DEVELOPMENT OF AN EXPERIMENTAL MICRO-SATELLITE

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ABSTRACT: On 20 April 2011, the first Singapore experimental micro-satellite (called “XSAT”) was piggyback launched with India PSLV-C16 rocket into a sun-synchronous orbit at altitude of about 820km. The launch was successful and the subsequent in-orbit-tests had been completed including the primary imaging operations with near real-time data down link to Singapore ground stations. The success of this project marked a historical event for Singapore to have an indigenously designed and developed micro-satellite launched into orbit for remote sensing applications. This paper describes the development of this 106.68kg micro-satellite using the three-model development philosophy. The various systems level environments tests conducted on the experimental micro-satellite would be briefly mentioned and that sample images were also included into the paper.

1. INTRODUCTION

1.1 Motivation

In 1999, Nanyang Technological University (NTU) had piggyback launched a store-and-forward communication payload with UoSat-12 mini-satellite from University of Surrey. The success of this project had generated much interest to work on a complete Research & Development (R&D) micro-satellite. To draw on more local partners to jointly undertake such development, NTU partnered DSO National Laboratories who has experience in complex project development to form a joint centre at NTU with the objective to design, develop and launch an experimental micro-satellite (called “XSAT”). It has also partnered National University of Singapore (NUS), Centre for Remote Imaging Sensing and Processing (CRISP) related to imaging payload data processing.

1.2 Missions of XSAT Micro-satellite [1]

The primary mission payload is an imaging payload (called “°I R”¡±) of 3 ml-spectral bands with a ground sampling distance of 10m (with respect to 685km altitude). The three spectral bands of the imaging instrument are: 0.52~0.6μm, 0.63~0.69μm and 0.76~0.89μm. The swath will be better than 50km. In addition, the imaging data will be down-linked to the ground segment in a near real-time fashion, i.e. within the same orbital pass. This feature is unique for micro-satellite application as it will bring about very high operational pay-offs besides pushing the technologies involved in such a micro-satellite configuration. The two secondary mission payloads are a GPS Receiver from German Aerospace Centre (DLR) for advanced navigation experiment and a software research payload (called “°parallel processing uni” or PPU in short) from NTU.

1.3 XSAT Project Objectives

The XSAT experimental micro-satellite project has the following aims:
(a) To develop a low cost micro-satellite bus capable of performing near real-time remote sensing operations.
(b) To build-up in country capability (resources and facilities) in satellite engineering.
(c) To promote academic interest for R&D in this area.

2. OVERVIEW OF XSAT MICRO-SATELLITE

2.1 Overall System Specifications

The micro-satellite meant for the development has been decided to be of 120kg class. This is consistent with the plan to get the satellite launched in a piggy-back fashion with India Polar Satellite Launch Vehicle (PSLV) rocket for which a launch service contract was signed in 2003. The satellite’¯s mission payloads include an imaging camera (called “°I R”¡±) from South Korea (SaTReC Initiative) and two secondary msion payloads (DLR GPS and PPU). The overall system specifications established through systems requirements engineering process and overall system design are summarized as follows:

Orbit	Sun-synchronous
Altitude	817km
Imaging Payload	Electro-optical with 3 MS bands
Ground Sampling Distance	12m
Swath	>50km
Mass	<120kg
Physical Size	0.6m ¡Á 0.6m ¡Á 0.
Attitude Control	3-axis with 0.33o (roll & pitch) and 1 o (yaw)
Solar Panels	247 watts at end-of-life (2 deployable and 1 fixed)
Battery	Li-Ion (13.5 A-Hrs)
Telemetry Tracking & Command	S-Band (CCSDS)
Downlink	X-Band 50Mbps

Table 1. Overall Micro-satellite System Requirements

2.2 XSAT Overall Configuration

The overall design configuration of the microsatellite is shown in Figure 1. The electro-optical camera together with the star tracker was mounted on a special deck (called “° optical dec”¡±) so that their performance in term of pointin direction for imaging and attitude control pointing can be harmonized. The TT&C components were deemed to be sensitive and were all mounted on a dedicated deck. The rest of the electronic modules such as on-board-data-handling, attitude control interface, power modules were stacked together in the form of 11 trays.

A mechanical frame was designed around the integrated electronic modules to provide the structure integrity [2]. This design consideration greatly facilitated the assembly and integration of modules such as solar panels. Carefully chosen locations around the satellite structure were used to implement mounting bolt for transportation and handling purpose. The base-plate of the satellite is designed to have good stiffness to be interfaced with the satellite’¯s separation ring (IBL-298) which will be provided by the PSLV launch service provider (ISRO).

The XSAT experimental micro-satellite has a body-mounted fixed solar panel and 2 deployable solar panels which were held by one metallic string each. This string will be cut by the respective pyrotechnic cable-cutter. The satellite will be launched with the solar panels in the stowed configuration so as to meet the launcher volumetric constraints. These pyrotechnic cable-cutters would then be activated by sending a ground command to the satellite during the in-orbit-test. The design consideration for using a fix and 2 deployable solar panels is to fully make use of available space to generate the required power needed for satellite operations. The Li-ion battery was located near the base of the micro-satellite and it is wrapped by a thermal blanket (not shown in Figure 1.) so as to have a passive control of the temperatures during its operation in space. The various attitude control actuators and sensors were mounted in locations inside (e.g. reaction wheels and magnetic torquers) and outside (e.g. sun-sensors) the satellite.

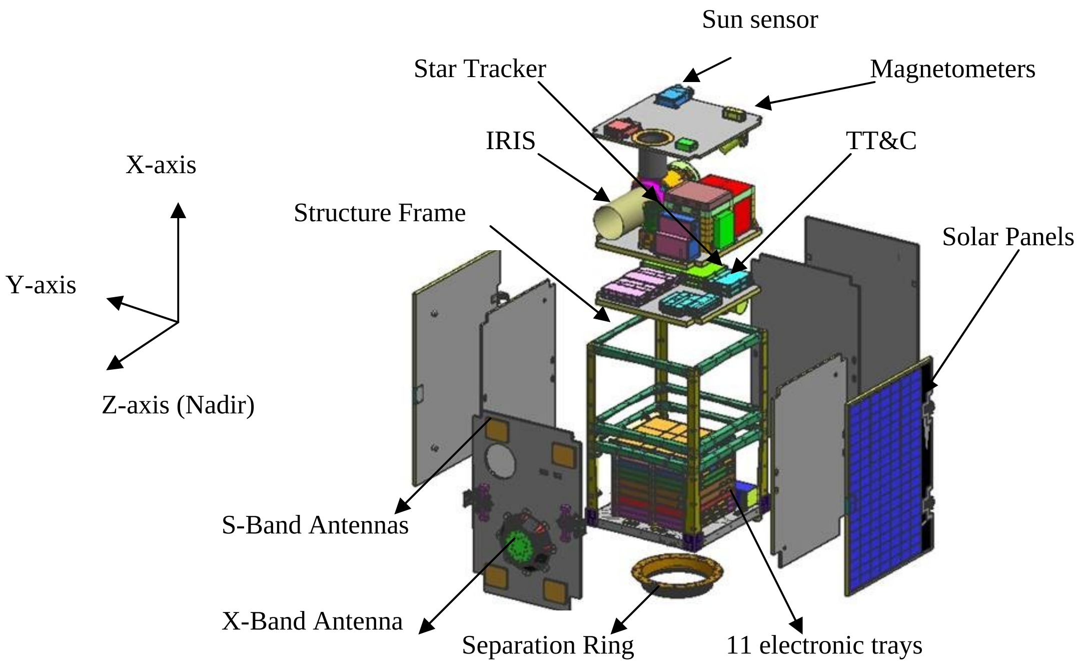

Figure 1. XSAT Configuration

3. SATELLITE DEVELOPMENT

3.1 Philosophy of the development

This was the very first time Singapore was developing a complete micro-satellite from scratch. The emphasis of the development is on micro-satellite bus, payloads-to-bus interface and integration and also launch-campaign. Being the first time in such complex system development, a cautious approach is taken in the project. It used a 3-model development approach. Essentially, the project had developed 3 physical systems/models for specific development objective so as to lead to a final flight model which would be ready for launch.

3.2 Engineering Model (EM) Development

The main purpose of developing an engineering model (EM) was to confirm the functional working of the micro-satellite (structure and electronics). The development of engineering model consisted of two parts, i.e. a structure model (SM) and an engineering-test-bed (ETB). The SM was used to confirm the structure integrity of the micro-satellite design that it would survive the launch environmental vibrations. The ETB was used to confirm the functional interface requirements of all electronic modules For the XSAT micro-satellite, the engineering model development took a period of about 18 months. Figure 2 & Figure 3 below shows the SM and ETB respectively.

The development of SM involved building up a one-to-one full size mechanical structure with the electronic modules modeled as mechanical dummies. The SM had mechanically same characteristics as that of the flight model. The SM was subject to a vibration test using the test profile provided by the PSLV launch service provider [3] at a general (non clean-room) facility in Singapore. The measurement of SM vibration test had confirmed that the structure design was able to cope with the launcher requirement in the aspect of fundamental modes.

The development of the ETB involved developing of all bus subsystem modules using COTS components. Engineering model of the payloads (space camera, and DLR GPS and PPU) was also included in the integration and test of the entire ETB. The integration and test of the ETB took about 6 months to complete. It started first with individual module-level test followed by subsystems test involving several modules. The system-level test of the ETB was then done at the last 2 months to establish that the functional interface of all electronic modules are in accordance to the specified requirements.

Remarks: EM was completed in January 2007 and the results were reviewed by an international review panel consisting of experts from India, South Korea, Israel and USA. The review panel assessed that the XSAT micro-satellite design as seen from EM had good redundancy considerations. They had encouraged the project team to move ahead with development of Qualification Model (QM) and Flight Model (FM).

Figure 2. XSAT Structure Model (SM)

Figure 3. Engineering Test Bed

3.3 Qualification Model (QM) Development

The main purpose of developing a qualification model (QM) was to confirm the micro-satellite system was able to perform its primary mission satisfactorily in the intended space environment with good margin. The QM development involved setting up of processes and procedures related to space systems development. Firstly, a clean room with class 10K was developed. A team of 9 certified technicians capable of doing manufacturing and assembly (M&A) works on project's printed circuit boards (PCBs) and harness was also trained The space standards attained are at the level of ECSS 70-08, 70-38 & 70-28 for soldering and IPC/WHMA-A-620 for wire harness. The technical process involved soldering, re-work, thermal coating, in-coming and in-process inspection and test, kitting records preparation and traveler logs. This was a unique capability previously not available in Singapore.

The product assurance (PA) approach for the project was built upon Quality Management System (QMS) of DSO National Laboratories related to complex project development and added with customized practices to address the unique requirements of XSAT satellite design. The quality standard achieved today in the project is on par if not higher than AS9100 (Standard for Aerospace Application). Besides qualified processes were built up, the project had developed and established a Parts Control Plan which covered electronic & electrical (EE) parts for approved use in the project. This had enabled us to deterministically control and manage parts that are used in the project such that these EE parts will survive the radiation environment in space (e.g. total-ionization-dose (TID) and single-event-effects (SEE)). All the EE parts used in the project were carefully analyzed to ensure its flight worthiness. Industrial or COTS parts can be used provided they had heritage (known to be used for similar space applications) and if not required permission from project director.

The qualification model (QM) development was done mainly in two stages. The first stage involved the integration and tests of all electronic and electrical modules in a flat-sat configuration inside the Assembly-Integration-Test (AIT) clean room. Once this stage was completed, the electronic modules would be integrated in a stack-up configuration. This completed micro-satellite QM would consist of mechanical structure, electronic hardware and also related software for the full functioning of the micro-satellite.

The development of QM basically started about 2 months after completion of EM. These two months were needed to close and follow-up on actions items related to improving the satellite design. The entire QM development took about 18 months and that QM was completed in November 2008. It was then transported to ISRO facilities in Mid November 2008 for a one-month long of environment test. It had completed the test in December 2008 except one area that was not satisfactory, namely the excess vibrations observed on the solar panels.


Figure 4. QM in flat-sat

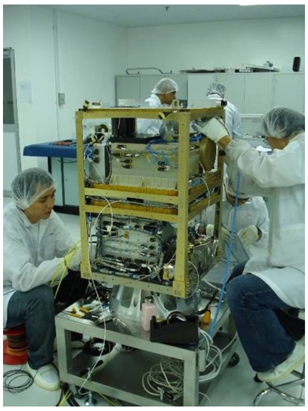
Figure 5. QM in stack-up


Figure 6. QM being containerized

To mitigate the excessive vibration of the solar panels, we had implemented a three-pronged solution covering structure design stiffening (to create separation between the satellite structure fundamental mode with that of the solar panels), use of CFRP face sheet material (to create better damping characteristics) and use of notching profile (to negotiate with launch service provider for notching the input vibration profile so as to avoid over-testing or over-stressing the satellite) in flight model acceptance test. The vibration test also revealed a structural weakness of the optical deck carrying the IRIS camera. This was resolved by using a denser core of the honey comb materials for the optical deck.

3.4 Flight Model (FM) Development

The purpose of developing a flight model (FM) is to prepare a final satellite for launch and operations. The FM development had made use of actual flight modules for integration and test. The qualified processes as set up for QM development were also used for FM development. The process of FM development was similar to that of QM as it also covered two stages, namely FM at flat-sat level and at stack-up level.

The development of FM took about 12 months. It started immediately after the completion of QM in December 2008 and was completed in October 2009 for it to be shipped to ISRO facilities for the final one-month long flight acceptance test. The flight model had successfully completed and cleared all the flight acceptance tests in December 2009. The XSAT experimental micro-satellite was ready-for-launch in December 2009.

It should be highlighted that the procurement of all parts and modules for both QM and FM was carried out together. This was the mainly reason that we could complete the FM development within a year once the QM development was able to confirm the design has adequate margins to survive the launch environment and to operate in space environment. For the XSAT project, although the development of FM was supposed to be straight forward, some nasty problems were encountered. These issues were not pretty as they occurred at an FM stage of the project. These issues were:

(1) Export control restriction with sun-sensors:
The sun-sensors that were successfully tested for QM could not be used for FM due to export control restriction that was only surfaced at the start of FM development. This had led the team to quickly look for replacement sun-sensors and make design change on the electronic interface.

(2) Discovery of counterfeit parts in some FM modules:
We had found out during the thermal cycling test that there were counterfeit LTC-1480 parts entering into FM TT&C module. As the part was widely used in other FM electronic modules, a decision was taken to replace all the LTC-1480 parts in the FM modules. This had led to an accelerated procurement from a qualified source of the LTC-1480 and also replacement re-works on all the affected FM electronic modules.

(3) Interference during the use of DLR GPS on the FM:
This issue was not shown in the FM flat-sat integration and test. It showed up during the FM phase. The suspected cause was the ground loop interference. This had led to a hardware change in isolating/breaking the ground loop and also a slight software change so the on-board-computer would not response to PPS signal of DLR GPS.

(4) No activity on the CAN-bus found on FM Flat-sat
This issue was only detected on the FM Flat-sat during one of the ground practice of launch-and-early-operation. It did not show up at the FM stack-up. The issue appeared to be because interrupt service requests were not serviced and cleared by on-board-computer with the version of the flight software we had on FM. To mitigate this, a small exception routine in the flight software was written and added to the final flight software of the FM meant for flight. Just to be careful that we did not create or trigger other problems by adding this exception code, this modified flight software was only loaded into the primary boot image of the on-board-computers whereas the secondary boot image still contained the previous version of the flight software (i.e. without this exception routine). As this exception code could not be tested by injecting/repeating this issue in the laboratories, long duration running of the FM with the modified software was also conducted to provide further confidence as to the flight software change.

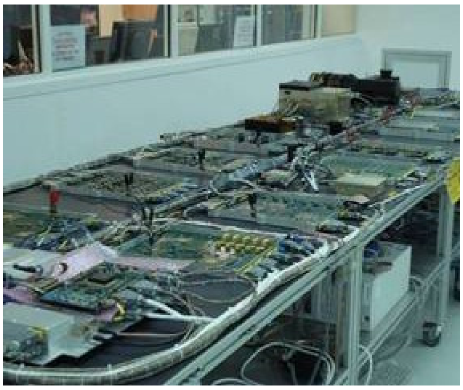
Figure 7. FM in flat-sat

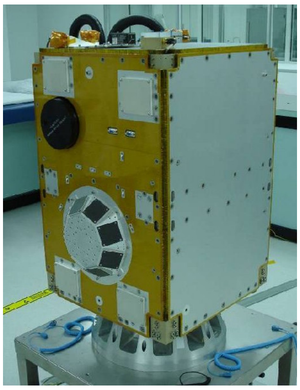
Figure 8. FM in stack-up

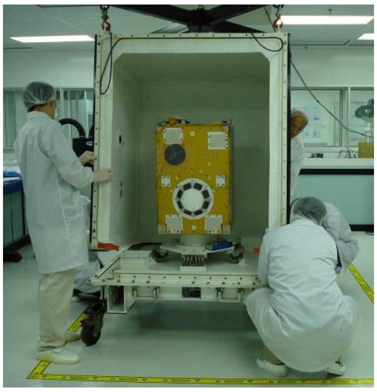
Figure 9. FM being containerized

4. Environment TESTS
The environmental tests for both the qualification model (QM) and flight model (FM) were part of the launch service contract with ISRO launch service provider. Both the environmental tests for XSAT micro-satellite were carried out in ISRO Satellite Centre in Bangalore. The test period was about one-month each. Generally, the environmental test for XSAT micro-satellite included the following activities [3]:

(1) Dynamic Balancing, Centre-of-Gravity (CG) and Moment-of-Inertia (MOI) measurements: These measurements basically established the balancing mass required to balance the satellite to meet the PSLV requirement. The MOI measurements were used for the attitude control team to fine tune the attitude control laws for the flight model.

(2) Thermal Vacuum Test: The QM/FM was placed inside a thermal vacuum chamber and put through about 5 days of continuous test. The test profile consisted of essentially a cold-soak, a ramp-up and a hot soak, each of about 8

hours. These tests basically “°pushe”¡± the various modules of the QM/FM as much as possible to near th qualification/flight-acceptance temperatures. During the process of the thermal vacuum test, the QM/FM was being operated involving its electronic modules hardware and software.

(3) Solar Panels Deployment Test: The QM/FM together with the installed pyrotechnic cable-cutters holding the solar panels was tested. This involved sending a command to the satellite (QM/FM) to trigger the “°firin”¡± of th pyrotechnic cable-cutters resulting into the solar panels being deployed.

(4) Vibration Test: The QM/FM was subjected to sine and random vibrations and the test input profiles were based on agreed test profile established during the coupled-load-analysis involving XSAT and PSLV rocket. The sine vibration was to make sure there was sufficient separation between the fundamental modes of the satellite and the PSLV rocket. The random vibration was to establish that the electronic onboard the satellite (QM/FM) would be able to survive the launch-induced vibration during the take-off. The test level for QM was higher and more stringent than that of FM. In addition, test profile for FM had included a notching profile so as to minimize over-testing the FM. The vibration test was the last test. The rationale was that immediately after the vibration test, the XSAT FM would not zero/minimal activities so that this tested configuration would stay till the satellite integration to the launcher.

5. SAMPLE IMAGES

The XSAT Flight Model (FM) was ready for launch in December 2009. Due to some delays with the launch service, XSAT was shipped to launch site (Sriharikota) in November 2010. This was followed by pre-launch preparations which lasted about total 5 months due to some start-stops of the launch campaign. The XSAT micro-satellite was eventually launched on 20 April 2011. It had managed to de-tumble to desired condition within one orbit. Three days later, the solar panels were deployed by sending a command from the mission control station to fire the pyrotechnic cable-cutters. Thereafter, the IRIS camera and the X-band downlink were switched on among other electronic modules. About 15 days after launch, the satellite had performed some imaging operations satisfactorily. Some of the sample images (courtesy of NUS Centre for Remote Imaging Sensing & Processing) are as follows:

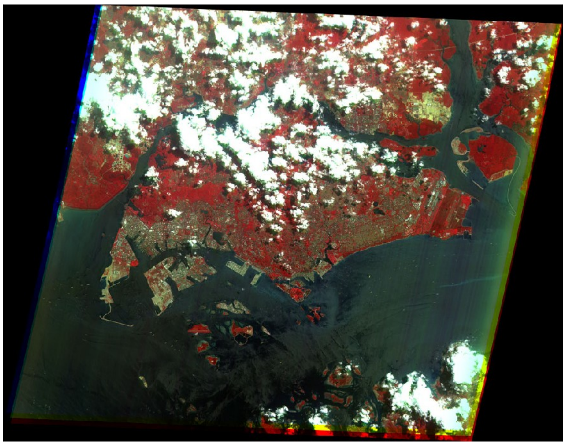

Figure 10. Image of Singapore (11 May 2011)

Figure 11. Image of Egyptian Pyramids (23 June 2011)

6. CONCLUSION

The XSAT experimental micro-satellite project is a path-finding project for Singapore/NTU to gain insights as to the design, development, launch campaign and operations of a micro-satellite. The satellite development via a three-model approach (EM, QM & FM) had led to build up of a full fledged micro-satellite expertise in Singapore.

References

[1] Timo Bretschneider, Soon Hie Tan, Cher Hiang Goh, K. Arichandran, Wee Eng Koh and Eberhard Gill, “° -Sat Mission Progress”±, Proceeings of the 5th IAA Symposium on Small Satellites for Earth Observation, Berlin, Germany, 4-8 April, 2005.

[2] Yu Qing, Yu Hao Yong, Choong Wai Fook, Tai Siew Hoong and Goh Cher Hiang, “°The XSAT Project and Description of the Payload Configuration and Structure Design”±, Proceedings of the Second Asian Space Conference, Hanoi, Vietnam, 8-11 November 2005.

[3] PSLV-XSAT Interface Control Document (ICD), Issue 2, Oct 2010.