Propulsion systems for ‘CubeSats’ & development status for the Pocket Rocket electrothermal thruster

C. Charles, R. Boswell, P. Alexander, Teck Seng Ho, A. Bennet, T. Charoy, A. Ellis, A. Stuchbery and D. Tsifakis,
1- Space Plasma, Power and Propulsion laboratory (SP3)
Centre for Plasmas and Fluids, RSPE, Australian National University, Australian

W. Liang, L. Raymond and J. Rivas Davila
2- Department of Electrical Engineering, Stanford University, USA

Cubesat 2017, Sydney / UNSW, April 19-20, 2017 Australia
Micro-satellite propulsion systems

- Chemical thrusters, Small gridded thrusters, Hall effect thrusters
- Cold Gas Thruster: No heating, low $I_{sp}$
- Arcjet: Arc heating, erosion issues, kW, part chemical
- Resistojet: Wall heating, $10^2 - 10^3$ W
- Hollow Cathode Thruster (HCT_SSTL)
- Pulsed Plasma Thruster (STRaND-1_SSTL)
- Electrospray thruster

$$T = \frac{d(mv)}{dt}$$

Cold Gas Thruster (Courtesy of moog.com)

Busek BIT-3 RF thruster

SSTL Hollow Cathode Thruster

Pocket Rocket rf plasma thruster

Busek 1mN

SSTL Pulsed Plasma Thruster

Electrospray: S-iEPS MIT 8 MEMS (0.1 $\mu$N)

Astrium’s hydrazine system
Micro-cathode arc thruster in orbit: \(\mu\text{CAT}\)

George Washington University (Prof Keidar’s group)

However, as of May 2015, the \(\mu\text{CAT}\) reached a NASA technology readiness level of seven (TRL7) with the successful launch of the United States Naval Academy’s BRICSat-P. The \(\mu\text{CAT}\) sub-system was not only able to successfully t into the BRICSat-P, it was also able to successfully de-tumble the CubeSat to less than 1 degree/minute.

SP3_ANU rf thrusters

HDLT (Helicon Double Layer Thruster) – 2002, electrodeless radiofrequency (rf) plasma thruster
Astrium (AIRBUS) 2006-2013

DS4G (Dual Stage Four Grid thruster) – 2005-2006, ion gridded rf thruster
European Space Agency (ESA)

PR (Pocket Rocket Thruster) – 2010, electrothermal rf plasma micro-thruster
Lockheed Martin US 2013-2015
Diagnostics:
- Thrust balance
- Langmuir Probe
- Energy analyser

Surrey Space Centre UK, VIPAC, ANU (2009)
Collaboration: Iwate Uni (2011), Japan
Tohoku University Sendai (2013), Japan

Takahashi et al, APL 2011
Lafleur et al, APL 2011
Charles et al, APL 2012
Large thermal-vac chamber: Wombat XL

develop expertise using HDLT
key technological challenges:
thrust balance for radiofrequency thrusters with $B_{\text{field}}$
Rf sub-system: impedance and power supply

Variable frequency
PCB Match
500 W rf system

Going from TRL 6 to 9 with no Australian space agency?
European Union QB50 CubeSat project

- INMS (Ion/Neutral Mass Spectrometer)
- FIPEX (Flux Φ Probe EXperiment)
- mNLP (multi Needle Langmuir Probe)

Constellation of 50 Cubesats from 27 countries: Dec 30, 2016 launch to ISS
Jan 2017 release from ISS, 1-2 year orbit, ‘open source’ www.qb50.eu

1- Lower thermosphere, ionosphere of the Earth
2- ‘plasma & gas’ sensors INMS (MSSL), mNLP (Oslo), FIPEX (Dresden)
QB50 INMS testing in ANU ChiKung plasma wind tunnel experiment

Collab with Dhiren Kataria

UCL INMS sensor (12QB50s)
QB50 Flight prototype (UK)
immobile ions & satellite at ~8 km/s

Ion analyser (RFEA) & baffle:
fast ions & neutrals (~10 km/s) & immobile satellite

Ground-based low ion beam energy calibration (<0-100 eV) + physics
QB50 Australian final Testing in Wombat XL

http://sydney.edu.au/inspire-cubesat/

INSPIRE-2: 30th September 2015, Wrapped and shipped to Europe
Flight-ready on 19th August 2016
See Iver’s talk

Disruptive technology & Need of propulsion unit
AU03 Ground Station in Wombat lab

Blue wren

UHF / VHF
Pocket Rocket rf micro-thruster: PR

Low-power (0.5-50 W) capacitive radiofrequency plasma source at ~ a few Torr

Electrothermal micro-thruster (1.5 mm diameter, 2 cm long)

Thrust from hot neutrals (ion-neutral charge exchange collisions) ~ 0.1-2 mN

Safe, low-cost ‘green’ propellants (Ar, H$_2$O, N$_2$, CO$_2$…), best with atomic gases

rf power subsystem and gas propellant subsystem not commercially available
Propellant sub-system: 1/3U

Ar propellant (not N₂ due to vibrational states at low power)
Bulk plasma heating (μs) by pulsing
COTS parts for propellant sub-system (gas canisters, 3D printed tubing)
Propellant sub-system: 1/3U

Ashley Ellis, Honours Thesis (2016)
Thomas Charoy, 6 months visit (2016)
Alex Stuchbery, Honours Thesis (2017 in progress)

Canister
Adaptor
Upstream Transducer
Regulator
Proportional Valve

Cold gas thruster (1/3 U)
propellant sub-system
Pocket Rocket

Battery (COTS)
rf generator
rf match
Electrothermal rf plasma thruster (<1 U)

10 cm
Pocket Rocket thrust in Wombat vacuum

Mounted on thrust balance
Immersed in vacuum
Gas and rf line connected
0.1-2 mN

Partner: Lockheed Martin

C. Charles et al, JPP 30 (2014)
C. Charles et al, Front Phys (2016)

Source of loss
Power sub-system: Switch Mode Amplifier

APEC 2017

Structurally supportive RF power inverter for a CubeSat electro-thermal plasma micro-thruster with PCB inductors

Wei Liang, Luke Raymond, Kawin Surakitbovorn, Prof. Christine Charles, Prof. Rod Boswell, Prof. Juan Rivas
Stanford-ANU test campaign March 2016:
RF sub-system prototype developed by Luke Raymond, Juan Rivas, Max Praglin & Wei Liang

Class Φ2 inverter: allows the use of lower voltage FETs by introducing a component of second harmonic into the amplifier and thereby reducing the peak height. Low weight, small, robust and efficient system power supply.
Complete system in WOMBAT showing (from right) battery box, DDS, rf amplifier and 2 stage match connected to Pocket Rocket (~10 shots).
Power sub-system: current prototype status

Stanford-ANU test campaign March 2017:

>100 plasma tests (~2.4 W nominal) in vacuum with no parasitic discharges
Summary

1- Resume 1U integration and testing in Wombat in preparation for IAC 2017
2- Assess scalability of the rf sub-system for MiniHel and BB thrusters
3- Launch to the ISS on April 18, 2017 (Orbital ATK Antares rocket) (Yes/No)
4- INSPIRE-2 Communications with Ground Station
5- Space plasma physics with QB50 INMS and mNLP data
6- Next mission: Flight heritage for Pocket Rocket

Planet Lab Dove CubeSats deployed from the ISS, Feb 2014

QB50p1, QB50p2
40 QB50-ISS
6 QB50-DS
2 QB50-DIOD