NANOSATELLITE TRACKING SHIPS: COST-EFFECTIVE RESPONSIVE SPACE

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ABSTRACT

The Space Flight Laboratory (SFL) at the University of Toronto Institute for Aerospace Studies and COM DEV Ltd have developed and launched a nanosatellite in less than seven months to rapidly perform experiments to study the space-based reception of Automatic Identification System (AIS) signals transmitted by maritime vessels. The satellite, known as "Nanosatellite Tracking Ships" (NTS) leverages both SFL's CanX-2 nanosatellite technology and Generic Nanosatellite Bus (GNB) mechanical design to house a custom AIS receiver payload developed by COM DEV Ltd. The 6.5 kg, 20 cm by 20 cm by 20 cm NTS was developed under an extremely tight schedule, with on-orbit results required within a year from contract start. This paper outlines how SFL and COM DEV were able to rapidly design, construct and deploy a custom satellite to respond to the opportunity to bring on-orbit AIS detection services to the international community. This paper also provides an overview of the on-orbit data collected thus far outlining the capability of the spacecraft. NTS continues to operate nominally in orbit and has celebrated two years of on-orbit operation. NTS has exceeded all of its requirements and continues to be an invaluable asset for space-based AIS monitoring.

INTRODUCTION

NTS (Nanosatellite Tracking Ships) is a 6.5 kg, 20 x 20 x 20 cm spacecraft built by the Space Flight Laboratory at the University of Toronto Institute for Aerospace Studies. The project was funded by COM DEV International Ltd and was intended to demonstrate COM DEV's new spaceborne AIS receiver. A rapid demonstration was highly desired because of the economic potential of this new capability. NTS was delivered into orbit 7 months after the project was started, demonstrating cost-effective responsive space capability.

<u>Space Flight Laboratory</u>

Established in 1998, SFL offers end-to-end capability from mission design and spacecraft manufacturing to launch services and on-orbit operations. SFL currently maintains a staff of 15 full-time professionals with multi-disciplinary expertise in spacecraft design, and actively engages in research and development activities in next generation nanosatellite and microsatellite technologies. SFL is currently the only laboratory in Canada that has built and retains the capability to build low-cost spacecraft such as microsatellites (under 100 kg) and nanosatellites (under 10 kg).

SFL currently has three operational spacecraft in orbit: the 53 kg MOST space telescope (launched in 2003), the 3.5 kg CanX-2 technology demonstration and atmospheric science satellite (2008) [1][1], and the 6.5 kg NTS satellite for ship tracking (2008).

SFL is currently building six nanosatellites: one is intended for performing ship tracking and providing semi-operational data (AISSat-1, to be launched in 2009), two are intended for space astronomy (UniBRITE and BRITE Austria, 2010), two are intended for carrying out formation flying demonstration (CanX-4 and CanX-5, 2010), and one is intended for studying aerosol distribution over India (NEMO-AM, 2010-2011). The first five nanosatellites are based on the Generic Nanosatellite Bus (GNB) and the associated technologies developed at SFL [2][3][4]. The latest mission is based on SFL's new NEMO bus, which is a 15 kg bus that is capable of generating up to 80 W of power and implements a innovative architecture. SFL is also a major subcontractor to COM DEV Ltd. in the Maritime Monitoring and Messaging Satellite (M3MSat) mission funded by the Defence R&D Canada and the Canadian Space Agency.

COM DEV International Limited

COM DEV is a leading global designer and manufacturer of space hardware subsystems. With facilities in Canada, the United Kingdom and the United States, COM DEV manufactures advanced products and subsystems that are sold to major satellite prime contractors for use in communications, space science, remote sensing and military satellites.

COM DEV Ltd. has developed a device that receives Automatic Identification System (AIS) transmissions from space. Ships of a certain class are required to carry AIS transponders to broadcast their identity, location and heading. Originally conceived as a collision avoidance system, the challenge now is to receive these signals from space despite the increased number of colliding signals. COM DEV's technology disentangles the colliding signals for greater detection success. This technology offers the ability to provide a new type of service that monitors ship positions throughout the world from space.

At the end of summer of 2007, COM DEV had determined the cost and schedule to build a spacecraft that would validate the concept of receiving AIS data from space. The cost of the deployment of the first spacecraft was reasonable, however it was also determined that it would require more than 2 years to design, build and launch the operational spacecraft and this was deemed too long. COM DEV needed to first demonstrate the concept of collecting AIS signals from space at a high detection rate. This capability had to be demonstrated without delay in order to capture commercial opportunities in a manner that was also cost-effective relative to the available budget [5].

Automatic Identification System

The AIS system is a ship-to-ship and ship-to-shore system that is used as an aid for collision avoidance and vessel traffic management. The AIS signals consist of short messages broadcast by ships at 162 MHz and include information about the ship, its course, speed, crew and cargo. AIS transmitters are mandated by the International Maritime Organization for specific classes of vessels and are being voluntarily added by others (including search and rescue aircraft).

Typically, AIS transmissions have a range of 50 to 100 km. This limits the overall knowledge of ship positions to this range. AIS transmitters use a self-organized time division multiple access scheme (SOTDMA) to allow all ships within a given 100 km self-organized cell to broadcast their information without interfering with AIS transmissions from the other ships within the same cell.
The ability to collect AIS messages from space would provide global marine traffic awareness and provide the input to a large number of applications, such as search and rescue, national security, environmental study and shipping economics [5].

DESIGN PHILOSOPHY AND DEVELOPMENT STRATEGY

The approach taken in designing the NTS spacecraft follows the *microspace philosophy*. The design is highly focused to meet a set of mission requirements. This approach is intended to result in a simplified design that is cost-effective and can be turned around in a relatively short period of time.

Top-Down Approach

In designing the NTS spacecraft, a top-down analysis was done based on the operational requirements of the mission. This included the lifetime requirement, data throughput requirement and attitude control and knowledge requirements. Schedule is also a top-down consideration; the launch date provided a fixed deadline for the team to work towards. Finally there was a constraint on the resources that were available to the program

Bottom-Up Approach

The top-down approach outlined above is balanced with a bottom-up analysis. The bottom-up analysis takes into account the limitations of existing hardware design. 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 considered 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 reasonably fast-tracked to meet the stringent program schedule.

Development Strategy

The development strategy involves iterating the mission requirements against the results of top-down and bottom-up analyses outlined above. The SFL team investigated the options in modifying existing CanX-2 subsystem design in order to satisfy the mission requirements. The modification also considers the complexity of the modification as well as the availability of resources for implementing the modifications. Schedule is a big consideration given a fixed launch date.

The SFL team also investigated the possibility of fast-tracking the development of several next generation technologies that were originally intended for the GNB spacecraft. In cases whereby the schedule does not allow for design modification and advancing the maturity of newer technology, the SFL team then set limits on hardware performance for the mission. For example, the development strategy also includes adjusting the AIS payload design in order to simplify its integration with the rest of the spacecraft.

RESULTS

Spacecraft Design

The development strategy led to the conclusion that NTS should use CanX-2 electronic. The electronics would then be housed in a new 20 cm by 20 cm by 20 cm GNB structure to allow for a larger payload volume. The GNB structure was also selected as it could easily be adapted to accommodate a fixed 46 cm AIS antenna.

The spacecraft design includes a housekeeping computer based on a ARM7TDMI processor with 2 MB of EDAC-protected RAM and 16 MB of Flash RAM. The housekeeping computer runs CANOE, a custom multi-threaded operating system developed by SFL. Power is generated by six body-mounted solar panels carrying triple junction solar cells, with each panel generating up to 4 W of power. Power is distributed using central control and decentralized switching. A 3.6 Ah Lithium-ion battery is used to support eclipse and peak-load operations.

The structure is made out of Aluminum, while the XPOD GNB separation system uses Magnesium alloy. Thermal control is passive and is achieved by surface coatings and thermal tapes.

A UHF receiver with fixed four quad-canted monopole antennas is used for command and software uplink at 4 kbps. An S-band receiver with two patch antennas is used for telemetry and data download at 32 kbps (nominal) up to 1 Mbps (maximum).

The mission requirements were fulfilled with a passively stabilized spacecraft. The passive stabilization scheme uses a single permanent magnet and six hysteresis rods to maintain the alignment of the AIS VHF monopole antenna to the local earth magnetic field lines. This orientation will ensure that the highest gain of the monopole is directed towards nadir during the majority of the orbit. To confirm the performance of the passive stabilization scheme, each of the six sides is fitted with a coarse sun sensor.

NTS is a simpler spacecraft as compared to CanX-2. Because a passive attitude control system was used, many circuitries originally designed for the CanX-2 nadir-pointing attitude control system were no longer required, and were therefore omitted in NTS. Furthermore CanX-2 carried a number of science experiments and technology payloads, while NTS only carried the AIS receiver as a payload

Figure 1 below shows the exterior layout of the spacecraft, outlining the position of the fixed 46 cm AIS antenna, the 17 cm UHF uplink monopole antennas, and S-band downlink patch antennas. Figure 2 below shows the resulting interior layout of the spacecraft.

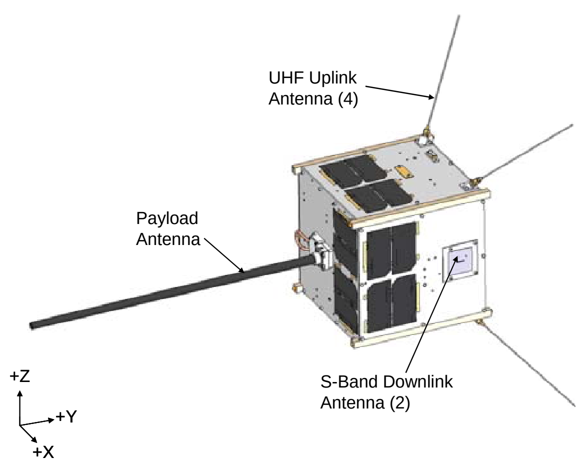

Figure 1. NTS Exterior Details

The new 20 cm by 20 cm by 20 cm GNB structure was chosen as this structural design can easily accommodate the larger AIS payload as well as additional structural support for a fixed 46 cm AIS antenna, as shown in Figure 1. The fixed antenna is highly desired as it reduces the risks associated with a deployable antenna. The implementation of a fixed 46 cm antenna results in a spacecraft that is approximately 80 cm long, and this poses an interesting challenge for the launch vehicle given the available accommodation.

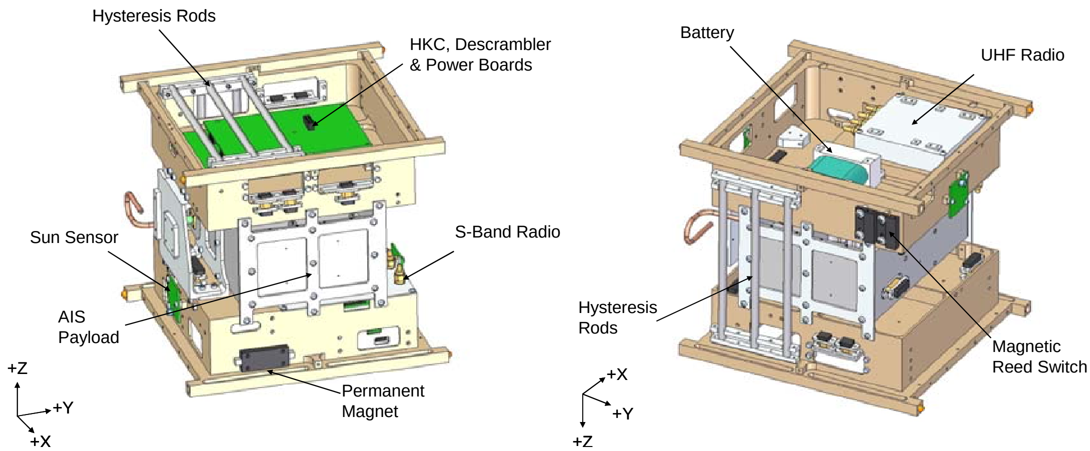

Figure 2. NTS Interior Details

The structure comprised of two trays that accommodate all of the electronics. The AIS payload was accommodated in the space between the two trays, as seen in Figure 2. Additional structural supports were also added to increase the rigidity of the overall structure.

The GNB structure requires the XPOD GNB separation system. The XPOD GNB is part of the XPOD family of separation systems developed at SFL, which can accommodate spacecraft of up to 15 kg and 20 cm by 20 cm by 40 cm in size. The XPOD separation system technology is capable to accommodate fixed (non-deployable) appendages that are fixed. This capability is highly advantageous as it allows NTS to have a fixed 46 cm antenna.

<u>Project Timeline</u>

The NTS project was started in October 2007. Within one month from project start the launch was procured.

The design of the spacecraft, including modifications to existing designs, was completed in November 2007. Flight build of the electronics and machining of structural components began shortly thereafter.

Integration activities began by mid December 2007. New software components were written and integrated with the operating system. System-level integrated tests with all the subsystems began as soon as each subsystem passed its unit-level acceptance test. By the third week of December, most of the spacecraft electronics were integrated into the flatsat, whereby all components were laid flat on the test bench and operated as they would in orbit. The flatsat setup shown in Figure 3 was running simulated orbital operations during the two weeks of Christmas holiday, approximately 3 moths after the project has started. The tests were monitored remotely during the holidays.

The integrated testing of the spacecraft continued throughout January. In the meantime the configuration of the launch vehicle upper stage was finalized following an extensive discussion with the launch vehicle team on the new accommodation scheme. NTS would share the launch with six other nanosatellites, including the CanX-2 spacecraft. SFL was responsible for managing the launch of all seven spacecraft as part of the NLS-4 (Nanosatellite Launch Service 4) and NLS-5 payload clusters on this launch.

The spacecraft successfully passed structural qualification in February 2008. Flight integration of the various electronics into the structure began in March, followed by full system-level integrated testing. This included full end-to-end tests where the spacecraft was controlled from the SFL ground station over RF link to perform an AIS observation and subsequently downloading the data. Figure 4 below shows the completed spacecraft.

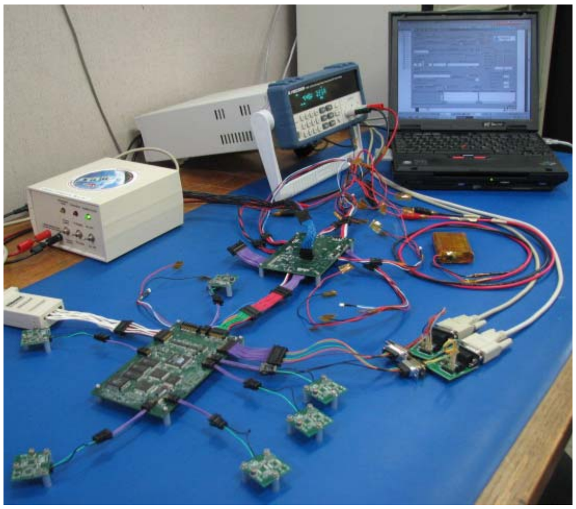

Figure 3. NTS Flatsat

Figure 4. The NTS Spacecraft

After all tests were completed and both the spacecraft and separation system were deemed ready for flight, the spacecraft was packed for shipment.

Launch and Commissioning

The spacecraft, the associated ground support equipment, and the launch campaign team arrived at the launch site on April 3, 2008. After extensive checks confirmed that both the spacecraft was functioning nominally and ready for launch, NTS was integrated to the PSLV-C9 launch vehicle on April 17, 2008. The integrated NTS/XPOD GNB assembly was mounted on the Payload Adapter cone, underneath the Cartosat-2A primary spacecraft, as shown in Figure 5. Figure 5 also shows the six other nanosatellites as part of the NLS-4 payload cluster.

The launch took place on April 28, 2008, at 03:53 UTC from the Second Launch Pad at the Satish Dhawan Space Complex, Shri Harikota, Andhra Pradesh, India. Successful release of the spacecraft from the launch vehicle was confirmed soon thereafter by the telemetry from the XPOD separation system. NORAD observation also indicated successful separation of all spacecraft. The SFL ground station in Toronto made first contact at approximately 13:30 UTC.

Figure 5. The PSLV-C9 upper stage showing NTS integrated on the XPOD GNB separation system mounted on the Payload Adapter cone.

During the commissioning period, NTS used the same SFL ground station in Toronto that was used to commission the CanX-2 spacecraft, and therefore the available contact time was shared between the two spacecraft at the outset. After the spacecraft telemetry was confirmed to be nominal and the spacecraft has been operating in orbit continuously over a period of time, the commissioning phase was declared complete and the spacecraft was declared ready for operations.

<u>Operations</u>

The first set of AIS data was successfully captured on May 6, 2008 and subsequently downloaded. Since then, much more data have been downloaded.

During normal operations, observation schedule is uploaded to the spacecraft. At the pre-calculated position in orbit, the spacecraft will begin collecting AIS data from specific surface area of interest.

Spacecraft operations are currently handled from SFL mission control center in Toronto. In addition to the SFL primary ground station in Toronto, In addition, a 9.1 m dish at the Defence Research and Development Canada in Ottawa is now available for use with SFL nanosatellites. This dish is now part of the SFL network of ground stations and is being remotely operated from the SFL mission control center in Toronto. The addition of this dish further enhances the data throughput from the spacecraft by permitting downlink at the highest data rate available over the entire pass. The third ground station is currently being planned jointly by COM DEV and SFL, and will be dedicated to NTS operations.

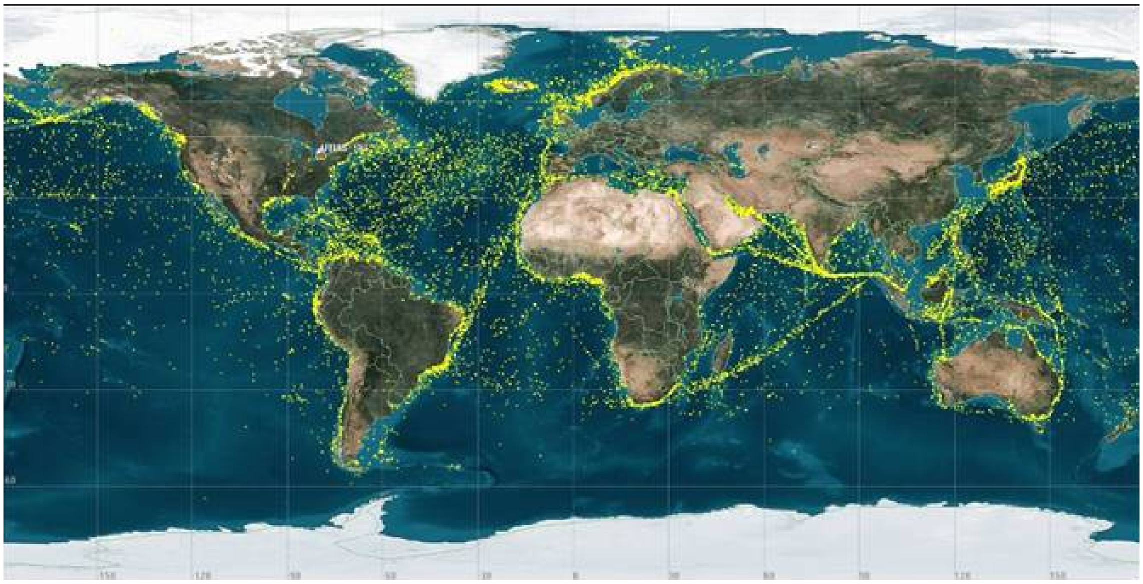

Figure 6. Composite Image of Ships Detected by NTS (Courtesy COM DEV)

Figure 6 above shows the composite image of ship positions as collected by NTS. This composite image combines the all observed data that were collected by the spacecraft up to summer of 2009. Figure 6 illustrates the capability of the nanosatellite as an observation platform and the performance of the COM DEV AIS receiver technology.

NTS is capable of performing one complete observation every 24 hours. This mode of operation is used to provide daily historical over a specific maritime region [6].

Follow-on Mission

The results from NTS are being incorporated into the development of an AIS microsatellite, the M3MSat (Maritime Monitoring and Messaging Microsatellite). M3MSat is jointly funded by the Defence Research and Development Canada and the Canadian Space Agency. COM DEV is the prime contractor for the mission while SFL is responsible for providing a number of critical subsystems including on-board computer, attitude control system and power system.

CONCLUSION

NTS has been in orbit for nearly two years, and continues to operate nominally. Originally intended as a short-lived technology demonstration satellite, NTS was quickly turned into an operational satellite with automated AIS observation. The satellite continues to outperform by collecting more AIS data and downloading it to the SFL mission control center in Toronto through the SFL ground station network. A software upgrade is being considered to further enhance its operational capability. A second dedicated ground station that is intended to double the spacecraft data throughput is also under discussion.

This program has successfully demonstrated a low-cost, responsive space mission for rapidly deploying new protoflight sensor technology. The success of the mission has been due in no small part to the willingness of COM DEV to trust in the microspace development expertise of SFL and the ability of the combined COM DEV / SFL team to work the problem without being constrained by traditional approaches or oversight.

More recently NTS was used to during detect the location of a ship that has gone off course and ran aground in a portion of the sensitive Great Barrier Reef. The ship was carrying approximately 65,000 tonnes of coal and was 15 km east of the shipping lane. This not only illustrate the capability of this platform, but also the value of having such asset for monitoring shipping lane and sensitive areas.

ACKNOWLEDGEMENTS

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