NEMO-AM: HIGH FIDELITY AUTONOMOUS NANOSATELLITE FOR EARTH OBSERVATION AND AEROSOL MONITORING

S. C. O. Grocott [(1)], N. S. Ibrahim[(1)], D. Diaconu[(1)], M. Dwyer[(1)], J. Elliott[(1)], D. Kekez[(1)], I. Majid[(1)], F. Pranajaya[(1)], M. Stan[(1)], R. E. Zee[(1)],

[(1)] Space Flight Laboratory, University of Toronto Institute for Aerospace Studies
4925 Dufferin Street, Toronto, ON, M3H 5T6, Canada
+1-416-667-7908, sgrocott@utias-sfl.net

ABSTRACT

The Space Flight Laboratory (SFL) at the University of Toronto Institute for Aerospace Studies is finishing its development of a 16 kg autonomous nanosatellite for high fidelity Earth observation. The Nanosatellite for Earth Monitoring and Observation Aerosol Monitor (NEMO-AM) is funded by the Indian Space Research Organization with the primary objective of observing aerosol content over specific geographic regions. There are a number of interdependent subsystems which must interact appropriately with one another in order to execute the overall mission objective. In this paper, the NEMO-AM system architecture and the designs of the various spacecraft subsystems, which allow Earth observation on a nanosatellite platform, are presented. In addition, the expected mission operational sequence and ground architecture are also overviewed. NEMO-AM is anticipated to be ready for launch by the end of 2014.

1 INTRODUCTION

The Nanosatellite for Earth Monitoring and Observation Aerosol Monitor (NEMO-AM) is a high performance spacecraft in the final stages of development at the University of Toronto Space Flight Laboratory (SFL). The mission is backed by the Indian Space Research Organization (ISRO) with the purpose of detecting atmospheric aerosols in multiple bands over particular geographical areas with sub-degree accuracy. The satellite design leverages the lessons learned on previous SFL missions [1] [2] [3] and, in part, is developed around the Generic Nanosatellite Bus (GNB) concept, where a multipurpose and adaptable satellite bus is designed to work with a wide range of payloads with little or no modification. Consequently, many of the hardware components on NEMO-AM are inherited from the GNB and likewise boast flight heritage. The satellite also employed new technologies facilitated by commercial off-the-shelf (COTS) hardware. This facilitated shorter design cycles, but allowed those periods to be focused more on mission specific goals.

The satellite bus envelopes a volume of 20cm x 20cm x 40cm and has a mass of 16.1kg with a power throughput capability of 80W. A large solar array of 62cm x 58cm is attached on the +X face for power generation. NEMO-AM will fly a standard suite of Attitude and Orbit Control Subsystem (AOCS) components found on the GNB, a GPS receiver, communication antennas (S-band for uplink and downlink), onboard computers for task management, a power distribution network including batteries and solar cells, and a multi-spectral imager to capture aerosol concentration. The satellite's external features are shown in Figure 1. The satellite subsystems and their underlying technologies which enable Earth observation on a platform weighing less than 20kg are described in this paper. Earth observation simulations are also overviewed to elucidate the anticipated in-flight performance.

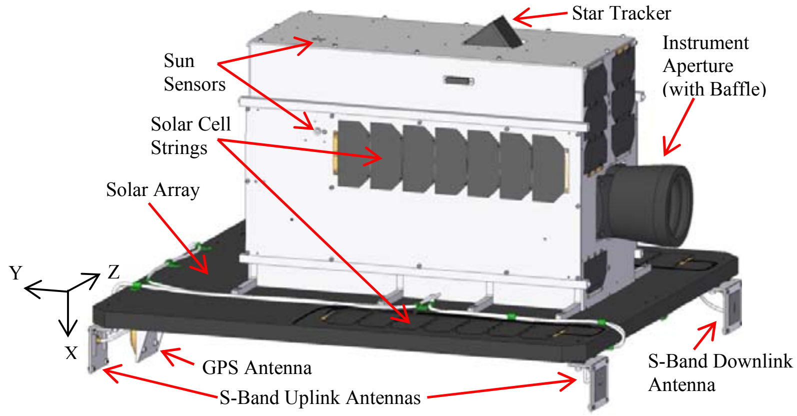

Figure 1. NEMO-AM general configuration.

2 OPERATIONS CONCEPT

NEMO-AM is anticipated to perform Earth observation by being injected in a sun-synchronous orbit with a local time of descending node between 09:00 and 11:00 and at an orbital altitude between 600km and 800km.

Earth observations will be repeated during what are deemed as Imaging Campaigns, by pointing at ground targets at different angles with respect to zenith, thereby allowing image capture at different scattering angles. This manner of pointing is done by autonomously constructing a targeting trajectory onboard and having the AOCS regulate this trajectory, thereby pointing the imager continuously at the target of interest. This maneuver is shown in Figure 2. NEMO-AM has an in-track look capability of slightly less than 90º and an off-track look capability of 30º (in one direction). When the satellite is directly over the target at an altitude of 650km, this imaging maneuver will produce an Earth footprint of 35km x 95km, with a ground sampling distance of approximately 42 m. High-speed image downlink is performed by pointing the S-Band antennas at a ground station by following a targeting trajectory similar to the Imaging Campaigns. In any given day, a maximum of 2 observations and 2 high-speed downlinks are expected. When the satellite is not imaging or downlinking data, a power-generation attitude will be held by inertially pointing its +X solar array to the Sun.

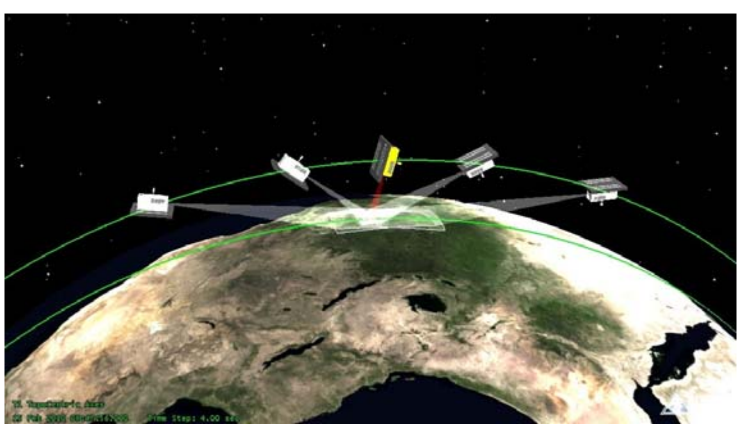

Figure 2. NEMO-AM pointing maneuver during an Imaging Campaign.

3 MECHANICAL DESIGN

The NEMO-AM structural subsystem uses a design concept that is based on an enhancement of SFL's proven GNB design. The primary developments implemented in the NEMO-AM bus consist of an improved payload carrying capability, along with a pre-deployed solar panel to meet more demanding power generation requirements.

At the core of the primary structure, a dual-tray system is used to support all subsystem components while facilitating rapid and flexible integration and testing. The trays also provide the primary load path from the satellite to the SFL XPOD Duo deployment system. An increased payload volume and a large pre-deployed solar array are allowed by the unique design features of the XPOD, which permit expansion of the bus outside of its 20cm x 20cm x 40cm internal volume. Figure 3 illustrates the internal configuration of the spacecraft.

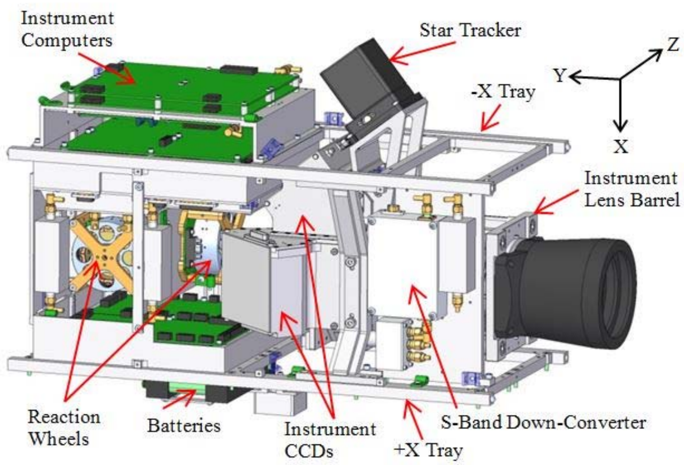

Figure 3. NEMO-AM internal configuration.

In order to achieve an optimal design that assures structural integrity while minimizing mass, NEMO-AM's primary structure, along with all brackets and internal panels, were manufactured using magnesium alloys. Oxidization resistance is critical for good electrical coupling of all metallic components, and as such all magnesium parts were plated using high-phosphorous electroless nickel. Space-rated plastics, such as Delrin and Tefzel were used on the satellite, with an atomic-oxygen-resisting coating applied on the surfaces directly exposed to space. The main solar array on the +X bus side consists of a total of 70 photovoltaic cells which were supported on a composite panel substrate that features a honeycomb structure sandwiched between two carbon fibre reinforced polymer facesheets. The total mass of the NEMO-AM spacecraft is 16.1kg. Table 3-1 details mass allocation by subsystem.

Table 3-1. NEMO-AM system mass budget.

Subsystem	Mass [kg]	Fraction Percent (%)
Structural	5.5	34
Thermal	0.1	1
Attitude and Orbit Control	1.6	10
Power	1.8	11
Onboard Computers	0.1	1
Communications	1	6
Payload	6	37
Total	**16.1**	**100**

An important part of the development work performed for the NEMO-AM structural subsystem were the finite element analyses under the launch environment mechanical loads, as well as under maximum cross-structure thermal gradients in on-orbit operations scenarios. For this purpose, increasingly detailed models were constructed for the preliminary and detailed designs, providing the basis for several revisions and improvements in the satellite configuration. Table 3-2 summarizes a number of general structural analysis cases and their results which drove the substantiation of the mechanical design.

Table 3-2. Structural analysis scenarios and results.

Analysis	Verification Criteria	Results
Modal	Must exceed launch vehicle requirement in all axes	First natural frequency of spacecraft bus occurs at 192.5Hz
Quasi-static Acceleration	Structure must exhibit positive margin of safety at 12Gs in all axes	Maximum stresses of 35MPa and 37.5MPa emerging at trays-to-XPOD and payload-to-trays interfaces with positive margin
Thermo-elastic Deformation	Design such that AOCS can tolerate angular misalignment between star tracker and payload under 30°C cross-structure temperature gradient	Pointing error due to thermally induced deformation is less than 0.1°, accounted for in pointing error budget
Ground Operations	Structure mounted on mechanical ground support equipment has positive margin of safety under handling loads	Dedicated mounting points on structure, as well as support equipment, operating under 25% of material yield strengths

4 THERMAL DESIGN

The NEMO-AM thermal control subsystem is semi-passive, allowing it to be simple and robust with low mass and power. The system is referred to as semi-passive rather than fully passive because all of the components are passive except for heaters attached to the power subsystem, which are critical to limiting the subsystems temperature range. Overall, the thermal control system relies on controlled radiation exchange with the external environment. The exterior structural panels are coated with thermo-optical control tapes that balance the heat absorbed from external sources (mostly from the Sun), with the heat radiated by each of the panels. Figure 4 shows an example of these tapes which will be placed on the satellite panels during the final integration stage. Internally, the satellite relies on good thermal coupling through the high conductivity magnesium structure. The power dissipating electronics are mounted so that heat exits these units and is conducted through the structure to the exterior structural panels, which then radiates this into space.

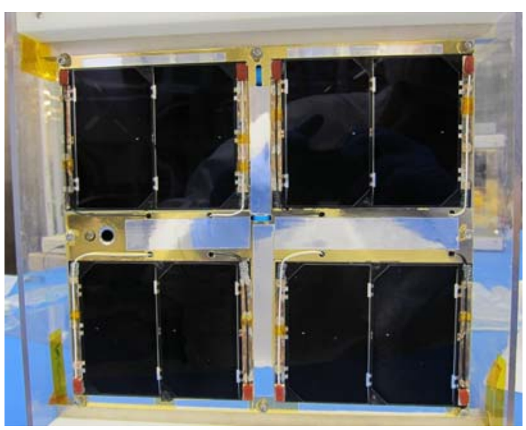

Figure 4. Example of gold and silver thermal tapes used for balancing heat loads.

One of the major challenges with the thermal design of the NEMO-AM satellite resulted from the requirement to maintain units within operational temperatures (typically –20°C to 60°C) at all times, in any attitude. While this simplifies the analysis and operations, and allows for an overall robust design, it presented some challenges specifically to the thermal design.

The elongated form factor of the bus makes it possible for the satellite to be in an attitude with the smallest structural panel pointed at the Sun and the large solar array on the +X axis to be edge-on to the Sun. In this orientation, the array acts as a radiator, while the attitude makes it difficult to absorb enough heat to keep the bus warm. To address this problem, a material with low in-plane conductivity was chosen for the array and the conductivity between the array and bus was tailored to keep the bus from getting too cold. Finite-difference thermal models were created using a commercial software package to perform thermal analyses of the satellite. Final results showed that the temperatures of the units in the satellite were maintained within required hardware ranges. Operationally, the array shadows the bus and helps to keep it cool which is especially important to reduce the noise on the payload CCDs. Similar analyses and solutions were effected for both operational and corner worst-case situations to ensure that temperature limits were being met for all plausible scenarios.

The plot in Figure 5 shows simulation results from the thermal model of some of the important satellite components in an operational hot case. In this case, the satellite is in a power-generation attitude with the large +X solar array directed at the Sun. The figure shows the results from four orbits in this mode. Depending on the operational scenario, the satellite may initiate an Imaging Campaign, perform a high-speed data downlink or remain in this attitude until one of the aforementioned events takes place. The results show that the operational temperatures of the satellite are maintained within a fairly cool and benign range of 10°C to 35°C.

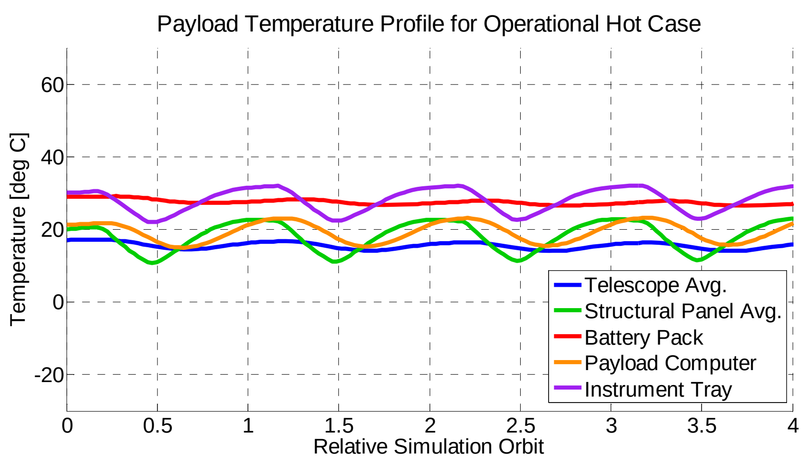

Figure 5. Temperature profiles of NEMO-AM components in operational hot case.

5 IMAGER DESIGN

The imager design of NEMO-AM is critical to precise aerosol detection. Imaging is done using a high transmissivity 150mm f/2.8 front end lens tested by focusing to infinity. The imager then divides the incoming light into blue, red and near infrared (NIR) spectral bands. The exposure times for these three wavelengths range from 2ms to 14ms. The instrument also includes a "p-s" polarizing beam splitter at the spectral band output which generates two identical images at two different polarizations. The p-polarization splits the image at 0º, whereas the s-polarization splits the image at 90º. Each polarization has a pixel density of 2444 x 888 pixels. The resulting images are focused onto the same Kodak CCD detector. The imager's optical parameters are summarized in the table below:

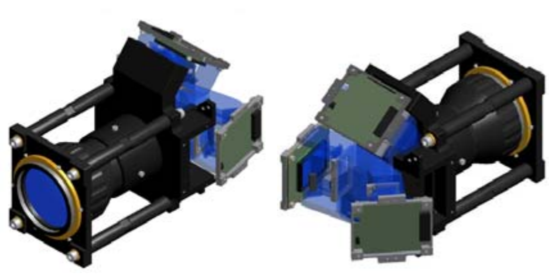

Figure 6. NEMO-AM imager.

Table 5-1. Main Characteristics of Imager

Property	Value
Focal Length	150 mm ± 2%
F.O.V. (diagonal)	± 4.46°
N.° of elements	7 elements in 6 groups
Resolution	MTF > 55% at 70 lp/mm
Transmission	≥ 89%
Distortion	< 0.2%
Vignetting	≤ 2.5%
Wavelength Range	400 – 1000 nm
Antireflection Coating	R ≤ 0.6%
Chromatic Aberration	< 5 µm

The transmission performance is summarized in Figure 7. Noise contributions at the detector include photon noise, dark current noise and noise due to bias variation. The maximum signal-to-noise ratio per pixel at either the p-polarized or s-polarized regions is 158.

Another metric of interest, is the polarimetric accuracy R which is measured using electron count. It can be written in terms of number of p-polarized electrons N_p and the number of s-polarized electrons N_s:

$$R = \frac{N_p - N_s}{N_p + N_s} \qquad (1)$$

Using noise generated in dark room conditions from previous SFL designed and flown imagers, and applying statistical analysis of photons occupying 75% full well capacity, polarimetric accuracy was qualified and validated. The crosstalk between p and s polarized signals is approximately 0.1%. The polarimetric accuracy due to the random variation in the received signal due to noise (R_n) was better than 1% across the spectrum (0.4-1.0 µm). This is plotted for range of R from -0.2 (more s – polarized than p-polarized) to 0.2 (more p-polarized than s-polarized) in Figure 8.

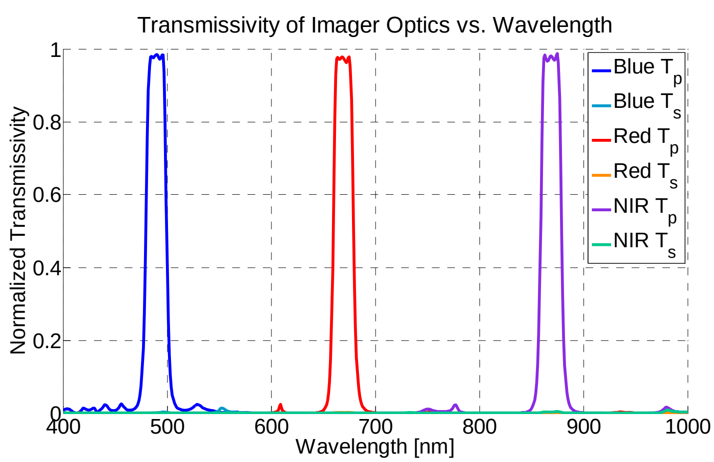

Figure 7. Comparison of different spectral bands on the NEMO-AM imager.

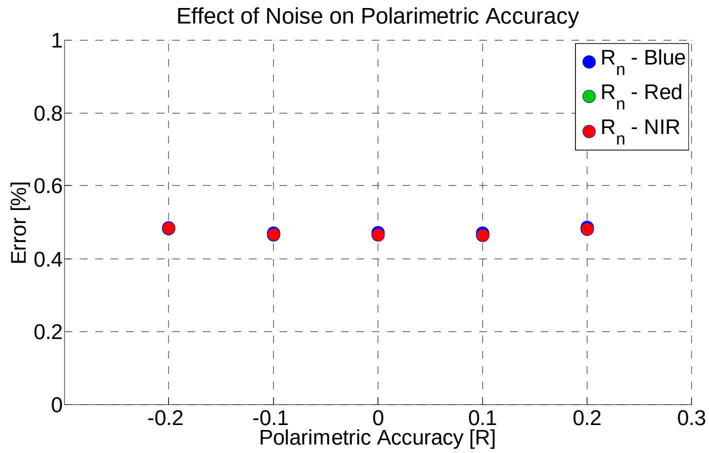

Figure 8. Effect of noise on polarimetric accuracy model developed at SFL.

6 ONBOARD COMPUTER ARCHITECTURE DESIGN

NEMO-AM utilizes the distributed On-Board Computer (OBC) architecture developed for the GNB. As part of this distributed architecture, dedicated tasks are assigned to individual OBCs. Figure 9 depicts the high level OBC architecture for NEMO-AM.

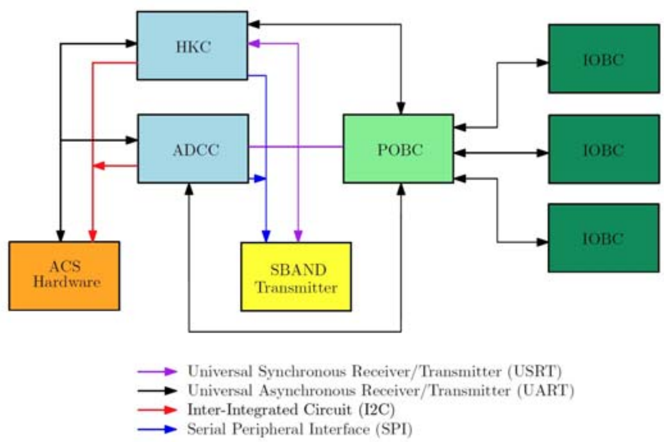

Figure 9. NEMO-AM OBC and Communications architecture.

There are two distinct software modes for each OBC on NEMO-AM: bootloader and application. The bootloader supplies basic spacecraft telemetry, and an interface for uploading/storing and executing application software. Application software is powered by the Canadian Advanced Nanospace Operating Environment (CANOE). CANOE is a multi-threaded, real time, embedded operating system developed at SFL for use in a wide range of nanosatellite missions. A priority based round robin scheduler, inter-thread messaging, alarms and system clock allow for the execution of real-time embedded applications.

The application software packages powered by CANOE execute a host of different tasks onboard NEMO-AM. The Housekeeping Computer (HKC) is responsible for the collection of Whole Orbit Data (WOD), overcurrent protection and the execution of Time Tagged Commands (TTC). The Attitude Determination and Control Computer (ADCC) is responsible for all attitude control related tasks, such as collection of attitude telemetry, executing attitude algorithms/tasks and commanding of actuators. The Payload On-Board Computer (POBC) is responsible for all payload related operations. This includes commanding individual imagers through three Instrument On-Board Computers (IOBCs), transferring observation data into onboard Flash and high speed transmission of payload data to the ground. In addition to processing tasks, data storage is also distributed across the different OBCs. Data collected on an OBC is stored locally on a NAND Flash chip, managed by a Flash file system developed in-house at SFL.

The implementation of the distributed OBC architecture allows for independent real time tasks to be executed simultaneously. Spacecraft attitude control is executed independent of CPU and bus loads created by payload or housekeeping operations. Additional power savings benefit arises from the fact that individual OBCs can be powered off without the operation of the others.

7 ATTITUDE AND ORBIT CONTROL DESIGN

The Attitude and Orbit Control Subsystem (AOCS) onboard NEMO-AM derives overall heritage from previous GNB missions, but implements new timing, guidance and navigation solutions which enable sub-degree Earth observation. These solutions are tailored in a modular manner which allows different terrestrial-based missions and hardware suites to leverage the technology.

The sensor suite on NEMO-AM is composed of six SFL sun sensors, one SFL magnetometer and a Sinclair Interplanetary (SI) star tracker. Sunlit coarse pointing, to an accuracy of better than 5°, is achieved using the SFL sun sensors and magnetometer. In eclipse, the attitude estimation solution is corrected only by the magnetometer. The star tracker is necessitated by the sub-degree pointing requirements and by implementing it as the only sensor during Earth observation, an attitude navigation solution of 0.036° (2σ) is achieved through the Attitude Extended Kalman Filter (AEKF). The actuator suite on NEMO-AM is composed of three SI reaction wheels and three SFL magnetorquers. The reaction wheels are the primary means of attitude control, providing 60Nms of momentum storage and applying up to 2mNm of torque, while having a maximum torque jitter of 5×10^{-5}Nm. The magnetorquers are current-controlled up to 100mA and, are used to dump momentum and exit poor attitudes when in safehold conditions. Although not an attitude sensor, a Novatel OEMV-1 series GPS receiver is used to obtain an orbital state solution. This solution is later corrected through an Orbital Extended Kalman Filter (OEKF) to achieve an orbital navigation solution of 12m (2σ) in position and 6cm/s (2σ) in velocity. The various attitude hardware are depicted in Figure 10.

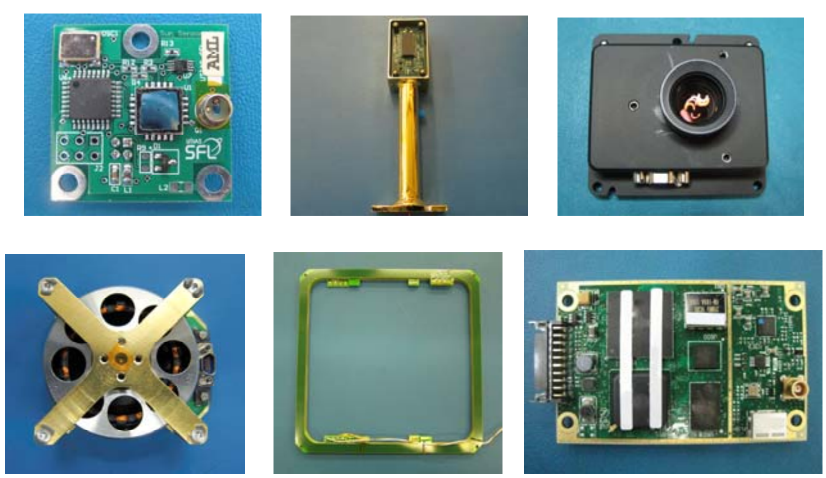

Figure 10. Attitude hardware onboard NEMO-AM.
Top, from left to right: SFL sun sensor, SFL boom-mounted magnetometer, SI star tracker
Bottom, from left to right: SI reaction wheel, SFL magnetorquer, Novatel GPS receiver

The AOCS is managed by the ADCC, which executes the Onboard Attitude System Software (OASYS) flight code on the computer operating system CANOE. OASYS encompasses all of the necessary ephemerides (IGRF-11, sun vector, FK5), orbit propagators (SGP4, gravity models), navigation filters (AEKF and OEKF), guidance solutions, control laws and AOCS management/housekeeping logic. An AOCS thread is executed on the ADCC once every second, where raw hardware telemetry is collected and passed to OASYS, telemetry is then interpreted, filtered and synchronized, celestial and trajectory algorithms are effected, control and actuator commands are synthesized and finally actuators commanded. A high-level flow diagram of OASYS is show in Figure 11.

Although scheduling observations is done using an in-house mission planning tool developed at SFL, the target trajectory which must be tracked by NEMO-AM for imaging operations is constructed entirely autonomously onboard. The terrestrial guidance solution constructs a real-time attitude, angular velocity and angular acceleration trajectory with the aid of the OEKF. Once the trajectory is initialized by a GPS measurement, it is robust to GPS blackouts throughout the Imaging Campaign, allowing the attitude, angular velocity and angular acceleration to be computed to an accuracy of 8.25×10^{-5}rad, 4.32×10^{-7}rad/s and 1.03×10^{-8}rad/s^2, respectively. Sensor dropouts during the Imaging Campaigns are less tolerable, but are anticipated to be negligible since the placement of the SI star tracker is specifically designed to maintain acceptable exclusion angles with respect to the Sun and Earth.

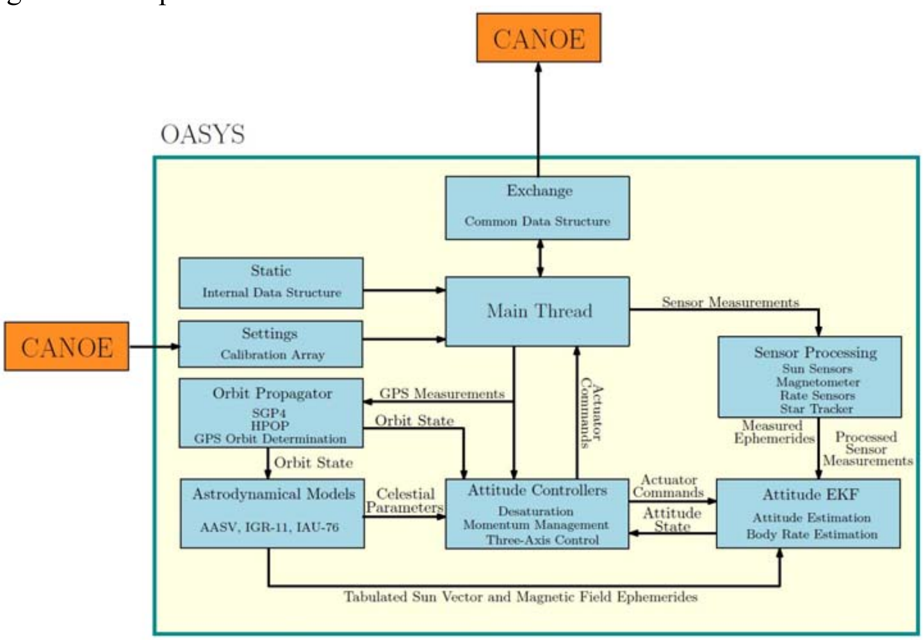

Figure 11. Flow diagram of AOCS flight code.

Control is achieved by using a state feedback proportional-derivative-integral law to regulate the quaternion and angular velocity errors with respect to the guidance trajectory. Compensation of gyroscopic terms, feedforward of angular accelerations and linearization of the trajectory all aid in Earth observation. In-house simulations which incorporate hardware models derived from unit-level tests, celestial models of the orbital environment and, truth models of the spacecraft and orbit dynamics, demonstrate that the AOCS is able to constantly track a target accurately to within 0.8° and with a stability of less than one tenth of a pixel.

8 GROUND SEGMENT DESIGN

NEMO-AM will be operated from the Multi-Mission Spacecraft Control Centre in Bangalore, India that forms part of the ISRO Telemetry, Tracking and Command Network (ISTRAC). The communications system and operations software are based on SFL's standard approaches and are tailored to work within the existing ISTRAC environment.

Both uplink and downlink communications are in the Space Research Science S-band. The downlink transmitter on NEMO-AM is capable of variable data rates (32kbit/s to 2Mbit/s) and modulation, as set by ground command. During nominal science operations, the satellite will track the ground station with one of its body-mounted S-band patch antennas and maintain a 2Mbit/s downlink. The same communication link is used for telemetry, control, and payload data downlink. Communications between ground software and on the radio links employ SFL's nanosatellite protocol. This is a low-overhead protocol that supports variable length packets with addressing to enable packet routing between ground terminal programs, on-board devices, and software threads in application software. The architecture was designed for closed-loop, real-time communication during contacts with the operations centre to permit the ground software to ensure that there are no gaps in the uplink of the telecommands or downlink of payload data. Time-tagged data dumps to downlink only stations are also supported by the software architecture.

Spacecraft observations and data downlinks are conducted through sequences of time-tagged commands. In nominal operations, NEMO-AM will observe one or two ground targets and then downlink that observation data on subsequent passes over the Earth Station. A mission planning tool permits the operations team to schedule observation targets according to the desires of the science team while complying with constraints such as ground target illumination and platform pointing restrictions. The tool propagates the satellite's orbital ephemeris from position and velocity information recorded from the on-board GPS receiver. The outputs from these processes are time-tagged command scripts that can be uploaded to the OBCs. Typically planning is done for up to a week in advance, depending on the accuracy of the orbit ephemeris.

8.1 Ground Software Architecture

The ground software architecture for NEMO-AM is composed of a series of specialized terminal programs that communicate with the satellite through a software multiplexer application. This is shown in Figure 12. All the communication between client programs take place over TCP/IP sockets, encapsulating packets in the same protocol as used on the spacecraft. This makes it easy to accommodate new client programs for specialized data handling and data distribution. For NEMO-AM, the client programs perform automatic query and validation of real-time telemetry, downloading stored spacecraft telemetry, and command and control of the platform and its experiments.

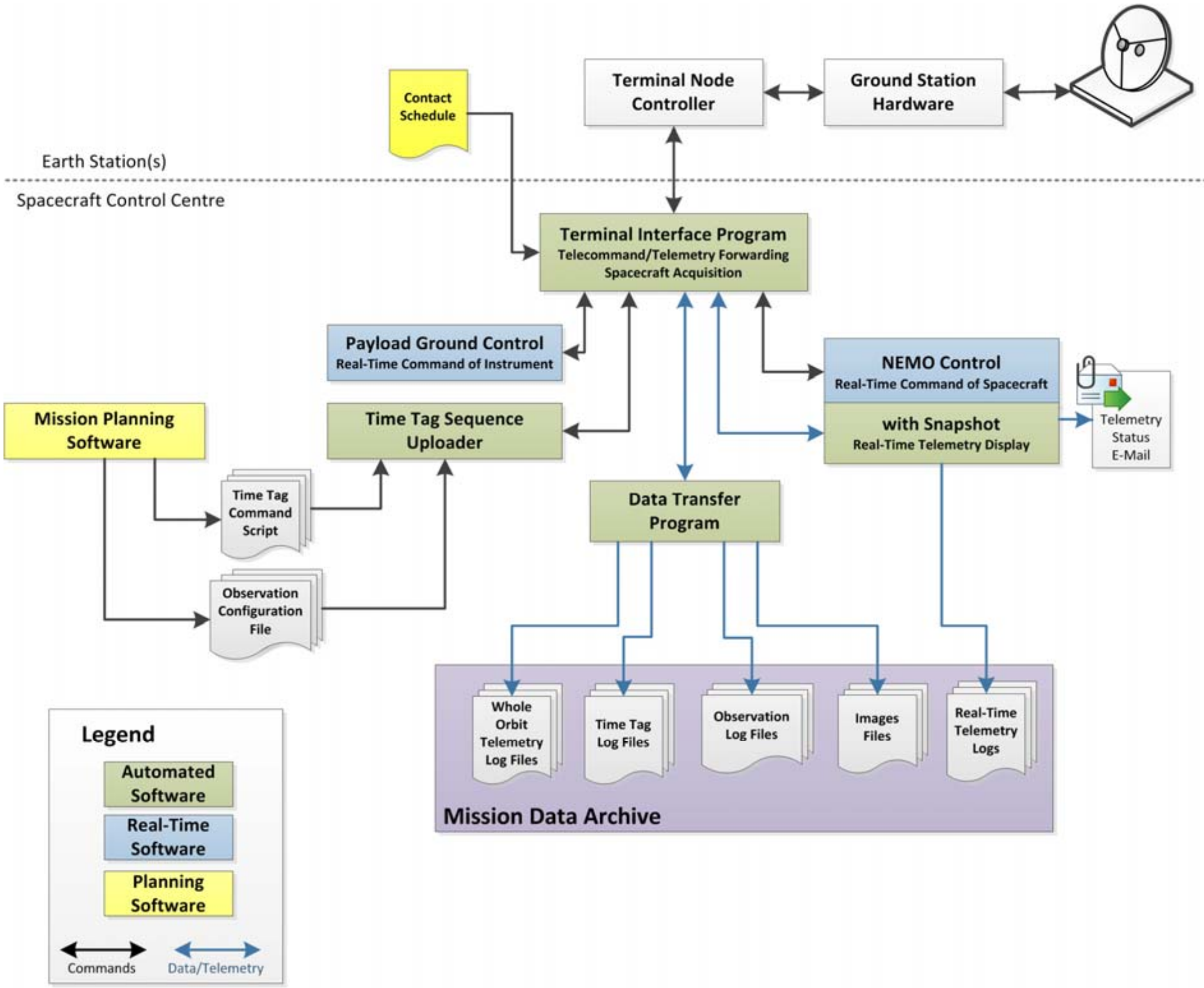

Figure 12. Spacecraft control centre software diagram.

Since the software interfaces are TCP/IP sockets, they can reside on one or more computers depending on the number of operators involved. All the software runs on standard Windows or Linux PCs. Additional software may be used and can run in other environments, provided they use the same TCP/IP interface.

SFL satellites are designed for automatic "lights-out" operation. During each contact, scheduled time-tagged command scripts are automatically uploaded, on-board bus telemetry and payload data are downloaded from OBC and real-time telemetry is beaconed during the contacts or requested by automatic software. Incorrect telemetry results in alarm notifications to the operations team, such that operator involvement is only required for contingency situations and preparation of upcoming task schedule.

All platform telemetry, command logs, and science data are stored in files on the OBC Flash file system. The downloaded platform telemetry consists of whole-orbit data continuously collected at a predetermined interval and, logs of uplinked commands and executed time-tagged commands. The science data consists of an Observation log with instrument telemetry, AOCS information during the image capture and up to 21 images per Imaging Campaign.

For manual operations, such as booting new software loads, the real-time control software executes scripted command sequences. The goal is to minimize repeated manual tasks, and allow the operations team to focus on planning, analysis, and new activities.

9 POWER ARCHITECTURE DESIGN

The NEMO-AM power system is customized to the instrument loads and mission specific operations throughout the different stages of the mission. Similar to other subsystems, the electronics chosen to build the power system were selected based on radiation testing. The primary means of power generation are 28% triple-junction solar cells. Each satellite face has at least a single string made up of 7 solar cells for keep-alive power generation. The large +X solar array shown on the left of Figure 13 is composed of 8 of these 7-cell strings and provides the principal means of power generation on NEMO-AM. The maximum power generation under worst case temperature end of life conditions is 48W.

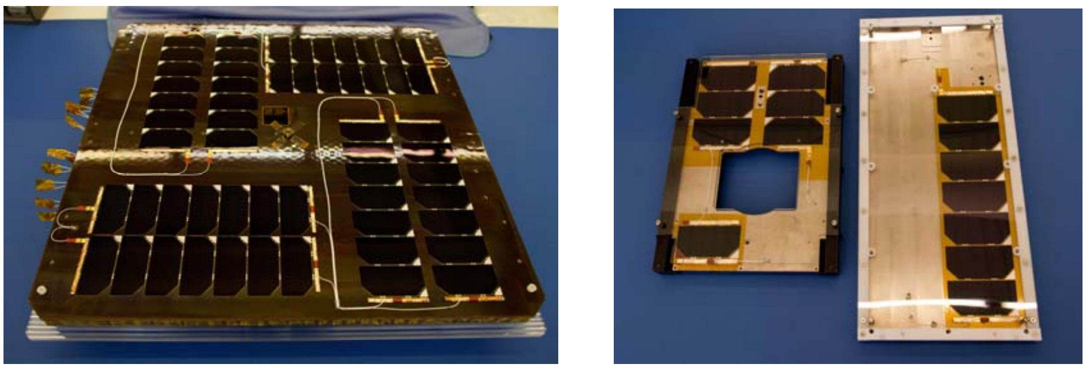

Figure 13. Large +X solar array (left) and bus panels with solar cells (right) on NEMO-AM.

Power from the solar arrays and battery is distributed through regulated power buses. The main power bus is programmable to operate up to 26V. Power to the lower-voltage avionics and payload is supplied through 5V and 3.3V regulated buses. The battery pack consists of 6 lithium ion batteries providing a total energy storage capacity of 108Wh. The charging and discharging of the battery pack is controlled by the battery charge/discharge regulator. Figure 14 illustrates the NEMO-AM power architecture.

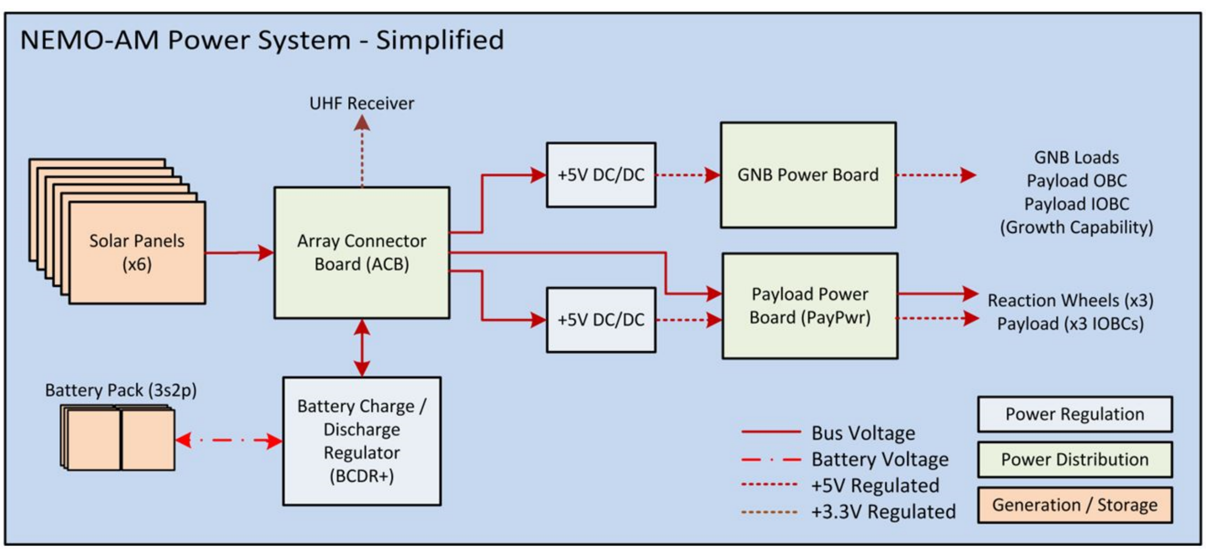

Figure 14. Block diagram of NEMO-AM power architecture.

The power system is capable of handling multiple consecutive Imaging Campaigns and data downlink periods over a single day, while charging the battery primarily through the +X panel in between these events. A worst depth of discharge of 14% of the battery is expected to occur in eclipse while downlinking data. Although the Imaging Campaigns represent the most demanding power consumption scenarios, with an average power consumed of approximately 20.7W, the power budget still retains a positive margin of 19% after imaging is complete.

The power architecture allows the spacecraft to isolate and recover from electronic power failures by implementing current limiting, under-voltage protection telemetry-based power management, switching power rails, battery load-sheds and intelligent recovery from load sheds. Communications within power distribution system is performed via an I^2C asynchronous bus. Flexibility in the architecture was derived from the ability to accommodate changing power loads and the ability to add new high-power components, if desired, after the preliminary design phase. This flexibility allowed for the introduction and integration of new supporting power and imager hardware to the satellite bus, as the design progressed through its different developmental stages and hardware updates were necessitated.

10 CURRENT DEVELOPMENT

As of 2014, NEMO-AM has been in the final stages of development. The electronic hardware and the satellite software designs have been completed and since January, have been integrated for collective testing in what is SFL denotes as flatsat testing. Flatsat testing involves employing all flight-ready units to affirm functionality, mitigate risk and root out any deficiencies in the integrated system before flight. The AOCS in particular has new modes and algorithms which have not flown on the GNB. To alleviate any AOCS-related risks, flatsat testing will specifically corroborate the performance and stability of the attitude flight code on the OBCs, and the synchronization of the hardware signals with the software estimation filters.

Similarly, the structural design has also been completed, with the majority of parts being manufactured, surface treated, inspected and fit checked at the end of 2013. Solar cell laydown has been completed for the main solar array and all body panels. At the beginning of 2014, a simplified structural assembly was used to carry out antenna pattern testing in an anechoic chamber (see Figure 15, right). The NEMO-AM structure is in its final developmental stage, being qualified for vibration. For this purpose, an integrated NEMO-AM mass dummy and XPOD Duo system are being used to verify structural integrity against launch vehicle requirements.
Figure 15 (left) shows the NEMO-AM/XPOD Duo system on SFL's vibration table.

Following the completion of flatsat testing and the qualification of the structure, NEMO-AM will engage in a full system integration test for component functionality and electromagnetic compatibility. Completion of this stage will also provide a baseline for final clean-room assembly procedures, followed by environmental and vibration acceptance testing of the flight NEMO-AM spacecraft.

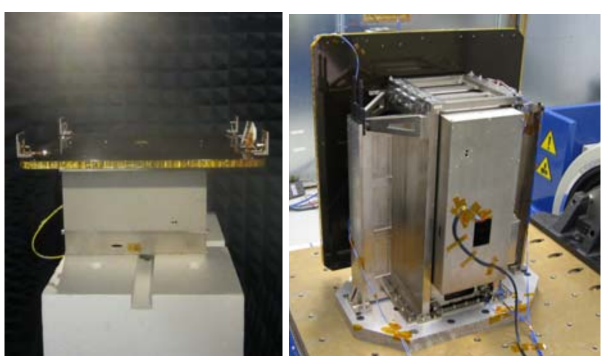

Figure 15. Test stages: antenna pattern testing (left) and vibration qualification testing (right).

11 ACKNOWLEDGEMENTS

The Indian Space Research Organization is the principal space agency in India, headquartered in Bangalore, Karnataka. It is one of the largest space agencies in the world, with the objectives of furthering space technology, applying these advanced technologies to solve real-world problems in society and utilizing these technologies for national development.

12 CONCLUSIONS

NEMO-AM is a high performance, multispectral, Earth pointing nanosatellite in the final stages of development at the University of Toronto Space Flight Laboratory. The leveraging of flight heritage, COTS electronics and engineering ingenuity have allowed the possibility of sub-degree Earth observation on a nanosatellite platform. The design of each individual subsystem has been completed and the majority of the spacecraft has been manufactured. The final risk mitigation, qualification and performance assessment tasks are well under way and NEMO-AM is anticipated to be ready for launch by the end of 2014.

13 REFERENCES

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