The Nemo Bus: A Third Generation Nanosatellite Bus for Earth Monitoring and Observation

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Presentation Outline

- UTIAS Space Flight Laboratory
- Generic Nanosatellite Bus
- NEMO Bus
- Bus Comparison
- NEMO-AM
- AM Instrument
- Conclusion
Space Flight Laboratory

- End-to-end capability: mission analysis $\Rightarrow$ hardware design and manufacturing $\Rightarrow$ assembly and verification $\Rightarrow$ launch and on-orbit operations

- Develops high-performance missions using nanosatellite (up to 20 kg) and microsatellite (up to 100 kg) using *microspace approach*

- Self-managed launch procurement and launch campaign to ensure responsive, cost-effective access to space

- Full-time professionals with microspace systems expertise
  Graduate students as part of University of Toronto M.Sc. Program

- Four operational spacecraft:
Generic Nanosatellite Bus

- **Architecture:**
  - Common technology and components
  - Scalable system: add or subtract subsystem as needed
  - Redundant connections and cross-strapping

- **Computer:** up to three computer in each spacecraft (HKC, ACC, Payload)
  - 60 MHz ARM7TDMI, 512+ MB flash, 2MB EDAC RAM

- **Power:** TJ cells, Li-ion battery
  - 9+W power generation, 3.6-4V bus, peak power tracking, battery charge/discharge regulator

- **Communication:** UHF uplink and S-band downlink
  - 4 kbps uplink, 1 Mbps downlink, omni-directional coverage

- **Attitude Determination and Control:** Passive to Full 3 axis:
  - Magnetometer, coarse and fine sun sensors, rate sensors, star tracker
  - Permanent magnet, hysteresis rods, magnetorquer, reaction wheel
  - Extended Kalman Filter, pointing accuracy is \( \sim 2 \text{ deg with FSS, } \sim 1 \text{ arc min with ST} \)
Generic Nanosatellite Bus

- **Propulsion:** Cold gas, SF$_6$
  - Up to 30 m/s cold gas, directly scalable to higher performance chemical

- **Structure:** Al or Mg alloys
  - Up to 17 x 13 x 8 cm, 2 kg payload in a 20 x 20 x 20 cm, 7.5 kg bus

- **Thermal Control**
  - Mostly passive, active control as required

- **XPOD Separation System**
  - Scalable separation system, up to 20x20x40 cm, 15 kg spacecraft mass

- **Current GNB Missions**
  - **AI SSat-1** A1S Monitoring Mission (July 2010)
  - **CanX-3A/ B/ C/ D/ E/ F** Bright Star Photometry (2011/2012/2013)
  - **CanX-4 & CanX-5** Formation Flying Demonstrator (2011)
  - **CanX-7** Technology Demonstrator (2013)
The Next Generation?

- **Look at past, present, future mission requirements, trend in technology**
- Advanced payloads requirements:
  - Power for high data throughput (high power transmitter in higher bands)
  - Volume
  - Aperture (exterior surface)
  - More system resources (three-axes stabilization)
- Improved system efficiency
  - Payload mass fraction
  - Power density ratio
- **SFL Philosophy**
  - Microspace Approach
  - Cost effective, fast-response
NEMO: Nanosatellite for Earth Monitoring and Observation

- **Architecture:**
  - Innovative connectivity for high-throughput, scalable system
  - Maintain heritage to GNB components
  - 15 kg, 20 by 20 by 40 cm bus

- **Power:**
  - 80 W power generation (based on 27% TJ cells)
  - 15V bus, peak power tracking, battery charge/discharge regulator
  - 100 Wh Lithium-ion battery

- **Communication:**
  - Omni-directional coverage
  - 4 kbps UHF uplink (TT&C)
  - 2 Mbps S-band downlink (TT&C, Data)

NEMO has sufficient resources to support a dedicated 30+ Mbps X-band TX as part of the payload
NEMO

- **Attitude Determination and Control:**
  - Passive to Full 3-axis
  - Magnetometer, Rate Sensor, Fine Sun Sensor, Star Tracker
  - Magnetorquers, Reaction Wheels

- **Instrument Computer:**
  - 100+ Mbps I/O
  - 512+ MB storage

- **Structure:**
  - Aluminum
  - Magnesium
  - Titanium
  - Carbon Fibre

- **Separation System:**
  - XPOD Duo
  - Compatibility across multiple LV
## NEMO vs. Others

<table>
<thead>
<tr>
<th></th>
<th>CanX-2</th>
<th>NTS</th>
<th>GNB</th>
<th>NEMO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spacecraft Mass</strong></td>
<td>3.5 kg</td>
<td>6.5 kg</td>
<td>7.5 kg</td>
<td>15 kg</td>
</tr>
<tr>
<td><strong>Spacecraft Volume</strong></td>
<td>10 x 10 x 34 cm</td>
<td>20 x 20 x 20 cm</td>
<td>20 x 20 x 20 cm</td>
<td>20 x 20 x 40 cm</td>
</tr>
<tr>
<td><strong>Peak Power @ 25 °C, BOL</strong></td>
<td>2-7 W</td>
<td>4-7 W</td>
<td>7-9 W</td>
<td>80 W</td>
</tr>
<tr>
<td><strong>Payload Mass</strong></td>
<td>1 kg</td>
<td>2 kg</td>
<td>2 kg</td>
<td>9 kg (4)</td>
</tr>
<tr>
<td><strong>Payload Volume</strong></td>
<td>1000 cm³</td>
<td>1700 cm³</td>
<td>1700 cm³</td>
<td>8000 cm³</td>
</tr>
<tr>
<td><strong>Payload Power @ % duty cycle</strong></td>
<td>1-2 W @100%</td>
<td>2 W @20-30%</td>
<td>3-4 W @100%</td>
<td>45 W @20% min</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6 W max</td>
<td>60 W max</td>
</tr>
<tr>
<td><strong>ACS stability</strong></td>
<td>~ 2 degrees (1)</td>
<td>Passive</td>
<td>~ 2 degrees (2)</td>
<td>~ 2 degrees (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>~ 60 arc-sec (3)</td>
<td>~ 60 arc-sec (3)</td>
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<tr>
<td><strong>Downlink</strong></td>
<td>32 k – 1 Mbps</td>
<td>32 k – 1 Mbps</td>
<td>32 k – 2 Mbps</td>
<td>32 k – 2 Mbps (5)</td>
</tr>
<tr>
<td><strong>Service</strong></td>
<td><strong>Operational</strong> (April 2008)</td>
<td><strong>Operational</strong> (April 2008)</td>
<td><strong>Operational</strong> (July 2010, AlSSat-1)</td>
<td>2011-</td>
</tr>
</tbody>
</table>

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1. Nadir pointing with magnetometer, sun sensor and one reaction wheel
2. With magnetometer, fine sun sensor and three reaction wheels
3. With star-tracker
4. Including payload-specific equipment
5. Using existing SFL transmitter; NEMO has sufficient power for a 30 Mbps X-band transmitter at 20% duty cycle

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10 Aug 2010

Pranajaya - The NEMO Bus – 24th Conference on Small Satellite
• Mission Objective
  - Aerosol Monitoring over India
  - High AOT has been reported

• Collaboration with
  Indian Space Research Organization (ISRO)
  - SFL-designed bus and instrument
  - ISRO science team
  - Funded by ISRO

• Instrument
  - Baseline instrument: three-band, multi-angle, dual-polarization instrument
  - Enhanced instrument: Addition of NIR and SWIR bands under consideration
    Instrument is SWIR capable, but not implemented in the baseline design
  - Scalable GSD, 40-200m
  - 120 km ground swath
  - 80,000 square km daily
NEMO-AM details:
- NEMO bus
- 15 kg, 20 by 20 by 40 cm main bus
- 100+ Mbps data generation rate
- Three-axes magnetometer and fine sun sensors.
  - 1.9 degrees pointing accuracy (ground tracking).
- Magnetic torquers and nano reaction wheels.
- 401-403 MHz uplink
- 2.2 GHz downlink.
- Ground stations in India (primary) and Canada (secondary)
  - As part of SFL ground station network.
- Polar Satellite Launch Vehicle
AM Observation

- Multi-spectral observation
  - Visible bands: 400-500 nm, 500-610 nm, and 610-780 nm (baseline)
  - NIR+ SWIR (enhanced)

- Polarization observation:
  - 0 degrees
  - 90 degrees

- Multi-angle observation
  - Adjustable observation angles:
    - observation angles can be adjusted along-track and cross-track
  - Ground target tracking mode

- Observation is downlink limited
  - Select Target → Select GSD → Select GS → Determine Coverage
  - Observation Planning → Perform Observation → Download Data
AM Observation

- Band choice:
  - Detection of different aerosol types
  - Similarity with current/upcoming missions

- Baseline Observation bands:
  - 480-500 nm – high scattering
  - 545-565 nm
  - 605-625 nm – aerosol detection aided by chlorophyll absorption

- Enhanced Observation bands under consideration
  - 860-880 nm – aerosol detection over oceans
  - 1580-1620 nm – detection of larger aerosol specimen
AM Observation

Source: Kurien, NEMO-AM Spectral Band Selection, ISRO-SAC, 2010
# AM Observation

<table>
<thead>
<tr>
<th>POLDER</th>
<th>PARASOL</th>
<th>APS</th>
<th>CALI PSO</th>
<th>EOSP</th>
<th>MODIS</th>
<th>NEMO-AM</th>
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<tbody>
<tr>
<td>480-500</td>
<td>480-500 P</td>
<td>402-422 P</td>
<td>395-425 P</td>
<td>405-420</td>
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<tr>
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<td>841-876</td>
<td>860-880 P *</td>
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<tr>
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<td>900-920 930-950</td>
<td>950</td>
<td>915-865</td>
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<tr>
<td>1020 L</td>
<td>1064 L</td>
<td>1020 L</td>
<td>1064 L</td>
<td>1220-1280 P</td>
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Source: Kurien, NEMO-AM Spectral Band Selection, ISRO-SAC, 2010
Conclusion

• NEMO-AM design feasibility has been established
  – Preliminary Design Review held on 8 Jul 2010 at ISRO Satellite Application Centre
  – Proceeding with characterization of the prototype instrument
  – Investigation into NIR and SWIR response
  – Instrument Qualification Test in Q3 2010
  – Target delivery in Q3 2011

• Third-generation bus that redefines the state-of-the-art of nanosatellites
  – Large payload capacity
  – High peak power generation
  – Resource for high-power payloads and support components

• Innovative architecture that builds upon the heritage of GNB design
  – Make use of many GNB components