CubeSat Technology

Current State-of-the-Art and Future Needs

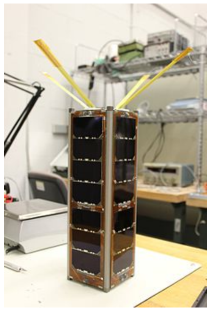
Matt Bennett

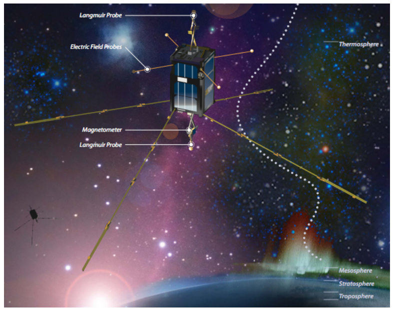
October 29, 2012

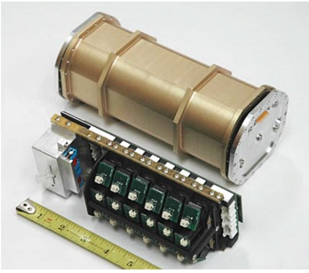
Note: The following package is not an exhaustive technology survey, but a representative sampling of available and forthcoming capabilities compatible with CubeSat and larger platforms

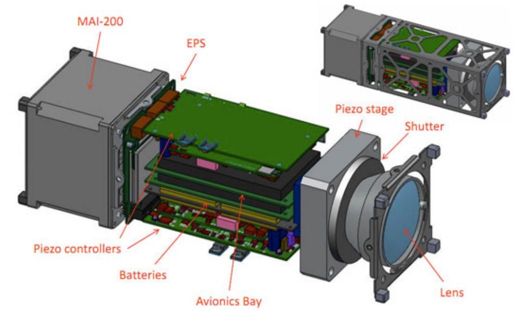
Introduction to CubeSats – Example Missions

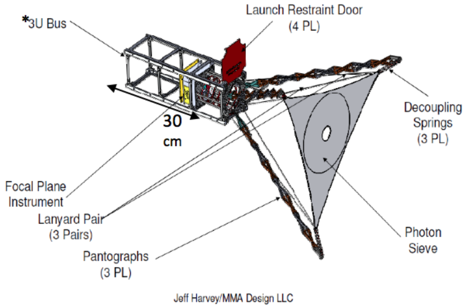
- Space Weather Science (NSF missions)
- Biological Science (NASA ARC missions)
- Astrophysics (Moorehead States's CXBN)
- Planetary Science (MIT's ExoplanetSat)
- Technology Demonstrations
  - Propulsion / Attitude (Nanosail-D)
  - Imagers (FalconSat-7)
  - Solar Arrays (NPS-SCAT)
  - FPGAs (M-Cubed/COVE)
  - Fractionated Space (DARPA F6)
  - Plug-n-Play architectures (AFRL)

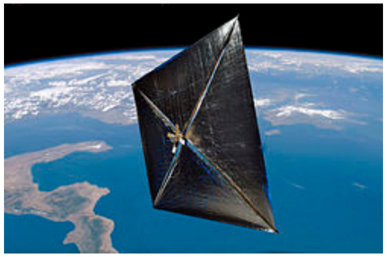


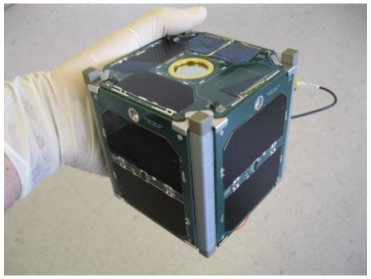


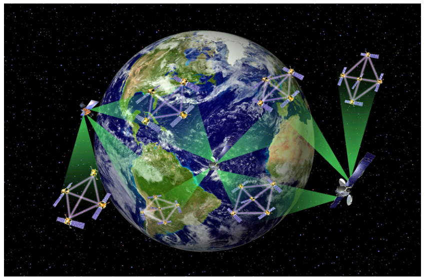








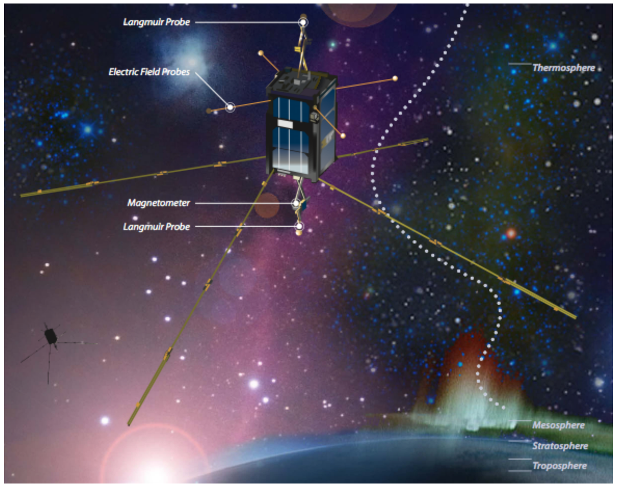


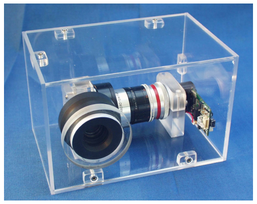


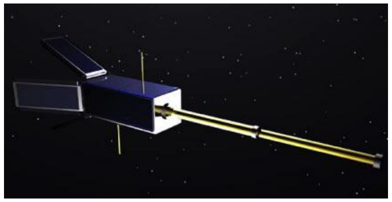
CubeSat Instruments/Sensors

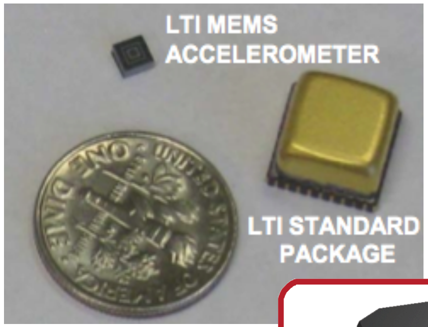
Instrument Examples

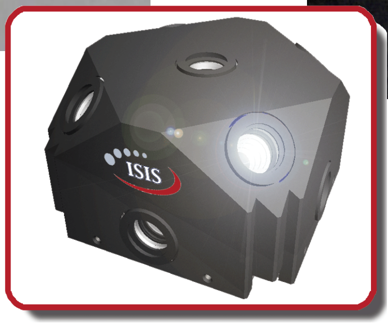
- Imagers (Vis, IR, Hyperspectral)
- Spectrometers
- Bolometers
- Field/particle sensors
- Radio science
- Magnetometers

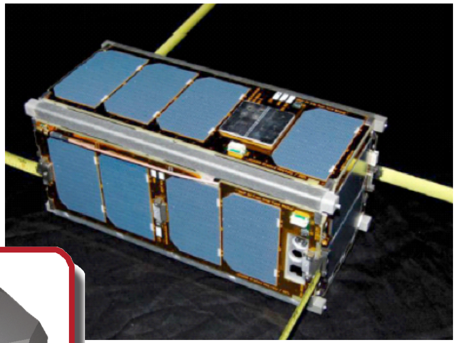












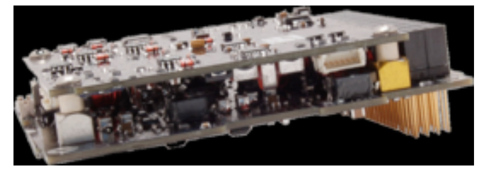
Navigation Sensor Examples

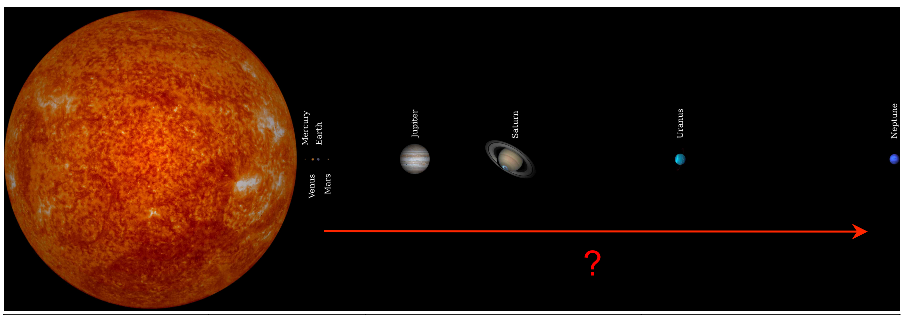
- Star trackers
- Sun sensors
- Horizon sensors
- MEMS gyros and accelerometers (<1 ug)
- X-band transponders

Some instruments/sensors can be dual-purposed!

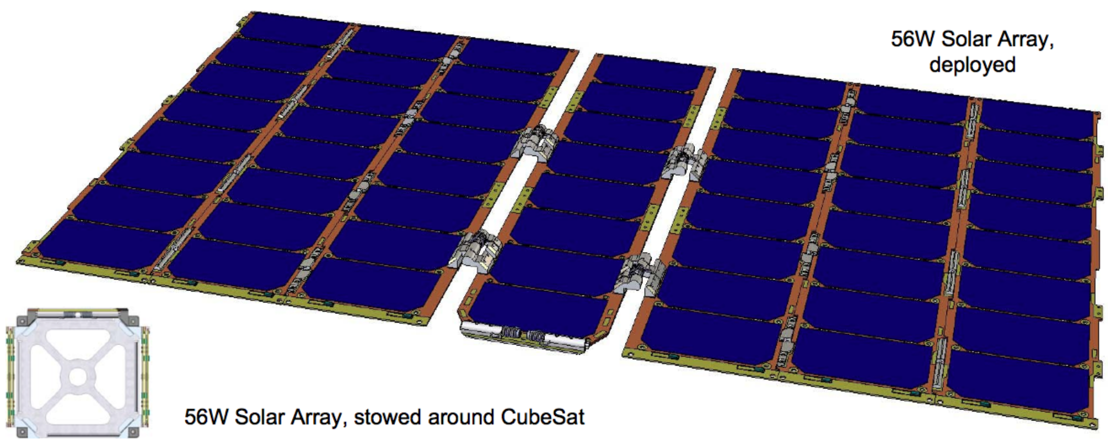
CubeSat Capabilities – Power Tech

- Deployable solar arrays pushing the power envelope
  - Current COTS-available maximum is 56-64 Watts instantaneous (SSO 35W avg)
  - Up to 80-Watt deployable arrays on the horizon
  - Solar array drive systems
- COTS Power Systems
  - 30 Watt nominal power regulation, up to 70 Watts instantaneous
  - Battery packs with up to 33 W-hr have been flown in LEO
- What about power beyond Earth/Lunar orbits?



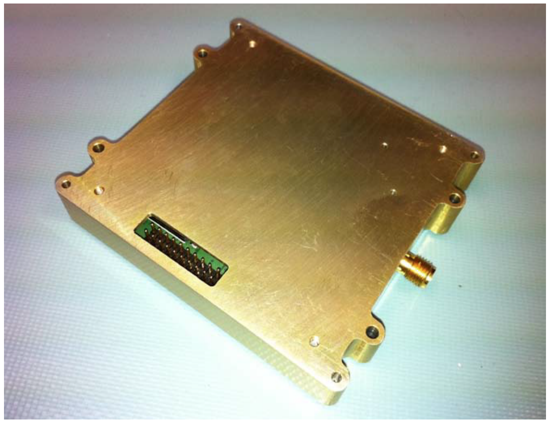


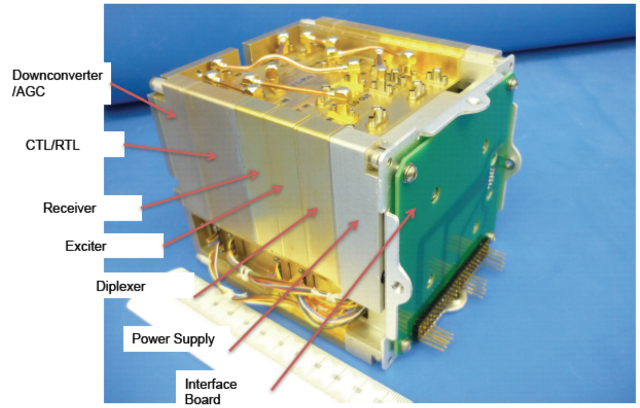
	Distance (AU)	Solar Power Reduction Factor	80-Watt Earth Array Power at Target (W)
Mars	1.52	2	35
Ceres	2.77	8	10
Jupiter	5.2	27	3
Saturn	9.5	90	1
Uranus	19.6	384	0.2
Neptune	30	900	0.1

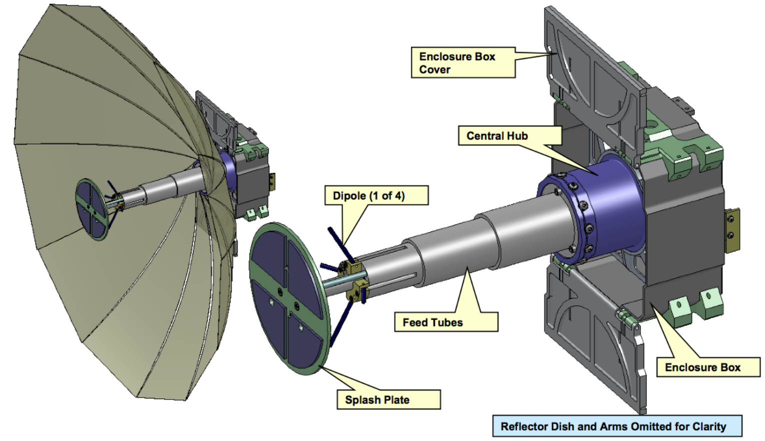


CubeSat Capabilities – Comm Tech

JPL







L-3 Cadet Radio

- UHF/S-band Radio
- 1-100 Mbps, 2 Watt RF output
- **3 Mbps demo'd in LEO**

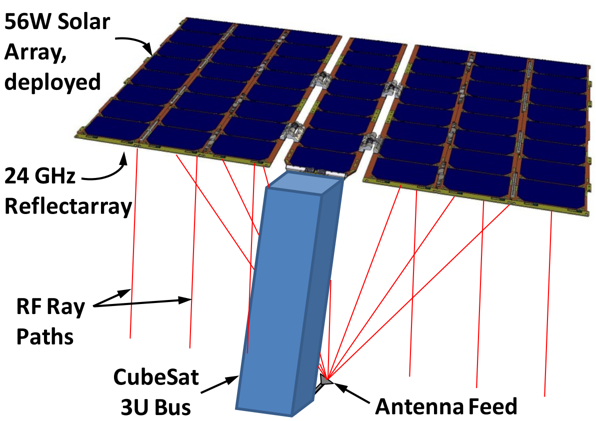
LMRST Nav Transponder

- 1U-size X-band transponder
- 0.5U SDR-based transponder w/ comm under development

Miniature Deployable High Gain S-band Antennas

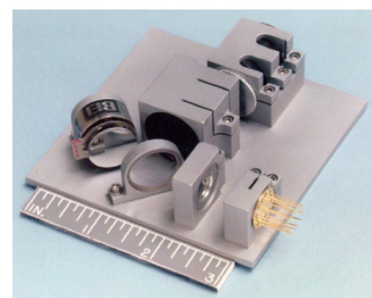
18 dBi gain, 50 cm DIA

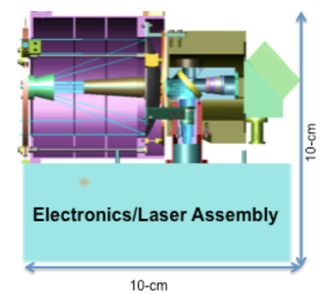
Boeing system pictured above;
NGC system demo'd on Mayflower CubeSat



JPL ISARA Tech Demo

- Ka-band transmitter
- 100 Mbps max rate
- High-gain reflectarray design built into solar array
- *To be launched circa 2014*





JPL SCOPE LaserCom Demo

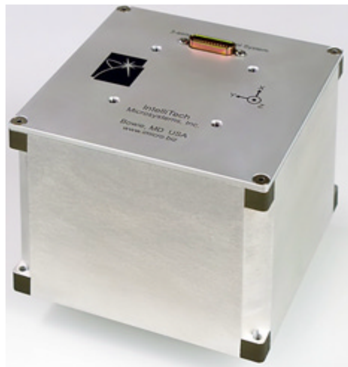
0.5 W average, 40-60 kbps from 2 AU

Note: High-rate comm systems will require capable receive apertures to achieve spec'd capability.
For example, The L-3 Cadet system required an 18-meter dish to achieve the 3 Mbps data rate.

CubeSat Capabilities – Attitude Control Tech

FLOWN

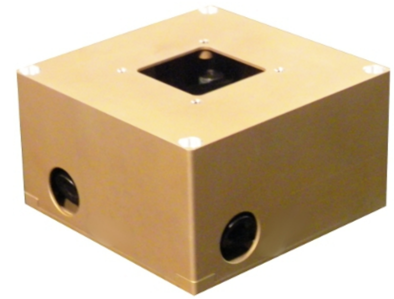
Maryland Aerospace MAI-100/200 Series



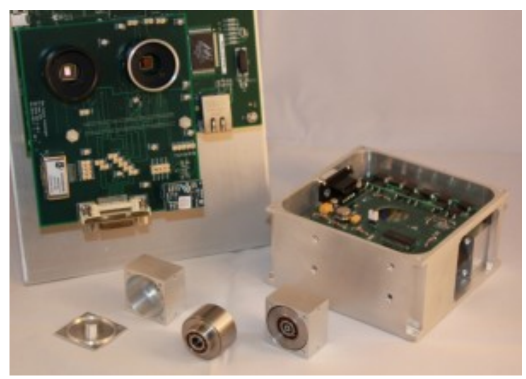
- 1U-size system
- Better than 1 deg RMS (3 reaction wheels, 3 x torquer, 6 sun sensors, 1 magnetometer)
- **TRL > 7**

Available for Flight

Maryland Aerospace MAI-400 Series



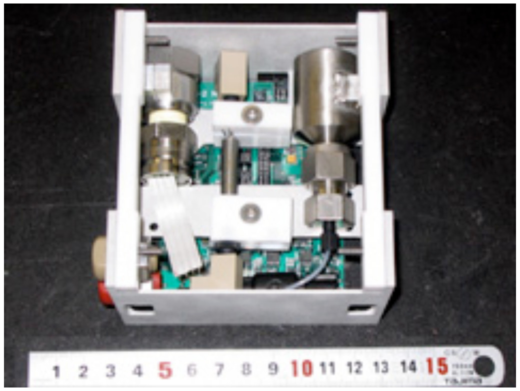
- Better than 1 deg RMS, but half the size of MAI-100 (3 reaction wheels, 3 x torquer, 6 sun sensors, 1 magnetometer)
- **TRL 6**



Blue Canyon Tech XACT Control System

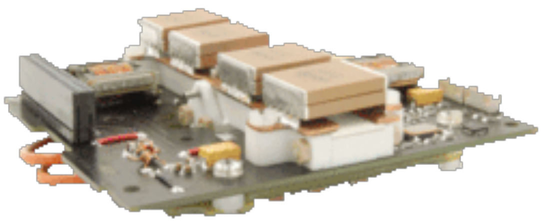
- +/- 0.02 deg accuracy
- 0.5U volume, 0.7 kg
- 0.5 W avg / 2 W peak
- 3 reaction wheels, magnetic torquers, and star tracker
- **TRL 6**

CubeSat Capabilities – Propulsion Tech

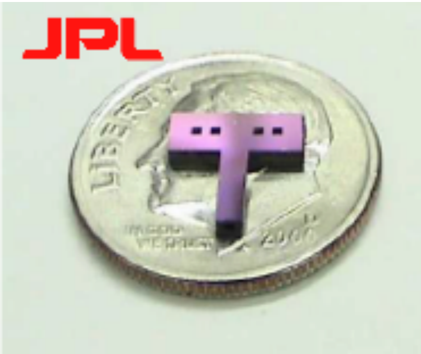


CanX-2 SF_6 Cold Gas Thruster (50 sec Isp)
TRL ≥ 7

VACCO Butane Thruster (90 sec Isp)
TRL ≥ 7

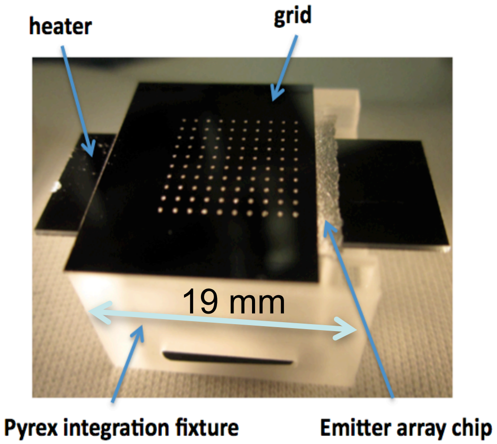


Clyde Space PPT (590 sec Isp)
TRL 6



Mini Resisto-Jet

Thruster Type	Resisto-jet	PPT	FEEP (Indium)	FEEP (Cesium)	Colloid	Miniature Ion
Thrust (mN)	0.1 - 10	0.002 - 0.7	0.001 - 1	0.001 - 1.4	0.001 - 1	0.5 - 3
Isp (sec)	75-150	500 - 1500	6,000 - 9,000	6,000 -9,000	100 - 1,500	3000 (typ.)
Ibit (Ns)	10^{-6}	10^{-4} - 10^{-6}	10^{-8} (est.)	10^{-8} (est.)	10^{-8} (est.)	TBD
Specific Power (W/ mN)	1-5	70 - 100	60	60	1	30
Propellant	Water	Teflon	Indium	Cesium	Glycerol, Ionic Liquids, Formamide	Typ. Xenon



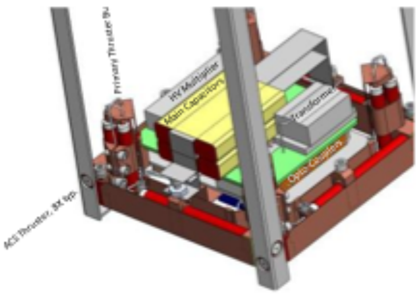
Micro Electrospray Thruster (5,000 sec Isp)

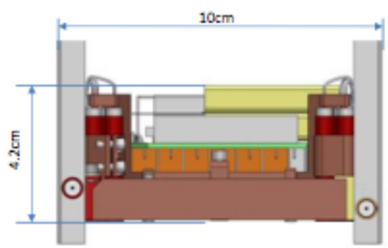
These technologies now enable CubeSats to perform proximity operations, deep space maneuvers, or orbit changes from initial deployment orbits

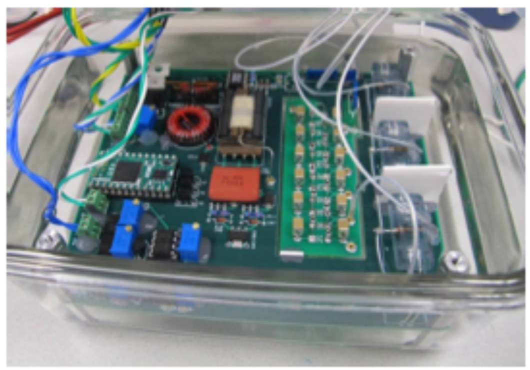
CubeSat Capabilities – Prop/ADCS Combos

JPL

Busek mPPT



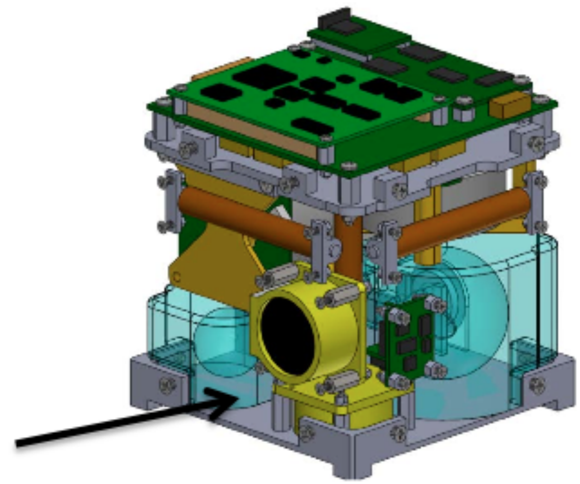


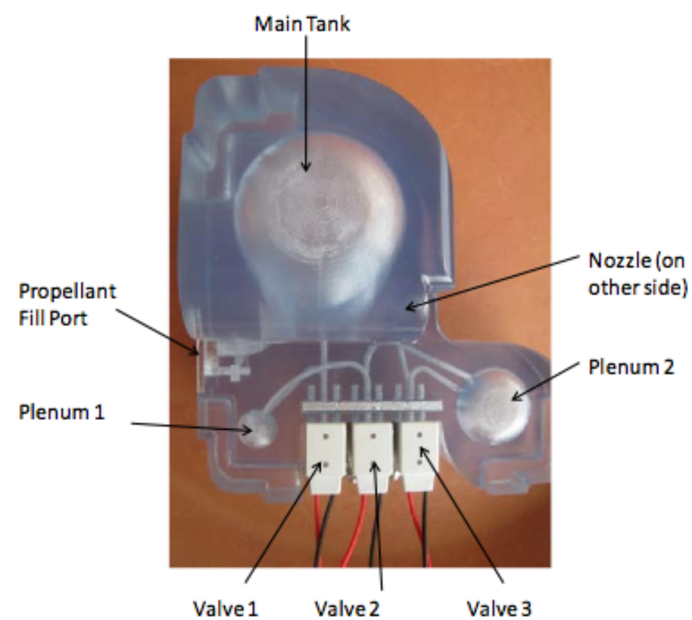


Key Performance Characteristics, Busek Micro-Pulsed Plasma Thruster

Characteristic	Description
Impulse (mN-s)	0.05 primary, 0.05 ACS
ISP (s)	800
System Power (W)	2 (2Hz firing rate)
System Volume (U)	< 0.5
System Mass (kg)	< 0.55
Delta-V for 4kg CubeSat (m/s)	51 primary, 95 ACS
TRL	4-5

Austin Satellite Cold Gas Thruster





3-Year CubeSat Capability Forecast

	Current State-of-the-Art	Projected Capability in 3 Years
Attitude Determination and Control	40 arcsec determination 200 arcsec control	< 10 arcsec determination < 50 arcsec control
Communications	3 Mbps on UHF	10 Mbps on S-band Up to 100 Mbps on Ka-band
Propulsion	Cold gas or butane (I_{sp} of 50-100 sec)	μPPT, colloid, and electrospray (I_{sp} of 500-5000 sec)
Solar Power	7-panel solar arrays at 56 Watts total power	8-panel solar arrays at 70-75 Watts total power

Capability forecast based on…

- Capabilities currently being developed by small satellite industry
- Published papers/presentations projecting capabilities of miniaturized propulsion and ADCS technologies
- Data rate trends in CubeSat industry constrained by physical considerations of spacecraft and ground station resources

Current State-of-the-Art Tech Summary

Typical Parameter	1U	3U
Mass	1.3 kg	4 kg
Volume (Before Deployment)	10x10x10cm	10x10x34cm
Solar Arrays	Fixed (few deployable)	Fixed Deployable and Articulated
Power	~3 W avg fixed	~8W avg body-fixed ~25W avg deployed
Battery	2200mAh	4400mAh (0.2U)
Antenna	Monopole / Dipole	Dipole, Turnstile, Patch 0.5m dish (1U)
Comms	UHF / VHF	S-Band, UHF/VHF
Data Rates	9600 kbps	3 Mbps demo'd
Attitude Control	~5 deg control (passive)	1-10 deg (torquer) ~0.02-1 deg (RW) (0.5U)
Attitude Determination	~3-4 deg (gyro, sun, mag)	<1 deg (horizon sensor) ~40 arcsec with star tracker (1 U)
C&DH	RISC, ARM Some Linux-based	RISC, ARM, Linux, FPGAs
Propulsion	None	Cold Gas, EP, Solar Sail (<100 m/s)
Deployables	Antenna	Antenna, Panels, Tethers, Boom (0.5m), Solar Sail (5m)
Demonstrated Lifetime	9 years + (XI-IV)	9 years + (Quakesat)
Payload Volume	0.5U max	0.5-2U

Where Are The Gaps?

- Propulsion and Proximity Operations
  - Solar sail proven on CubeSat in LEO and larger spacecraft outside of LEO, but not both at the same time (early flight demo feasible)
  - Efficient solar electric propulsion (lower-Isp ready; high-Isp in development)
  - COTS RF-based proximity sensing available → optical nav is need
  - Lander system propulsion

- Structures and Deployables
  - Large, light-weight, deployable structures

- Power Systems
  - Deep space power systems (generation/storage) out of usable SA range

- Communications and Navigation
  - LEO high data rate on horizon → limited ground resources
  - Communications for large constellations under study, but not ready
  - Nav/comm beyond LEO (LMRST on horizon, <u>deep space comm is needed</u>)

- Thermal (instrument operation, atmospheric transit)

How Good Is “Good Enough”?

- Spacecraft lifetime and environment?
- How much power?
- Earth orbiting / deep space position knowledge?
- Proximity accuracy?
- Earth orbiting / deep space data rates?
- Temperature requirements?
- Other requirements (spacecraft or instruments)?