Miniaturization Techniques to Realize Very Small and Cost-Efficient Satellites

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ABSTRACT

The Space Flight Laboratory (SFL) at the University of Toronto Institute for Aerospace Studies (UTIAS) develops advanced nanosatellites for various applications using the microspace philosophy. SFL currently has four operational spacecraft in orbit. Three of the four spacecraft are nanosatellites: the 3.5 kilogram CanX-2, 6.5 kilogram NTS, and 6.5 kilogram AISSat-1. Launched in April 2008, CanX-2 is three-axis stabilized spacecraft for technology demonstration and atmospheric science. NTS is a passively stabilized spacecraft for ship tracking. NTS was also launched in April 2008 following a 6-month development schedule, demonstrating responsive space. AISSat-1 was launched in July 2010 and is serving as a ship tracking spacecraft. AISSat-1 is the first spacecraft that is based on the SFL's Generic Nanosatellite Bus (GNB) with three-axis attitude control capability enabled by reaction wheels, magnetic torquer, magnetometer, and fine sun sensors. Eleven additional nanosatellites are currently at various stages of development at SFL. These include the BRIght Target Explorer (BRITE) space astronomy constellation, comprising six 6.5 kilogram spacecraft each carrying a 3-cm aperture telescope and with 1 arc-minute pointing stability. Two 6.5 kilogram spacecraft, CanX-4 and CanX-5, intend to demonstrate precision formation-flying using differential GPS and a liquid-fueled nano propulsion system. Another spacecraft called CanX-7 will demonstrate a new de-orbiting technology. AISSat-2 is under construction and will follow the footsteps of AISSat-1. SFL is also developing a 15 kilogram bus called the NEMO (Nanosatellite for Earth Monitoring and Observation) bus. The NEMO bus is an extension of the GNB for larger payloads that require more power and data throughput. The first satellite based on the NEMO bus is NEMO-AM (Aerosol Monitoring), which will be used to study regional aerosol distribution in the atmosphere over India using a multi-band, dual-polarization optical instrument. SFL also builds its own separation systems called XPOD and arranges cluster launches through its Nanosatellite Launch Service (NLS) program. In addition SFL maintains a network of ground stations across Canada and Europe.

1.0 INTRODUCTION

The Space Flight Laboratory (SFL) at the University of Toronto Institute for Aerospace Studies (UTIAS) builds advanced nanosatellites for various applications. These spacecraft weigh anywhere from 3.5 kg to 15 kg. These spacecraft incorporate a number of advanced technologies which enable these spacecraft to realize a level of performance that is state-of-the-art [1][2][3].

These spacecraft build upon a set of common components and technologies that are shared across multiple missions and implement an architecture that is directly expandable to larger, operational missions. The development of these missions follows the microspace approach for managing risks and ensuring rapid development, which maintains cost-effectiveness and responsiveness for new missions.

A spacecraft can be put together and achieve flight-readiness in as little as 6 months from the time of project inception, depending on the complexity of the mission [4]. Typically each spacecraft implements multiple on-board computers, high data rate radios, sensors and actuators in a robust system architecture with significant, yet inexpensive redundancy. The subsystem complement and the complexity of the spacecraft can be tailored to meet various mission needs, from a passively stabilized spacecraft using permanent magnets to a three-axis stabilized platform with reaction wheels with optional propulsion system. The spacecraft can also accommodate fixed appendages such as booms, antennas, and additional solar panels.

2.0 PHILOSOPHY

2.1 Microspace Approach

The *microspace approach* focuses the design efforts on the established mission requirements. By focusing on what is important for the mission, the design of the spacecraft can be simplified. A simplified design typically results an improved reliability, as the design is less complex and has lower part count. This approach is intended to result in a simplified spacecraft that is cost-effective and can be turned around in a relatively short period of time.

2.2 Top-Down Approach

Top-down analysis is done based on the operational or mission requirements. This includes the lifetime requirement, data throughput requirement and attitude control and knowledge requirements, etc. Top-down approach also considers the funding level and the resource that is available to the program. Schedule is also a top-down consideration, and in turn may drive certain design decisions.

The orbit requirement is typically one that has to undergo a trade study. A nanosatellite typically launches as a secondary payload, therefore it is subject to the launch parameters of the primary payload on the launch. The availability of launches will in turn drive certain design requirements. SFL nanosatellites are typically designed to work in a wide range of orbital inclination and altitude. Once a launch has been selected, associated launch date provides a fixed deadline for the team to work towards.

2.3 Bottom-Up Approach

The bottom-up analysis takes into account the limitations of existing hardware. For example, this includes limits on the amount of on-board memory available, the downlink data rate, the available power, the available payload volume, etc.

The maturity and readiness of next generation technologies are also included in the bottom-up analysis. Next generation technology can be an alternative, higher-performance solution, but only if the maturity of that particular technology can be fast-tracked to meet the stringent program schedule [4].

SFL implements commercial off-the-shelf (COTS) technologies in its nanosatellite. This allows SFL spacecraft to benefit from the latest COTS technologies, which tend to have better performance, higher power efficiency, smaller package, and lower cost, as compared to their aerospace-grade equivalent. Once a promising COTS technology has been identified, it is then put through a rigorous acceptance procedure. This includes a multitude of functional testing and radiation testing. Technologies and components that have successfully passed the tests can then be implemented on the nanosatellite.

2.4 Multi-Disciplinary Approach

SFL employs a multi-disciplinary approach to the design of its spacecraft and subsystems. This is enabled by a team with diverse background, expertise and experience in designing space systems. The multi-disciplinary approach results in a system that has integrated functionality. Such system can better make use of the limited resources that are available in a nanosatellite.

2.5 Balance Between Risks and Rewards

Traditional space approach typically concentrates in minimizing risks, and this typically results in an extended development time and higher cost. SFL approach to spacecraft design balances the risks and the rewards (return of investment). By accepting some risks, a space system can be developed faster with lower cost and can be deployed faster [4].

3.0 STRATEGY

3.1 Iterative Top-Down and Bottom-Up

The development strategy of SFL nanosatellites typically involves iterating the mission requirements against the results of top-down and bottom-up analyses outlined above.

The iteration process looks at the possibility of relaxing the mission requirements when warranted. This requires an understanding of the mission requirements and the implications of the individual mission requirement on the spacecraft design, and the implications of certain design decisions on the mission objective(s).

Tailored implementation of specific technologies is also considered. The implementation of each technology should be tailored to meet specific requirements. Certain new technologies may be well suited in a particular implementation. In some cases, the maturity of a certain technology may be advanced for a specific implementation.

3.2 Rapid Prototyping

A design concept is tested through prototyping. Prototyping will provide rapid feedback on whether a solution works as intended, and will outline the strengths and weaknesses of a particular design approach. The required adjustments can then be implemented in the next iteration of the design. This iterative process will help bring the design to maturity at a rapid pace and shorten the overall development phase.

3.3 Tightly Integrated Team

The design team typically works very tightly with the principal investigator and/or the payload provider of the mission. This ensures that the approach to the mission and hardware design is consistent with all of the requirements and constraints throughout the various phase of the program. This also allows both the design team and the principal investigator to become familiar with the various requirements and constraints of the program, and to adjust the requirements as necessary to meet the constraints, and vice versa.

4.0 CURRENT TECHNOLOGY

4.1 Spacecraft Platform

SFL has three different spacecraft platforms to suit various mission needs, comprising the 10 cm by 10 cm by 34 cm CanX-2 platform (Figure 1), the 20 cm by 20 cm by 20 cm Generic Nanosatellite Bus (GNB) platform (Figure 3), and the 20 cm by 20 cm by 40 cm Nanosatellite for Earth Monitoring and Observation (NEMO) platform (Figure 6). Table 1 below summarizes the capabilities of each platform.

Table 1: Nanosatellite Platform Comparison.

	CanX-2	GNB	NEMO
Spacecraft Mass	3.5 kg	7.5 kg	15 kg
Spacecraft Volume	10 x 10 x 34 cm	20 x 20 x 20 cm	20 x 20 x 40 cm
Peak Power at 25 °C, BOL	2 to 7 W	7 to 9 W	80 W
Payload Mass	1 kg	2 kg	9 kg
Payload Volume	1000 cm^3	1700 cm^3	8000 cm^3
Payload Power @ % duty cycle	1 to 2 W @ 100%	3 to 4 W @ 100 % 6 W max	45 W @ 20% min 60 W max
Battery Capacity and Type	17 W h Li-ion	34 W h Li-ion	Up to 160 Wh Li-ion
ACS Stablity	2 deg	2 deg to 60 arc-second	2 deg to 60 arc-second
Downlink	32 k to 1 Mbps	32 k to 1 Mbps	32 k to 2 Mbps
Status	Operational since 2008	Operational since 2010	Under development for 2011

4.1.1 CanX-2 Platform

The CanX-2 platform is named after the CanX-2 spacecraft (Figure 1), which has been operational since April 2008. The three-axis stabilized, one-axis controlled CanX-2 continues to perform as a technology demonstrator and an atmospheric science platform.

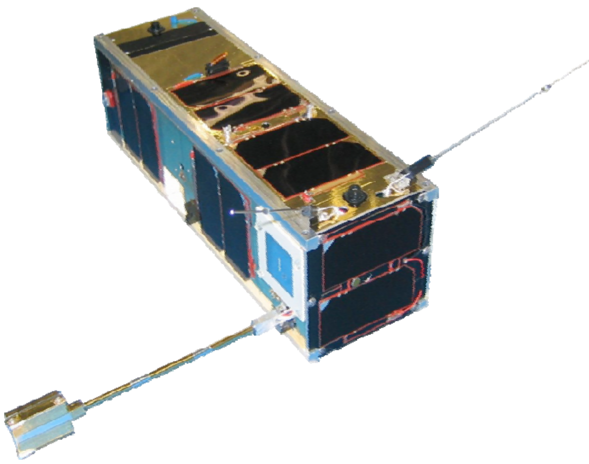

Figure 1: The CanX-2 Platform.

The NTS spacecraft implements CanX-2 electronics in the GNB form factor and includes a 46 cm fixed payload antenna. NTS was developed within seven months, from contract start to launch, demonstrating responsive space. NTS is passively stabilized, using permanent magnet and hysteresis rods. It has been operational since 2008, launched alongside CanX-2.

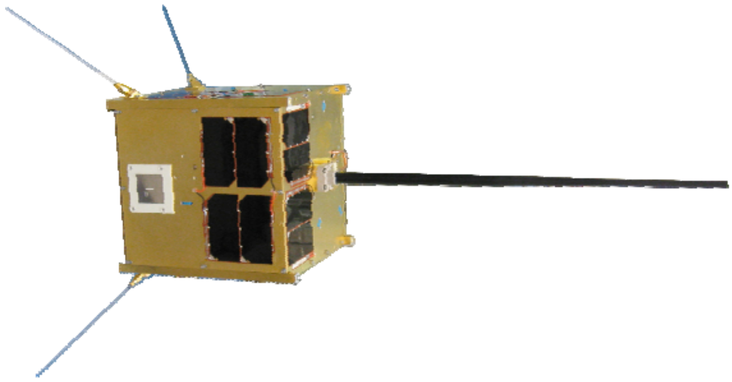

Figure 2: NTS Spacecraft.

4.1.2 GNB Platform

The 20 cm by 20 cm by 20 cm GNB platform is a three-axis controlled platform (Figure 3). The platform is able to accommodate payload up to 2 kg, and 8 cm by 13 cm by 17 cm payload (Figure 4). In addition, the GNB can be equipped with fixed appendages such as antennas and booms.

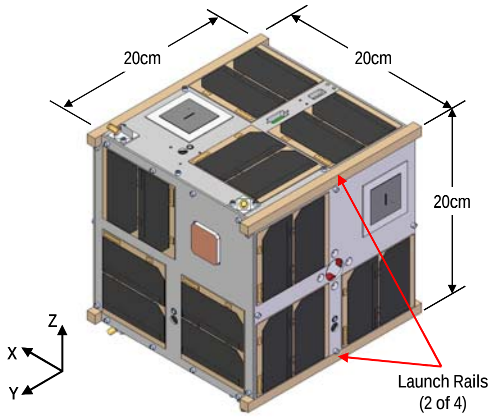

Figure 3: The GNB Platform.

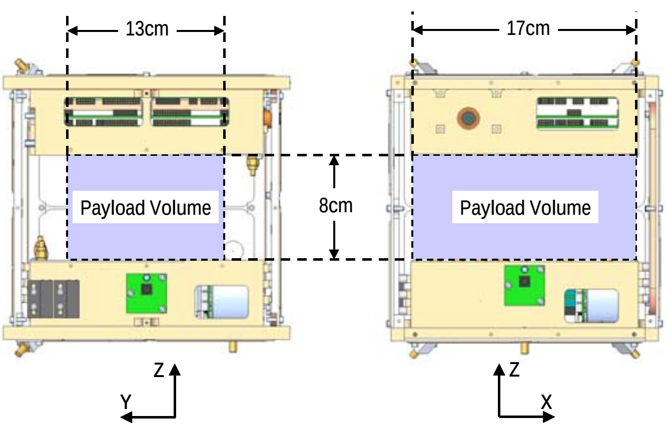

Figure 4: Payload Accommodation within the GNB Platform.

The platform has been operational since July 2010 with the launch of AISSat-1 (Figure 5). In addition to the four 17 cm UHF monopoles and a magnetometer boom, AISSat-1 also includes a 46 cm fixed payload antenna.

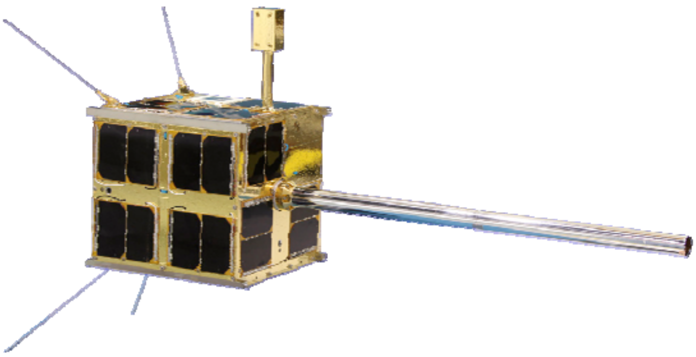

Figure 5: AISSat-1 Spacecraft.

4.1.3 NEMO Platform

The experience obtained during the development of the GNB missions helped shape the development of the next generation bus. A survey of past, present, future mission requirement was performed to understand the requirements for advanced missions and payloads. The survey suggests a requirement of higher power for high data throughput (use of high power transmitter in higher bands); larger payload volume; larger instrument aperture (exterior surface); additional system resources overall (three-axes stabilization, larger reaction wheels, etc.). The new bus shall also improve the overall system efficiency, including payload mass fraction and power density ratio.

This results in the evolution of the SFL GNB technology into the NEMO bus [5]. The new bus builds upon existing GNB components and subsystems to maintain heritage as well as to shorten the development cycle. The NEMO bus implements these existing components and subsystems in an innovative architecture to further enhance the capability and performance of a nanosatellite. NEMO adds a new power system with a higher generation and storage capability, as well as a new computer capable of handling a data rate in excess of 400 Mbps.

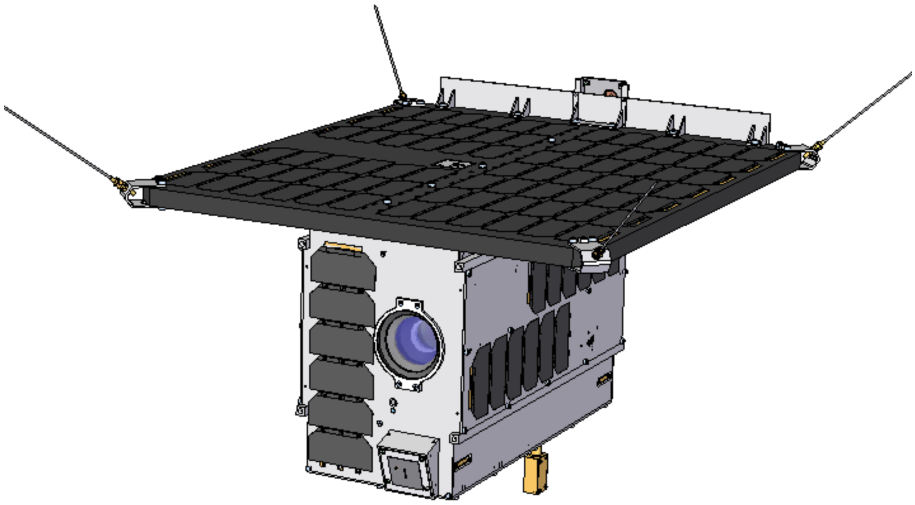

Figure 6: NEMO Platform.

4.2 Architecture

All SFL spacecraft implement a near single-failure tolerant bus architecture. All sensors and actuators have dual connections allowing for operational redundancy. This allows the spacecraft to recover from a failure in one of multiple on-board computers or in one of multiple sets of battery electronics. The spacecraft implements a single-string communication system, due to constraints of the external surface on antennas. This architecture is extendable into a full single-failure tolerant system, which is easily accommodated on a larger spacecraft.

4.3 Subsystem

4.3.1 On-Board Computers

The on-board computers on SFL nanosatellites are based on the ARM7TDMI processors. This family of processors is known for its low power and high performance. In nominal mode with 48MHz clock speed, it is expected that the computer will consume 325 mW, while in the low-power mode with 12 MHz clock speed the power consumption is estimated at 165 mW. Current GNB missions implements a design a 2MB SRAM with Triple-vote EDAC protection, a 256 MB NAND Flash, and a 128 KB ROM. The actual processor used has undergone subsystem-level radiation test.

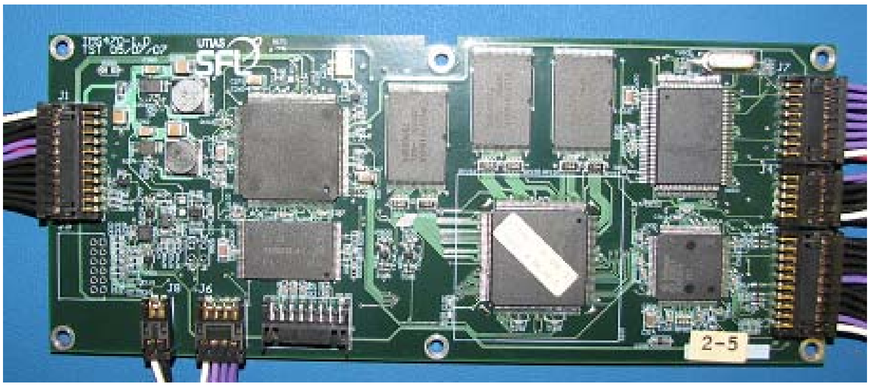

Figure 7: On Board Computer.

The on-board computer uses a multi-threaded operating system developed at SFL. The operating system may be customized to work with a specific application code, or it may also be run as a "black-box" that would only perform data collection from the payload, and data download control to the ground via the radios.

The on-board computer incorporates synchronous and asynchronous serial interfaces, general-purpose input/output channels, 12-bit analog-to-digital converter channels, and pulse-width modulation/timer channel. These may be used to communicate with the payload and the other subsystem on the spacecraft, and may be further customized on a specific build.

A typical SFL spacecraft will include three on-board computers. The first computer is dedicated for housekeeping duties, the second for attitude determination and control subsystem, and the third for payload-related functions. Additional computers may also be added as required.

4.3.2 Power

The power system uses triple-junction solar cells to generate power. Up to 18 two-cell strings may be accommodated on the exterior wall of the GNB. The main array of NEMO can accommodate up to 13 6-

cell strings, for a peak generation of 80 W using a 26-27% efficient solar cells. Power generated by the solar array is transferred to the power system through a peak-power tracking system.

Excess energy is stored on Lithium-ion batteries. A battery charge and discharge regulator (BCDR) is used to manage the operations of the battery (Figure 8). A number of Lithium-ion batteries may be placed in series to increase the storage capacity and to improve the depth-of-discharge. The GNB platform can be equipped with up to 34 Wh of energy storage, while the NEMO platform can be equipped with up to 160 Wh of energy storage.

Figure 8: BCDR (left) and Power Distribution Unit (right).

The power system also incorporates current-limiting circuits. This is designed to alleviate the risks associated with radiation-induced latch-up.

4.3.3 Communications

SFL spacecraft utilizes the UHF frequencies for uplink. An uplink rate of up to 4 kbps is available for command, data and software uploads. Although originally developed for the 437 MHz Amateur UHF frequencies, the design of the radio is compatible a wide range of frequency. This includes the 401-403 MHz earth-to-space band and the 450 MHz band.

Downlink from the spacecraft utilizes the S-band frequencies around 2.2 GHz. The downlink rate is adjustable from 32 kbps to up to 1 Mbps. This intends to make use of the excess link margin available as the spacecraft approaches the ground station during a pass.

Figure 9: UHF receiver (left) and S-Band transmitter (right).

4.3.4 Attitude Control

The attitude control system is capable of providing three-axis control with a 1 arc-minute stability. The altitude control software implements an Extended Kalman Filter that uses the various attitude sensors to predict and corrects the attitude of the spacecraft.

Available attitude sensors include three-axis magnetometer, fine sun sensors, three-axis rate sensor, GPS receiver, and star-tracker (Figure 10). Available attitude actuators include permanent magnet, hysteresis rod, magnetic torquers, and nano reaction wheel (Figure 11).

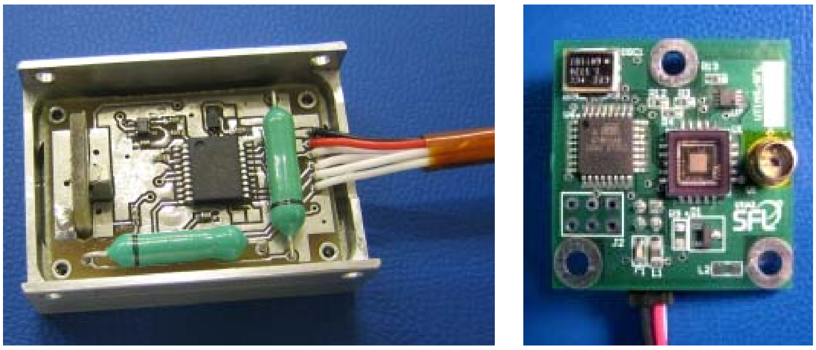

Figure 10: Magnetometer (left) and Fine Sun Sensor (right).

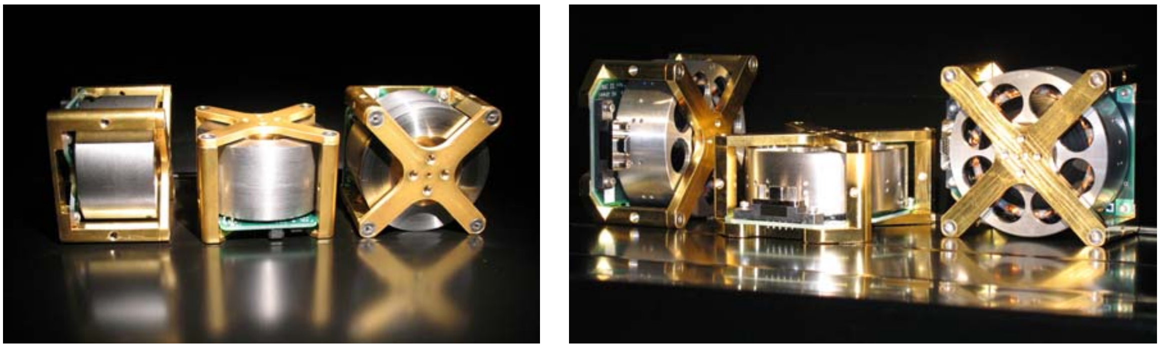

Figure 11: 30 uNm-sec Reaction Wheel (left) and 60 uNm-sec Reaction Wheel (right).

4.3.5 Propulsion

SFL nanosatellite may be equipped with a propulsion system. The system, called CNAPS, is currently under construction for the CanX-4 and CanX-5 formation flying missions (Figure 12). CNAPS is based on the experimental propulsion system that was successfully flown on the CanX-2. CNAPS is based on commercial technology that has been specifically tailored for nanosatellite application.

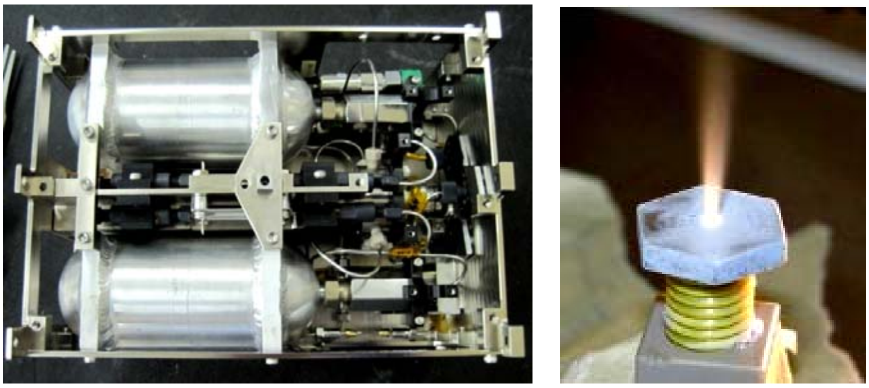

Figure 12: CNAPS.

CNAPS operates as a cold gas and utilizes Sulphur Hexafluoride (SF_6) as propellant to give a specific impulse of 40-45 sec. CNAPS stores SF_6 in liquid form and electronically regulates its operating pressure. The current design of CNAPS incorporate two propellant tanks, fits within a 7 cm by 12.5 cm by 18 cm volume, and is able to provide up to 23 m/s delta-V capability on a 6.5 kg spacecraft. CNAPS can be adapted to carry additional propellant by using larger storage volume. CNAPS implements four thrusters. Each of these four thrusters may be independently activated to trim out any unwanted torque due to thruster offsets.

The system has also been designed to be compatible with Nitrous Oxide (N_2O). N_2O is expected to provide up to 65 sec of specific impulse when operated in cold-gas mode.

4.3.6 Structure

The structure of the spacecraft currently typically uses Aluminum. High-strength Magnesium alloy may also be used in cases where there is a more stringent mass requirement. NEMO will implement a carbon-fibre reinforce panel for the main array, and an advanced Aluminum alloy for the payload structure.

4.3.7 Thermal

The thermal control on SFL nanosatellites is primarily passive. These nanosatellites rely on the use of thermal coatings to adjust the absorptivity and emissivity of its exterior surface to meet the mission's temperature requirements. Active thermal control is only implemented on temperature sensitive components, such as battery and payload.

4.3.8 Separation System

Each spacecraft is secured to the launch vehicle using SFL's space-proven, proprietary XPOD separation system. The XPOD separation system is customizable for spacecraft up to 15 kg in mass and up to 20 cm by 20 cm by 40 cm in size. The XPOD separation system is also able to accommodate fixed appendages, such as a magnetometer boom, a quad-canted circularly polarized UHF (437-450 MHz) monopole system, or a 46 cm VHF (162 MHz) antenna.

To date, SFL's family of XPOD separation systems includes four flight-proven designs (Figure 13):

- XPOD Single, for 1 kg, 10 cm by 10 cm by 10 cm, 1U CubeSat.
- XPOD Triple, for 3.5 kg, 10 cm by 10 cm by 34 cm, 3U CubeSat.
- XPOD Triple-M1, for 3.5 kg, 10 cm by 10 cm by 34 cm, modified 3U CubeSat with additional exterior features.

- XPOD GNB for 7.5, 20 cm by 20 cm by 20 cm GNB spacecraft with fixed antennas and long appendages.

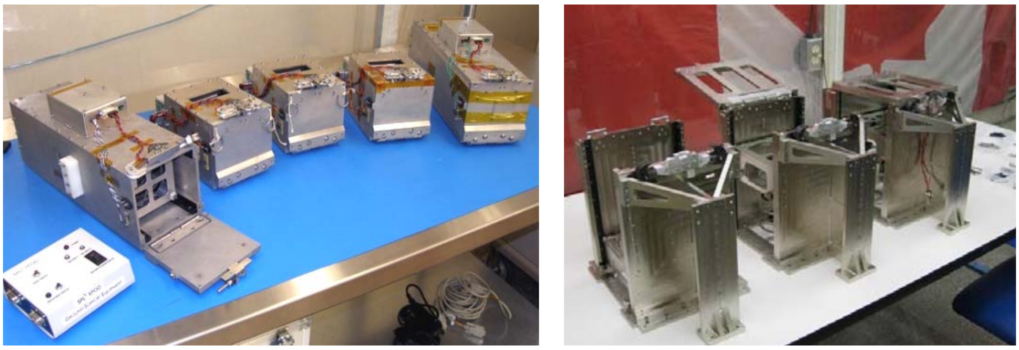

Figure 13: XPOD Separation System.

Additional XPOD designs that can accommodate spacecraft up to 15 kg in mass and 20 cm by 20 cm by 40 cm in size are currently undergoing qualification testing.

SFL procures and manages its own launch activities under the Nanosatellite Launch Service (NLS) program [6]. To date the NLS program has successfully launched sixteen nanosatellites from nine countries in six cluster launches. Two additional launches with a total of five spacecraft have been manifested at the time of writing, while additional launches are under discussion. SFL maintains relationships with several launch providers and has access to different launch opportunities into different orbits, from the sun-synchronous orbits with various ascending or descending node times, to low- and medium-inclination orbits as well as other unique orbits.

4.4 Payloads

4.4.1 Optical Payload

SFL developed and integrated the astronomical instrument for the BRITE mission (Figure 14). The 3-cm aperture telescope is designed to observe the variation in the brightness of bright stars (magnitude +3.5 and brighter). The telescope is then paired with the SFL-developed an ultra-low-noise CCD camera.

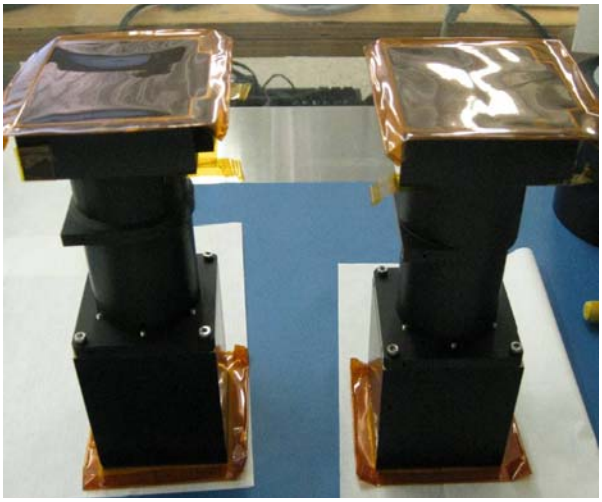

Figure 14: The BRITE Telescope.

SFL is currently developing a multi-spectral, dual polarization instrument. The instrument is able to detect light in the blue, green, red, and near infrared bands, as well as the two polarization components in each band. The instrument will have a nominal ground sampling distance (GSD) towards nadir that is scalable between 40 m to 200 m. The instrument is designed to detect aerosols in the atmosphere, and is being developed as part of the NEMO-AM mission.

The multi-spectral, dual-polarization instrument is a derivative of a high-resolution multi-spectral instrument that is capable of a ground sampling distance of 6 m with 15 km swath (towards nadir from 500 km altitude).

4.4.2 Radio Payload

Expanding upon SFL know-how in RF systems, SFL provided a payload antenna for the AISSat-1 mission. The 46 cm long antenna is tuned to the 162 MHz maritime Automatic Identification System (AIS) frequencies. The antenna is fixed (non-deployable) onto the AISSat-1 structure (Figure 15).

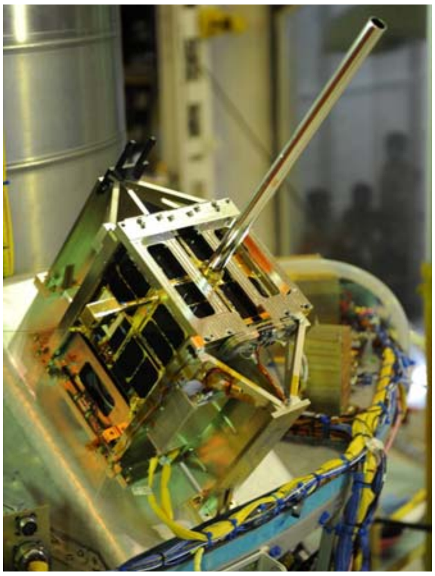

Figure 15: AISSat-1 Launch Configuration, showing the 162 MHz payload antenna.

5.0 OPERATIONAL MISSION

SFL currently has four operational missions: the MOST space telescope; the CanX-2 technology demonstrator and atmospheric science platform; the NTS responsive maritime AIS demonstrator; and the AISSat-1 maritime surveillance platform.

5.1 MOST

To date, SFL's family of XPOD separation systems includes four flight-proven designs (Figure 13):The 53 kg, 60 cm by 60 cm by 30 cm MOST (Microvariability and Oscillations of Stars) spacecraft was launched on June 30, 2003. MOST is now in its eighth year of operations. The spacecraft carries a 15 cm space telescope for accurately measuring the oscillation on a star's brightness, in order to determine the star's properties. SFL played a key role in the development of MOST by providing the on-board computers, telemetry and command subsystem, structure, thermal, assembly, integration, test, launch support, and spacecraft operations.

5.2 CanX-2

The 3.5 kg, 10 cm by 10 cm by 34 cm CanX-2 (Figure 1) was launched on 28 April 2008 as a dual-purpose platform [1]. It is intended to demonstrate several key technologies, and also serve as a atmospheric science platform. CanX-2 is now in its third year of operations, and has successfully demonstrated a number of key nanosatellite technologies from SFL. This includes a nano-reaction wheel, a SF6-based nano propulsion system, low-power computer, various attitude sensors, and a high-speed transmitter.

CanX-2 also carries a GPS receiver. In addition to testing its performance in orbit, the GPS receiver is also being used to obtain GPS radio occultation data to study the upper atmosphere. CanX-2 also carries an atmospheric spectrometer from York University, and a materials experiment from the University of Toronto and Integrity Testing Laboratory.

5.3 NTS

NTS (Nanosatellite Tracking of Ships) was a responsive space mission intended to test a payload that will track the movement of ships. The payload is a maritime AIS (Automated Identification System), designed and built by COM DEV Ltd. NTS was designed, built, and delivered to the launch site within six months from the contractual start date. It was launched on the seventh month, on 28 April 2008 alongside CanX-2. It is now in its third year of operations. NTS has a mass of 6.5 kg and has a main bus measuring 20 cm by 20 cm by 20 cm. In addition, NTS has a fixed 46 cm payload monopole antenna and four UHF monopole antennas (Figure 2).

Figure 16 shows ship traffic near Australia's Great Barrier Reef [7]. This data was captured following an incident in which a cargo ship went off course and ran aground in one of the world's most ecologically sensitive area. The ability for spacecraft like NTS to pinpoint the location of a ship will help to avoid this type of incidents. Results obtained by NTS are now being incorporated in the M3MSat operational AIS microsatellite.

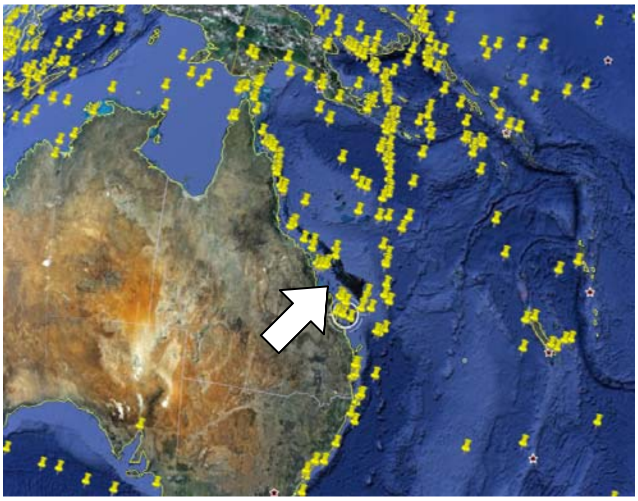

Figure 16: Ship traffic around Australia as detected by NTS. The arrow indicates the location of the cargo ship incident.

5.4 AISSat-1

AISSat-1 (Figure 5) was built for the Norwegian Defense Research Establishment, for the purpose of monitoring ship traffic in the Norwegian waters. The 6.5 kg, 20 cm by 20 cm by 20 cm AISSat-1 carries a Kongsberg-Seatex AIS receiver, connected to a SFL-built 46-cm payload monopole antenna.

AISSat-1 is the first of the GNB spacecraft to be launched. The three-axis stabilization and control on AISSat-1 are being used to experiment with the position of the payload monopole antenna with respect to the local ground directly below the spacecraft. AISSat-1 was launched on 12 July 2010. The spacecraft has a design lifetime of 3 years, while the mission has a lifetime requirement of 1 year.

Figure 17 shows ship locations around the Arctic region and the Norwegian territory, based on the data captured by AISSat-1 within 24 hours after launch [8]. AISSat-1 is now fully operational and provides updated ship positions within the Norwegian territory every one orbital period to the Norwegian authority.

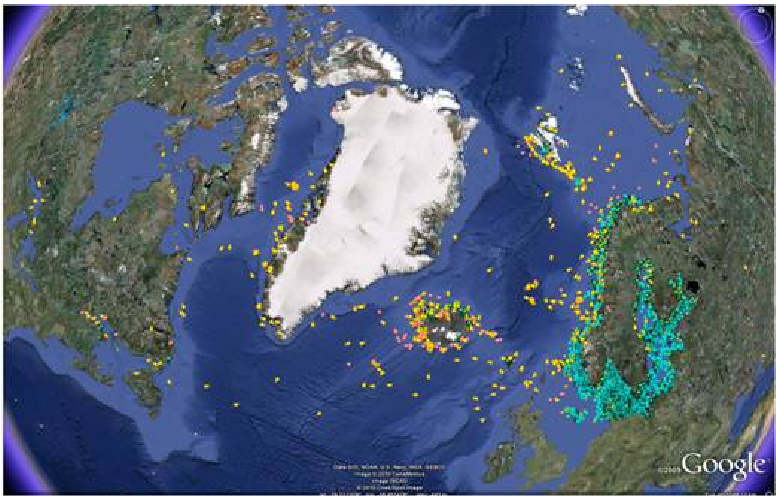

Figure 17: First capture of AIS data by AISSat-1.

6.0 UPCOMING MISSIONS

The components and technologies outlined above are being implemented into eleven nanosatellites that are currently at various stages of development at SFL. Out of these eleven nanosatellites, ten are based on the GNB platform and one is based on the NEMO platform.

6.1 BRIght Target Explorer (BRITE) Constellation

The 6.5 kg, 20 cm by 20 cm by 20 cm BRITE spacecraft (Figure 18), also known as CanX-3, are intended to study oscillations in the light intensity of the most luminous stars (brighter than magnitude +3.5). A total of six spacecraft are under construction: two for Austria (CanX-3A/UniBRITE for University of Vienna, CanX-3B/BRITE-Austria for Graz University of Technology), two for Poland (CanX-3C/BRITE-PL, CanX-3D/BRITE-PL2 for Space Research Centre Polish Academy of Sciences) and two for Canada (CanX-3E/BRITE-Toronto, CanX-3F/BRITE-Montreal for the Canadian Space Agency).

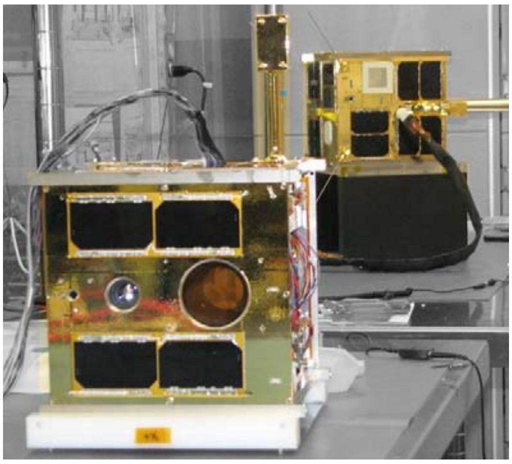

Figure 18: One of the BRITE spacecraft.

Each of the six spacecraft carries a 3-cm aperture optical telescope. There are two variants of the telescope: one incorporates a red filter, and one incorporates a blue filter. The six-spacecraft constellation will be deployed in three pairs. Each pair will have a “blue” and “red” spacecraft and be deployed into different sun-synchronous orbits.

Each BRITE spacecraft is equipped with a miniature star tracker. The star tracker is used in conjunction with the three reaction wheels to achieve a pointing stability of 1 arc-min.

6.2 CanX-4 and CanX-5 Formation Flying Demonstrator

Two 6.5 kilogram spacecraft, CanX-4 and CanX-5, intend to demonstrate precision formation-flying using differential GPS in conjunction with the CNAPS propulsion system.

CanX-4 and CanX-5 are two identical 6.5 kg, 20 cm by 20 cm by 20 cm spacecraft. The mission intends to demonstrate precision formation flying with centimeter-level position determination and sub-meter accurate position control, using low-cost spacecraft. Both spacecraft will fly in formations with distances between 50 m to up to 1000 m. The University of Calgary will contribute the determination algorithm that based on carrier phase differential GPS, while the University of Toronto will be responsible for the sub-meter position control algorithm.

Each spacecraft is also equipped an intersatellite separation system and an intersatellite radio link. Both spacecraft will be connected to one another when they are first released from the launch vehicle, and will then separate after both spacecraft are confirmed to be functional.

6.3 NEMO-AM Aerosol Monitoring

NEMO-AM (Aerosol Monitoring), which will be used to study regional aerosol distribution in the atmosphere using a multi-band, dual-polarization optical instrument. NEMO-AM (Figure 6) is the first spacecraft that is based on the NEMO bus.

NEMO-AM’s optical instrument is designed to observe in the blue, green, red, and near-infra-red optical bands and separating the incoming light into its two orthogonal polarization components. The instrument has been designed with a best ground sampling distance of 40 m. In addition, NEMO-AM has the capability of pointing its instrument in three axes to realize a multi illumination angle capability; the pointing angle is continuously adjustable in-orbit for maximum observation flexibility. The nanosatellite is also equipped with a new high-speed instrument computer capable of sustaining data transfer rates in excess of 400 Mbps.

6.4 CanX-7 De-Orbiting Demonstrator

CanX-7 intends to demonstrate a new de-orbiting technology. This de-orbiting technology is based on a scalable drag-sail. The device is intended to safely de-orbit a nanosatellite of up to 15 kg from an orbital altitude of 800 km or less, within 25 years after the end of its operational lifetime. CanX-7 will implement GNB electronics in the 3.5 kg, 10 cm by 10 cm by 34 cm CanX-7 form factor. The mission is targeting a launch in 2013.

6.5 AISSat-2 Ship Tracking

The development of AISSat-2 builds on the success of AISSat-1. AISSat-2 will be virtually identical to AISSat-1: a 6.5 kg, 20 cm by 20 cm by 20 cm spacecraft with a fixed 46 cm AIS antenna. The AISSat-2 program is targeting a completion in late 2011/early 2012, followed by a launch later in 2012.

7.0 CONCLUSION

This paper has presented an approach and strategy to implementing very small and cost efficient satellites. The nanosatellites implement the latest COTS technology that has been tested and adapted to work in the harsh environment of space. The highly focused approach results in a spacecraft that is cost-effective, can be rapidly developed and deployed, and has a state-of-the-art performance.

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9.0 REFERENCES

[1] Pranajaya, F. M., et. al., “Low Cost Microspace Missions that Push the Performance Envelope”, NATO AVT-171 Workshop, Antalya, Turkey, 2010.

[2] Pranajaya, F. M., et. al., “Advanced Nanosatellite Development at the Space Flight Laboratory”, 1st IAA Conference on University Satellite Mission, Rome, Italy, 2011.

[3] Pranajaya, F. M., et. al., “Aerosol Monitoring Mission using an Advanced Nanosatellite”, 38th COSPAR Scientific Assembly, Bremen, Germany, 2010.

[4] Pranajaya, F. M., et. al., “Nanosatellite Tracking Ships: Responsive, Seven-Month Nanosatellite Construction for a Rapid On-Orbit Automatic Identification System Experiment”, AIAA-RS7-2009-3010, AIAA 7th Responsive Space Conference, Los Angeles, California, United States, 2009.

[5] Pranajaya, F. M., et. al., “The NEMO Bus: A Third Generation High-Performance Nanosatellite for Earth Monitoring and Onservation”, SSC10-VI-8, 24th Annual AIAA/USU Conference on Small Satellites, Logan, Utah, United States, 2010.

[6] Pranajaya F. M., et. al., "Overview of the Nanosatellite Launch Service Program at the Space Flight Laboratory", 1st IAA Conference on University Satellite Mission, Rome, Italy, 2011.

[7] exactEarth: Ship Traffic around Australia, 2010.

[8] Norwegian Defense Research Establishment, First Data from AISSat-1, 2010.