

TOPSAT: DEMONSTRATING HIGH PERFORMANCE FROM A LOW COST SATELLITE

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ABSTRACT:

Advances in technology continue to yield improvements in satellite based remote sensing but can also be used to provide existing capability at a lower cost. This is the philosophy behind the TopSat demonstrator mission, which was built by a UK consortium led by QinetiQ, and including SSTL, RAL and Infoterra. The project is funded jointly by the British National Space Centre (BNSC) and UK MoD.

TopSat has demonstrated the ability to build a low cost satellite capable of generating high quality imagery (2.8m panchromatic resolution on nadir, 5.6m multispectral). Since it was successfully launched on 27th October 2005, it has down-linked imagery daily to a fixed QinetiQ ground station in the UK in order to support a wide range of users. Rapid data delivery has also been demonstrated using a low cost mobile ground station.

The main achievement of the project is the fact that this capability has been achieved for such a relatively low cost. The cost of the entire programme (including the imager and all other development, build, launch, commissioning and ground segment costs) has been kept within a budget of approximately 20M euros.

TopSat enables a low cost, whole mission approach to high-timeliness imagery. The low cost of the satellite makes a small constellation feasible for improved revisit times. Coupled with low cost mobile ground stations, end to end turnaround times can be reduced from days to hours. Such a capability can be seen as an important complement to higher resolution (and higher cost) systems.

1. INTRODUCTION

1.1 Aims

The TopSat Mission was established to demonstrate to the UK government the potential capability of low cost satellites with very credible performance levels. It was also intended to demonstrate how low cost satellites could be used in ways different from more traditional spacecraft, such as having tasking and data dissemination co-located with the user.

1.2 Overview

TopSat is an electro-optical satellite, built by a UK consortium, aimed at demonstrating the feasibility of a high resolution, low cost imaging satellite. The TopSat system comprises a data acquisition satellite, a mobile reception station, and command and control ground segment elements.

The consortium is a collaboration between four UK partners. QinetiQ is leading the mission, provided the on-board data handling unit, data down-links and data ground segment and built and run the payload operations centre. Rutherford Appleton Laboratory (RAL) developed the camera, Surrey Satellite Technology Limited (SSTL) built the platform and Infoterra Ltd is responsible for developing commercial data markets.

The programme is jointly funded by the UK Ministry of Defence (MoD) and the British National Space Centre (BNSC) under the Mosaic Small Satellite Initiative. The project

encompasses the design, build, launch and operation of the satellite, in addition to the development of a mobile ground station to demonstrate in-the-field delivery and interpretation of image data, and the exploration of commercial markets in which to exploit the high quality, low cost imagery. An artist's impression of the spacecraft in orbit is given in Figure 1.

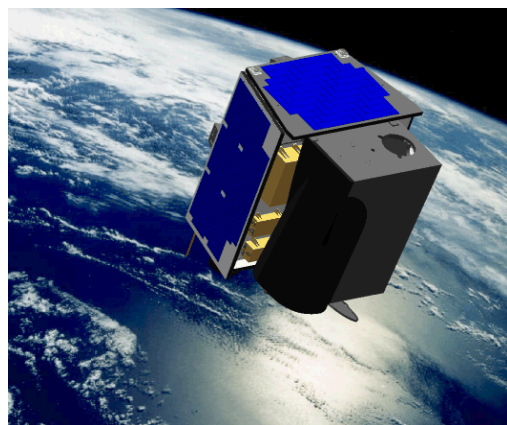


Figure 1: TopSat spacecraft in orbit

The satellite has completed an initial period of government funded operations and is now providing data to commercial users.

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Section 2 of this paper describes the low cost approach. The system implementation is discussed in section 3 which describes the spacecraft, the camera, data handling unit, satellite platform, and its imaging modes, ground segment and launch. The overall performance and coverage of the system is described in section 4. Section 5 then describes key achievements and section 6 the lessons learned. Future, follow-on concepts based on the TopSat demonstrator are discussed in section 7. Conclusions are presented in section 8.

2. LOW COST APPROACH

TopSat has adopted a low cost approach from its inception. The use of a low mass bus coupled with a purpose designed high performance but extremely compact and robust imager has been fundamental to the approach.

Unusually for a space hardware programme, considerable freedom has been allowed for different members of the consortium to use their own heritage build standards, minimising supervision and verification overheads.

A shared commercial launch was selected, resulting in a very cost effective ride to orbit on a Cosmos launch vehicle with 4 other spacecraft.

Simplicity of approach was vital, for example, no mechanical deployable structures were used. The complexity and permutations of operational modes were also minimised.

3. SYSTEM IMPLEMENTATION

3.1 Overview

The TopSat spacecraft is designed to provide high resolution imagery direct to users in the vicinity of the imaged area. Its objectives are to demonstrate the performance to cost ratio available from small satellites, the utility of direct reception of remotely sensed imagery, and the affordability of constellations and individually owned assets.

3.2 Camera

The TopSat camera was designed to meet the requirement to provide high-resolution imagery over a wide field of view, with the minimum loss of light and maximum image contrast. A key driver was the need to be robust to survive the expected launch vibration environment. This is particularly challenging when mounting the imager on a micro satellite platform and using a commercial shared launch.

These requirements led to the development of a three-mirror anastigmatic off-axis design, which allows high performance over a wide field of view in one axis (ideal for push-broom imaging) with no obstructive elements. An extremely robust and low mass CFRP structure was chosen, using QinetiQ's patented CrenLok joint. The aperture size was then selected to provide the desired angular resolution. Signal to noise requirements were fulfilled for different illumination conditions by the use of time delay integration achieved by means of a spacecraft manoeuvre during imaging.

The camera is a compact, all reflective 3 mirror system, capable of producing images with a ground resolution of 2.5m from an altitude of 600km. It has a focal length of 1680mm and aperture of 200mm. The camera occupies a volume of approximately 80x61x40cm and has a mass of 30kg, excluding the data storage subsystem. With no refractive optical elements there are no design requirements associated with chromatic aberration or glass darkening. The basic layout of the camera is shown in figure 2.

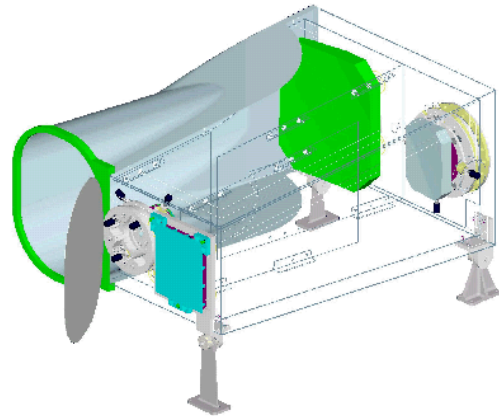


Figure 2 TopSat Camera

The camera optics are capable of a 25km field of view (FOV) at 600km altitude. The TopSat 17km FOV is a result of CCD and data throughput limits. The specification for the on orbit modulation transfer function (MTF) of optics, at Nyquist frequency of 71.43lp/mm, is better than 0.31 over 2/3 of this FOV.

The camera has two linear CCD arrays. The first provides panchromatic images at 2.8m ground sampling distance (GSD) and uses 6000, 7 μ m pixels. The second CCD contains three linear arrays with red/green/blue filters, and provides three colour imaging at 5.6m GSD. Each array has approximately 2100, 14 μ m pixels. Data is read out of the two CCDs during imaging, and stored in an on-board data handling unit (DHU) in solid state memory.

During development, the camera passed a demanding qualification programme, proving its fitness for launch.

3.3 Data Handling Unit (DHU)

Data from the camera needs to be read, stored without power and then transmitted to a fixed or mobile ground receiving station. Towards this end fast-DRAM was used as the main mass memory of the DHU to enable rapid storage and re-transmission when required. However, in order to minimise the power consumption FlashRAM was adopted for store and forward events. TopSat provides the capability to store up to four full size images in non-volatile memory, and download a single full scene to a 2.7m receiver within 60 seconds – with no further pointing of the spacecraft or down-link antenna.

A picture of the data handling unit undergoing integration testing is shown in Figure 3.

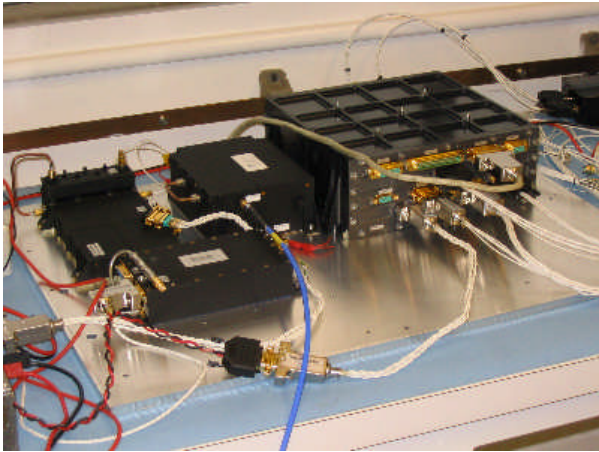


Figure 3 Data Handling Unit (larger unit on the right)

The image data, along with formatting and attitude information, can be down-linked via purpose built payload X or S band transmitters. These are used with either QinetiQ's fixed ground station at West Freugh, Scotland, or the mobile ground station.

3.4 Satellite Platform

The design of the optical payload has had a strong impact on the design of the satellite platform, thus TopSat incorporates some significant differences to other SSTL modular microsattellites. The size and mass of the payload, in addition to requirements for structural and thermal stability, have had a very visible impact on the design of the platform, illustrated in

Figure 4. Notable are the canted panels and external accommodation of the payload. Many changes lie deeper in the design, such as an advanced attitude determination and control system (ADCS) capable of accurate pointing, agile manoeuvring and TDI slew manoeuvres.

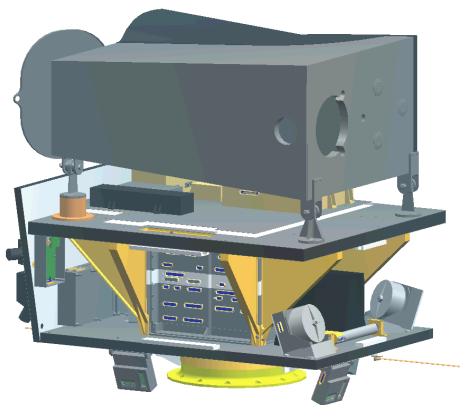


Figure 4: TopSat Spacecraft platform

Virtually the entire payload sits on the payload panel, easing design and AIT tasks, which were carried out by the various members of the partnership. Housing the payload internally

would have added to the mass and volume of the platform, reducing launch opportunities and increasing launch costs.

TopSat uses a VHF uplink for commanding and UHF for telemetry down-link. The RF link is responsible for the typical platform housekeeping tasks as well as for payload commanding and telemetry retrieval.

The on-board computer (OBC) is an Intel 386. The computer is responsible for uplink and down-link tasks, running ADCS software and numerous other housekeeping functions. The OBC stores commands for the payload and passes them on prior to imaging.

3.5 Imaging Manoeuvre

As stated above, to compensate for the relatively small optics and aperture, an imaging manoeuvre is used to effectively slow down the rate at which the camera boresight scans over the ground, allowing longer integration times and so boosting signal. This is known as a time delay integration (TDI) manoeuvre, and the factor by which the ground speed is reduced, compared to the pushbroom case, is called the "TDI factor". A TDI factor of up to x 4 is required for the mission to meet signal to noise requirements, with a factor of 8 being available if required.

The manoeuvre takes the form of a pitch rotation in a direction which slows down the motion of the boresight over the ground. For short time periods, a constant rate rotation is sufficiently accurate to give an effectively constant ground rate.

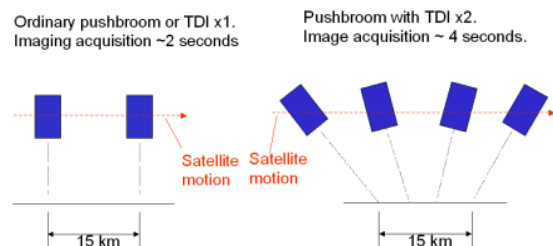


Figure 5 TDI Manoeuvre

A satellite in a 600km altitude orbit has a speed of 7558m/s, and its sub satellite point on the Earth's surface has a speed of 6908m/s, ignoring Earth rotation. The boresight of a pushbroom imager will travel, and so image, a swath 15km in along track direction in 2.17s. A pitch rate of 0.384°/s increases this time by a factor of 2, giving a TDI factor of 2.

3.6 Ground Segment

TopSat payload tasking is controlled via the QinetiQ Farnborough Payload Operations Centre. Command files are then transferred to the SSTL ground station for uplink to the spacecraft. Image data down-link occurs to either QinetiQ's fixed or mobile ground station.

TopSat uses the 13m antenna at West Freugh (Scotland, UK) as a main data ground station, allowing large volumes of imagery to be received and archived.

Using its mobile ground station TopSat can provide near real-time imagery directly to a field-based user. QinetiQ has developed a fully mobile ground system, known as the RAPIDS transportable ground station, with the system electronics and computers mounted in a customized Land Rover Defender. The ground station can be operational at a remote site within a few hours, and provides its own generator power.



Figure 6 RAPIDS Mobile Ground Station

Use of a deployed ground station enables more rapid dissemination of image data to end users than can be achieved by down-linking to a fixed ground station remote from the imaging target. This capability is of particular importance to applications requiring a fast turnaround from tasking to delivery, such as disaster management.

3.7 Launch

TopSat was successfully launched as one of 5 satellites on a Cosmos launch vehicle provided by Polyot. The launch site was Plesetsk in Northern Russia.



Figure 7: TopSat (on left) mounted on the launch adaptor with ride share partners

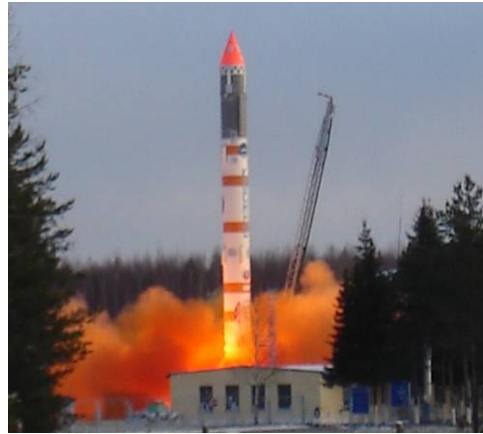


Figure 8: Ignition of the Cosmos launch vehicle

4. PERFORMANCE AND COVERAGE

TopSat acquires panchromatic imagery at 2.8m resolution (at nadir) from a 686km altitude sun synchronous orbit. The Local Time of Ascending Node crossing is 1030. The image size is 17km square. It can also acquire multispectral images at 5.8m resolution. The satellite routinely acquires up to four images per day.

The predicted coverage opportunities for TopSat are shown in Figure 9.

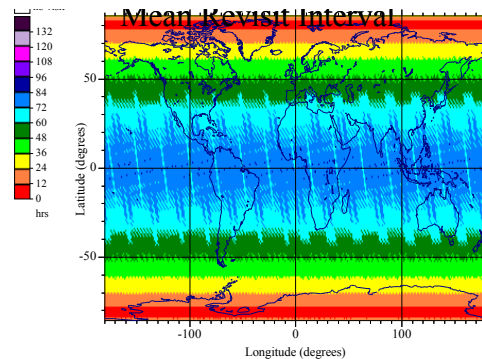


Figure 9: Mean revisit Interval (single satellite)

As with any imaging satellite in low earth orbit, there is a revisit interval of several days at lower latitudes, reducing significantly nearer the poles. For TopSat, there is a mean revisit interval of 2-2.5 days at European latitudes.

5. ACHIEVEMENTS

The overriding achievement of the TopSat mission is the building and successful launch of a micro satellite capable of sustaining routine operations with a 2.5m class imager, whilst meeting its budgetary targets. This required considerable developmental challenges to be overcome, particularly in ensuring that the imager would maintain performance post launch. Figure 10 shows an early example of a TopSat image.



Figure 10 One of the first images ever captured by TopSat: the Queen Elizabeth bridge at Dartford, East London

Although built as a demonstrator and not an operational system, TopSat has sustained many months of intensive use, routinely delivering 4 images per day in response to its user image requests. Availability of >96% has now been achieved based on the number of images successfully captured, down-linked and processed vs those tasked. Figure 11 & Figure 12 show examples of user tasked images.

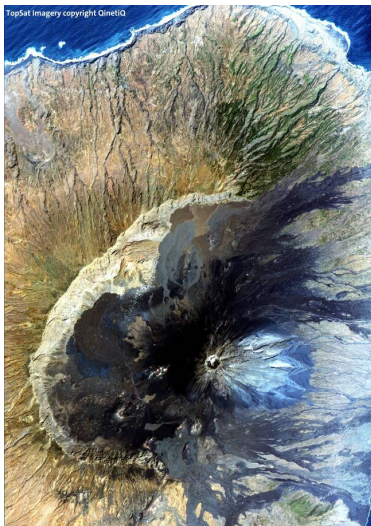


Figure 11: A multispectral user tasked image of the Fogo volcano in the Cape Verde Islands



Figure 12: Multispectral image of the Isle of Wight

The scheduling of TopSat is performed in a very flexible way whereby the full list of outstanding image tasks is reviewed each day. High priority requests for imaging globally are routinely turned around from tasking to delivery in 2-6 days, demonstrating the flexibility of the scheduling system. Delivery times of less than 1 hour from image capture in orbit to a processed image with the user have been demonstrated when using the mobile ground station.

Figure 13 shows an image captured as part of such a demonstration.

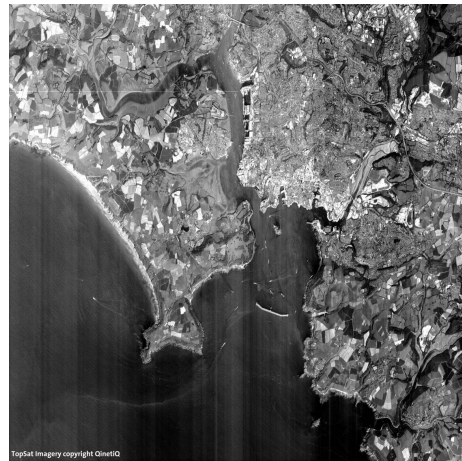


Figure 13: Image of Plymouth captured as part of a rapid timeliness demonstration

In addition, geo-rectification of imagery has been achieved to better than 50m absolute localisation by use of 4 Ground Control Points. By the use of GCPs, very widely available from public domain data, localisation has been achieved in line with much more expensive systems based on down-linked metadata.

At least as important as its technical achievements, TopSat has greatly increased the awareness amongst UK and overseas government and industry data users as to the potential for space imagery sourced from a low cost system to support their day to day activities.

6. LESSONS LEARNED

The principal lesson to be learned is that the low cost build approach works and given the experience gained on TopSat, can be used again in the future to provide even more capable missions, opening the door to a much wider community of users.

For the demonstrator, the flexible scheduling allowed fast turnaround times during routine operations. This can readily be extended to cope with larger task and image throughputs.

Very importantly, a range of data users, not previously exposed to the direct control of a space imaging asset, found that having local tasking with the ability to deliver imagery rapidly to them on a known timescale opened up new possibilities in areas such as disaster and flood management, mapping updates and support to humanitarian aid and peacekeeping activities. Demand for demonstrations in this area is strong.

7. THE FUTURE

The operation of a high performance imaging sensor in orbit, delivered at remarkably low cost opens up the prospect of many more such sensors in orbit. This will increase the availability of such data on the market to the user and drive down costs. As technology improves, imaging quality and quantities will increase and other mission parameters such as attitude determination and control will improve. Quite rapidly the point will be reached whereby low cost Earth Observation missions have taken over the role of their larger and more expensive brethren, whilst offering additional flexibility and timeliness due to their greater numbers and shorter build times.

Where timeliness of data is the driver, affordable constellations of such sensors become practicable. This will bring global revisit times down to a day for a small constellation of for example 3 or 4 spacecraft. Larger constellations will drive these times down further.

Delays inherent in command up-linking and data downlinking can be greatly reduced by the use of lightweight mobile command and data ground stations (or a pre-deployed network). Tasking to delivery turnaround times of a few hours or less are feasible if such systems are employed.

An intermediate capability would make use of fixed ground stations and commercial mobile communications systems, allowing tasking and data delivery to the location of the user but subject to the usual ground station pass time constraints. The interface with the user would be greatly enhanced by incorporating a web enabled interface, allowing user friendly tasking of the spacecraft, monitoring of progress and delivery of tailored data and products. Such systems (based on a constellation) could deliver imagery on a 1-2 day turnaround basis, when needed

8. CONCLUSIONS

The overriding conclusion based on the experience of the TopSat mission is the proven feasibility of building and successfully launching and operating a micro satellite with a

payload capable of supporting real operations (a 2.5m class optical imager in the case of TopSat) whilst meeting tight budgetary constraints. This has, however, required considerable developmental challenges to be overcome.

Missions of this class are set to revolutionise the space remote sensing business through reductions in costs and thus greater numbers of spacecraft. This will allow missions to be tailored much more exclusively to the requirements of major users. In the case of imaging spacecraft, this will reduce image costs when compared on a truly commercial basis and increase availability of the data. It will increase the timeliness of data such that extremely responsive systems provide, for example 1-2 day's turnaround on a global basis. Faster turnarounds still, to support applications such as disaster management could be supported by the use of correctly sited (usually mobile) ground stations for both command up-linking and data down-linking.

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