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DMC3 and Carbonite-1: Two Sides of Small Satellites

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ABSTRACT

Launched in July 2015, the DMC3 constellation was designed with a "smallsat mentality" and represents the coming of age of small satellites for Earth Observation, offering performance that until a few years ago could only be found in satellites costing ten or twenty times more. The low cost of the individual satellites made it possible to deploy a constellation of 3 spacecraft, for daily global access, without any compromises in performance, at a fraction of the price of equivalent single EO satellites. The constellation started generating data 10 days after launch and has been in regular operation since the last quarter of 2015 and some results are presented in this paper. On the same launch as DMC3, SSTL deployed a prototype "video from space" satellite. Designed and built in under 8 months, Carbonite-1 demonstrated the use of very fast, low cost techniques to design and build satellites for "super-constellations". In this paper, results from Carbonite-1 are presented and we undertake a discussion on the merits of DMC3 versus Carbonite-1 and what they offer to the EO community. We also discuss the future evolution of the DMC3 spacecraft design (the SSTL-300 S1) as well as the future plans for Carbonite.

INTRODUCTION

The current trend in the Earth Observation (EO) market is on deploying and operating large constellations of small satellite platforms. This is driven by the need to provide high temporal resolution in order to enable downstream market applications that require frequent revisits. However, this requires reliable satellites that are designed for mass-manufacturability, shared launch, and automated operations in order to reduce cost and schedule.

At the same time as providing high utility with increased revisit, there is a need to provide high-resolution imagery with high fidelity. Traditionally, these classes of satellites have typically been large, costly, and often built one at a time. However, the "smallsat mentality" has pushed the performance envelope of small satellites thereby enabling high capabilities that until a few years ago could only be found in satellites costing ten or twenty times more.

SSTL, leveraging its 30 years of small satellite design, manufacturing, testing, and operations experience, has launched two different types of high resolution missions in July 2015: the DMC3 and Carbonite-1 satellites. The "smallsat mentality" was applied to both these missions but to varying degrees. The DMC3 mission was designed to provide a robust, agile platform with high fidelity imaging capability. Whereas the Carbonite-1 satellite was designed with the mindset of reducing schedule and cost in order to enable high utility imaging missions. Though these two types of satellites are on either ends of the performance spectrum, they are designed to meet the niche needs of the EO market in a cost efficient manner.

This paper will provide an overview of both missions, compare and contrast their capabilities, provide a current update on their status, and lastly look at the future evolution of these two mission classes.

DMC3

The DMC3 mission consists of three high resolution satellites that were launched together aboard the Polar Satellite Launch Vehicle (PSLV). The three satellites are phased equally around a sun-synchronous orbit (SSO) at an altitude of 651 km with a Local Time of Ascending Node (LTAN) of 10:30. Each satellite has a main payload that provides images of regions of interest at a high resolution of 1m Ground Sample Distance (GSD) in panchromatic and 4m GSD in four band multispectral over a swath width of 22.6 km. Individually these satellites are very capable, but significant additional benefit comes when used together as a constellation. With the given orbital parameters and the agility of the platform, the constellation can achieve a 1-day revisit to any location in the world.

Figure 1: DMC3 constellation of satellites and founder for SSTL, Professor Sir Martin Sweeting

Lineage

The DMC3 satellites are all based on an enhanced SSTL-300 series platform which has heritage back to NigeriaSat-2 (launched in 2011). The DMC3 variant, referred to as the SSTL-300 S1 platform (the "SSTL S1"), is an enhancement of the original 300 with current SSTL systems and equipment, giving the best performing solution with the highest degree of confidence due to SSTL's successful heritage baseline approach proven over 47 missions. Building on the success of the SSTL-300, the DMC3 mission offers improved resolution with all the benefits of an SSTL mission: fast delivery, low risk and cost efficiency.

Figure 2: DMC3 and Carbonite-1 satellites in shared PSLV-XL launch

Innovative Business Model

The DMC3 constellation is a new Mission Service offered by SSTL, whereby SSTL builds and operates the satellites whilst the customer operates the payloads and exploits the data generated. Under this model, customers can focus on the business of exploiting imagery and associated services, while SSTL uses its considerable experience to deliver a turn-key satellite solution.

The Twenty First Century Aerospace Technology Company Ltd (21AT), a commercial Earth observation satellite operator based in Beijing, has bought 100% of the imaging capacity of the three satellites for 7 years to provide their satellite data services from the TripleSat Constellation. 21AT handles satellite tasking, data download, ground segment data operations, and image processing. The TripleSat Constellation is the newest 21AT capability, giving them high resolution imagery to sell on the commercial market and to build on their remote sensing applications services for intelligent cities management, agriculture and other applications.

SSTL's Mission Service allow customers to concentrate their capital and human resource investments in data handling and analytics whilst SSTL handles the delivery of the space based assets and the ground network for operations.

Platform and Imager Capabilities

The SSTL S1 uses the tried and tested basic layout of the SSTL-300, adding a new high resolution payload and more advanced avionics. The satellite is designed for an operational mission lifetime of 7 years.

The spacecraft is conceptually split into two sections, the platform and the payload. The dimensions are approximately 3 m tall x 1.35m wide x 0.65m deep (Z, X, Y dimensions respectively). The shape of the structure is optimized for a triple launch – three satellites can easily fit in the fairing of the most popular small launchers.

The imaging payload is a new design and has been developed entirely in-house by SSTL. The optical design for the S1 class imager is essentially a modified Newtonian telescope. This design allows for a smaller central obstruction and avoids complex mirror forms and alignment issues. The imager includes multispectral channels and a high resolution panchromatic waveband that can be provided as a standalone image product, or used in conjunction with the multispectral bands for a pan-sharpened multispectral image product.

Table 1 provides an overview of the system parameters for the DMC3 platform and imager.

Table 1: Overview of DMC3 system parameters

Mission Overview	
Reference Orbit	651km altitude, SSO, 10:30 LTAN
Design Lifetime	7 years
Platform Overview	
Dimensions	3 m x 1.35m x 0.65m
Mass	447 kg
RF Communication	X-band @ 500 Mbits/s
	TTC S-Band @19.2kbits/s uplink and 38.4kbits/s downlink
Total Onboard Data Storage	544 GByte (4.35 Tb)
Delta-V available	27.2 m/s
Geolocation	<25 m (CE90 without GCP)
Off-pointing	± 45°
Imager Overview	
Ground Sample Distance	1 m Panchromatic (450nm to 650nm)
	4 m Multispectral Red: 600nm to 670nm Green: 510nm to 590nm Blue: 440nm to 510nm NIR: 760 to 910nm
Scene Size	22.6 km (swath) x 22.6 km
Typical Throughput Per Day*	115,000 km^2 (2:1 lossless compression) – 225 scenes
Data Quantization	10 bits
Data Compression	JPEG-LS configurable
Signal to Noise Ratio	>100:1
Modulation Transfer Function (MTF) – on axis @ Nyquist	PAN > 10% Multispectral > 20%

** Based on a single, mid-latitude ground station; can be improved with additional distributed ground stations*

Imaging Modes

The system provides support for five imaging modes. Modes are broadly split into "single scene" or "strip modes" and "compound modes". An S1 scene is defined as a combination of the single Panchromatic (PAN) band image and the four Multispectral (MS) band images.

For scene modes, there are two sets of similar modes – a standard set of modes employing each combination of imager and a fast response set of modes. The fast response modes allow imaging to be performed with minimal delay between images at the expense of pointing accuracy. When the attitude control system is given time to settle after a pointing maneuver, the pointing accuracy is improved.

The compound modes allow for along-track and across-track imaging as shown in Figure 3 and Figure 4 respectively. This allows for a target on the ground to be imaged from two different viewpoints in order to build up a stereo image. In addition, a wider target area can be covered with the Mosaic mode, as shown in Figure 5.

It is possible to perform a downlink in a Near Real-Time (NRT) fashion for all scene modes. That means that the downlink will be activated during the imaging event, and the data made available to the ground station immediately after image capturing.

Table 2: Mission imaging modes

	Name	Description
Scene Mode	S1 Scene – Fast Response	Fast response imaging mode that permits short delays between images. Allows optional off nadir pointing up to 45° and near real-time download.
Scene Mode	S1 Scene	High accuracy imaging mode. Requires settling time between images. Allows optional off nadir pointing up to 45° and near real-time download.
Compound Mode	Along-Track Stereo	Stereo image mode with 30° pitch angle. Off-nadir pointing permitted up to 20°.
Compound Mode	Across-Track Stereo	Stereo image on different passes. The roll angle is determined by orbital geometry.
Compound Mode	Mosaic	Mosaic comprise of 2x2 scenes. Pitch offset by 41° and off-nadir pointing permitted up to 20°.

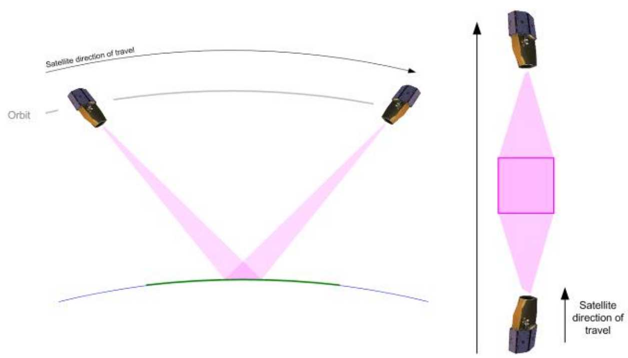

Figure 3: Along-track stereo mode

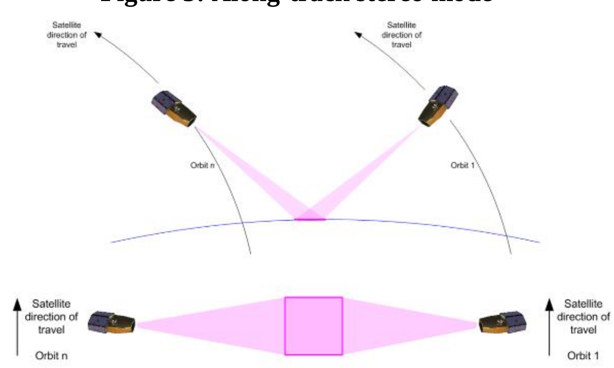

Figure 4: Across-track stereo mode

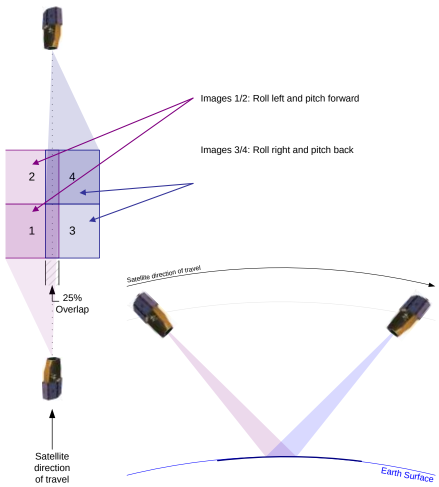

Figure 5: Mosaic mode

Current Status

The DMC3 constellation has been in orbit for over a year. Following the launch in July 2015, all three satellites were quickly stabilized and preliminary checkout of platform and payload equipment was completed shortly thereafter. The first image capture was completed within 14 days of launch on 24th of July.

Since then, the three spacecraft have completed the commissioning campaign which includes: phasing maneuvers to space them out equally in the orbit plane, completing in-orbit verification and calibration campaign, and demonstrating high throughput capacity.

As of May 2016, a total of 36139 scenes have been successfully captured and downlinked across the constellation. This equates to 18.5 million km^2 captured in 10 months since launch; this is approximately twice the area of the US or nearly 76 times the area of the UK. A total of 44.5 TBytes of imager data has been generated. Note that this period included the Launch and Early Operations Phase (LEOP) and commissioning phase, during which the satellites were not being fully utilized.

In the month of May alone, 13950 scenes were successfully imaged and downlinked by 21AT; approximately 7.1 million km^2 was captured and 17.1 TBytes of data generated. Each satellite captured an average of 150 scenes per day (an area of 76 600km^2) and generated 185 GBytes of data.

SSTL S1 Evolution

The SSTL S1 was designed to be launched and operated in a constellation. The high performance capability and throughput demonstrated over the last year, coupled with the overall cost per satellite and schedule to deliver of 24 months, makes the S1 an attractive offer for emerging and existing EO operators interested in starting a new constellation or extending existing constellations.

Figure 6: Raw DMC3 image of Thames River in London with Tower Bridge is lower right corner

Figure 7: Raw DMC3 image of Athens Olympic Stadium

Figure 8: Close-up DMC3 image of Sydney Airport

SSTL has echanced the design of the S1 imager so that for future missions it will be possible to achieve sub-meter imagery down to a native (i.e. without processing) GSD of 0.7m. The imager was designed to be modified to achieve this while still maintaining the agility of the SSTL-300 platform. The changes made to the imager leverage the design and heritage of the S1 platform which will enable costs to be kept down and risks to be kept to a minimum.

The upgraded variant of the SSTL S1 is now available and is expected to fly by 2018/2019, subject to successful commercial agreements with customers.

CARBONITE-1

The SSTL S1 design offers a high fidelity performance solution for EO constellations, as demonstrated by the cost effectiveness of the DMC3 constellation. Given the size and cost per unit of the SSTL S1, these satellites are optimal for constellations of 3 to 6 satellites, offering high quality / high fidelity imaging capability.

The limitation of such constellations is their temporal resolution, limited to 1 to 3 imaging opportunities per day. For higher temporal resolutions, particularly for the use of video imaging, it is desirable to have constellations that offer multiple imaging opportunities every day. Numbers in the order of 10s of satellite are required, posing a challenge to the satellite designers to reduce the cost of each unit. Only in this way will such constellations be commercially successful.

In 2014, based on earlier studies, SSTL decided to build a prototype, very low cost, high resolution satellite as an in-house technology demonstrator mission. This would become the leading satellite in a new class of in-orbit demonstrator missions aimed at trialing new advanced concepts for use in future missions.

To keep costs to a minimum and to make use of an existing launch opportunity, the satellite had to be developed and built in six months. The decision to start was taken on the 1st July 2014 and the satellite manufacture was completed on 12th January 2015. This was followed by nearly two months of environmental testing, with the satellite ready to launch within eight months from start.

Figure 9: Carbonite-1 during AIT

Carbonite-1, as the satellite was named, was launched on the 15th July 2015.

Platform and Imager Capabilities

To achieve the challenging schedule and price targets, the satellite design is based on five key principles:

- Image quality to be "good enough" for the intended application
- Single string (except for the receivers that are hot redundant)
- Extensive use of COTS components, including in the imager
- Simple, non-optimized structure
- Use of existing technical solutions whenever possible

The project organization was based around a very small core team of 5 engineers, substantially increasing decision speed. The team was given full autonomy to decide and implement the best solutions, within the wide boundaries set by the business.

The platform is similar in size to the heritage SSTL-100 platform. The main difference is the structure is built around the telescope using central shear walls made of milled aluminum. The avionics equipment was mounted to the shear walls around the imager. The closure and solar panels were made of sandwiched honeycomb panels.

The camera is based on a CMOS detector and provides color imagery with a GSD of 1.5m at an altitude of 650 km. The satellite can generate still images or videos of the area of interest. By flying the satellite at a lower altitude the GSD can be improved to 1m.

Current Status and Future Evolution

Carbonite-1 has been operational since October 2015 and is regularly capturing images and videos around the world. As a prototype, the main objectives of the mission were to demonstrate the rapid build capability and the low cost of the final product, rather than focus on performance. The mission has been a complete success and has in many cases surpassed the original expectations.

The satellite is the first in a series of demonstrators that will have increasing performance while bringing down cost and time to build. The next satellite will incorporate new on-board data processing capability and demonstrate several new material technologies, including additive layer manufactured parts and new deployment systems.

It is SSTL's objective to launch these demonstrators on a yearly basis, and future missions are being planned that use different sensors for remote sensing. The series will be merged with the new SSTL-12 platform technology to further reduce the cost of these missions.

MERITS OF DMC3 AND CARBONITE

The DMC3 and Carbonite series of spacecraft are two sides of the same coin: one provides high fidelity imagery and the other provides high utility; but they both provide high resolution imagery. DMC3 is designed to provide high precision pointing capability with fast slewing in order to acquire multiple targets within a single pass. The images captured provide a high degree of precision with respect to the scene being captured. This enables the continuation of many of the commercial applications that have already been established which include: agriculture, deforestation, land use, and disaster monitoring.

The Carbonite series of spacecraft provide high utility by reducing the cost of entry for new and existing business models which includes the deployment of super-constellations. The addition of video capability from a large constellation can lead to new use cases which include persistent monitoring of regional hot spots for change detection. By reducing the cost and schedule per satellite, the Carbonite series can enable these super-constellations thereby providing a unique ability for sub-daily accesses. It will also enable new opportunities and bolster the capabilities of DMC3 type missions by providing higher revisit at a lower cost. This has the potential of disrupting the market by opening up new service areas with new applications that require a high revisit frequency, supplemented with high fidelity imagery, by providing data at a lower cost.

Figure 10: Raw Carbonite-1 strip image of Walnut Ridge, USA (top) and Dubai, UAE (bottom)

CONCLUDING REMARKS

With the emergence of concepts for super-constellations, the highly bespoke design and production of satellites that has dominated the satellite industry needs to be supplemented. Specialized manufacturing processes that require hand procedures slow down production and keep costs high which make constellation scale manufacturing uneconomical.

SSTL's design and manufacturing philosophy, honed over 30 years, has allowed the development and deployment of a high resolution constellation at a very low cost. In addition, new processes utilizing automated manufacturing and testing processes have been demonstrated on Carbonite-1. Future iterations of the mission will enable improved capability and in conjunction with SSTL S1 style imagers will enable a high fidelity constellation with high utility.

Acknowledgments

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