State-of-the-Art for Small Satellite Propulsion Systems

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Overview

- State-of-the-Art Overview
- Obstacles to System Development
- SmallSat Propulsion System Performance
- System in Flight
- Conclusion

State-of-the-Art Overview

- **SmallSats enable low-cost access to space.**
- **Their uses and capabilities are growing to the point where a propulsion system is required.**
- **Current state-of-the-art for SmallSat propulsion systems is rapidly evolving. However, their technology readiness level (TRL) is still relatively low.**
- **Desired SmallSat propulsion system SoA:**
  - Lowest cost possible
  - High performing
  - High reliability
  - Simplest design feasible
- **Current SmallSat propulsion system SoA:**
  - Low-cost, unreliable, and low performing, or
  - High-cost, reliable, and high performing

Obstacles to System Development

- **Reliability**
  - Low quality standards
  - Components not tested in harsh environments (radiation, thermal, vibration)
- **Maturity**
- **Safety**
  - Academia and hobbyists have low quality standards compared to government agencies and large private organizations.
  - Primary payloads and NASA/Johnson Space Center (NASA/JSC) (for ISS) will not allow additional hazards to be flown, e.g., high pressure systems (>100 psia) or hazardous propellants.
- **Cost**
  - Power Processing Unit (PPU) development is hindered by availability of space-flight qualified components (e.g., radiation hardened) at a low cost
  - Exceeding or well-documenting U.S. Range Safety compliance demonstrating that the system will not create undesirable risk.

SmallSat Propulsion Systems

- **Chemical Propulsion Systems**
  - Cold gas propulsion system propellants use primarily saturated liquids:
    - Refrigerants
      - R134a – used in air conditioning systems
      - R236fa – used in fire extinguishers
    - Sulfur Dioxide
    - Isobutane
  - High energy propulsion system development has primarily focused on green propellants (AF-M315E, LMP-103S). However, there are some hydrazine systems in development.
- **Electric propulsion system**
  - Electrospray (ionic liquids)
  - RF Ion (iodine or noble gases (xenon, krypton, etc.))
  - Electrothermal (refrigerants, ammonia, sulfur dioxide, isobutene)
  - Helicon Plasma (iodine or noble gases (xenon, krypton, etc.))

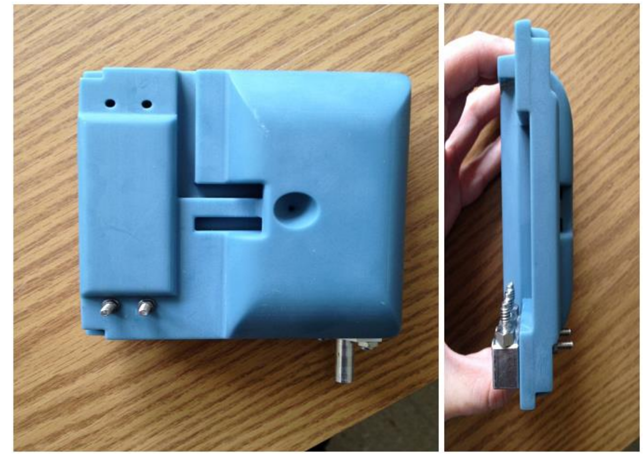
Performance & Development Metrics

- **The following are the performance metrics used to evaluate SmallSat propulsion system capability:**
  - Change in Velocity, Δv (m/s)
  - Specific Impulse, I_{sp} (sec)
    - System's fuel efficiency
  - Thrust, F (N or lbf)
  - Power, P (W)
  - Total Impulse, I_t (N-sec)
    - Total momentum applied to a body
  - Volumetric Impulse, I_t / V ((N-sec)/U or (N-sec)/L)
    - The amount of total impulse a system can impart to a body per unit volume
    - Volume in this case is based on a 1U CubeSat
    - An efficiency parameter (i.e., amount of performance per U)
- **Technology Readiness Level, TRL, is a fundamental development metric used to evaluate technology maturation.**

SmallSat Cold Gas Propulsion

CubeSat MEMS Propulsion System (NanoSpace)

- Propellant: Isobutane
- Wet Mass: 0.30 kg (Prop: 0.05 kg)
- Performance:
  - Thrust: 0.01 to 1 mN (x4 thrusters)
  - Specific Impulse: 110 sec
  - Vol. Imp.: 133.3 Ns/U
- Power Req: < 2.5 W
- TRL: 6
- Salient Features:
  - MEMS thruster chips contain flow components
  - Closed loop control

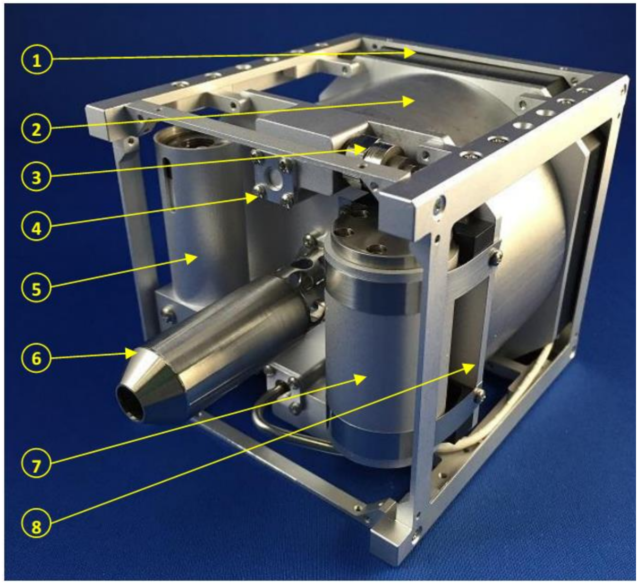


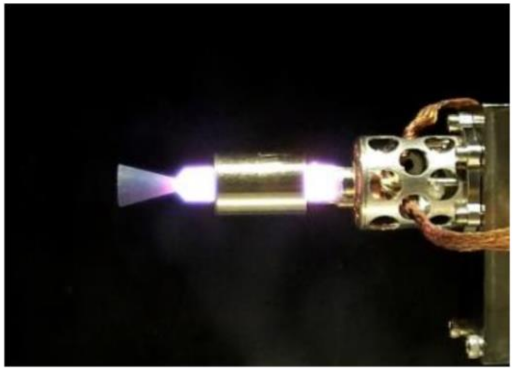
3D Printed Cold Gas Propulsion System (UT-Austin)

- Propellant: R-236fa
- Wet Mass: 0.38 kg (Prop: 0.09 kg)
- Performance:
  - Thrust: 40 mN (Bevo-2 model shown above)
  - Specific Impulse: 35 sec
  - Vol. Imp.: 146.5 Ns/U (Bevo-2 model shown above)
- Power Req: 1.5 W
- TRL: 6
- Salient Features:
  - Accura Bluestone resin
  - SLA provides flexible system architecture

SmallSat Green Propulsion

Component	ID#
Power Processing Unit (PPU)	1
Bellows Propellant Tank	2
Pressure Transducer x2	3
High-Pressure Burst Disc	4
Piezo-Actuated Thruster Valve	5
0.5N Thruster BGT-X5 with Thermal Shield	6
Post-Launch Pressurization System (PLPS) Cell	7
Tank Manifold & Component Mounting Plate	8

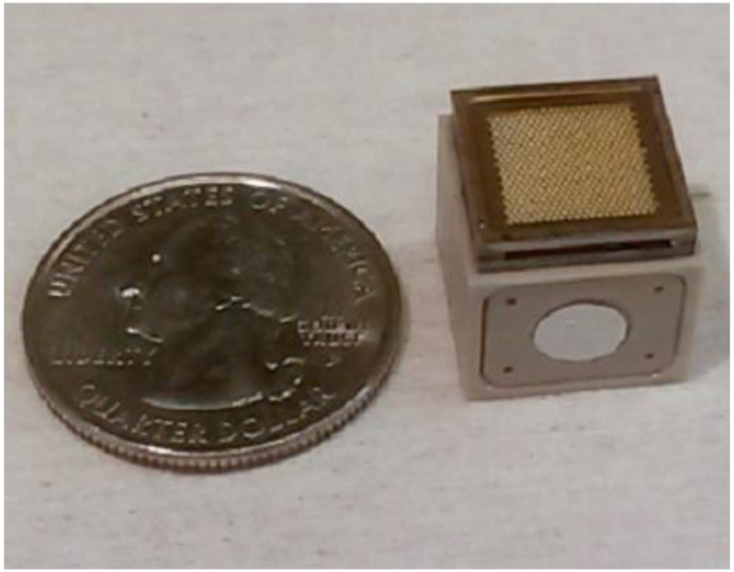


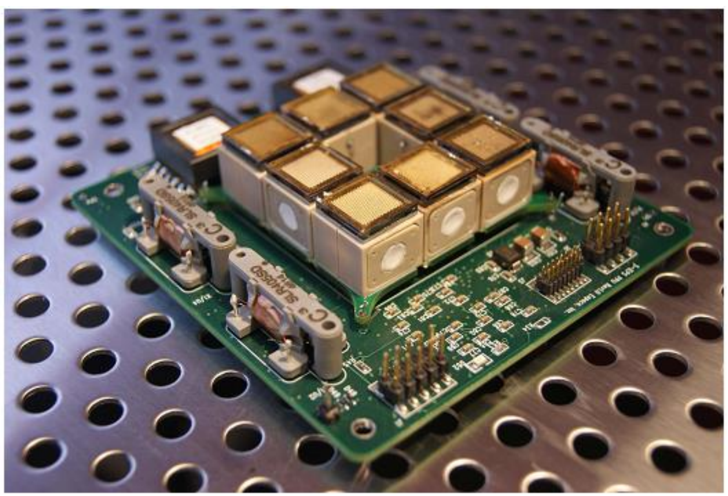


Advanced Monoprop Application for CubeSats (Busek)

- Propellant: AF-M315E
- Wet Mass: 1.49 (Prop: 0.29)
- Performance:
  - Thrust:425 mN
  - Specific Impulse: 220 sec
  - Vol. Imp.: 565.0 Ns/U
- Power Req: 20 W
- TRL: 5
- Salient Features:
  - Developed 500 mN thruster & catalyst
  - Post-launch Pressurization System (PLPS)

SmallSat Electric Propulsion

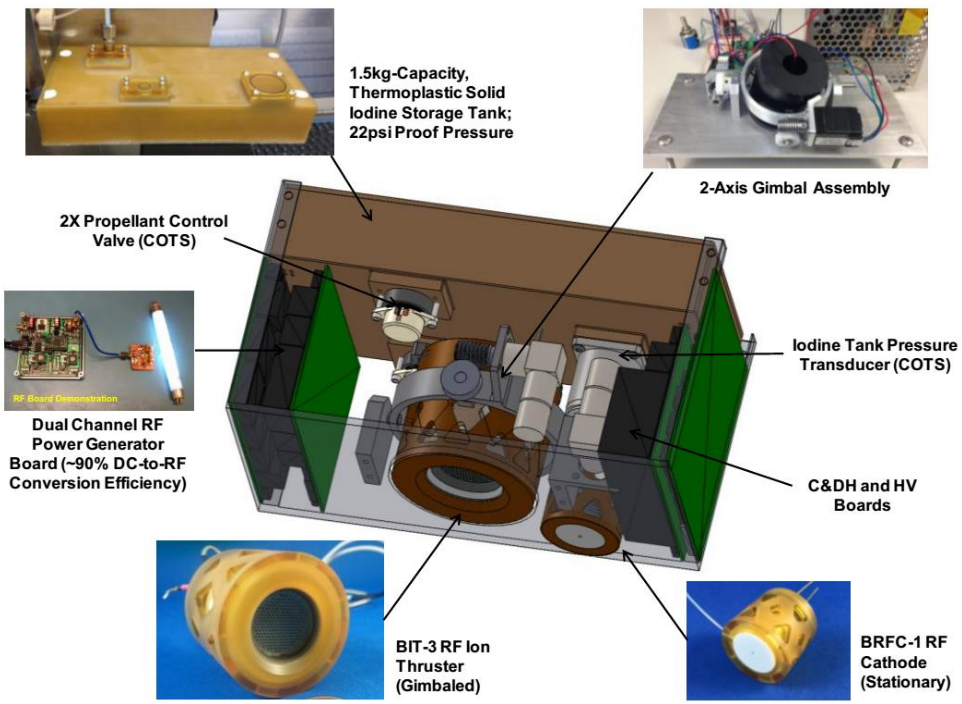




Scaleable ion Electrospray Propulsion System (MIT/Accion Systems)

- System Type: Electrospray
- Propellant: Ionic Liquid
- Wet Mass: 0.028 kg (Prop: 0.01 kg)
- Performance:
  - Thrust: 0.075 mN
  - Specific Impulse: 1000 sec
  - Vol. Imp.: 260.6 Ns/U
- Power Req: 1.5 W
- TRL: 5
- Salient Features:
  - Low power usage
  - Useful for fine maneuvering

SmallSat Electric Propulsion



BIT-3 (Busek)

- System Type: RF Ion
- Propellant: Iodine
- Wet Mass: 3 kg (Prop: 1.5 kg)
- Performance:
  - Thrust: 1.15 mN
  - Specific Impulse: 2100 sec
  - Vol. Imp.: 15,451 Ns/U
- Power Req: 45 W
- TRL: 5
- Salient Features:
  - First system that will use iodine in flight

SmallSat Electric Propulsion

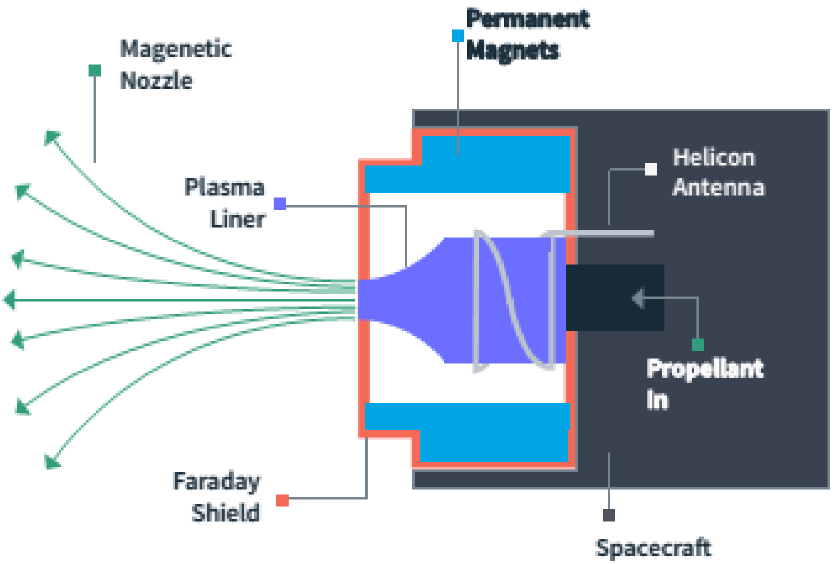
Propulsion Unit for CubeSats (CU Aerospace/VACCO/AFRL)

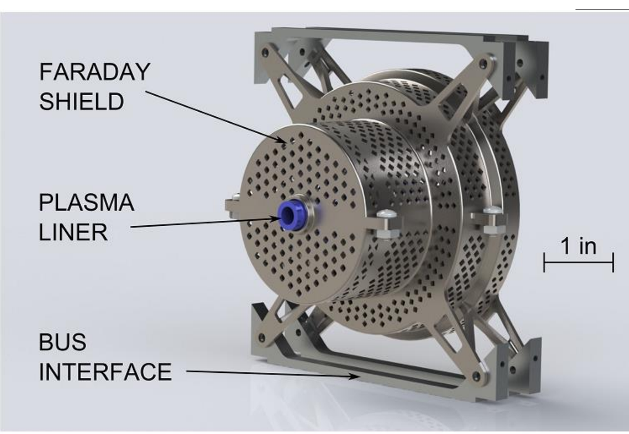
- System Type: Electrothermal
- Propellant: R-134a, R-236fa, SO_2
- Wet Mass: 0.72 kg (Prop: 0.27 kg)
- Performance (R-236fa/Warm Gas):
  - Thrust: 5.4 mN
  - Specific Impulse: 72 sec
  - Vol. Imp.: 514.5 Ns/U
- Power Req: 15 W
- TRL: 6
- Salient Features:
  - Compact

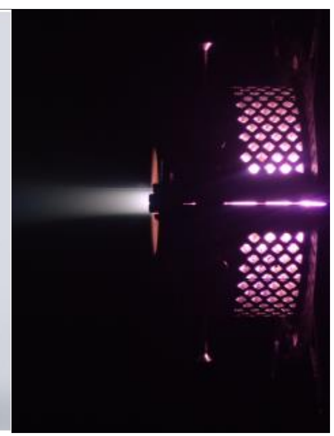
CubeSat High Impulse Propulsion System (CU Aerospace/VACCO/AFRL)

- System Type: Electrothermal
- Propellant: R-134a, R-236fa, SO_2
- Wet Mass: 1.2 kg (Prop: 0.7 kg)
- Performance (R-236fa/Warm Gas):
  - Thrust: 30 mN
  - Specific Impulse: 82 sec
  - Vol. Imp.: 526.2 Ns/U
- Power Req: 30 W
- TRL: 5
- Salient Features:
  - Integrated battery pack
  - Cold Gas ACS thrusters

SmallSat Electric Propulsion





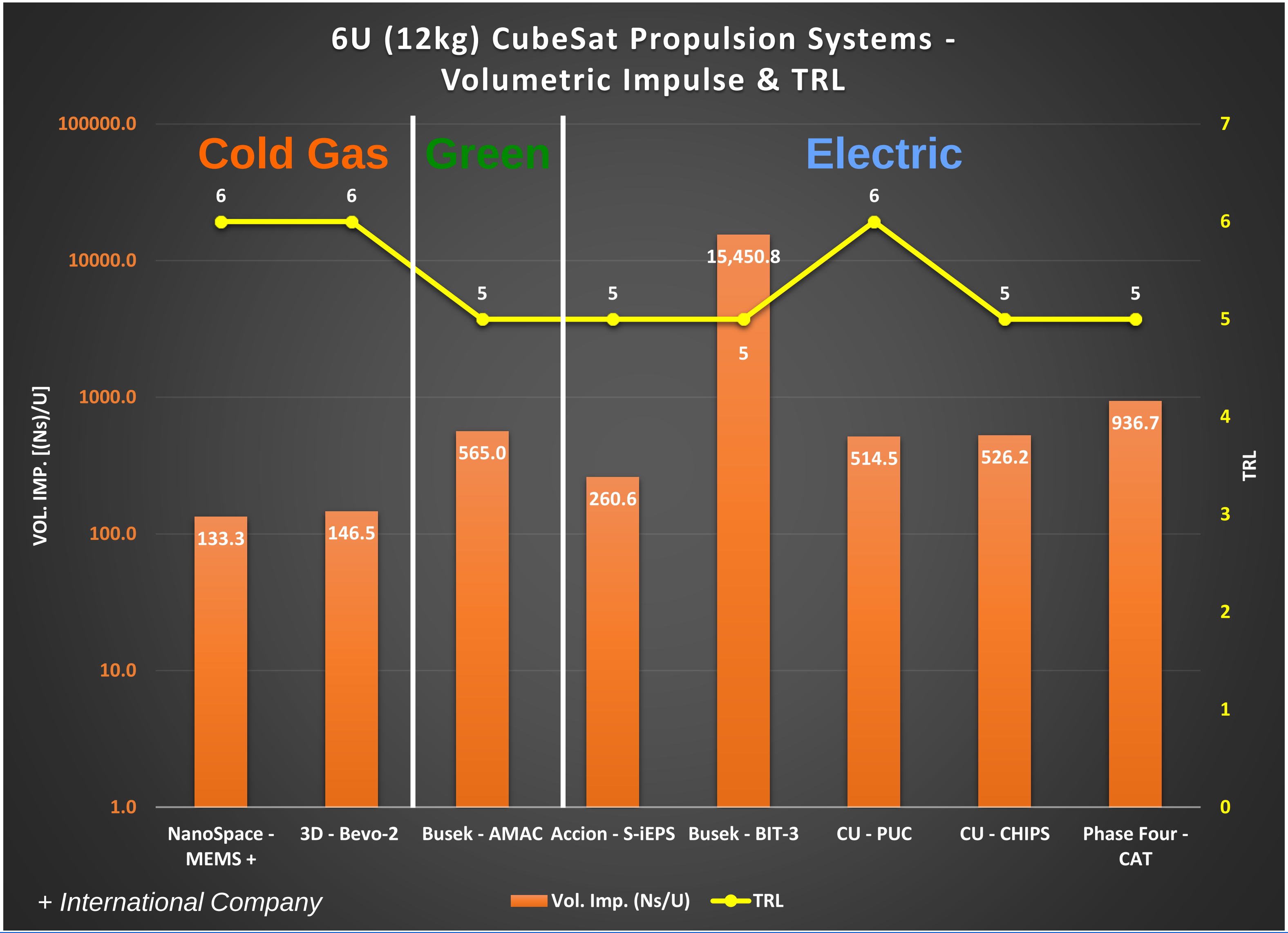


CubeSat Ambipolar Thruster

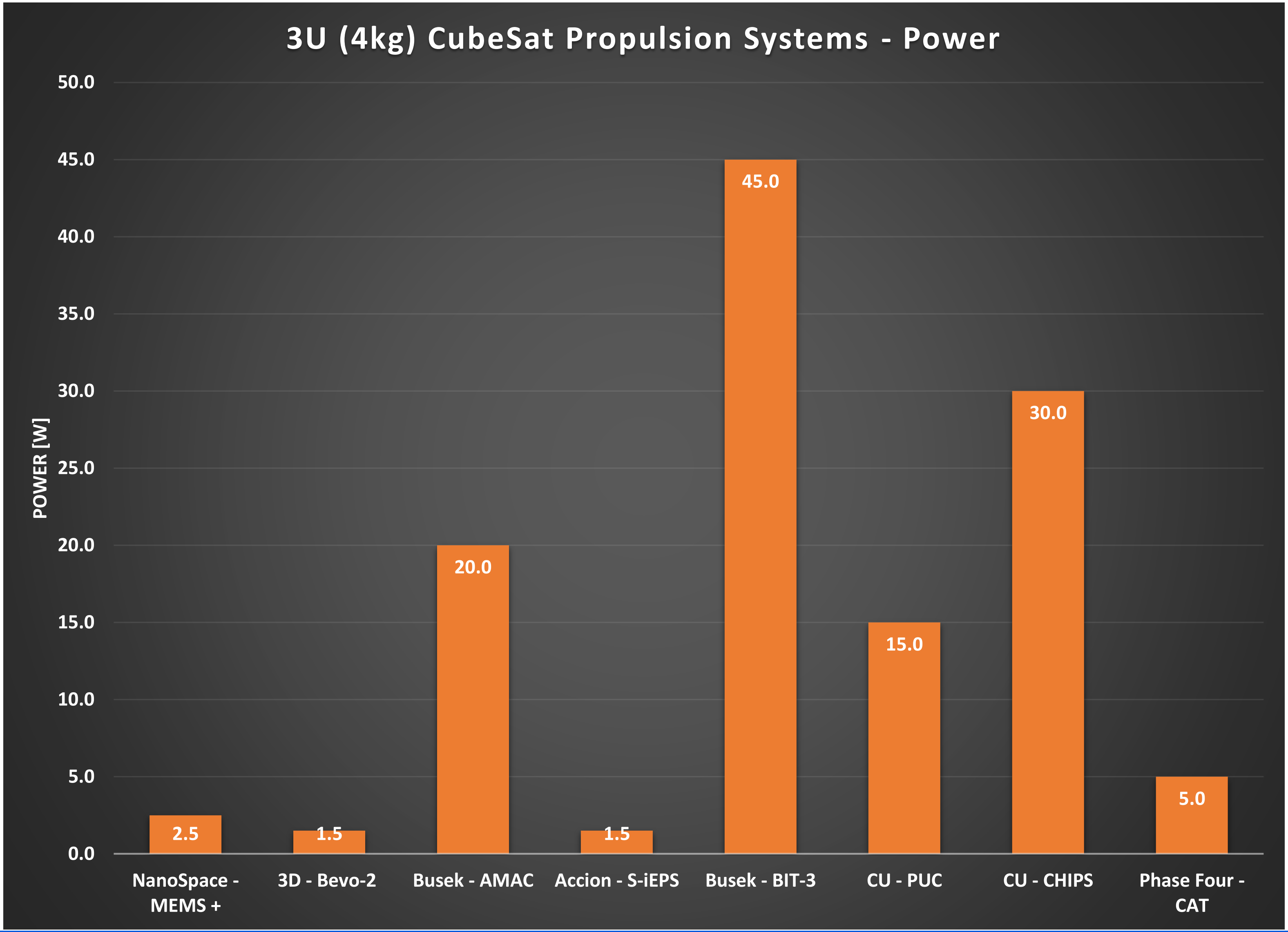
(Univ. Of Mich./Phase Four/NASA-ARC)

- System Type: Helicon Plasma
- Propellant: Xenon & Argon (as tested)
- Wet Mass: 1.5 kg (Prop: 0.5 kg)
- Performance (as tested w/ Xenon):
  - Thrust: 1.0 mN
  - Specific Impulse: 800 sec
  - Vol. Imp.: 936.7
- Power Req: 5 W
- TRL: 5
- Salient Features:
  - No Cathode necessary
  - Magnetic Nozzle

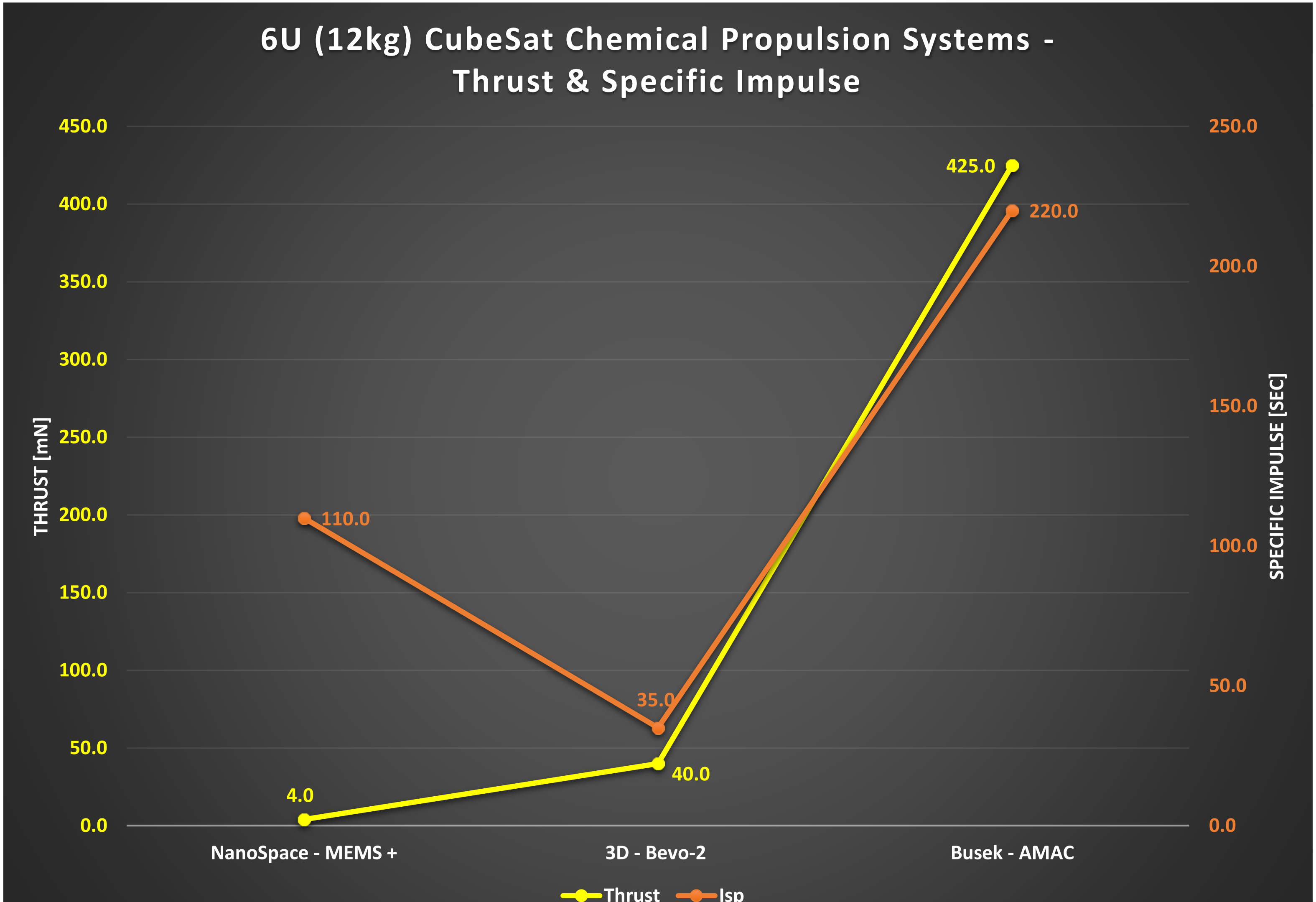
SmallSat Propulsion Performance



SmallSat Propulsion Performance

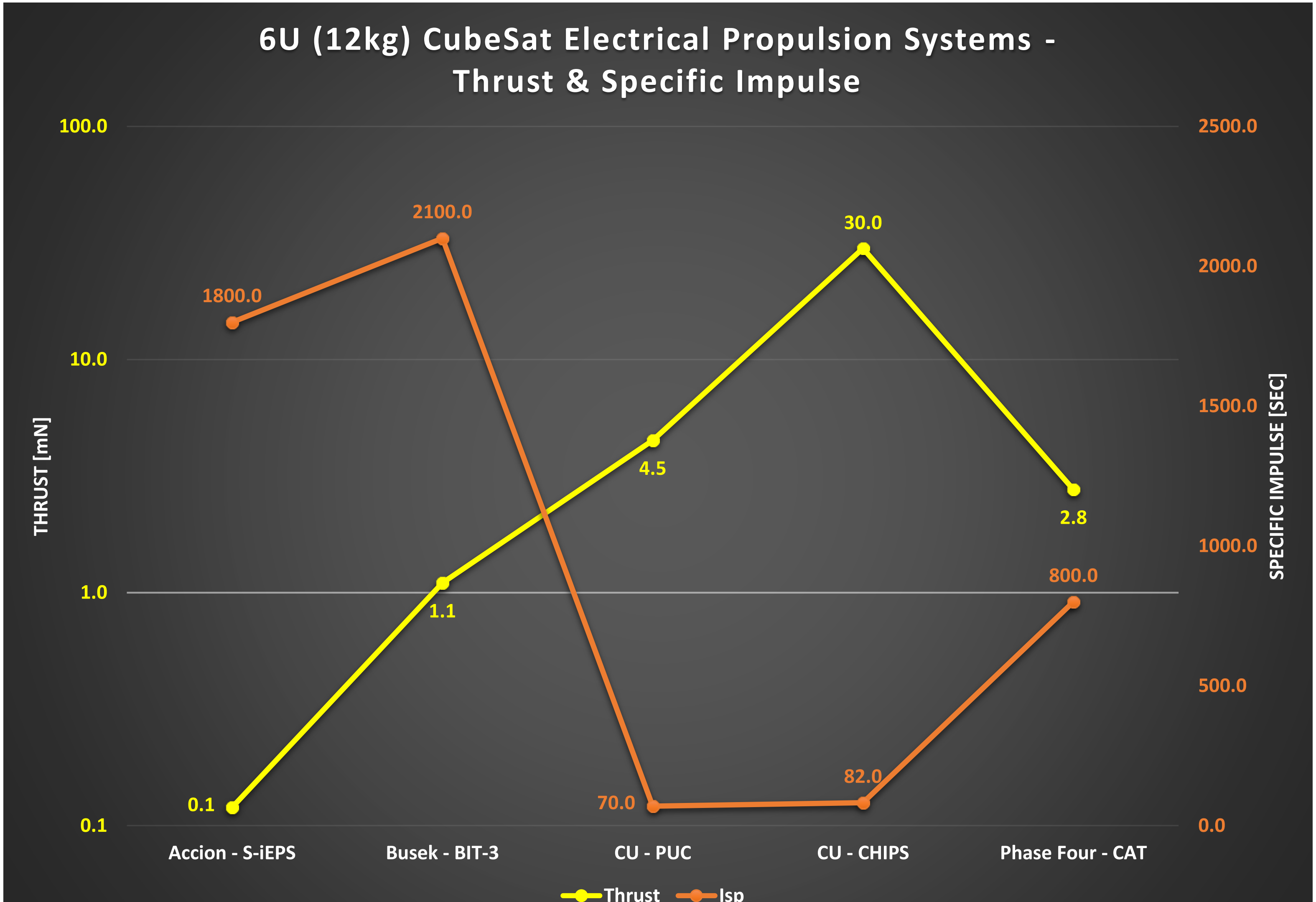


SmallSat Propulsion Performance



+ *International Company*

SmallSat Propulsion Performance



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System Flight Opportunities

- **MEMS CubeSat Propulsion Module (NanoSpace)**
  - Mission: Tianwang-1 (China)
  - Launch: Late Sept. 2015
  - S/C Bus Size: 3U (Tianwang-1C)
- **3D Printed Cold Gas Propulsion Module (UT-Austin)**
  - Mission: LONESTAR/Bevo-2 (Texas A&M & UT-Austin)
  - Launch: Late Jan. 2016
  - S/C Bus Size: 3U (Bevo-2)
  - Upcoming: BioSentinel (NASA/ARC, 2018)
- **BIT-3 (Busek)**
  - Mission: Lunar IceCube (Morehead St.)
  - Launch: 2018
  - S/C Bus Size: 6U

Conclusion

- **SmallSats are a low cost access to space with an increasing need for propulsion systems.**
- **NASA, and other organizations, will be using SmallSats that require propulsion systems to**
  - Conduct high quality near and far reaching on-orbit research
  - Perform technology demonstrations
- **Increasing call for high reliability and high performing for SmallSat components**
- **Many SmallSat propulsion technologies are currently under development**
  - Systems at various levels of maturity
  - Wide variety of systems for many mission applications