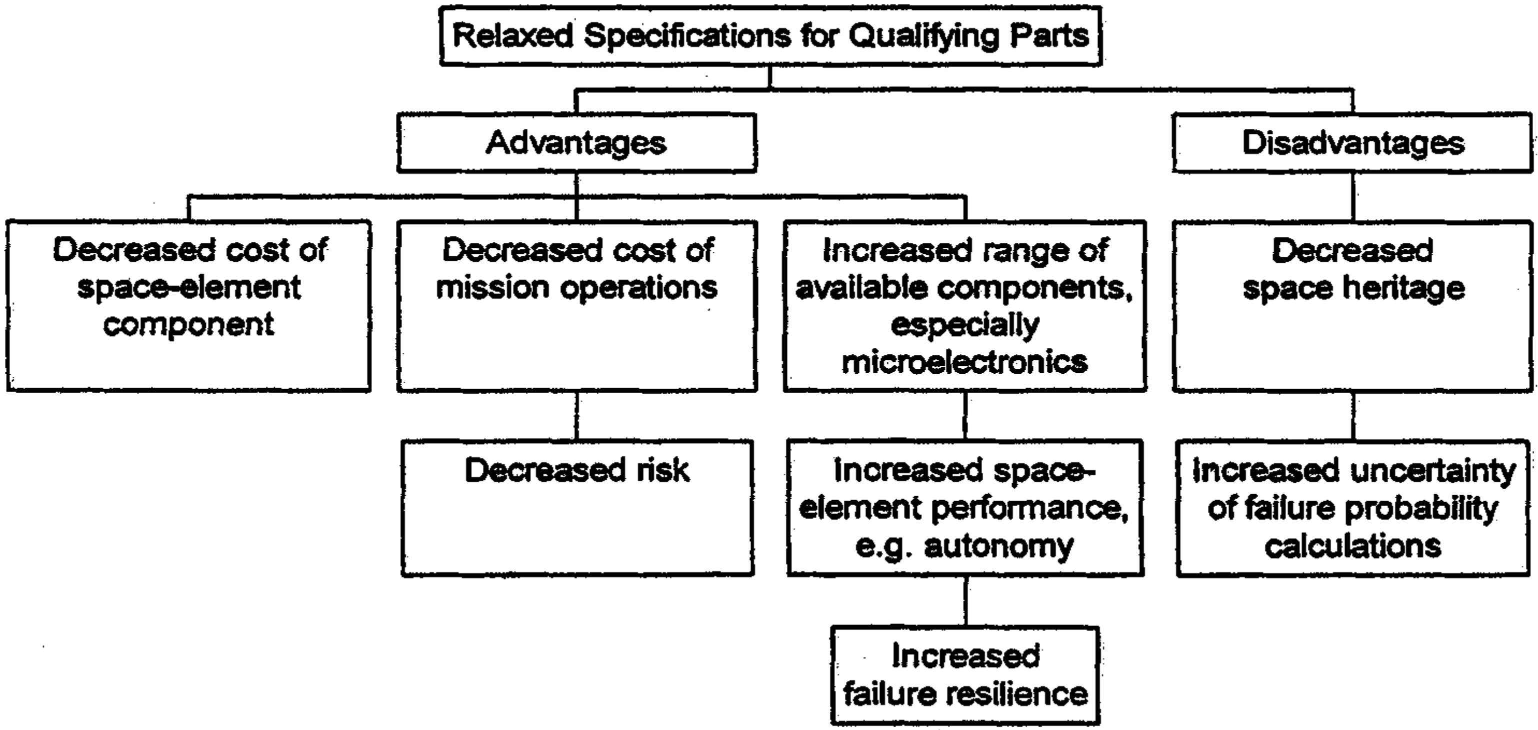
The end user must accept this process, which, includes risks as well as benefits.

*Low cost & fast turn-around for repeat missions gives a higher level of acceptable risk*

# Small Satellites

## Standards, PA/QA

### Consequences of Relaxed Component Qualification Requirements



# Small Satellites

The University of Surrey began its UoSAT programme with the launch of the 50 kg UoSAT-1 in 1981, followed by UoSAT-2 in 1984.

SSTL (Surrey Satellite Technology Ltd) was formed in 1985 to commercialise this technology to the marketplace.

The Surrey approach to spacecraft design is focussed on reducing costs of space missions through "batch" production of small, highly modular spacecraft.

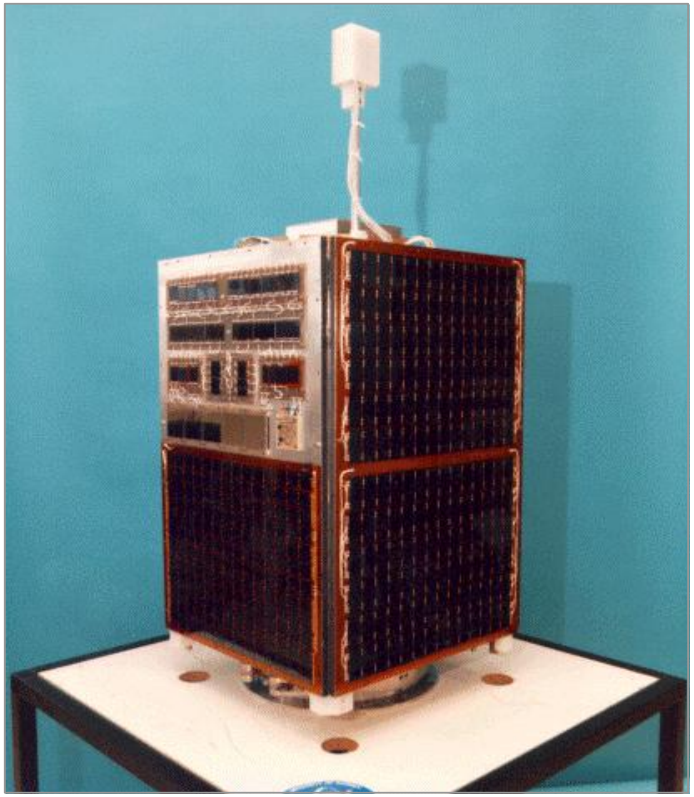
SSTL relied on export markets in developing countries to whom affordability was essential.

# Small Satellites

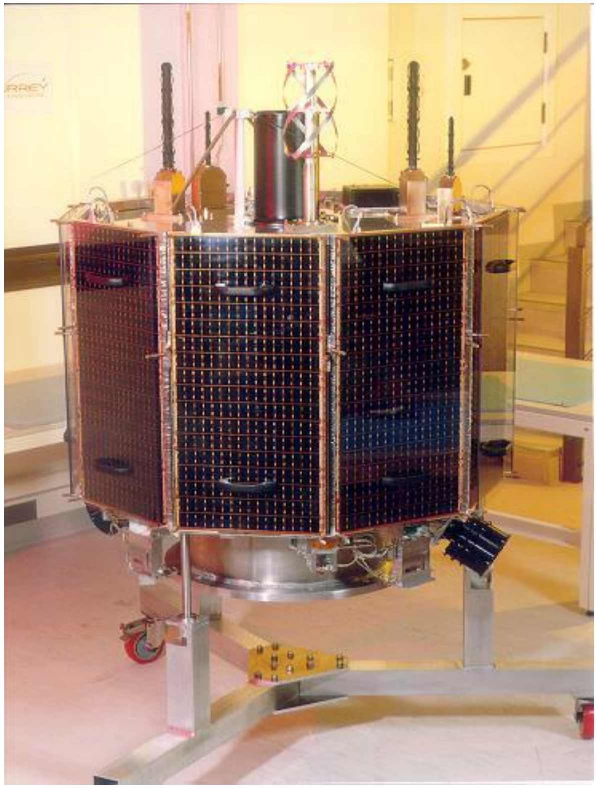
The market drivers of low cost, rapid response and minimisation of risk led to a number of fundamental “unique” approaches:

- Design with proven appropriate technologies
- Design to cost and minimise risk by focussing on core requirements (challenge unnecessary requirements with customer)
- Design for low cost launchers, eg. piggyback on Russian ICBMs
- Low-cost ground station operations, i.e. Autonomous Operations
- Incremental technology development
- Integrated design and manufacture
- Offer appropriate flight-proven technologies
- Manufacture appropriately and rapidly
- Leverage off terrestrial hardware/software technology (customised COTS)

# Small Satellites



*UoSAT-5 50kg*



*UoSAT-12 325kg*

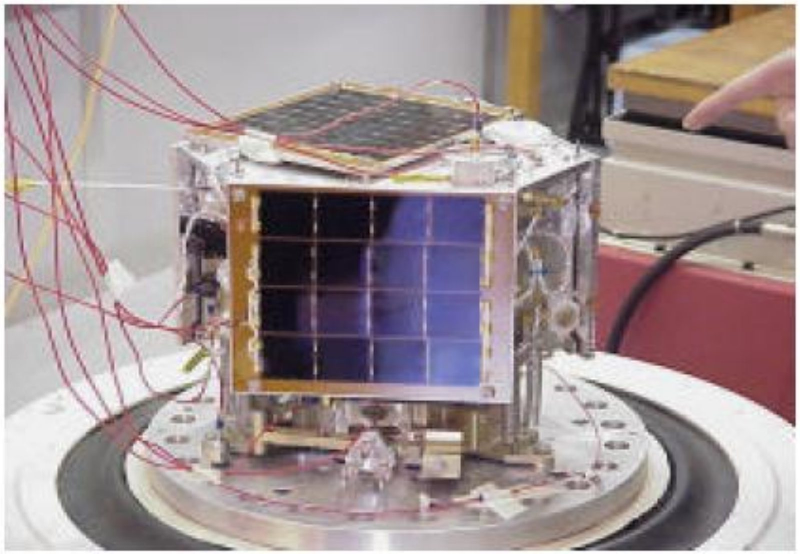
UoSAT platforms are modular and are undergoing increasing miniaturisation.

# Small Satellites

SNAP (Surrey Nano-satellite Applications Programme)-1 was based on Eurocard-sized (165 mm x 120 mm x 20 mm) Al alloy bus and payload modules.

The objective of SNAP was to develop and flight-prove modular COTS (commercial off-the-shelf) technology for the nano-satellite application <10 kg.

SNAP was conceived, designed, built and launched in 9 months – mass 6.5 kg.



*SNAP-1 6.5kg*

*SNAP's Butane Propellant Orbit Control System Thruster*

# Small Satellites

## Design Principles (The UoSAT Engineering Philosophy)

- **Keep it simple** and examine thoroughly the task and the environment of each sub-system and specify components/ techniques that will accomplish the task with a realistic safety margin. Do not simply go for the highest rated/ quality approach as this will generally increase costs dramatically.

- Essential housekeeping systems should use standard, proven designs and hardware wherever possible -***'evolutionary design approach'***.

- In view of the short timescales involved, keep indeterminate software development out of critical paths - even if this involves more hardware.

# Small Satellites

## Design Principles

- Redundant paths and experimental sub-systems, may use less proven designs or technologies providing that this does not result in potential single point failures for the spacecraft as a whole.
- Use flexible design to provide redundancy via alternative technologies rather than by duplication (where appropriate).
- Use easily defined, simple interfaces between sub-systems wherever possible (including the bus-to-payload interfaces). Sub-systems should be capable of independent operation unless this is not possible.

# Small Satellites

## Design Principles

- Design essential systems around established, industrial high-grade volume production components and attempt to procure 'Mil-SPEC' versions. 'COTS' devices with flight heritage may also be used. None essential systems may use relaxed specifications.
- Ensure that all components can be procured within the development timescale. Identify and order long-lead items early on in the mission.
- Use a restricted range of materials which are acceptable for use in space. Avoid toxic or otherwise hazardous materials wherever possible.

# Small Satellites

## Design Principles

- Make maximum use of CAD/CAM techniques to speed up the design process for both electrical and mechanical systems.

- Relationship is established with manufacturers to ensure that quality/delivery requirements are met.

- Use software FE models to analyse and optimise the structure and thermal design of the spacecraft prior to real testing. Keep the number of physical test models (OM/EM) as small as possible.

- CDR is held to give customer confidence, and to review specifications, manufacturing procedures -EM/OM test results and reliability assessments.

# Small Satellites

## AIT Phase

- Assemble the kit-of-parts under controlled conditions and deliver to clean-room with a data- pack containing schematics, parts lists and assembly instructions and procedures.
- Design engineers check the kit and sign-off.
- The flight model is assembled under proper clean-room conditions, observing full anti-static precautions, using ESA-qualified staff to hand- solder the components.
- Job cards are completed and appended to the data pack, and all operations are signed and inspected.

# Small Satellites

## AIT Phase

- Periodic PA reviews are carried out - key inspection points (internal) and mandatory inspection points (customer). These reviews are always carried out before irreversible operations.

- Sub-systems are tested at module level, and when integrated into the spacecraft. All tests and results are logged. Non-conformances are documented, reviewed and action is taken.

- Burn-in and thermal cycling tests
(under dry N2 atmosphere) are carried out in clean-room.

- TRR held prior to environmental testing, and test procedures are reviewed.

# Small Satellites

## Environmental Testing

- With low cost small satellites, environmental testing is usually reserved for the FM only, and is the first chance to practice realistic operations scenarios. The main tests carried out are:

  - EMC/ RF/antenna pattern test
  - vibration (mandatory: sine/random/acoustic - all 3 axes)
  - spin balance (optional)
  - thermal vacuum (mandatory)

- The spacecraft is tested to flight **acceptance** standards (having previously tested a QM. To qualification standards).

- TDR is held to evaluate test results and compliance matrix

# Small Satellites

## Launch Campaign

- Any problems which occurred during environmental testing are followed up and actions are taken which are finally reviewed at the LRR.
- The satellite is then delivered to the launch site.
- Further functional testing and burning-in is carried out until the launch vehicle is ready for the satellite to be mated. The satellite is now inert - except for trickle-charging of the batteries.
- Immediately following launch, the satellite is stabilised, and over the next few weeks all its systems are evaluated in orbit (in case of insurance claims), prior to formal delivery.

# Small Satellites

## Exploring the Mission Concept

- Small satellites are not suitable for all missions. They are highly constrained by volume, mass, and mechanical complexity.
- Reliable complex mechanical sub-systems are usually too expensive for a low-cost small satellite budget and so (in general) deployable solar panels and complex stabilisation systems are avoided, limiting the power and attitude stability of the spacecraft.
- However, if a preliminary analysis shows the bus *could* support the mission, we must further analyse the critical architectural items: **Orbit, Communications, Architecture, Attitude Control and Operations**.

# Small Satellites

## Exploring the Mission Concept

- What is the impact of choice of **orbit** on a small satellite?
  - LEO, GTO, GEO, interplanetary?
  - ionising radiation
  - thermal impact
  - profile of visibility
  - communications link budget
- What is the effect of **communications architecture** on a small satellite mission?
  - dedicated ground-stations, how-many?
  - data-rates, on-board storage, visibility time

# Small Satellites

## Exploring the Mission Concept

- What is the impact of **attitude determination and control** on the small satellite mission?
  - passive control, active control?
  - gravity gradient, magnetorquers, wheels, thrusters?
  - ground motion, thermal issues, power profile?
  - attitude sensing -sources, accuracy, requirements?

- What **operational scenarios** may occur? LEOP - random attitude, no OBC control?
  - dealing with anomalies - loss of control
  - ground station outages
  - OBC issues -autonomy, adaptability, resilience
  - delivering data products - autonomy, internet?

# Summary

## Small Satellites

- Provide affordable and regular access to space
- Enable research in a realistic space environment
- Demonstrate new technologies, systems and services
- Enable satellite constellations to be constructed cost-effectively
- Allow first-hand training and experience for scientists and engineers
- Involve both technology and management skills
- Generate new opportunities for industry

# Conclusions

## Key Issues for Small Satellite Missions

- Design to Cost
  - design to meet the mission objectives, avoid 'nice-to-have' features.
  - understand the space environment and design to meet it realistically.

- Innovative Engineering
  - failure resilience by use of 'layered' system architecture.
  - employ high-performance components in non-critical areas.

- Reasonable PA/QA
  - avoid Hi-Rel 'over-insurance' - use volume components and burn in (subject to environment).

- Effective Project Management
  - small dedicated teams, short lines of communication.
  - minimum bureaucracy - concise but necessary documentation.

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