TopSat – High Resolution Imaging from a Low Cost Satellite

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ABSTRACT: TopSat is designed to demonstrate the capabilities of low cost small satellites for high resolution and high image quality optical sensing missions. TopSat has a mass of 108 kg and is designed to provide 2.5 m resolution imagery from a 600 km altitude direct to users near the imaged area. Launch is currently planned for August 2005, and the satellite will be placed into a sun-synchronous orbit. The satellite is capable of high resolution despite its small size as a result of a novel camera design and an agile and accurate spacecraft attitude control system. These features are described along with the management and programmatic aspects of the mission which assure performance while minimising cost. The TopSat mission is a collaboration between four UK partners with widely differing heritage. The novel approaches adopted relating to the use of standards and standard methodologies across a disparate consortium have been important in achieving the dramatically low cost mission. These are described from the Lead Partner Perspective. QinetiQ leads the mission, will operate the satellite and is providing on-board data handling and ground segment elements. Rutherford Appleton Laboratory (RAL) has developed the camera, Surrey Satellite Technology Limited (SSTL) is providing the platform, and Infoterra Ltd is responsible for developing potential commercial data markets. The programme is supported by the UK government.

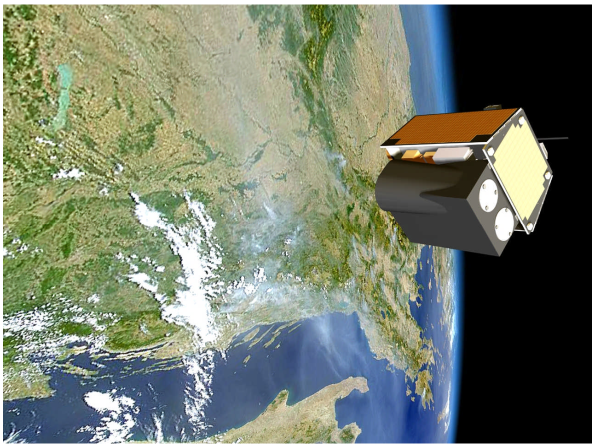

Figure 1. TopSat in operation

INTRODUCTION

TopSat is a low cost Earth observation micro-satellite (~108 kg), developed by a consortium of UK industrial partners, and is due for launch in August 2005. An artist's impression of TopSat in orbit is shown in Figure 1.

The TopSat mission aims to determine and validate the mission performance of a low budget system. To reduce costs, small satellite technology, building on past experiences, was required to meet the budget.

The key question of whether small satellites have the capability to maintain the high-tolerances required for an optical remote sensing mission from dynamic and structural perspectives was to be answered.

The financial constraints and technical considerations led to the development of:

- A novel 3-mirror off axis camera maximising the available light from a small aperture and minimising effects of obscuring elements
- A simple pitch compensation manoeuvre to increase the effective integration time utilising an agile and accurate spacecraft attitude control system

The TopSat satellite is designed to provide 2.5 m resolution panchromatic and 5 m resolution multispectral imagery of a 15 × 15 km area from a nominal 600 km sun synchronous orbit. Given the planned shared launch, the expected orbit altitude is 686 km leading to 2.7 m and 5.9 m resolution on the panchromatic and multispectral detectors respectively with an image area of 17 × 17 km. The satellite will be capable of imaging up to 30° off nadir and will be able to revisit any ground location with a mean revisit of around 4 days. As well as the panchromatic and multispectral imagery, TopSat will provide demonstration of the small satellite capability within the UK and the provision of low-cost satellites for timely information delivery to the local user.

The TopSat mission is sponsored jointly by the UK Ministry of Defence (UK MoD) and the MOSAIC small satellite initiative provided through the British National Space Centre (BNSC). The consortium which is led by QinetiQ also includes Surrey Satellite Technology Ltd (SSTL), the Rutherford Appleton Laboratory (RAL), and Infoterra.

This paper provides details of the satellite and its capability and outlines the current status as of June 2005 in anticipation of launch onboard a Cosmos rocket later in August 2005.

THE TOPSAT SATELLITE

The micro-satellite platform is provided by SSTL and hosts the high-resolution imaging system designed and built by RAL, and the data-handling unit (DHU) and downlink equipment provided by QinetiQ.

In addition to building some of the satellite hardware, QinetiQ are leading the consortium and are providing payload operations and mobile and fixed ground stations. Infoterra are responsible for commercial data exploitation.

Micro-satellite Platform

The TopSat platform is an enhanced version of previous SSTL designed and built micro-satellite platforms. The majority of the bus systems are stacked in a series of aluminium modular trays which form the main load bearing structure of the spacecraft. The camera payload, data handling and downlink units are located above the modular structure with the reaction wheels and launcher associated separation system located underneath the main structure.

The spacecraft attitude determination and control system (ADCS) is crucial to the success of the mission. To obtain an appropriate signal-to-noise ratio to achieve the desired resolution the spacecraft must perform a time delayed integration (TDI) manoeuvre in which the apparent ground track slows down. This slow down is usually by a factor of 4, but can be by a factor of 8. To achieve this requirement four reaction wheels, in a tetrahedral configuration, will control the pitch to 0.0025 degrees per second. Data from the gyroscope will be used to assist image processing.

The Earth facing panel accommodates the X- and S-band antennae which are described later in this paper. The side and zenith panels are equipped with solar arrays. A cut-away representation of the spacecraft with payload is shown in Figure 2. The attachment to the launch vehicle is shown in the lower part of this representation.

Figure 2. The TopSat spacecraft showing the structure, bus and payload

High-Resolution Imaging System

The camera, developed by RAL, is designed to meet the requirements of high-resolution and optical quality whilst being accommodated on a small satellite bus. The 3 mirror off-axis system with a 1.68 m focal length and a 20 cm aperture is accommodated in a volume of 75 × 52 × 35 cm. The off-axis primary and tertiary mirrors and on-axis secondary mirror configuration is shown in Figure 3.

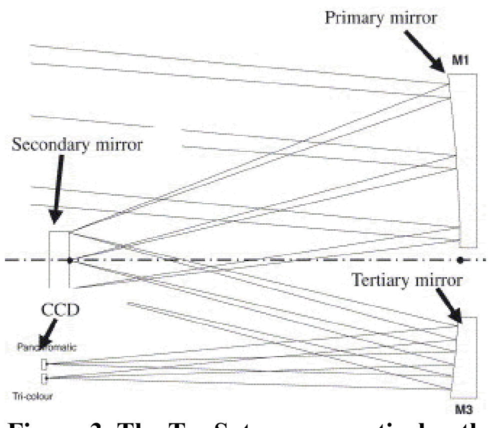

Figure 3. The TopSat camera optical path

The focal plane electronics consist of 2 commercial linear CCDs: a 7 µm pitch panchromatic array and a 14 µm pitch tri-colour array sampling red, green and blue wavelengths. The system provides an image swath of 15 km for panchromatic images and a 10 km swath for multispectral imagery.

The optics and electronics are mounted on a monocoque optical bench design consisting of panels constructed of an aluminium honeycomb core with a carbon fibre reinforced polymer (CFRP) faceskin joined using the CrenLok corrugated joint developed by QinetiQ. The CrenLok technique provides joints which are at least 4 times stronger than conventional techniques. The primary mirror is attached to the structure via an invar ring which is bonded to the mirror. The secondary and tertiary mirrors are attached to mounts allowing fine translation and rotation to fine tune for an alignment tolerance of 10 µm. These mirrors are locked in position for launch.

A cut-away of the camera showing the location of the aperture, the mirrors and the focal plane electronics is shown in Figure 4.

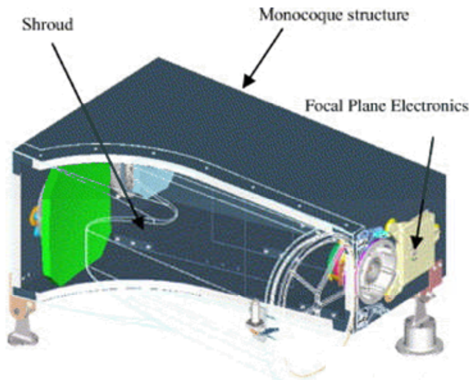

Figure 4. The TopSat camera

The camera unit is attached to the spacecraft by 3 titanium blade mounts whose design removes the effects of thermal stressed between the camera and the spacecraft. With a low CTE and high strength this optical system has the capability to maintain alignment during thermal cycling and launch vibration. Vibration testing to the levels expected during launch, with an appropriate safety margin, was performed and the results indicate the unit is very resilient to launch vibrations.

Data-Handling Unit

The DHU provides payload commanding via an I^2C RS422 interface as well as processing image data from the camera via a high speed low voltage differential signal interface. The DHU can store up to 4 images in non-volatile memory with an additional one in volatile memory.

The unit performs image encoding to ESA CCSDS packet telemetry standards and controls the flow of data to and from the antenna system.

Downlink Equipment

The downlink is provided by an X-band system with the following configuration:

- X-band modulator
- X-band power amplifier
- Lightweight cross dipole antenna
- An S-band transmitter by QinetiQ is also provided as a back-up

The X-band modulator performs the convolution encoding, QSPK modulation and X-band up-converting. A data rate of 11 Mbps is provided to a fixed ground station.

The cross dipole antenna is designed to provide a constant link margin as the transmitter passes over the ground station. For downlink to a mobile ground station, the S-band transmitter is provided with a tracking beacon mode.

Ground Segment

The TopSat mission will make use of the QinetiQ 13 m ground station located at West Freugh, Scotland. As a capability demonstrator, a mobile ground station will be used to provide direct data delivery to a local user on a real-time basis. The real time acquisition and processing integrated data system (RAPIDS) ground station will be deployed on various trials throughout the TopSat mission. The system, shown in Figure 5, consists of a transportable 2.7 m trailer-mounted antenna using hydraulic pointing with PC based tracking control and image processing. The mobile ground station has also demonstrated its capability in receiving ERS, SPOT and RADARSAT data allowing for extensive data acquisition and analysis of a variety of data sources to be performed at near real time *in situ*.

Figure 5. The RAPIDS mobile ground station

Operations

Operations will be managed by QinetiQ using a combination of COTS and bespoke scheduling and data management software with commands up-linked via a ground station. Up to 3 day's worth of commands can be uploaded per session with an expected imaging rate of 5 per day.

LAUNCH ENVIRONMENT

As a low cost mission, TopSat is planned to be launched as part of a collaborative commercial launch arrangement. This approach inevitably introduces uncertainty in the mechanical environment as an adapter must be built for each launch, tailored to the specific payload spacecraft. This adapter will introduce significant changes to the standard launch environment.

A key challenge in producing a micro-satellite with a sensitive and high performance optical payload is in ensuring that the payload can withstand the launch environment. A micro-satellite bus provides little inherent mechanical isolation.

In the case of the TopSat launch, an increase in predicted levels of around 10dB at certain critical frequencies occurred once the manifest was fully defined and the adapter designed.

To overcome this problem, QinetiQ developed an anti-vibration system in close consultation with the launch provider. A joint approach was identified and tested on the flight adapter (Figure 6). This was successful in reducing the vibration levels by around 20dB at most of the frequencies of interest. Figure 7 indicates the order of reduction achieved.

Assembly and integration of the Flight Spacecraft has now been successfully completed.

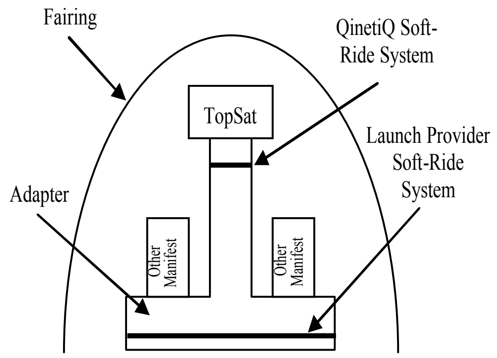

Figure 6. Test configuration for the QinetiQ anti-vibration system

LAUNCH AND OPERATION

Launch on a Cosmos rocket by Polyot is scheduled for August 2005. TopSat will be launched as a co-manifest consignment. Satellite and payload commissioning are expected to be completed by October 2005.

MANAGEMENT AND STANDARDS

The consortium consisted of a variety of organisations with differing internal structures, sizes, working practices and customer bases.

The space division of QinetiQ, a large technology company which was previously a government laboratory, has diverse interests with a track record of building micro-satellites and payloads. Work has been completed to national, NASA and ESA standards.

Surrey Satellite Technology Ltd is a medium sized space manufacturer specialising in micro-satellites for commercial customers and build to commercial standards.

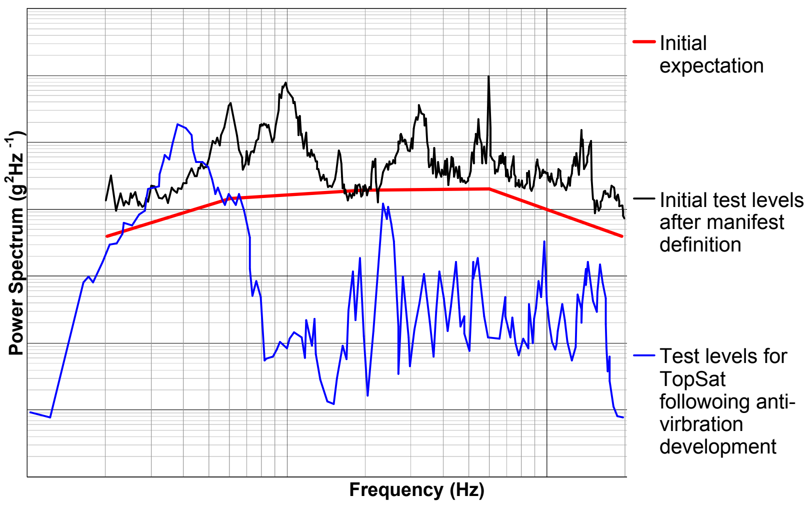

Figure 7. TopSat launch spectrum

The Rutherford Appleton Laboratory is owned by the Council for the Central Laboratory of the Research Councils and provides facilities for research organisations and academia and works to NASA, ESA and national standards.

A novel *modus operandi* was adopted where each organisation worked to its own internal standards utilising the methods most suitable for their aspect of the mission including aspects such as product assurance measures. This is in contrast to the convention where the prime contractor decrees the working practices to be adopted by subcontractors. To maintain appropriate organisation, a project-specific consortium-wide documentation frame work was established.

In addition to allowing flexibility in internal management of subcontractors, QinetiQ developed its own lightweight but rigorously applied product assurance system specifically designed for micro-satellite construction and integration. This yielded significant improvements in efficiency without introducing a large product assurance overhead. The success of this method of working has resulted in it now being applied to other parts of the company.

Allowing the disparate organisations to work in the manner most appropriate to their company resulted in low costs and prompt delivery.

SUMMARY AND CONCLUSIONS

The successful launch and commissioning of TopSat during the summer of 2005 will allow for the demonstration of high-resolution imagery from a low-cost small satellite.

ACKNOWLEDGEMENTS

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