Commissioning of the NigeriaSat-2 High Resolution Imaging Mission

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ABSTRACT

The manufacture of the NigeriaSat-2 spacecraft was completed in 2010, and was successfully launched in August 2011. This is a state-of-the-art small satellite Earth observation mission including several innovations not previously seen on small spacecraft, which will provide high duty cycle imaging of the Earth in high resolution. It will be used by the Nigerian government for mapping and to monitor a number of environmental issues within the country. The key requirements of this mission are to provide high volume mapping data, coupled with highly accurate image targeting and geolocation, and sufficient agility to enable a wide range of complex operational modes.

This paper focuses on the challenges associated with designing a spacecraft system that can meet these requirements on a satellite with a mass of less than 270kg. The paper will describe how the stereo, mosaic and other imaging modes can be employed using the agility of the spacecraft. Inertia calibration and on-board navigation techniques used to give the required targeting accuracy are discussed, and the interaction between the attitude control system and the mechanical design is detailed. The payload isolation system used to ensure image quality and geolocation performance is also described. An overview of the final test and launch campaign, and first in-orbit results from the satellite commissioning are provided.

INTRODUCTION

In 2003, Nigeria commenced its Earth Observation program with the launch of NigeriaSat-1. This spacecraft, built as part of a training program by SSTL, joined the Disaster Monitoring Constellation along with spacecraft from several other nations. Since then the spacecraft has had great success, and in addition to its national and commercial imaging programs, regularly delivers images used in the international community for disaster response.

The next step in Nigeria’s Earth Observation plan was for the NigeriaSat-2 mission to support large scale mapping of the country. This is a much more advanced spacecraft than NigeriaSat-1, comprising of a high resolution panchromatic instrument, and an additional wide area multi-spectral instrument providing data continuity for the instrument flying on NigeriaSat-1. In addition to the higher performance payloads, the spacecraft is also advanced in terms of agility, data throughput and accuracy.

NigeriaSat-2 system is a turnkey solution, comprising of space segment, ground segment and image processing facilities, together with an extensive training program.

NigeriaSat-2 will achieve 2.5m imagery in a panchromatic waveband along with 5m and 32m imagery in four multi-spectral channels. The spacecraft will deliver high data throughput on an agile platform, whilst still maintaining high levels of pointing accuracy. Figure 1 shows the fully assembled spacecraft.
Nigeria has particular needs in mind when it set the objectives for its next satellite mission. These objectives are:

- To support food supply security, agricultural and geology applications
- To support mapping and security applications
- To support development of national GIS infrastructure
- To provide continuity and compatibility with the existing NigeriaSat-1 system

By analysing these objectives, SSTL was able to translate them into the key requirements of the system, which could then be used to tailor the SSTL 300 platform to the mission.

NigeriaSat-2 carries two payloads onboard which are capable of providing medium resolution images (32m) in Red, Green, Blue and Near Infra-red bands, high resolution images (5m) in Red, Green, Blue and Near Infra-red bands and high resolution (2.5m) in a panchromatic band, from an altitude of 700km. The medium resolution imager (MRI) has a swath of 300 km, while the very high resolution imager (VHRI) has a swath of 20km.

A VHRI scene is defined as a 20km x 20km image that is a combination of one panchromatic scene with GSD of 2.5m and four multi-spectral image scenes each with GSD of 5m in the blue, green, red and near infrared spectral bands. An MRI scene is defined as a 300km x 20km image scene that is a combination of four multi-spectral image scenes each with a GSD of 32m in the blue, green, red and near infrared spectral bands.

**Scene Mode**

The standard image product produced by the high-resolution imager is a 20x20km scene in all 5 available bands. The medium-resolution imager product is an image 300km across-track by 20km along-track in the four spectral bands. When using the ‘Scene’ mode, any location on the ground visible within the roll and pitch capability can be targeted and imaged with either or both of the imagers. Thanks to the high agility of the platform, images that are separated in the across-track direction but not in the along-track direction can still be imaged. Figure 2 illustrates an example spread of images taken whilst in ‘Scene’ mode.

The spacecraft has two maneuver modes: standard and fast response. The standard maneuver mode allows the spacecraft to set itself up for an image event slowly, thus consuming a small amount of power. In instances where image targets are closely located, the fast response maneuver uses a more powerful actuator to quickly achieve the required attitude.

**IMAGING MODES AND PRODUCTS**

As the first SSTL 300 platform to be built, NigeriaSat-2 is a highly versatile spacecraft capable of a set of extensive modes. The compact nature of the satellite, its lack of appendages, such as large deployable solar arrays, and fewer requirements for large quantities of propellant mean that it can be much more agile than equivalent larger satellites.

Based on its 700km sun-synchronous orbit, a number of imaging modes are defined for the satellite. The standard modes are the scene and strip modes, and then more complex compound modes make use of the high agility to deliver stereo and area modes.
Figure 2: The High Agility of the Spacecraft Allows a Series of Geographical Diverse Targets to be Captured in a Single Pass

Strip Mode

To support applications such as mapping, individual scenes can be strung together to produce strip images up to 2000km in length.

As with the ‘Scene’ mode, target locations anywhere in the wide field of regard can be imaged. Typically, strips would be set up using the standard maneuver mode, reserving the fast response mode for applications where a more responsive image is required. Figure 3 shows an example area that could be imaged in ‘Strip’ mode.

Figure 3: An Example of the Area that Can Be Imaged in ‘Strip’ Mode

This stripping capability applies to both imagers, enabling a detailed mapping strip with the high-resolution imager, or a very wide area coverage strip of 300x2000km in medium resolution.

Stereo Mode

The compound modes focus on the use of the high-resolution imager. The first of these modes is the ‘Stereo’ mode. This compromises a pair of images taken of the same location on the ground but from different view angles. This allows the two images to then be processed together to obtain height information about the target. Figure 4 shows an illustration of the way a stereo pair is created. The exact angle at which the two stereo images are taken can be varied depending on the application, and the available settling time between images varies accordingly.

Figure 4: an Illustration of the Way a Stereo Pair is Created

Area Mode

The most complex of the modes is the ‘Area’ mode. This uses a combination of roll and pitch maneuvers to artificially widen the swath of the image for a limited period of time. By initially pitching forward and rolling to one side, the spacecraft can image a first strip of images. Following this, the spacecraft pitches back and rolls in the opposite direction to take a second strip, partially overlapping the first. This process can be repeated a third and fourth time to create an image area up to 4 scenes across by 4 scenes along-track. Figure 5 shows the steps for a 3x3 area mode image, and Figure 6 shows an example of the imaging process.
Swath
Length

Nadir
Facing
view

Figure 5: an Illustration Showing how a 3x3 Area
Mode Mosaic Image Can be Built Up. The
Spacecraft Transitions through Steps 1-5 through a
Series of Pitch and Roll Maneuvers.

Figure 6: Examples of NigeriaSat-2 Stripmode and
Mosaic Imaging

SMALL SATELLITE SOLUTION
To fit an agile, high-resolution Earth Observation platform into a small-satellite mission (weighing in at just 268kg) required a design that exploits the win-win potential of such a compact spacecraft. NigeriaSat-2 has no deployable solar arrays, with only fixed panels of the primary structure for power generation. This minimizes the inertias and ensures that there are no flexible modes of the structure that need to be controlled. This makes it easier to perform high-rate maneuvers, both in terms of the torque and control bandwidth required, but it also constrains the available power for use in attitude control.

The AOCS subsystem of the SSTL 300 platform consists almost entirely of SSTL built units. The primary actuators for attitude control are four Microwheel 10SP momentum wheels (Figure 7), mounted in a tetrahedral configuration such that the failure of any one wheel will not affect performance. These wheels, which use less than 2W each in normal operations, are used continuously to maintain pointing at the required attitude.

During background operations, when the payload is not in use, coarse attitude estimation is maintained using Magnetometer and 2-axis Sun Sensor measurements. Microwheel actuation is supplemented by Magnetorquers aligned to all three axes for off-loading momentum. This combination provides a very low power mode to maintain attitude stabilization. In addition there is full redundancy in the event of the failure of any unit.

For fine attitude control during payload operations a star tracker is used, supplemented by the MIRAS-01 MEMS Inertial Rate Sensor (Figure 8). The Micro Advanced Stellar Compass star tracker supplied by Danish Technical University is the only AOCS unit on NigeriaSat-2 that is not built by SSTL. The two star camera heads are orientated to allow a 45-degree roll/pitch maneuver cone for imaging operations. The MIRAS inertial sensor is used to maintain accurate pointing knowledge during high-rate slew maneuvers and occasional Moon blinding events where the star tracker measurement becomes unavailable.
Although ideally suited for precise pointing, the four Microwheels do not have sufficient torque or momentum capacity to provide the agility required to support the agile imaging modes described above. To facilitate this, an additional set of four Smallwheel 200SP reaction wheels (Figure 9) is included to support these modes. These larger wheels are mounted in a pyramidal configuration, arranged to give optimum acceleration in roll and pitch, and to ensure that agility is retained in the event of a wheel failure. They have a 200Nm torque capability and are operated with zero momentum bias such that they are only rotating during slew maneuvers. In this way the orbit average power required to support agile operations is kept very low since the higher power consumption of the larger wheels is only used when needed.

In principle, a set of four wheels the size of the Smallwheel 200SP would be sufficient to support all the modes of operation of the SSTL 300 spacecraft. However, the additional mass of the four smaller Microwheel 10SP actuators is more than offset by the facility to maintain pointing with much lower power consumption for the great majority of operations. Furthermore, it is beneficial to image quality to have the larger wheels stationary during imaging as there is less mechanical noise generated that may disturb the payload.

**AGILE TARGETING**

NigeriaSat-2 is required to be able to image at attitudes within a 45-degree cone from nadir and move between targets quickly on the same pass over an area of interest. This facility, combined with the stereo and area imaging modes, requires a high level of agility to be provided by the AOCS. The compact small satellite design has resulted in moments of inertia of <65kgm² about all of the principle axes.

With the four Smallwheel 200SP reaction wheels, this platform has an acceleration capability of >0.35 Deg/s² and a slew rate capability of >6 Deg/s. A 60 degree roll maneuver from -30 degrees to +30 degrees can be achieved in <30 seconds. Roll and pitch maneuvers of this nature can then be used in quick succession to support the imaging modes described above.

The 1Hz attitude control cycle has limited opportunity to respond in feedback control during these short, high-rate slews. Therefore, to ensure that accurate pointing is maintained during agile operations it is necessary to precisely calibrate the spacecraft inertia tensor. An initial measurement of the inertia tensor is undertaken pre-launch but this must be refined in-orbit to achieve the required accuracy.

**Autonomous Navigation**

To make the most of the precise, agile attitude control capability of the SSTL 300 platform, it is necessary to ensure that the timing and orientation of each image capture is calculated using accurate, up-to-date knowledge of the spacecraft’s orbit. To support this, a redundant pair of SSTL SGR-10 space GPS receivers is incorporated in the NigeriaSat-2 platform (Figure 10).
recursively update the estimated orbit ephemeris such that it can accurately project forward the spacecraft’s trajectory. This uses functionality developed for the TopSat technology demonstration mission. These calculations can be performed quickly on-board by using the epicycle orbit model, developed in collaboration with the University of Surrey. This facility is used to autonomously refine the timing of each imaging sequence and calculate final attitude demands.

**Precision Image Geolocation**

The NigeriaSat-2 system is able to geolocate images of Nigeria to an accuracy of <35 meters (CE90) without using ground control points. This is achieved through precise measurement of the position and attitude of the payload at the time of image capture. Monte Carlo simulation results from the performance assessment of geolocation accuracy are shown in Figure 11. The relative orientations between the star camera heads and the payload are calibrated during commissioning by imaging geo-referenced targets, removing the need for precise alignment during build. This can also be used to verify in-flight performance. For the calibration process to be effective it is essential that thermo-elastic distortions are kept to a minimum. This is achieved through a combination of thermal design and the mechanics of the payload and star tracker mounts.

![Figure 11: Geolocation Error Distribution](image)

The mission is to be able to geolocate images to better than 35m without ground control points. To achieve this, the thermo-elastic distortions between star cameras and the imager bore sight are kept to less than 0.001 deg. Additionally, microvibration of the imager must be kept under control to achieve the required image quality. These issues are managed by mounting the VHRI, MRI payloads and the star cameras on a thermo-elastically stable optical bench which is supported on a compliant kinematic mount.

The compliant kinematic mount consists of a number of compliant links. The design of the compliant link is such that effectively it only constrains the optical bench in the axial direction of the link. Each link constrains 1 degree of freedom of the optical bench payload assembly. Thus with 6 correctly placed links the optical bench payload assembly would be fully constrained. The solution adopted uses 7 links which slightly over constrains the assembly. The layout of the optical bench payload assembly is shown in Figure 12.

![Figure 12: Layout of the Optical Bench Payload Assembly](image)

**Thermo Elastic Relief**

The thermal design on NigeriaSat-2 is mainly passive. The satellite therefore experiences significant changes in mean temperature and temperature gradients. The satellite primary structure is fabricated from aluminum-skinned aluminum honeycomb core sandwich panels which distort as a result of the thermal environment. Optimizing the design for thermo-elastic and microvibration produces a solution that is not optimal for strength under launch loads. It was therefore decided to decouple the requirements for the in-orbit performance and launch performance by incorporating a launch lock.
During launch the optical bench payload assembly is supported by 5 hold-down and release devices. Each hold-down and release device consists of a cup and cone pair, a low shock separation nut and an instrumented bolt. During on-orbit commissioning the hold-downs are released and the optical bench payload assembly deploys 2 mm, at which point it engages the kinematic mount. The kinematic mount must survive this deployment shock event. These loads size the kinematic mount but are orders of magnitude lower than the launch loads.

The deployment is driven by a set of springs. These springs are adjusted during assembly to control the deployment energy. For ground testing, different springs are used which compensate for the 1 g gravity loading on the system. This allows deployment tests and microvibration tests to be carried out on the ground without complicated MGSE (Mechanical Ground Support Equipment).

Finite element analysis shows that the 0.001 deg requirement is met under the worst case combinations of 30 deg C variation in the mean temperature of the primary structure, 10 deg C variation in the mean temperature of the optical bench assembly and 5 deg temperature gradients. Since these analyses, the thermal load case has been revised and has been shown to be much better than originally analyzed.

Qualification of the hold-down and release system has been achieved by a spacecraft level structural qualification vibration test. Figure 13 shows the EQM optical bench payload assembly installed in the satellite structural qualification model. Following the spacecraft level structural qualification vibration test, ground deployment tests were performed. These tests were completed without issue.

The deployable optical bench approach has performed as per the original design intent. This enables the satellite to meet the geolocation requirement and the same approach will be applied to our upcoming <1 m GSD imaging missions with 10m geolocation performance.
Small satellites are typically limited in the amount of power that can be devoted to the payload. This becomes a severe limitation in small Earth Observation missions, where a large volume of data is generated, which must then be transmitted to the ground. Many simpler spacecraft systems are limited in their ability to image and downlink simultaneously, to retrieve real-time or stored data during imaging. Simple spacecraft and downlink configurations tend to limit either the data rates achievable, or the timeliness with which imagery in the groundstation vicinity can be returned. SSTL carried out a number of system trades in the SSTL-300 platform design in order to maximize the data throughput. The various configurations considered and choices are discussed further in this section.

The requirement for the SSTL-300 platform is illustrated in Figure 15. There is a need to image, whilst at the same time downlinking stored or real-time image data. In the worst case, the angle between image target and groundstation could be up to ~100 degrees.

An omnidirectional spacecraft antenna is the simplest and cheapest way to support the downlink. It copes well with the needs for an agile mission, but it provides poor gain and drives up the size of the groundstation dish and the cost of the ground segment. In this case, the link budget would be sized for the range with the spacecraft near the local groundstation horizon, but the resulting design will be significantly overdesigned for the case with the spacecraft at zenith.

An isoflux antenna can be used to counteract the change of free-space loss throughout an orbital pass to maintain a constant link margin. The SSTL Beijing-1 and RapidEye platforms include such isoflux antennas. An isoflux antenna provides equal power flux density on the ground. Due to its beam shaping, an isoflux antenna can have gain of up to 2-3dB above that of an omni-directional antenna on the horizon. This configuration is well suited to mapping missions which mostly image at nadir, however when the satellite platform is required to downlink and offpoint simultaneously, for instance to image areas in the same coverage circle of the groundstation, the isoflux antenna solution is no longer efficient other than under some very limited circumstances.

There are various means of improving the link budget, and these include data compression, more efficient modulation schemes, or improvements in power efficiencies of the on-board communications system. Although each of these provides small factors of improvement, none of these can provide the orders of magnitude of improvement demanded in the SSTL-300 system design. On-board data compression seems attractive, but also requires consideration of efficient use of the limited available power. Improvement in the groundstation dish size can provide significant improvement, but this also rapidly increases the lifecycle costs of the groundstation. To gain larger improvement factors, it is necessary to consider the downlink antenna further.

The spacecraft antenna could be configured as a high gain antenna, to improve the link budget. In this case the RF beam is narrower, and the spacecraft must be slewed to track the groundstation during transit. Again, this configuration cannot support simultaneous downlinking and imaging in the groundstation coverage circle. In this case, imagery can only be stored on-board, and retrieved on a subsequent pass, unless a second groundstation is included downrange in the system design.

This situation could be improved by switching between multiple high antennas, but large numbers of antennas would be required in order to make significant
improvements to the link budget. It is also possible to equip the instrument with a steering mirror, but this is also difficult and costly to implement in practice.

In considering this dilemma, SSTL studied how these constraints have been solved on larger spacecraft systems, and has developed a small satellite Antenna Pointing Mechanism (APM) for use on-board its highly agile satellites. This permits SSTL to steer a high gain downlink antenna to focus the available on-board energy in a tight beam to the groundstation, whilst leaving the spacecraft free to point a larger Earth Observation instrument. The system provides a greater than 10-fold improvement in the communications link, which can be used to increase the date rate, or reduce the amount of power required for downlinking. The cost of using the mechanism is more than offset by the savings that can be made, and has been carefully considered in the trade with an electrically steered antenna. Although a mechanical system requires careful design in order to avoid mechanical disturbances, this is not unlike the problem faced with the on-board reaction wheels. SSTL can build on its mechanical and electrical system heritage with its line of reaction wheels, to minimize the development risks for such a mechanical system. A mechanical system also tends to have fewer implementation losses than an electrically steered system, allows different gain and polarization antennas to be implemented for different missions, and thus provided a very attractive solution to improving the SSTL-300 downlink capacity.

**Antenna Pointing Mechanism**

The Antenna Pointing Mechanism (Figure 16) was developed using largely heritage components and technologies, but required testing to qualify it for a 7 year mission. Although antenna pointing mechanisms are used extensively on geostationary missions, for LEO missions such mechanisms are much rarer, and must cover a much greater angular range.

Several configurations of the two axis mechanism were considered and prototyped, but an X-Y mechanism was eventually selected and developed balancing compactness and simplicity in operation. Although flexible coaxial cables were tested, the final design employs RF and power connections internal to the two hinges. A small modular X-band horn antenna was designed, which can be configured for left-hand or right-hand circular polarization.

A qualification unit was developed, which was then tested extensively. The unit was vibration tested using random and sine profiles, and thermally tested in a vacuum chamber. The unit was also life tested in a thermal vacuum chamber, simulating sufficient cycles for nearly 20 years of on-orbit operation. RF tests were performed before and after these tests to ensure there were no changes in performance.

In order to provide a simple interface, the driver electronics are integrated in the unit, and the TM/TC interface is via CAN. A microcontroller and memory are included, so that a predefined track, containing time, elevation and azimuth angles can be uploaded to the unit prior to use.

![Figure 16: Fully Assembled NigeriaSat-X and NigeriaSat-2 Flight Model in Thermal Vacuum Test](image)

**Table 1: Antenna Pointing Mechanism Specifications**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
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<tbody>
<tr>
<td>Articulation</td>
<td>2-axis</td>
</tr>
<tr>
<td></td>
<td>± 110deg elevation</td>
</tr>
<tr>
<td></td>
<td>± 270deg Azimuth</td>
</tr>
<tr>
<td>Pointing</td>
<td>0.024deg steps</td>
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<tr>
<td></td>
<td>Up to 19deg/s rate</td>
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<tr>
<td></td>
<td>0.72deg accuracy</td>
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<tr>
<td>Gain</td>
<td>15dB&gt;C</td>
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<td>Polarisation</td>
<td>LHCP or RHCP</td>
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<tr>
<td>Mass</td>
<td>2.7kg</td>
</tr>
<tr>
<td>Volume</td>
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</table>
ENVIROMENTAL TEST PROGRAM

The NigeriaSat-2 spacecraft was put through SSTL’s standard environmental verification and test campaign (Figure 17). This included vibration test, thermal vacuum test and EMC test as well as mass properties measurement. In addition to these standard test campaigns, the spacecraft also underwent a microvibration test to ensure that the actuators on the spacecraft do not affect the image quality.

SHIPPING, LAUNCH SITE OPERATIONS AND LAUNCH

Both NigeriaSat-2 and NigeriaSat-X were completed in the middle of 2010, and the satellites were placed in storage prior to shipping out to the launch site. Both satellites were finally shipped in April 2011 to the Yasnij Cosmodrome via Moscow in Russia, and subsequently the launch date was set for the 17th August 2011.

Launch site operations included functional test and verification of the key satellite systems, propellant loading, and integration with the DNEPR launch upper stage. The NigeriaSat-X satellite was mounted on the lower section alongside several other co-passengers, and NigeriaSat-2 was mounted on the top-most platform by itself (Figure 18).

LAUNCH AND EARLY ORBIT OPERATIONS

The NigeriaSat-2 and NigeriaSat-X satellites were launched on the 17th August 2011, and placed into a
680 km sun-synchronous orbit. The First contact with both satellites was established in the first passes.

Early operations were highly successful, with the NigeriaSat-X platform being commissioned, with attitude stabilized, and delivering its first images within 3 days from launch. NigeriaSat-2 commissioning also was successful, but due to the larger number of attitude modes and equipment to test took a little longer. The first images were also obtained within a 10 day period, but a longer period was planned to include full image calibration of the mission payload.

Once NigeriaSat-2 was found to be in a healthy condition, the application software was loaded to the On-Board Computer during passes over both the Abuja and Guildford ground stations (Figure 19). The first task was to run the Housekeeping task, which allows telemetry to be sampled and logged outside of ground station coverage. The first telemetry survey sampled magnetometer measurements around a full orbit, to allow the health of the magnetometers to be assessed and to gain a better estimate of the tumble rate of the satellite before starting to detumble. Following the upload of the Housekeeping task, the AOCS software and drive file (containing configuration settings) was loaded.

The AOCS was commanded into DTM at 9:30 UTC on the 18th of August. Detumble converged rapidly and by noon on Day 2, rates had settled into a stable Y-Thompson mode. In this mode, further magnetometer surveys were performed during and the orbital elements in the AOCS software updated in preparation for transition to nadir pointing. Transition into coarse 3-axis pointing mode was commanded on Day 3 and the satellite achieved stable nadir pointing shortly afterwards.

Figure 19: The Abuja Groundstation for NigeriaSat-X and NigeriaSat-2

COMMISSIONING

With the satellite in an Earth-pointing attitude, the commissioning phase began. At this stage, the emphasis moved from AOCS related activities to performing a full check of the platform in preparation for payload operations. The system is built up in a stepwise fashion with individual units being powered on for the first time and checked out as well as the upload of the OBC software required to operate the payload chain.

For the AOCS, this means operating the units that will be used for the operational modes without running them in the loop. After performing the initial checkout of the star tracker and bridge nominal precise 3-axis mode was entered for the first time on Day 5. This mode was then available to support payload commissioning activities. A major driver for the system commissioning schedule was image acquisition for geometric and radiometric calibration of the imaging system. It was found that no tuning was required to the control system or the star trackers as there were no pointing performance issues that affected payload operations. The first image was captured by the spacecraft 8 days after launch.

One notable unplanned event occurred three weeks after launch when SSTL Mission Control received a conjunction warning indicating a 26 meter miss distance between NigeriaSat-2 and a piece of space debris. Operational plans were changed at 2 days notice to complete commissioning of the propulsion system.
(including a short test firing) and perform a collision avoidance maneuver. The rapid response to this, at an early stage of the mission, was in part due to the use of the same control mode for imaging and delta-v and therefore no additional checkout of the AOCS was required beyond a slew to the firing attitude during the propulsion system test firing.

Over the following weeks, the full AOCS to payload chain (including dual head star tracker operation) was fully commissioned. Agile slews were successfully attempted during week 2. Some adjustments to the attitude estimator and wheel command timings on the bridge were required to fine-tune the settling response. A number of AOCS specific calibration activities were performed during commissioning, including:

- Magnetometer calibration in nadir pointing against ground-based modeling.
- Measurement of the relative orientation of the star trackers.
- Calibration of the payload to star tracker orientation using geolocation and image data.
- Calibration of the inertia tensor.

As of late-November 2011, NigeriaSat-2 was beginning the process of being handed over to the customer with the major AOCS calibration activities having been performed. Regular automated imaging sessions were being performed and the system was producing high quality images. The pointing and geolocation performance was shown to be well within pre-launch expectations and all modes of operation of the AOCS had been tested.

Before final handover to The National Space Research and Development Agency (NASRDA), propulsion firings were performed to circularize the orbit, followed by the final Inertia calibration. Ahead of the handover, some minor software modifications have been made to the AOCS software and operating procedures to improve the robustness of the AOCS and improve ease of operations. Finally, with the system in its operational state, a representative scenario involving image capture in all modes has been performed to contractually verify that the system meets its mission requirements.

CONCLUSIONS

Increasingly sophisticated small Earth Observation satellite missions are becoming feasible. The SSTL-300 class of platforms, of which NigeriaSat-2 is the first instance, will provide cost effective operational service competing with classical systems costing an order of magnitude greater. In addition, thanks to their smaller, more compact nature, a wide variety of modes of operation are enabled that larger satellites would struggle to achieve.

NigeriaSat-2 has demonstrated just how much performance can be achieved with a satellite of this class. The mission will enable NASRDA and Nigeria as a whole to reap even more benefits from those gained from NigeriaSat-1.

REFERENCES


Figure 20: An Early Image of Dubai, Taken with Extreme Off-Pointing