Development of a Nitrous Oxide Monopropellant Thruster

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2016 CubeSat Developers’ Workshop – Utah, USA
Motivation

• The use of small satellites is booming.

• Capabilities are always evolving:
  - Powerful computing
  - High performance 3-axis ADCS
  - High speed communications
  - Highly capable payloads

• Propulsion requirements
  - Orbit acquisition
  - Station-keeping
  - Formation flying
  - Collision avoidance
  - De-orbit

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Background

- 2008: NANOPS (the CanX-2 mission)
- 2014: CNAPS (the CanX-4&5 mission)

- SFL wins a Canadian Space Agency contract to develop next generation propulsion systems.

- Two systems chosen: CHT and monopropellant.

- The primary propulsion system requirements were:
  - 150 kg spacecraft
  - 100 m/s delta v
  - >50 mN thrust
  - <25 kg wet mass
  - Safety and ease of handing
CNAPS

- SF$_6$-based cold gas propulsion system
- $F = 12 \text{ mN to } 50 \text{ mN}$
- $I_{\text{sp}} = 45 \text{ s}$
Nitrous oxide (N\textsubscript{2}O)

- Nitrous oxide is:
  - Safe to handle; i.e., it is non-toxic, non-flammable, and ~non-explosive.
  - Self-pressurizing (733 psia at 20 °C).
  - Easily obtainable.
  - A decent resistojet propellant.
  - Capable of being operated as a monopropellant.
SFL’s Resistojet

Performance with Nitrous Oxide (N₂O)

- $I_{sp} = 105 \text{ s}$
- $F = 100 \text{ mN}$
- $P = 75 \text{ W}$
- $m_p = 13.6 \text{ kg}$
Monopropellant

• Under the right conditions nitrous oxide will exothermically decompose according to:

\[ N_2O \rightarrow N_2 + \frac{1}{2} O_2 - 82 \text{ kJ/mol} \]
Monopropellant

http://www.chem.ufl.edu/~itl/2045/lectures/lec_m.html
Monopropellant

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Monopropellant

[Diagram showing a person pushing a ball down a hill, with chemical symbols indicating a reaction]
Nitro-100

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<th>Thruster performance</th>
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<td>Specific impulse [s]</td>
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<th>Chamber details</th>
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<td>Diameter [mm]</td>
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<td>Max. temperature [°C]</td>
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<td>Casing material</td>
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<td>Heater voltage [VDC]</td>
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<td>Heater power [W]</td>
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<td>Pre-heat temperature [°C]</td>
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<td>Pre-heat duration [minutes]</td>
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Nitro-100

Performance

• $I_{sp} = 131$ s
• $F = 100$ mN
• $P = 0$ W
• $m_p = 11.0$ kg
Vacuum thrust testing
Vacuum thrust testing
Vacuum thrust test
Vibration testing
Preheat from cold

- Housing
- Mount
- Baseplate
- TC Cold Junction
- Interface plate
- Heater
- Exhaust

Temperature [°C] vs. Time [minutes]
Lifetime testing

Thruster Chamber Temperature

Temperature [°C] vs. Time [minutes]
Summary

• A nitrous oxide-based monopropellant thruster was developed and qualified.
• The thruster provides 100 mN at 131 s while requiring no power following pre-heat.
• The propellant to provide 100 m/s to a 150 kg spacecraft is 11 kg.

• Evidence of catalyst degradation hints at an potential upper limit on thruster lifetime.
• Research into catalyst deactivation is currently ongoing.

• Propellant feed system and tank are in prototype phase.
• System will be ready-to-fly by late 2016.
Lifetime testing

Catalyst Activity Vs. Age

Time to Reach 750 °C [s]

Cumulated Run-Time of Catalyst [hr]
Monoprop. Vs. Resisto.

[Graph showing the specific impulse vs. stagnation temperature of exhaust for Monoprop and Resistojet.]
Vacuum thrust test

August 7, 2016  CubeSat Developers' Workshop 2016 - Development of a Nitrous Oxide Monopropellant Thruster
Monopropellant

- Under the right conditions nitrous oxide will exothermically decompose according to:

\[ N_2O \rightarrow N_2 + \frac{1}{2} O_2 - 82 \text{ kJ mol}^{-1} \]

- That’s a release of 145 W per 100 mN thrust!
- This heats up the exhaust gases for free.
- There’s a theoretical limit of about 1640 °C.
- There’s another advantage in that the products have a lower molar mass.
Catalyst lifetime testing

- For the reference mission the system will run for a total of 40 hours.

- A dedicated lifetime test was performed to demonstrate that the system will perform as expected for the whole mission life.

- The system was run with a single catalyst pack for a total of 50.4 hours, resulting in about 25% margin.

- Changes in catalytic activity were observed.

- Ultimately, decomposition could not be initiated after 50 hours runtime.

- System can be restarted with fresh catalyst.