International Journal of Remote Sensing ›
Volume 29, 2008 - Issue 15

24,003 Views | 107 CrossRef citations to date | 0 Altmetric

Review Article

An overview of small satellites in remote sensing*

Herbert J. Kramer & Arthur P. Cracknell

Pages 4285-4337 | Received 04 Jan 2008, Accepted 04 Jan 2008, Published online: 17 Jul 2008

Cite this article https://doi.org/10.1080/01431160801914952

Abstra

This arti … opments
since the … g new
opportu

*. Based … rvation
Small S … 0–23
Nove

The earl … ere flown
were de … and more
expensi … e extreme
example … be made
between … le system
meant t

The future is likely to see more small satellites, each of which is dedicated to a particular mission objective and carries a single instrument. Through this approach more and more countries around the world are becoming involved in Earth observation from space, not just in using the data from the major established systems but also in constructing their own systems.

There were some small, low-cost satellites in the early days, but they were overlooked or considered toys by the space community. The first microsatellites were built by enthusiasts of the amateur radio community and launched in the early 1960s. The invention/introduction of the microprocessor in the 1970s represented a quantum jump for the onboard capabilities of a spacecraft. This technology introduction represented a prime catalyst in the development of microsatellites since it enabled small physical structures in support of sophisticated data handling applications. The engineering of microsatellites, which emerged in the early 1980s, took a radical change of approach from the custom design of traditional spacecraft, namely a design-to-capability scheme to achieve cost reductions by focusing on available, and existing technologies using a general purpose bus and 'off-the-shelf' components and instruments.

The new approach of small satellite design was pioneered by Surrey Satellite Technology Ltd (SSTL) of Surrey University, UK. SSTL's lead has now been followed by
various companies and space agencies throughout the world. A key feature of this work
is the de iding
partners ational
organiza not in a
position velopment
of their

In additi satellite
classi ent in the
rest satellites,
and sma ogramme.

Today, s aft embrace
cutting e l and less-
expensiv e are
various t AR) and

1. Introduction

The fact that we have just been celebrating the 50th anniversary of the beginnings of space flight in October 2007 means that it is a fitting occasion to give an overview of small satellite developments in Earth observation/remote sensing and other fields of space flight. In particular, this involves the history of small satellites with reliance on remote sensing.

At the start of the space age, all satellites were small – not by choice, but by necessity. The world's first artificial satellite, Sputnik-1 (which was launched on 4 October 1957), was a 58.0 cm diameter aluminium sphere with a mass of 83 kg and it carried four whip-like antennas that were 2.4–2.9 m long. The first successful US satellite, Vanguard-1 (which was launched on 17 March 1958), was a sphere with a diameter of 16 cm and a mass of 1.6 kg (Meurer 2006).

Practically all the satellites of the first two decades of the space age featured custom designs (in shape, size, stabilization methods, power provision, instrument mounting techniques, onboard data handling, data communications, mass, etc.) to suit the
requirem … spacecraft
builders … g with very
specific … for a
particula … he 1970s.

These cu … nents and
definitio … ndustry was
to desig … the
requ … wer,
propu … tions,
comman … and
iterative … er unique
missions … ellite to
another … eloped by
the US N … 1980s used

accomplishing its mission. On the negative side, such spacecraft are extremely expensive to develop due to the large amounts of manpower needed to design each subsystem separately, often leading to considerable cost overruns (Jilla and Miller 1997).

After a number of early spacecraft or subsystem failures were experienced, the reliability issue became a big hurdle for spacecraft designers due to the requirement of space-qualified components. Electronic devices had to be radiation-hardened to sustain the hostile environment of space. This was another cost driver as well as a performance killer, since the so-called Commercial Off-The-Shelf (COTS) products of newer designs provided much better processing power than the much older space-qualified products. In addition, the critical subsystems of a spacecraft had to be designed in a redundant or dual-redundant configuration (alternate path selection capability) to guarantee operational service in case of a single-point failure.

The MagSat mission (which was launched in October 1979), a dual-spin stabilized satellite, demonstrated for the first time to NASA in particular the usefulness of a general-purpose bus for science applications. The bus could support a variety of bolt-on experiments. The concept has been used extensively ever since. Integration of flight hardware and subsystems has become an important aspect of modular design. The modular design methodology means that the satellite subsystems were developed in
the sam ite design
were ba ed range of
missions need to be
designe

Spacecr ed
interesti ns of launch
capab ellites (100–
1000 with regard
to mass) bilities of
launch v the space
infrastru e complex.
In parall ms could be
combine with its
demand ng

Article contents
Related research

bureaucracy and large organizations. As a consequence, overall creativity suffered considerably while costs increased rapidly.

At the end of the Cold War (in the early 1990s), there was a reduction in launches with longer in-between periods. Large and complex projects of NASA and ESA encountered planning and re-planning phases alone that came close to a decade or longer. Some examples are:

The planning for the Hubble Space Telescope (HST) started in the early 1970s (and it was launched in 1990). After launch, the spacecraft required a repair mission to start operations (the primary mirror suffered from spherical aberration). This was followed by several servicing missions requiring Space Shuttle flights.

The International Space Station (ISS) programme was started in 1984. The ISS station build-up began in 1998 until 2010; this is to be followed by regular operations.

The Earth Observing System (EOS) programme planning of NASA started in the early 1980s, and was rescoped in 1992. Eventually the spacecraft in this system were finally launched – Terra in 1999, Aqua in 2002 and Aura in 2004.

The planning for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) programme started in 1993 with the intention of combining the US civil
program OAA)
and the nt of
Defense w
generat
substan
restruct pected
in 201

The as in
2002 (w rth
observa

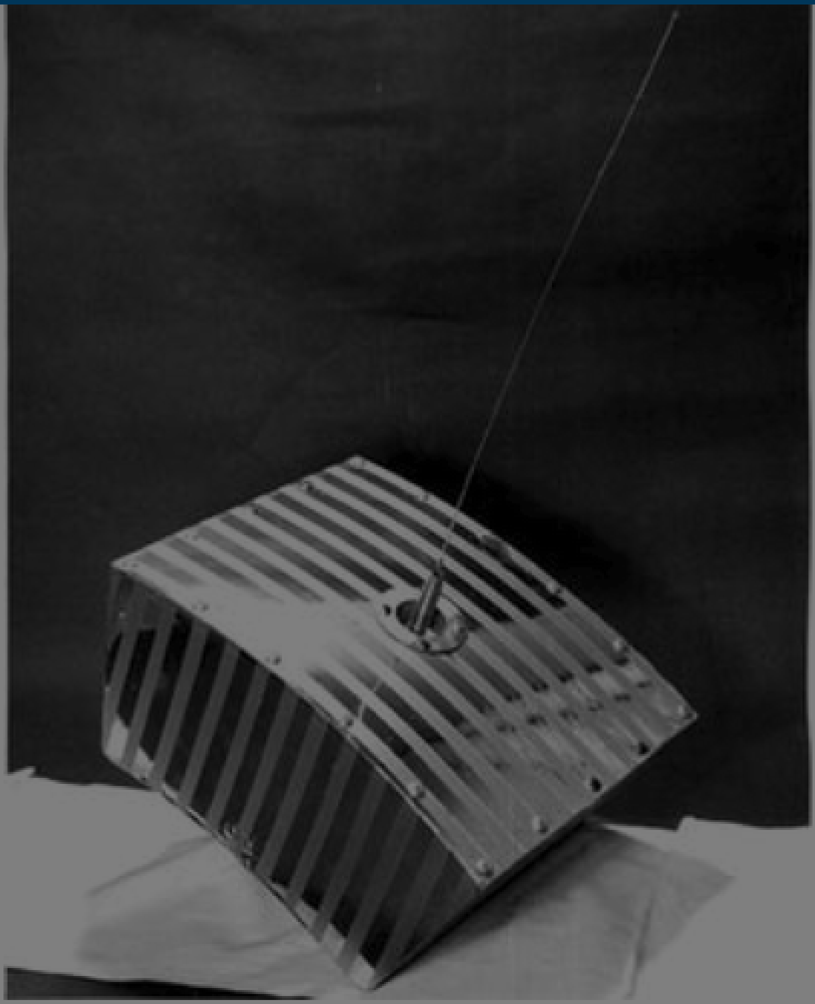
For the e ations as
well as a ideas, new
compon elatively
cheaply d scientists

to gain first-hand experience of space before moving to larger projects' (Sweeting 1991).

Already in the early 1960s, the first spacecraft of a family of tiny communication satellites, referred to as OSCAR (Orbiting Satellite Carrying Amateur Radio), was designed and developed by a California-based group of amateur radio enthusiasts. OSCAR-1 (figure 1), the first battery-powered amateur satellite with a mass of 4.5 kg, was launched on 12 December 1961 (piggyback to the Discover-36 spacecraft of the USAF) from Vandenberg Air Force Base (VAFB), California (orbit of 372 km×211 km, inclination of 81.2°, period of 91.8 min). OSCAR-1 orbited for 22 days, and over 570 amateur radio operators in 28 countries reported receiving its simple 'HI-HI' Morse code signals in VHF (A Brief History of Amateur Satellites, URL: http://www.amsat.org/amsat/sats/n7hpr/history.html).

In 1969 the Radio Amateur Satellite Corporation (AMSAT) was founded in Washington DC as an educational organization to give amateur radio satellites an international base. Some OSCAR family advancements include the launch of the very first satellite voice transponder (on OSCAR-3, which was launched on 9 March 1965), and the development of highly advanced digital S&F (store and forward) (on OSCAR-9, alias UoSat-1, which was launched on 6 October 1981) messaging transponder techniques.

Figure 1



Display full size

Like many new developments, the small satellites of the early space age were simply overlook s by the media. T oviet Union and the the Moon in the 1960

The inte sities must be regar iven by very real cons lve a highly prag as the only practi

2. Sm

The term AT-NA (North A acecraft, all

Article contents Related research

when compared with the established spacecraft missions of the time. Most experts in the field had a smile when asked about the objectives and the future of such toys in space, which became eventually known as ‘microsatellites’. Could these toys do anything worthwhile? There were many prejudices in the space community when the topic of ‘microsatellites’ was mentioned.

Martin Sweeting of SSTL wrote in his paper of 1991: ‘It may come somewhat as a surprise to learn that some 20 microsatellites have been placed into orbit in the amateur satellite service over the last 25 years! Within Europe, the University of Surrey and its technology transfer company Surrey Satellite Technology Ltd leads research into microsatellite engineering techniques through its UoSat microsatellite programme.’(Sweeting 1991)

In the same paper Sweeting proposed also the first known classification of small satellites, as shown in table 1. Views on what constitutes a small satellite depend on the perspective of the beholder. A small satellite to NASA or to Roskosmos may be considered a monster to a university department. Naturally, there are many different ways to classify artificial satellites – by function, type of orbit, cost, size, performance, and so forth. However, a classification by mass turns out to be quite useful because it has a direct bearing on the launch cost of a spacecraft, representing a considerable hurdle for every mission. Since ‘microsatellite’ was the only term in use in the time
frame pr es at the
time, es e
‘microsa Then he
selected r decimal
system t lence, the
diminuti al terms
steps of e various
smal mass
classe

Table

Downl

Subsequ 's original

500 kg to the 100–1000 kg range, to keep to the logic of magnitude orders. The revised version is given in table 2. Within this classification, the term ‘small satellite’ class is used to cover all spacecraft with a launch mass of less than 1000 kg.

Table 2. Satellite classification by mass criterion.

Download CSV Display Table

Various authors/organizations have advocated these changes in the recent past. An upper limit of 1000 kg for ‘minisatellites’ was for instance adopted at UNISPACE III (Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space), Vienna, Austria, 19–30 July 1999. At this conference, the cost for developing and manufacturing a typical minisatellite was indicated to be in the order of US$ 5–20 million, while the price tag for microsatellites was estimated as between US$ 2–5 million and for nanosatellites could be below US$ 1 million (all at 1999 price levels) (Sandau 2006a; Sandau et al. 2006).

In particular, the small satellite mission philosophy at UNISPACE III was described to require a design-to-cost approach, within strict cost and schedule constraints, mostly combined with a single mission objective. This focused approach was noted to be supporte

advance ity;

the rece the use
of modi

the poss ordable
way for bility,
without

ongo d with
manag

The adv

more fre and for
applicat

larger v ntial

Article contents Related research

more rapid expansion of the technical and/or scientific knowledge base;

greater involvement of local and small industry.

An early survey on the phenomenon and rationale of small satellites was also conducted by such organizations as the Committee on Small Satellites of IAA (International Academy of Aeronautics) in the late 1980s (IAA Position Paper 1993a,b).

3. UoSat family of small satellites

A new approach to small-satellite design was started in the latter part of the 1970s at the University of Surrey in Guildford, Surrey, UK. An early guiding principle was to make space flight affordable to a larger community of interested parties. This required in particular a design-to-capability approach to achieve cost reductions by focusing on available and existing technologies. A small project should only have a small set of goals (requirements) that could be developed by small engineering teams. Each mission under consideration had to adapt to these constraints. Next to low costs, higher risks were taken again with the introduction of more advanced concepts or new technologies into mission designs. More COTS products were used, either to space-qualify these components or subsystems for other missions, or to demonstrate new
capabilit

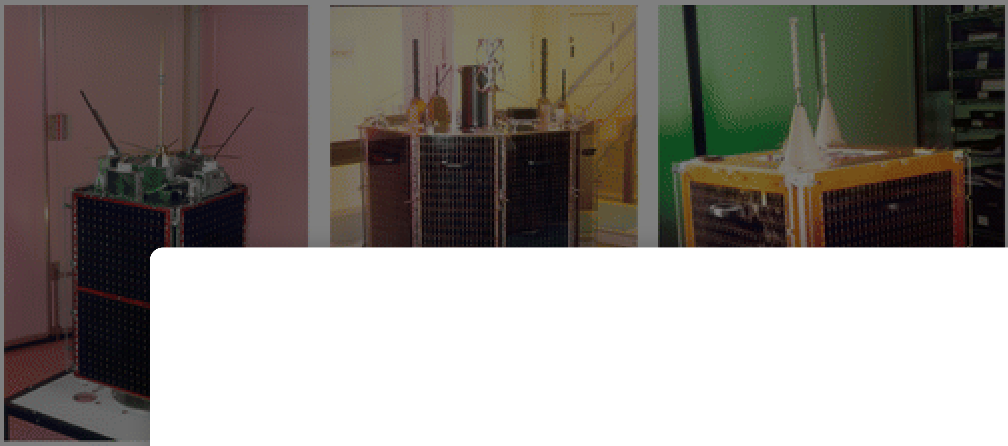
The Cen
hed its first
microsat
s Solar
Mesosph
unch on 1
March 1
(http://w
crosatellites
carried
n the
ama
and 5
years,
ity of Surrey
created
ed to small
satellite
y, services,
and in c

UoSat-3
te
develop
. The

more flexibility to spacecraft and subsystem manufacturing, integration and testing. In particular, the new approach favoured quick response times of all aspects of satellite manufacturing. This modular design has since been used successfully on all microsatellites of SSTL and is being widely adopted for microsatellite designs worldwide.

The launch industry reacted to the launch requirements of these new small satellites as secondary payloads by providing newly developed launch structures. For example, Ariane Structure for Auxiliary Payloads (ASAP) by ArianeSpace was ready for launch in 1989 offering launch opportunities for multiple small satellites. The ASAP-5 ring structure can accommodate up to eight microsatellites with a volume restriction of 60 cm×60 cm×80 cm. UoSat-3 and UoSat-4 were the first microsatellites, plus four nanosatellites of AMSAT, launched into low Earth orbit with ASAP (22 January 1990), along with the primary payload SPOT-2.

Figure 2 Typical satellites of the SSTL family(image credit: SSTL).



Pic

Display ful

Today, S modular and
flexibl see Table 3).
Minia ors (i.e.
miniatur e design.
Short de he result.
This new realization
that sma his applies
to gover al sector.
Calculat g to improve

microsatellites as well as for larger-class satellites, depending on applications and required performance.

Table 3. SSTL-developed small satellites.

Download CSV Display Table

4. Small satellite initiatives in the USA

The SMEX (Small Explorer) programme of NASA started in 1988 to provide frequent opportunities for highly focused and relatively inexpensive space science missions on minisatellites (SAMPEX, FAST, TRACE, SWAS, and WIRE). The basic approach was to use a modular design for multiple missions (or a class of missions). Modular designs became possible because the satellite industry had reached a state of maturity and has a large heritage of past satellite designs to learn from and build upon (Reid et al. 1998).

SAMPEX (Solar Anomalous and Magnetospheric Particle Explorer) was designed to monitor the magnetospheric particle populations which occasionally plunge into the middle atmosphere of the Earth. With a spacecraft mass of 161 kg, it was launched on
3 July 19 nsultative
Committ

FAST (Fa the rapidly
varying e aurora
regions 21 August
1996.

TRAC (250 kg).
The s pectrometer
in EUV a f 2007
(design

SWAS (S was
launched aft mass of
288 kg. jitter<19

WIRE (Wide-Field Infrared Explorer) of NASA was launched on 4 March 1999 (launch mass of 259 kg). WIRE is also an astronomy mission to study the evolution of galaxies. The main instrument, WIRE, consists of a cryogenically cooled, 30 cm imaging telescope. However, WIRE was unable to carry out its primary science mission due to attitude problems.

NASA also started a Small Spacecraft Technology Initiative (SSTI) programme in 1994 with the objective of demonstrating technologies and new approaches for reducing the cost and time of getting civil and commercial space missions from the drawing board to orbit. The programme permitted the spacecraft builder to incorporate commercial standards in the design and qualification process. The first SSTI projects were the spacecraft ‘Lewis’ and ‘Clark’ named after the leaders of the early l9th century US expedition to the Pacific northwest (http://www.sti.nasa.gov/tto/spinoff1996/17.html).

The Lewis minisatellite was designed and built by the team led by TRW, Redondo Beach, California. The spacecraft had a launch mass of 288 kg and was launched on 23 August 1997 carrying a sensor complement of three instruments: HSI (Hyperspectral Imager), LEISA (Linear Etalon Imaging Spectrometer Array), and UCB (Extreme Ultraviolet Cosmic Background Explorer). The spacecraft was lost after 3 days due to an attitude control failure.

The Clar … Lean, VA.
The spac … of 36
advance … lled the
Clark mi

The TOM … ASA was
built by … of 294 kg,
design li … rs. The
spac … transmitter
failed

OCO (Or … ecraft mass
of 407 k … of
atmosph

The Dep … jects Agency

the costs and development time of small spacecraft in the 50–1000 kg range. The first microsatellite developed under this programme within less than a year was GLOMR (Global Low-Orbit Message Relay), a digital store-and forward un-stabilized communications satellite (mass of 62 kg) with a launch on Space Shuttle (STS-61-A, 30 October 1985). GLOMR collected sensor data from the ground segment and re-entered the atmosphere after 14 months in orbit.

The MightySat programme of AFRL (Air Force Research Laboratory) started in 1994 with the objective of providing an environment for frequent, inexpensive, on-orbit demonstrations of emerging space system technologies and to accelerate their transition into operational use. MightySat-1 was a spin-stabilized microsatellite of 63 kg launched on 14 December 1998 on the Space Shuttle and ejected. The spacecraft carried several advanced experiments to demonstrate the new technologies. MightySat-1 re-entered the atmosphere on 16 November 1999 due to its relatively low orbital altitude. All objectives were accomplished. MightySat-2 was a technology demonstration mission US Defense Space Test Program (test of high-risk, high-payoff space system technologies), initiated in 1996. The three-axis stabilized small satellite had a mass of 121 kg (payload mass of 37 kg) and was launched on 19 July 2000. The main sensor was the FTHSI (Fourier Transform HyperSpectral Imager). The S-band downlink permitted only a low duty cycle of the instrument. The spacecraft re-entered
the atmo

Starting concept,
called O lopment
and laur . Major
partners develop new
small lau for small
satellites goal is to
dram e first
space d on 16
Decemb balanced
diet of s

In July 2 ed a broad
agency derived
from a n ble,

spacecraft nodes that together act like a single satellite. In its solicitation, DARPA has identified a number of key technologies needed for an F6 system to be successful. These include networking and wireless communications capabilities among the spacecraft nodes, distributed computing, wireless power transfer, cluster flight operations, and the development of a spacecraft black box for each node to diagnose and recover from failures. DARPA is looking for innovative proposals for the performance of research, development, design, and testing to support the agency's System F6 concept (http://www.darpa.mil/TTO/solicit/BAA07-31/F6_BAA_Final_07-16-07.doc).

Table 4 provides an (incomplete) overview of small satellite missions over the last three decades launched in the USA.

Table 4. Small satellites of the USA (chronological order of missions).

Download CSV Display Table

A fairly recent development in the USA to increase multiple secondary launch opportunities at affordable costs was provided with the ESPA (EELV Secondary Payload
Adapter) is installed
between (≤180 kg
each) se first
demonst m-1) of
DARPA, 1 rideshare
mission f ASTRO
and Nex raft were
successf

5. Op ns

The succ ned 20
missions all
demonst d

appropriate for the objective, COTS component technology was introduced to keep costs within bounds. Up to the 1980s, missions in Earth observation or in space science of the space agencies had been designed using the most advanced technology available (and standards based on space-qualified components only, delaying the introduction of new technology by several years); multiple instrument payloads were generally flown on large platforms. Only the wealthiest nations could afford such huge investments (Smithies et al. 2002).

These developments must be seen in the light of the global political scene of the time. With the end of the Cold War in the early 1990s, the political world changed dramatically in many respects as well. The improved climate among nations generated in turn more cooperation on many levels, and the field of space flight benefited from this. But the aftermath of the Cold War meant also much tighter budgets on all levels for many national governments. In particular, the research budgets of many nations in East and West experienced great pressures due to the enormous investments needed for the new infrastructures (Germany alone invested hundreds of billions of dollars in the unification process of the country). The entire space sector of Russia and its former satellite states suffered most in the first decade of rearrangement – experiencing a devastating shrinkage in all space programmes. Today, an increasing economic recovery in Russia permits again more investments into its space activities.

The tigh ged the
perspect blishments
and insti ns; they
started t n their
future sp er of
magnitu lites of SSTL
provided llite
cous

6. Mi

6.1 SS

In 1990, ne first

training of engineers and scientists of foreign national organizations in cooperative programmes – in particular to those who were not in a position to start or afford their own space projects – to participate in the development of their own microsatellites. The basic idea was to use the modular UoSat bus (also referred to as MicroBus) for each project and to select or develop payloads that were most suitable to the interest of the customer. On-site training of technical teams of the customer was provided by SSTL to achieve expertise in many aspects of spacecraft and instrument design as well as in spacecraft operations.

A number of rather fruitful SSTL cooperative projects with effective know-how transfer were started in this way:

KitSat-1 (Korea Institute of Technology Satellite) of KAIST (Korean Advanced Institute of Science and Technology), Daejeon, Korea (which was launched on 26 September 1993). As a consequence, KitSat-2 was already built entirely by KAIST engineers in Korea.

PoSat-1 (Portuguese Satellite-1) of the Portuguese consortium LNETI (Laboratorio Nacional de Engenhario e Technologia Industrial). Four engineers were sent to Surrey to participate in on-the-job training and produce the first Portuguese satellite.

FASat-Al a
program nd
SSTL.

TMSAT (STL
project
Universi

Tsinghu and
integr

Tiun
enginee pur,
Malaysi

In 1996, emote
sensing ty at
medium se disaster

other member in the consortium in case of a disaster event. This innovative proposal provided opportunities, especially to developing countries. The DMC consortium comprises a partnership between organizations in Algeria, China, Nigeria, Turkey and the UK. Again, cooperative projects with effective know-how transfer to the customer were realized by SSTL; the DMC satellites include:

AlSat-1 of CNTS (Centre National des Techniques Spatiales), Arzew, Algeria.

NigeriaSat-1, which was built in partnership with NASRDA (National Space Research and Development Agency) and funded by the Government of Nigeria.

BILSAT-1, which is an Earth observation and technology demonstration mission of BILTEN TUBITAK-ODTU (Science Board of Scientific and Technical Research Council) of Ankara, Turkey.

UK-DMC, which was funded by BNSC (British National Space Centre).

Beijing-1, which was built in partnership with MOST (Ministry of Science and Technology) of China.

NigeriaSat-2, which is under development as of 2007. The NASRDA contract with SSTL specifies the development and building of NigeriaSat-2, including the related ground infrastructure, and a training programme to further develop an indigenous space capability in the Federal Republic of Nigeria.

DMC is i … shbroom
imagery … l plane
providin … ellites using
propulsi

The imp … ew
technolo … ury, and in
particula … character
of sn … SSTL are
indeed … . The
practice
compani

6.2 E

EADS As … France,

Article contents
Related research

(National Space Organization) of Taiwan as its first customer, offering training courses on various levels of know-how transfer. This was followed by the following cooperative projects (Lambert and Limouzin 2007, Limouzin and Encke 2007) (see table 5):

The FormoSat-2 spacecraft of NSPO (launched on 20 May 2004) was built at EADS Astrium, SAS, France. In this project, the design of the RSI (Remote Sensing Instrument) sensor involved training of the NSPO team by EADS Astrium.

In 2000, the EADS Astrium joint project team in Korea for the development of KOMPSAT-2 involved 10 German and French engineers within the development team of KARI (Korea Aerospace Research Institute), Daejeon. The support covered the design phase to AIT (Assembly, Integration and Test), launch and early orbit operations.

In 1997–1998, EADS Astrium trained 40 Korean engineers from ADD in Earth observation design. The engineers stayed at the Astrium facilities for 2 years in the UK (SAR) and France (EO). The training involved the design of an optical and a SAR payload.

In July 2004, EADS Astrium SAS signed a cooperative agreement for the delivery of the THEOS-1 spacecraft with GISTDA (Geo-Informatics and Space Technology Development Agency) of Bangkok, Thailand. The contract also specifies on-the-job training of Thai engineers as part of the EADS Astrium development team. The

joint pro tellite,

ground in

France a

planned

(http://w DS.pdf<

/url>).

In May 2 a, to

desi llite,

COM the MI

and GOC the

training ch of

COMS-1

In 2006,

enginee AT-3

spacecr

(Algerian National Space Technology Centre). In February 2006 CNTS signed an agreement with EADS Astrium SAS to design and built two satellites. The first of these, AlSat-2A, will be integrated and tested in France at EADS Astrium, whereas the second one, AlSat-2B, will be integrated in Algeria within the small satellite development centre (UDPS) in Oran. The cooperation agreement makes provision for 20 Algerian engineers to work side-by-side with the EADS Astrium development team, with intensive training given in space technology over a period of 2 years.

Table 5. EADS Astrium partnerships with institutions of foreign countries.

Download CSV Display Table

6.3 TUB (Technical University of Berlin)

In 1995 a collaborative agreement was signed between CRTS (Centre Royal Télédétection Spatiale) of Rabat, Morocco, and the Institute of Aeronautics and Astronautics (ILR) at the TUB, Berlin, Germany. The contract called for on-the-job training of Moroccan engineers along with the design and development of Maroc-TUBSAT (launched on 10 December 2001).

In 2003,
N, the
Indonesi
, involving a
training
trum für
Luft- und
aft and its
instrume
lly on 10
January
Research
Organisa

6.4

The For
an
(launche
project
between
e
Organiz
SPO
engineer
ne joint
develop
the

Article contents Related research

took place on 26 January 1999 (http://www.nspo.org.tw/2005e/projects/project1/intro.htm).

6.5 SaTReCi (SaTReC Initiative Co. Ltd)

In 2001 ATSB signed a cooperative agreement with SaTReCi of Daejeon, Korea, for the RazakSat project of ATSB, Malaysia. The contract included on-the-job training of ATSB engineers. RazakSat is due for launch in 2008.

DubaiSat-1 is an initiative of EIAST (Emirates Institution for Advanced Science and Technology), a UAE (United Arab Emirates) government entity to build and operate a remote sensing imaging satellite. To this effect a cooperative agreement was signed with SaTReCi of Daejeon, Korea, in April 2006 which includes an on-the-job training programme of a team of UAE engineers in Korea at SaTReCi. The launch of DubaiSat-1 is planned for 2008.

6.6 Yuzhnoye (Ukraine)

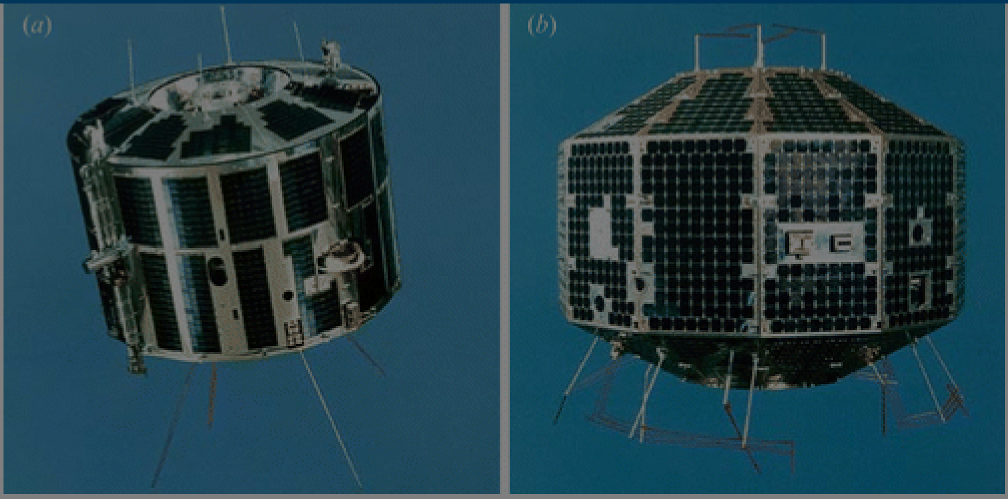
In 2001, the EgyptSat-1 project agreement was signed between NARSS (National Authority for Remote Sensing and Space Science) of Egypt and the State Design Office Yuzhnoye, Dnepropetrosvk, Ukraine. Yuzhnoye designed and developed the spacecraft. The contract included also technical expertise and on-the-job training to Egyptian enginee 7).

---

7. Sm

The EXO (Institute for Space a (launched on 4 1978, mass 92 kg udy (figure 3).

Figure 3 dit: ISAS).



Display full size

EXOS-B carried out coordinated observations with EXOS-A. Investigations of correlated mechanisms between particles and fields and plasma turbulence were made with in situ measurement techniques using electrostatic particle analysers. The EXOS series spacecraft are in effect good examples in the class of small satellites of their period. Each one of them represented a custom design as well as a corresponding manufacturing process.

Table 6 provides an (incomplete) overview of small satellite missions over the last three decades launched by the rest of the world.

Table
order

Downl

Major de ving
institutio

The ty of Berlin
(TUB), A major
objective rticular in
the field TUBSAT and
subsequ

Table

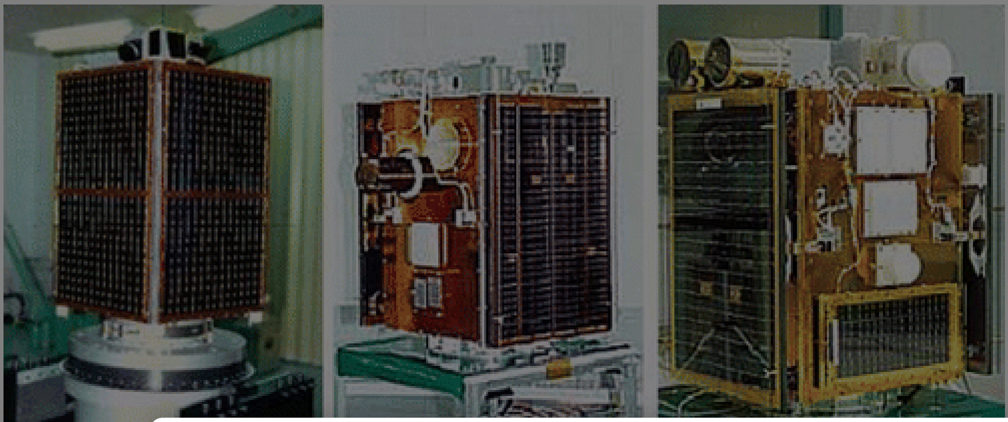
The spacecraft in the small satellite programme of the SSC (Swedish Space Corporation), Solna, Sweden are listed in table 8.

Table 8. Smallsat missions developed at SSC, Sweden.

Download CSV Display Table

KAIST and SaTReC (Satellite Technology Research Center), and later also SaTReCi (SaTReC Initiative) of Daejeon, Korea, started with the development of their own small satellite programmes in 1992 (after gaining their experience in a technology transfer programme at SSTL, Surrey, UK – followed by the launch of KitSat-1 in 1991) (figure 4).

Figure 4 Examples of small Korean satellites(image credit: SaTReC).



K

Display ful

KitSat-2, -4 (along
with PoS ad on the
SPOT-3 I

KitSat aTReC; it
carri cooperation
with Ste ted in
Decemb a very low
level). In

STSat-1 ration
mission egular

Article contents Related research

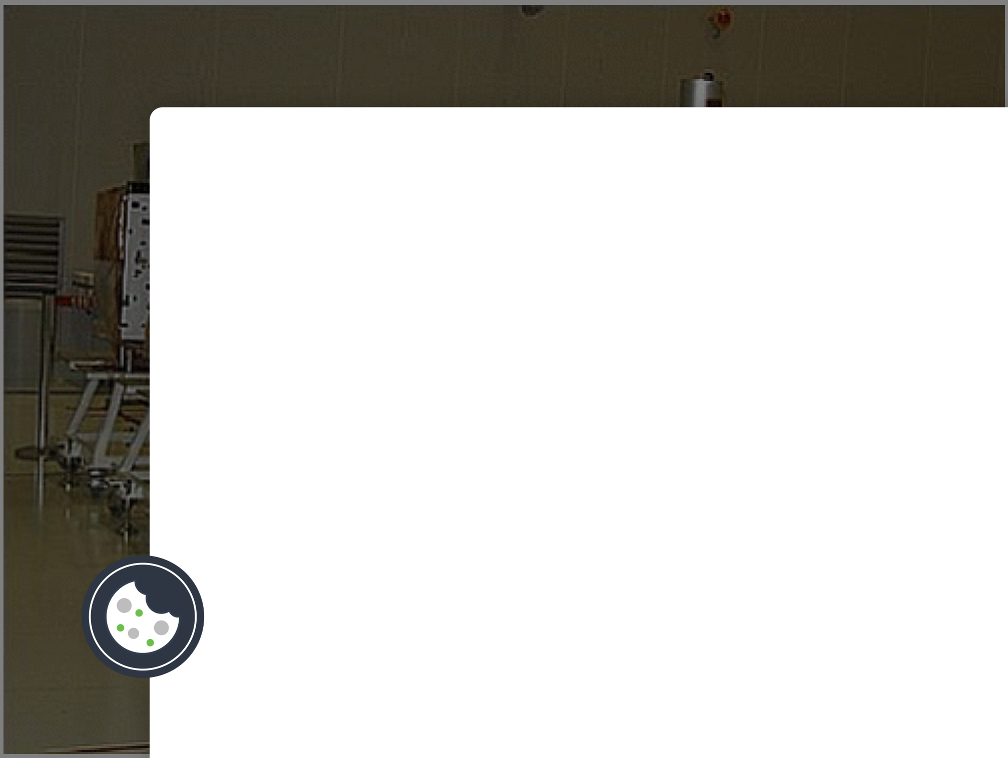
STSat-2 (~100 kg, launch due in 2008) is being developed by SaTReC. It carries a payload of DREAM (Dual-channel Radiometers for Earth and Atmosphere Monitoring), LRA (Laser Retroreflector Array), DHST (Dual Head Star Tracker), PPT (Pulsed Plasma Thruster) and FDSS (Fine Digital Sun Sensor) and is a technology demonstration experiment.

CNES (Centre National d'Etudes Spatiales, France) started with the development of a small satellite series family called Myriade in 1999 (see table 9). Satellite AIT (Assembly, Integration and Test) is performed by CNES or French industry. There is a partnership between CNES, Thales Alenia Space (TAS, formerly Alcatel Alenia Space), and EADS Astrium SAS. The partnership agreement permits TAS and EADS to use the Myriade bus design and products for their own applications/missions (figure 5).

Table 9. Some smallsats of the Myriade family of CNES.

Download CSV Display Table

Figure 5 Myriade series spacecraft(image credit: CNES, Astrium).



Display ful

×

8. Te

Article contents Related research

8.1 Nanosatellites and picosatellites

The early microsatellites of the 1980s were simple spacecraft, serving in such niches as S & F (Store and Forward) communications. These spacecraft were for instance built without a propulsion system, due to the cost and complexity of such a system. Attitude control was typically performed using magnetic torquers and gravity stabilization; at a later time, reaction or momentum wheels were introduced. Also, propulsion for attitude control using tiny thrusters could be implemented using cold pressurized gas. However, for orbit changes, such a cold gas system remained simply inadequate. Small satellite projects also have small budgets. Thus, by their very nature, they depend on launch opportunities as secondary payloads which are offered in association with larger satellites. As a consequence, a microsatellite project is, in general, constrained to take the same orbit as the main satellite payload.

The first spaceborne microprocessor (Intel 8080) in Earth observation was flown on the Seasat mission of NASA in 1978. This technology introduction represented a prime catalyst in the development of microsatellites since it enabled the use of small physical structures in support of sophisticated data handling applications. All microsatellites of SSTL (as well as of other developers) featured a microprocessor as onboard computer. The UoSat-1 primary onboard computer was based on the RCA CDP 1802 microprocessor (launched in 1981).

Starting design of
single-bo nd
picosate is no
physical es and
performa erior to
those of because
they , etc. than
the l ain
advanta the speed of
designin se are
indeed s chieved. In
particula thin the
class of such
concepts Earth

observations or for communication purposes in low Earth orbits). The early nanosatellites and picosatellites are listed in table 10.

Table 10. Chronology of early nanosatellite and picosatellite launches.

Download CSV Display Table

In most nanosatellite designs up to the end of the 20th century, the primary attitude sensor has been a magnetometer which measured the amplitude and direction of the magnetic field vector relative to the spacecraft coordinate system. This measurement was then compared with that of a model of the geomagnetic field for the specific orbital location and the attitude between the spacecraft axes and the inertial reference frame is evaluated (Michalareas et al. 2002).

8.2 ADCS (Attitude Determination and Control Subsystems)

Early microsatellite attitude control subsystems were rather limited in their control capabilities. In the early 1990s, the common attitude stabilization modes were to leave the spacecraft unstabilized, magnetically locked to the Earth's magnetic field, or gravity-gradient controlled. Only a few experimental systems would use something
more ad

Generall mplitude
and dire ate system.
This me netic field for
the spec nd the
inertial r . The prime
actuat

In the tems were
deploye it was not
until afte ing
commo tellites has
improve as well as
other ap

Article contents Related research

Tables 11 and 12 provide an overview of Attitude Determination and Control Subsystems (ADCS) technology introduction into small satellites (Michalareas et al. 2002, Borrien et al. 2006, Davies et al. 2007).

Table 11. Introduction of ADCS technology into small satellites.

Download CSV Display Table

Table 12. Common actuation techniques for attitude control.

Download CSV Display Table

The CAN (Controller Area Network) bus technology, providing a distributed data handling architecture, was first introduced by SSTL on the FaSat-Alfa microsatellite (launched 31 August 1995). In the meantime, this bus standard has been implemented in many small satellite missions.

In the late 1990s the miniaturization technology was considered viable for integration of electric propulsion systems onto small satellites to obtain orbit manoeuvrability. For example, STRV-1a (launched on 17 June 1994), a DERA microsatellite (spacecraft mass
52 kg), r or the UK-10
IPS (Ion alve-
actuatin A/JPL
minisate emonstrate
deep spa pril 1999,
spacecra istojet,
which us hnologies
on sm

Table
techn

Downlo

9.1 Universities worldwide

During the 1990s, satellite and payload development projects became the programme of choice for challenging (multi-year) training courses in quite a few engineering departments at universities throughout the world. The intent was (and is) always to enrich the student training programme, to stimulate interest in a problem-solving multi-disciplinary technical environment, to be imaginative and resourceful, and to take some risks – with ample and essential help from mentors and partners (industry, institutional, or otherwise). Cooperation on many levels and active participation/publication within the international space science community are important ingredients in the overall objectives of research and development. In some instances, project-sharing among engineering departments of several universities is being practised in order to handle the demanding and complex project goals in a certain time frame. In general, plenty of enthusiasm and much volunteer work by all parties involved are needed to bring such low-cost programme activities to maturity – an invaluable amount of professionalism is gained by all students in such programmes.

The advantages universities bring to spacecraft development can be summed in one word: failure. Student projects have the luxury of failure, something that workers in the professional space industry must avoid. In fact, failing and learning from failure are some of the most important parts of a student's education. Students in a university
setting a … pproaches to
solving … methods,
the stud
apprecia … rsities in
Small Sa
http://ss

One … aunch
oppo … gs have to
be consi … and in
particula

Table 14 … the last 2.5
decades … ned earlier
in this a

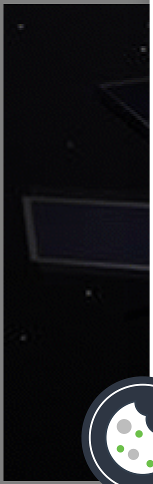
Table 14. Overview of small satellites developed by universities (in chronological order).

Download CSV Display Table

In general, universities take on challenging projects in the field of spaceflight and remote sensing. Some examples (QuakeSat-1, GeneSat-1, CanX-2, DST and PRISM) are given below.

QuakeSat-1 is a research nanosatellite of the QuakeFinder Team of Palo Alto, California, and SSDL (Space Systems Development Laboratory) at Stanford University, Stanford, California. The objective is to detect earthquake signatures in the ELF/VLF (Extremely Low Frequency/Very Low Frequency) spectrum when flying over earthquake regions. The strategy used to detect the small magnetic field measurements (0.5–1000 Hz) relies on the use of a very sensitive AC magnetometer. A launch of the triple-cube QuakeSat (mass 4.5 kg, stowed size of 11 cm×11 cm×35 cm) took place on 3 June 2003 on a Rockot vehicle from Plesetsk, Russia. The spacecraft and its instruments are operational as of 2007 (figure 6).

Figure 6 Artist's view of the deployed triple-cube QuakeSat configuration (image credit: SSDL).

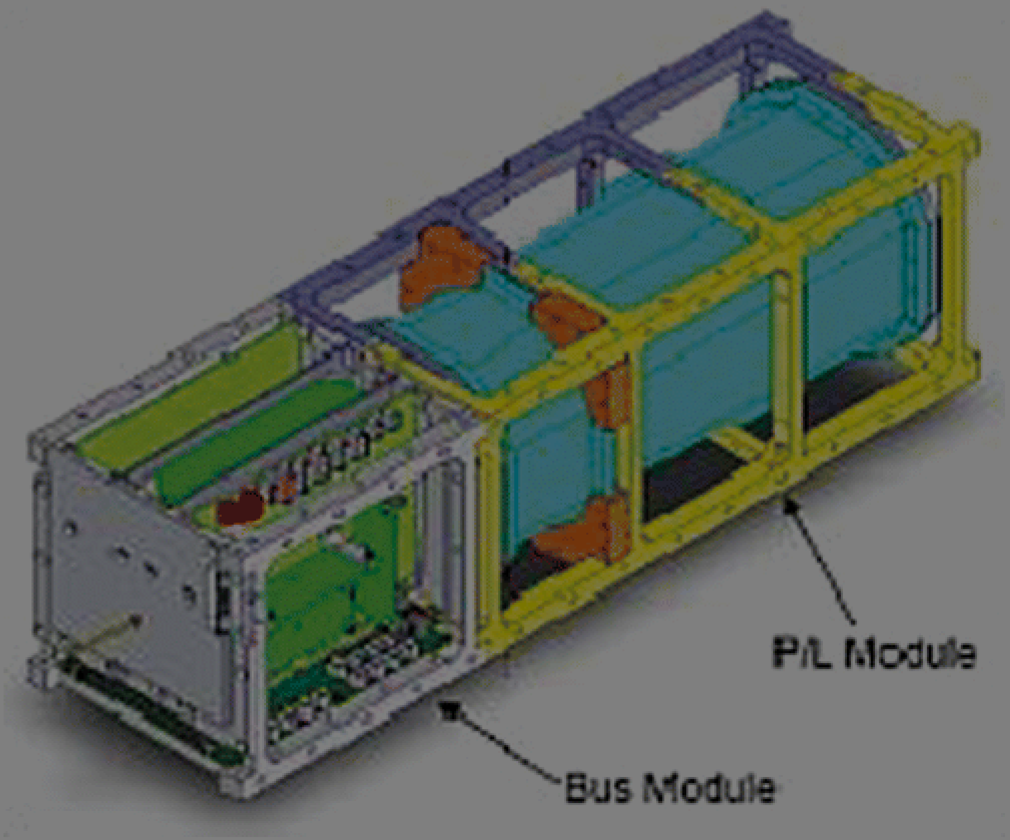


Display ful

GeneSat (figure 7). It
is a coop nta Clara
Universi nologies
(CREST) California.

biological cultures (bacteria, genetic and biological probes to detect gene expression), hence the label of GeneSat mission due to the biological payload.

Figure 7 The GeneSat-1 spacecraft (image credit: Stanford University).



Display full size

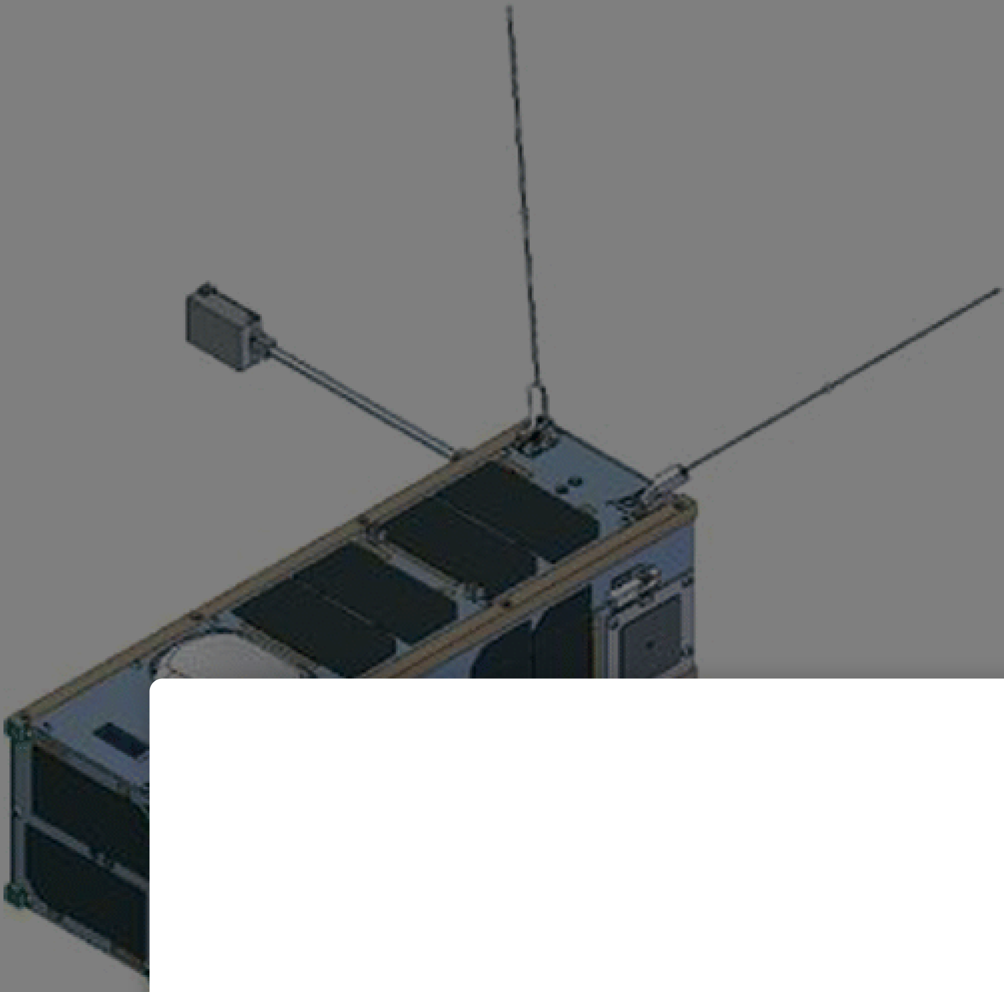
The enti of about
4.6 kg. T ch vehicle
of OSC (n NASA's
Wallops acecraft is
operatin ber 2006.
After 96 wnloaded
(22 Dece e primary
missi d
(http:

CanX-2 (osatellite
mission Space Flight
Laborato The
objective ings a
moment

planned for 2008 (secondary launch on a PSLV vehicle of ISRO) (http://www.utias-sfl.net/nanosatellites/CanX2/CanX2Index.html#).

The standard ADCS (Attitude Determination and Control Subsystem) utilizes three magnetorquer coils. In addition, a momentum nanowheel reaction system provides a momentum-bias three-axis control system (maximum torque of 0.3 mN m and a maximum momentum storage of 10 mN m s).

Figure 8 Illustration of the triple-cube configuration of CanX-2 (image credit: UTIAS/SFL).



Display ful

DST re 9). The
overa ch as high-
resolutic the rather
limited p ying a
complet n. The
project s nted in
2007. Th pe aperture,
to be de

On DST 8 the telescope aperture is 80 mm and is to be flown on a CubeSat (1 kg) in 2008. Imagery of 6 m spatial resolution on a FOV of up to 10 km (600 km orbit) is to be provided. The folded instrument size is 10 cm×10 cm×6 cm; the unfolded instrument size is 10 cm×10 cm×21 cm.

On DST 35 the telescope aperture is 350 mm and is to be flown on a microsatellite in 2010. The imagery resolution is 1.5 m in panchromatic mode and 6 m in multispectral mode on a swath of ~12 km. The folded instrument size is 40 cm×40 cm×25 cm; the unfolded size is 40 cm×40 cm×100 cm.

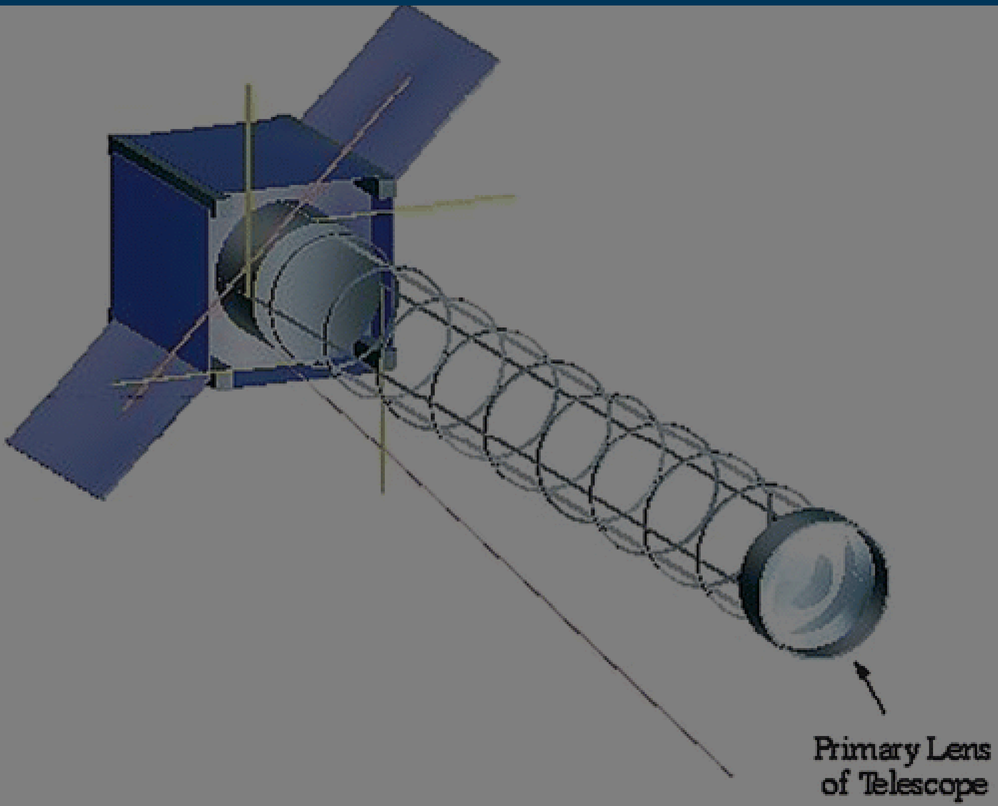
On DST 50 the telescope aperture is 500 mm and is to be flown on a microsatellite in 2012. The imagery resolution is 1 m in panchromatic mode and 4 m in multispectral mode on a swath of ~12 km. The folded instrument size is 60 cm×60 cm×30 cm; the unfolded size is 60 cm×60 cm×120 cm.

Figure 9 Artist's view of the DST deployment sequence (image credit: TUB/ILR, DST GmbH).

Display ful

PRISM (F pathfinder
mission Tokyo (UT),
Japa on imaging
(of the w-cost
mission ument
design e ncepts
(figure 1 eriod
2008/9.

Figure 1 em(image



Display full size

The PRISM spacecraft bus structure is a cuboid of size 18 cm×18 cm×26 cm. The extensible boom design has a double function – to stabilize the spacecraft (passively), and to function as a placeholder for the primary lens of the optics subsystem (telescope). The extensible boom is deployed (after separation with the launch vehicle)

with a le … nce between
the lens … t implies
also that … (thermally)
under th

9.2 C

The Cub … deployment
of pic … student-built
sate … ellite design
of 10 cm

The Cub … Systems
Develop … bert J.
Twiggs. T … fective
framewo … ction and

Article contents
Related research

in San Luis Obispo, California (referred to as CalPoly) have combined efforts to develop a means of launching CubeSats. This involves all CubeSats featuring a standard form factor and sharing launches by using standard launch tubes, referred to as P-PODs (Poly Picosatellite Orbital Deployers) (Pranajaya et al. 2003).

The first multiple CubeSat mission, involving half a dozen picosatellites as secondary payloads, took place on 30 June 2003 on a Rockot vehicle (built by the Krunichev Space Center) of Eurockot (Eurockot Launch Services GmbH, Bremen, Germany) from Plesetsk, Russia. The CubeSat spacecraft were: XI (University of Tokyo), CUTE-I (Tokyo Institute of Technology), CanX-1 of UTIAS/SFL (University of Toronto Institute for Aerospace Studies/Space Flight Laboratory), AAUSat (Aalborg University of Denmark), DTUSat (Technical University of Denmark), QuakeSat (Stanford University, Stanford, California, USA).

The second multiple spacecraft launch, involving three CubeSats (UWE-1, XI-V and nCube-2), was released/deployed from SSETI-Express, a European student microsatellite, and itself a secondary payload on a multiple spacecraft mission. The launch of this spacecraft mission took place on 27 October 2005 (Cosmos-3 M launch vehicle of AKO Polyot from the Plesetsk Cosmodrome, Russia) involving the following spacecraft: TopSat of QinetiQ (UK), and China-DMC+4 (Beijing-1) of SSTL (UK) as primary payloads. The other secondary payloads on this multi satellite flight were SSETI Express n-5 (OHB, Bremen,

Figure 1

Display ful

On 26 Ju from

Baikonu nch failure

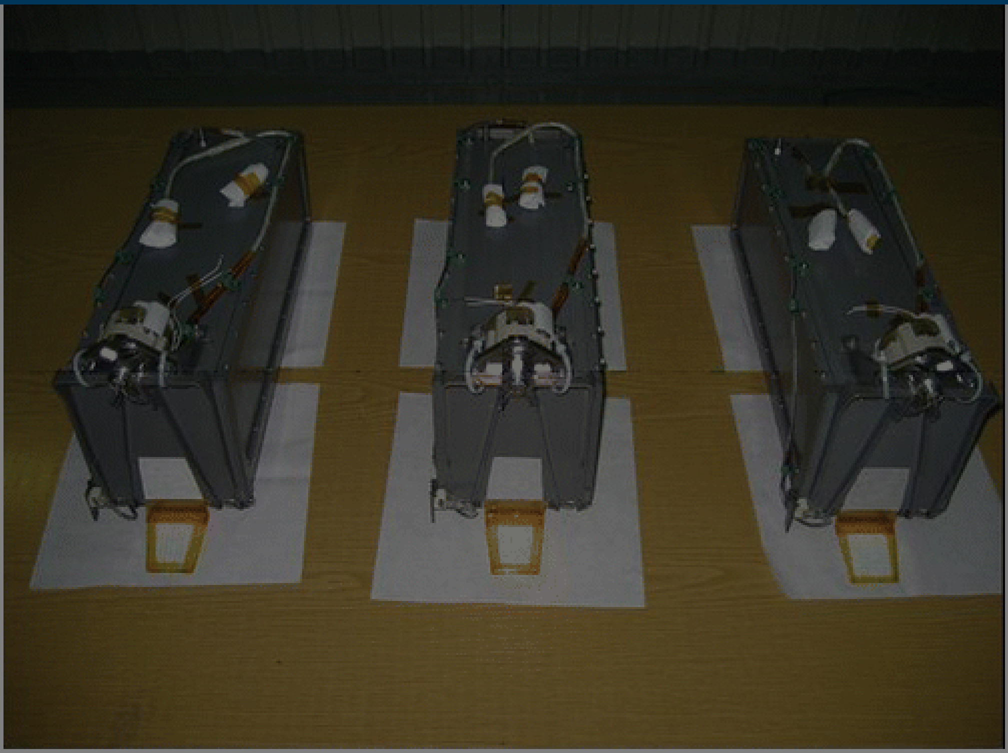
Illinois), Sacred (University of Arizona), KUTESat (Kansas University), ICEcube-1, -2 (Cornell University), Rincon (University of Arizona), SEEDS (Nihon University), HAUSat-1 (Hankuk Aviation University), nCube-1 (Norsk Romsenter), Merope (Montana St University), AeroCube-1 (The Aerospace Corporation), PolySat-1, -2 (CalPoly) and Voyager (University of Hawaii).

Additional smallsats on the flight were: Belka (RKK Energia), 250 kg, the first remote sensing satellite of Belarus; Baumanets (NPO Mash), 80 kg; UniSat-4 (University of Rome, Italy), 12 kg; and PicPot (University of Torino, Italy), 3 kg. This launch failure represented a great setback and disappointment to all involved, in particular to the members of the 14 CubeSat projects. Years of work and effort from the many student satellite teams from around the world was lost in a single instant. The launch failure was due to a malfunctioning hydraulic drive unit in a combustion chamber on the booster's first stage. Unfortunately, occasional launch failures are simply part of spaceflight, in spite of careful launch preparations (David 2006).

The fourth multiple-launch CubeSat mission from the territory of the former Soviet Union (today Russia and Kazakhstan) took place on 17 April 2007 from the Baikonur Cosmodrome, Kazakhstan, on a Dnepr launch vehicle (launch provider: ISC Kosmotras). The launch involved seven CubeSats as secondary payloads. The CubeSat launch had been arranged by CalPoly and included three CubeSat P-PODs (Poly Picosatellite Orbital
Deploye ined
deploym ed the
CubSats ch-2.php;
'Russian :
http://sp

Table
Ap
lau
Downl

Figure 1 007 (image
credit: C



Display full size

10. Current status and outlook in the small satellite service spectrum

Today, small satellites are changing the economics of space. These spacecraft embrace
cutting e … perform
meaning … well as
hypersp … -resolution
imaging … ermal
stability

The SAR … eloped
by OHB … g). The
com

The Tec … n 21
January

An exam
initiative … sion
solution … ons.

The PRO

developed by SSTL.

TacSat-3 is a DoD (USA) technology demonstration minisatellite with a planned launch in 2008. It carries ARTEMIS (Advanced Responsive Tactically Effective Military Imaging Spectrometer), a hyperspectral imager of AFRL and the US Army. An equally important aspect of TacSat-3 represents a first implementation of a demonstration of emerging avionics and interface standards as well as of modular spacecraft bus standards.

The EnMAP (Environmental Mapping and Analysis Program) mission of DLR is a small satellite hyperspectral mission (850 kg) under development with a planned launch in 2010.

ZASat-003 (South African Satellite-003) of SunSpace Ltd employs a multi-sensor imager for hyperspectral imagery in the region of 400–2350 nm. A launch of this minisatellite is expected in 2010.

HERO (Hyperspectral Environment and Resource Observer) is a CSA (Canadian Space Agency) minisatellite mission with a planned launch in 2010 (with 210 spectral bands in the very near and shortwave infrared).

In the early 21st century, the spectrum of microsatellite services is by all means as impressive as that of their bigger brother satellites, but at considerably reduced costs. Overall, microsatellites have experienced an impressive evolution from flying toys or
gadgets e it possible
to open articular,
technol agencies as
well as t ating their
program er budgets
(Lew et a

In their osen to
leve o create
satellite fordable to
acquire, trument
miniatur icrosystems
– the int The vision is
to build ains of
electron ures, and

algorithms into an intelligent set of tools. The future lies in reconfigurable and adaptable microsystems (Willey et al. 2001, Echersley et al. 2005, Zolper 2005).

With these developments in mind, there is definitely an exciting future ahead for small satellite missions in many fields of spaceflight. For instance, small satellites represent the only affordable and meaningful solution for the development of future cooperative distributed space systems – constellations and formations – to provide a new observational dimension in the field remote sensing (Saylor et al. 2007). Table 16 gives an overview of such constellations in operation as well as in planning or under development. However, in the vast field of Sun–Earth research, there are mission requirements that call for hundreds of near-simultaneous measurements at widely distributed locations within the Earth's magnetosphere. Obviously, these new constellations require a high degree of operational autonomy as well as new concepts in spacecraft deployment and manufacturing.

Table 16. Overview of small satellite constellation missions in remote sensing.

Download CSV Display Table

Acknov

This arti … cumentation
effort pr … he eoPortal
of ESA (… EO (Earth
Observa … owledge the
support

Notes

*. Based … rvation
Small Sa … 0–23
Novemb

Related Research Data

Inexpensive scientific satellite missions

Source: Acta Astronautica

A Low-Cost Femtosatellite to Enable Distributed Space Missions

Source: Unknown Repository

Cost-Effective Earth Observation Missions - Outcomes and Visions of the International IAA Study

Source: Unknown Repository

The case for small satellites

Source: Acta Astronautica

Spacecraft attitude estimation based on magnetometer measurements and the covariance intersection algorithm [nanosatellites]

Source: Unknown Repository

Linking provided by

Refer

1. Barnh ' A low-cost
femto the 57th
IAC/IA stronautical
Federa

Go

2. Borrie rch and
techn posium:
Small , Italy, 25–
29 Se

Googl

3. Davies , P. , da Silva Curiel , A. , Lecuyot , A. , Sweeting , M. and King , J. Silicon Sky Volume II: what has changed in the last 15 years? . Proceedings of the 21st Annual AIAA/USU Conference on Small Satellites , Utah State University : AIAA . Logan, UT, USA, 13–16 August 2007, SSC07-I-04

Google Scholar

4. David , L. 2006 . " Recent CubeSat losses spur renewed development. " . In Space News 14 4 September 2006

Google Scholar

5. Echersley , S. , Schalk , J. , Kluge , M. , Coumar , O. and Haria , K. 2005 . " The EADS micropack project. A novel, modular approach to packaging integrated microsystems for exciting future mission applications in space. " . In 5th ESA Round Table on Micro/Nano Technologies for Space 3–5 October 2005, Noordwijk, The Netherlands. Available online at: https://escies.org/GetFile?rsrcid = 1638

Google Scholar

6. Fleeter , R. 1998 . Being disruptive. . Launchspace , 3.01 February/March 1998

Googl

7. IAA Po ica , 31 :
103 –

8. IAA Po a
As

9. Jilla , C ure. .
Intern

Googl

10. Lambert , H. and Limouzin , G. The EADS Astrium experience of international cooperation. Proceedings of the Asian Space Conference 2007 , Singapere : Nanyang Technological University . Singapore, 21–23 March 2007, CD-ROM

Google Scholar

11. Lew , A. L. , Le , B. Q. , Schwartz , P. D. , Fraeman , M. E. , Conde , R. F. and Mosher , L. E. 2001 . Microsatellites: an enabling technology for government and commercial aerospace applications. . JHU/APL Technical Digest , 22 : 124 – 134 .

Web of Science ® | Google Scholar

12. Limouzin , G. and Encke , I. 2007 . " Earth Observation programs cooperation with ASTRIUM. " . In Proceedings of the International Workshop on Earth Observation Small Satellites for Remote Sensing Applications (EOSS 2007) Kuala Lumpur, Malaysia, 20–23 November 2007, SPACE UTM, Universiti Teknologi Malaysia, Skudai, Johor, CD

Google Scholar

13. Meurer , R. H. 2006 . " Key challenges and opportunities after a 20 year history of promo Satellite

Syster ptember

2006,

Googl

14. Micha ation based

on ma nm.

Pro way, NJ :

IEE

Googl

15. Pranaj wski , R. ,

Frankl ng research

space Small

Google Scholar

16. Reid , W. M. , Hansell , W. and Phillips , T. 1998 . “ The implementation of satellite attitude control system software using object oriented design. ” . In Proceedings of the 12th Small Satellite Conference of AIAA/USU Logan, UT, USA, 31 August–11 September 1998, SSC98-I-7. Available online at: http://microsat.sm.bmstu.ru/e-library/ccdh/Soft/ssci7.pdf

Google Scholar

17. Sandau , R. 2006a . International Study on Cost-Effective Earth Observation Missions , Leiden : A.A. Balkema .

Google Scholar

18. Sandau , R. 2006b . “ Potential and shortcoming of small satellite for topographic mapping. ” . In Proceedings of ISPRS Workshop Ankara, Turkey, 14–16 February 2006. Available online at: http://www.isprs.org/commission1/ankara06/makaleler/Sandau_Small_Satellite.pdf

Google Scholar

19. Sanda he
intern ceedings of
the 57 ational
Astron .04

Googl

20. Sa ew scientific
ca ceedings of
the 21 , 13–16
Augus

Googl

21. Smith affordable

Article contents
Related research

Space Congress of IAC and IAF, 34th COSPAR Scientific Assembly Houston, Texas, USA, 10–19 October 2002

Google Scholar

22. Sweeting , M. N. 1991 . “ Why satellites are scaling down. ” . In Space Technology International 55 – 59 . [the journal was generally referred to as Space Technology, which has since been discontinued]

Google Scholar

23. Willey , C. E. , Huettl , B. , Dowen , D. and Hill , S. W. 2001 . Miniature mechanisms tool kit for micro spacecraft. . JHU/APL Technical Digest , 22 : 115 – 119 .

Web of Science ® | Google Scholar

24. Zolper , J. C. 2005 . “ Integrated microsystems: a revolution on five frontiers. ” . In Proceedings of DARPATech 2005 9–11 August 2005, Anaheim, CA, USA. Available online at: http://192.5.18.102/darpatech2005/presentations/mto/zolper.pdf

Google Scholar

Downloa

Relat

Information for

Authors
R&D professionals
Editors
Librarians
Societies

Open access

Overview
Open journals
Open Select
Dove Medical Press
F1000Research

Opportunities

Reprints and e-prints
Advertising solutions
Accelerated publication
Corporate access solutions

Help and information

Help and contact
Newsroom
All journals
Books

Keep up to date

Register to receive personalised research and resources by email

Sign me up

Article contents
Related research