Smallsat Propulsion Survey

IPPW Smallsat Workshop

June 9, 2018

NASA Space Technology Mission Directorate and
NASA Science Mission Directorate

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www.nasa.gov/smallsat-institute

S3VI Charter

- Advance clear communications, coordination, and consistent guidance regarding small spacecraft activities across NASA.
- Provide the US smallsat research community with access to mission enabling information.
- Maintain engagement with small spacecraft stakeholders in industry and academia. Support the overall small spacecraft community.

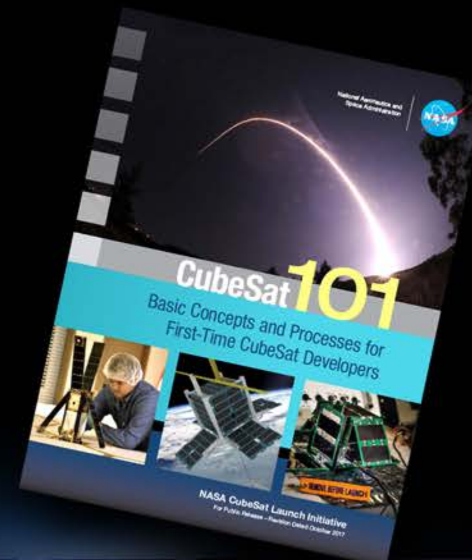
S3VI is a NASA-wide institute managed at NASA Ames Research Center, with participation from LaRC, GSFC, JPL, MSFC, and GRC.

S3VI is jointly sponsored by NASA's Space Technology Mission Directorate (STMD) and the Science Mission Directorate (SMD).

National Aeronautics and Space Administration

S3VI Web Portal Implementation

- Small Spacecraft Body of Knowledge
- Working Groups
  - Small Satellite Reliability Initiative
  - Access to Space (in work)
  - Debris Mitigation (proposed)
- Federated Parts Databases
  - Smallsat Parts on Orbit Now (SPOON)
  - NASA Electronic Parts Packaging (NEPP)



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NASA Smallsat Investments

Science Mission Directorate (SMD)

- ESTO InVEST
- Planetary Deep Space Smallsat Studies (PSDS3)
- PICASSO/MatISSE
- Astrophysics Smallsats
- SMEX, SALMON, MOO
- Undergraduate Student Instrument Project (USIP)

Human Exploration Mission Directorate (HEOMD)

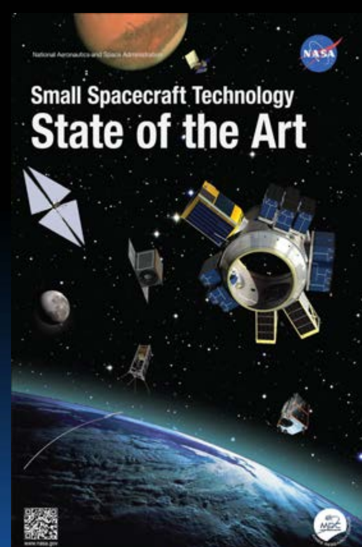
- Cubesat Launch Initiative
- EM-1 Deep Space missions

Space Technology Mission Directorate (STMD)

- Small Spacecraft Technology Program (SSTP)
  - Flight Capability Demonstration Projects
  - Smallsat Technologies Partnerships
  - Technology development
- Small Business Innovative Research (SBIR)
- Tipping Point and Public/Private Partnerships
- Centennial Challenges Program
  - CubeQuest Challenge

State of the Art Report

- Published by the STMD Small Spacecraft Technology Program (SSTP) in 2013 and again in 2015
- Now published by the S3VI beginning in 2018
- Based on previous versions plus new data from SPOON
- Will be reviewed/edited by NASA SMEs prior to publishing in August.



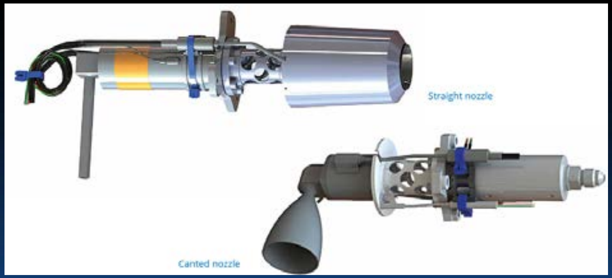
https://sst-soa.arc.nasa.gov/

Propulsion Overview

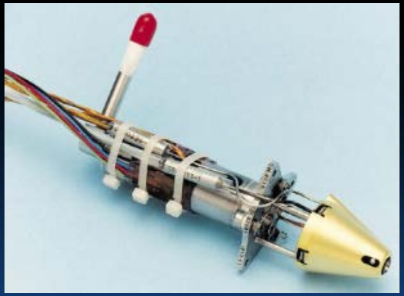
Table 4.1: Propulsion Systems Types for Small Spacecraft			
Product	Thrust	Isp (s)	Status
Hydrazine	0.5 – 30.7 N	200– 235	TRL 7
Cold Gas	10 mN – 10 N	65 – 70	GN2/Butane TRL 9
Non-toxic Propulsion	0.1 – 27 N	220 – 250	HAN TRL 8, ADN TRL 6
Pulsed Plasma and Vacuum Arc Thrusters	1 – 1300 µN	500 – 3000	Teflon TRL 8, Titanium TRL 7
Electrospray Propulsion	10 – 120 µN	500 – 5000	TRL 6
Hall Effect Thrusters	10 – 50 mN	1000 – 2000	Xenon TRL 8, Iodine TRL 4
Ion Engines	1 – 10 mN	1000 – 3500	Xenon TRL 8, Iodine TRL 4
Solar Sails	0.25 – 0.6 mN	Not applicable	TRL 6 (85 m^2), TRL 7 (35 m^2)

Chemical - Hydrazine

Table 4.1: Hydrazine Propulsion Systems				
Product	Manufacturer	Thrust (N)	Isp (s)	Status
MR-103D	Aerojet Rocketdyne	0.28 – 1.02	209 - 224	TRL 7
MR-111C	Aerojet Rocketdyne	1.3 – 5.3	215 - 229	TRL 7
MR-106E	Aerojet Rocketdyne	11.6 – 30.7	229 – 235	TRL 7
1N Ariane	Ariane Group	0.32 – 1.1	200 - 223	TRL 7
20N Ariane	Ariane Group	7.9 – 24.6	222 - 230	TRL 7



ArianeGroup 20N thruster.
Image Courtesy of ArianeGroup (2018)



Aerojet Rocketdyne MR-103D thruster.
Image Courtesy of Aerojet rocketdyne (2018)

Aerojet Rocketdyne MR-106E thruster.
Image Courtesy of Aerojet rocketdyne (2018)

Chemical – Non-toxic

Table 4.2: Non-toxic Propulsion Systems				
Product	Manufacturer	Thrust (N)	Isp (s)	Status
GR-1	Aerojet Rocketdyne	0.26 – 1.42	231	TRL 6
GR-22	Aerojet Rocketdyne	5.7 – 26.9	248	TRL 5
1 N HPGP	ECAPS	0.25 – 1.00	204 – 235	TRL 8
HYDROS	Tethers Unlimited, Inc.	0.2 – 0.6	258	TRL 8
BGT-X5	Busek	0.5	220	TRL 5
EPSS C1K	NanoAvionics	0.1	210	TRL 9

Figure 4.1: ECAPS HPGP thruster.
Image Courtesy of SSC ECAPS (2105).

Figure 4.2: GR22 thruster.
Image Courtesy of Masse et al. (2015).

Figure 4.3: GR1 thruster.
Image Courtesy of Masse et al. (2015).

Chemical – Cold Gas

Table 4.3: Cold and Warm Gas Propulsion Systems					
Product	Manufacturer	Thrust	Isp (s)	Propellant	Status
MicroThruster	Marotta	0.05 – 2.36 N	65	Nitrogen	TRL 9
Butane Propulsion System	SSTL	0.5 N	80	Butane	TRL 9
Nanoprop CGP3	NanoSpace (GOMSpace)	1 mN	60 - 110	Butane	TRL 9
POPSAT-HIP1	Micro Space	0.083 – 1.1 mN	32 – 43	Argon	TRL 9
CNAPS	UTIAS/SFL	12.5 – 40 mN	40	Sulfur hexafloride	TRL 9
CPOD	VACCO	25 mN	40	R134a	TRL 6
Nanoprop 6U	Nanospace (GOMSpace)	1 – 10 mN	60 - 110	Butane	TRL 6
MarCO	VACCO	25 – 50 mN	N/A	R236fa	TRL 9

Figure 4.8: NanoSpace MEMS cold gas system. Image Courtesy of NanoSpace.

Figure 4.5: Marotta cold gas thruster. Image Courtesy of Marotta.

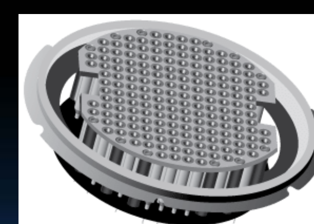
Figure 4.6: SSTL butane propulsion system. Image Courtesy of Gibbon (2010).

Chemical – Solid Rockets

Table 4.4: Solid Rocket Motors					
Product	Manufacturer	Total Mass (kg)	Average Thrust (N)	Isp (s)	Status
ISP 30sec motor	Industrial Solid Propulsion	0.95	37	187	TRL 7
STAR 4G	Orbital ATK	1.5	258	277	TRL 6
CAPS-3	DSSP	2.33	0.3	<900	TRL 8
MAPS	PacSci EMC	Customized	N/A	210	TRL 9

Figure 4.10: Module of DSSP thrusters. Image Courtesy of Nicholas et al. (2013).

Figure 4.9: SpinSat Mission deploying from International Space Station



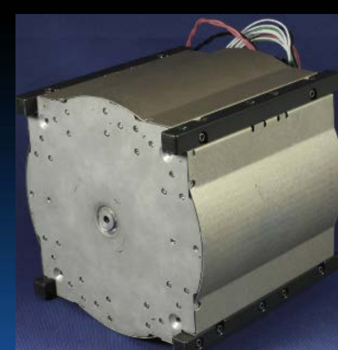
MAPS solid propulsion system. Image courtesy of PACSI EMC (2018)

Electric Propulsion – Resistojets/Warm gas

Table 4.5: Resisojet Propulsion Systems

Product	Manufacturer	Thrust	Power (W)	Isp (s)	Status
Micro Resistojet	Busek	2 – 10 mN (primary) 0.5 mN (ACS)	3 – 15	150 s (primary) 80 s (ACS)	TRL 5
PUC	AFRL and VACCO	5.4 mN	15 W	70	TRL 6
CHIPS: Cubesat High Impulse Prop systems	CU Aerospace and VACCO	17 – 22 mN (R236fa) 31 mN (R134a)	25 W	66-38 (R236fa) 76 – 52 (R134a)	TRL 5

Figure 4.11: PUC module. Image Courtesy of AFRL and VACCO (2018).



Micro Resistojet. Image Courtesy of Busek (2018).

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Electric Propulsion – Electrosprays

Product	Manufacturer	Thrust	Power (W)	Isp (s)	Status
S-iEPS	MIT	74 μN	1.5	1160	TRL 6
IMPACT	Accion Systems Inc.	60 μN per axis	0.75 per axis	1200	TRL 5
MAX-1	Accion Systems Inc.	120 μN	1.6	2000	TRL 5
1 mN Electrospray	Busek	0.7 mN	15	800	TRL 5
100μ	Busek	0.1 mN	5	2300	TRL 5
TILE-V1	Accion Systems Inc.	1.8 mN	25	1500	TRL 5
TILE-500	Accion Systems Inc.	1.5	8-25	1250	TRL 5

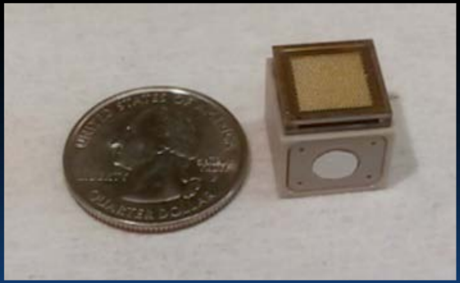


Figure 4.12: Electrospray thruster. Image Courtesy of MIT SPL.

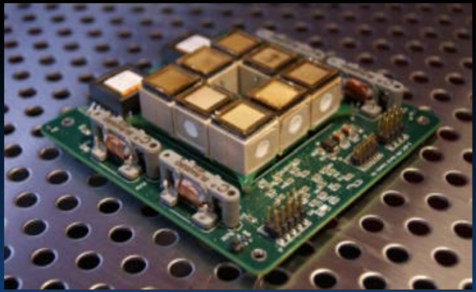


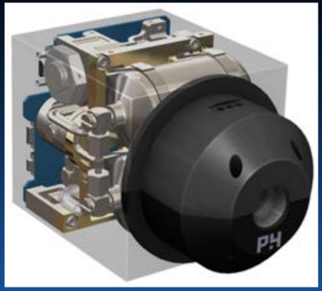
Figure 4.13: S-iEPS propulsion system. Image Courtesy of MIT SPL.

Electric Propulsion – Ion Engines

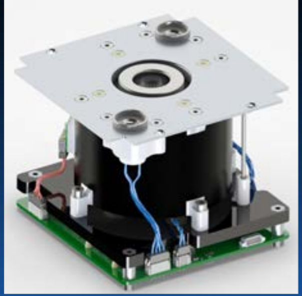
Table 4.7: Ion Propulsion Systems and Thrusters

Product	Manufacturer	Thrust	Power (W)	Isp (s)	Propellant	Status
BIT-3	Busek	1.4 mN	60	3500	Xenon-Iodine	TRL 6
BIT-1	Busek	0.1 mN	10	2250	Xenon	TRL 5
I-COUPS	University of Tokyo	0.3 mN	N/A	1000	Xenon	TRL 9
RIT-µX	Airbus	50 – 500 µN	50	300 – 3000	Xenon	TRL 5
Cubesat Ambipolar Thruster (CAT)	Phase Four	0.35 – 1.5 mN	40-125	65 - 510	Xenon	TRL 5
IFM Nano Thruster	Enpulsion	0.01 – 0.5 mN	8-40	2000-5000	N/A	TRL 5

Figure 4.15: RIT-µX .
Image Courtesy of Airbus.



CAT Thruster
Image Courtesy of P4.



IFM Nano Thruster
Image Courtesy of Enpulsion, GMBH.

Electric Propulsion – Pulsed Plasma and Vacuum Arc Thrusters

Table 4.8: Plused Plasma and Vacuum Arc Propulsion Systems

Product	Manufacturer	Thrust	Power (W)	Isp (s)	Propellant	Status
PPTCUP	Mars Space and Clyde Space	40 μN	2	655	PTFE	TRL 6
NanoSat PPT	Mars Space and Clyde Space	90 μN	5	640	PTFE	TRL 5
μ-CAT	GWU and USNA	1 – 50 μN	2 – 14	2500 – 3000	Titanium	TRL 7
BmP-220	Busek	20 μN-s Impulse bit	1.5	536	PTFE	TRL 5
MPACS	Busek	80 μN-s Impulse bit	10	827	PTFE	TRL 8

Figure 4.17: The BmP-220.
Image Courtesy of Busek.

Figure 4.16: PPTCUP propulsion system.
Image Courtesy of Ciaralli et. al (2015).

Electric Propulsion – Hall Effect Thrusters

Table 4.9: Hall Effect Propulsion Systems and Thrusters

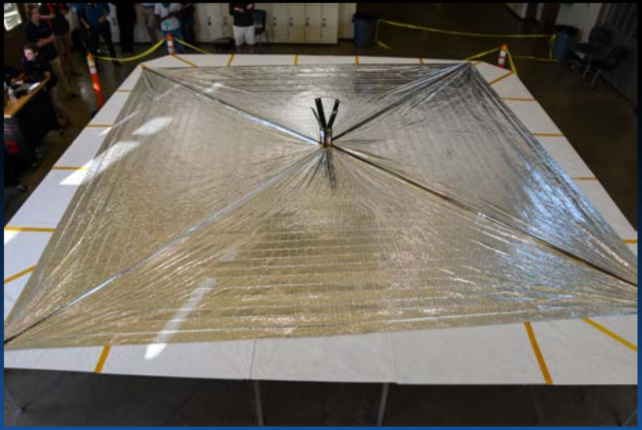
Product	Manufacturer	Thrust (mN)	Power (W)	Isp (s)	Status
BHT-200	Busek	13	200	1390	Xenon TRL 8, Iodine TRL 4
HT100	SITAEL	5 – 15	175	<1350	Xenon TRL 6
CHT	UTIAS SFL	6.2	200	1139	Xenon TRL 5

Figure 4.19: Cylindrical Hall Effect Thruster. Image Courtesy of UTIAS SFL.

Figure 4.18: BHT-200 during operation. Image Courtesy of Busek Co Inc.

Propellant-less Systems

Table: Hall Propellantless systems						
Product	Developer	Surface area	Mission	Mass	Material	TRL
Nanosail-D2	NASA Ames/ NASA Marshall	10 m2	3U Cubesat	4.2 kg	Highly reflective CP-1	9
LightSail-A	The Planetary Society	32 m2	3U CubeSat (demonstration and testing)	5 kg	Mylar	9
LightSail 2	The Planetary Society	32 m2	3UCubesat (additional maneuvering: orbit raising)	5 kg	Mylar	8



LightSail 2 Solar sail. Image Courtesy of The Planetary Society (2018).

Conclusions

Commercial propulsion systems for small spacecraft offer a variety of technologies with increasing maturity levels.

Large maneuvering for large orbit transfers (interplanetary) or long orbit maintenance require high specific impulses/non-propellant: electric systems or solar sails. In this category, systems can be selected depending on mission requirements and limitations. Ion and electrospray systems provide a good compromise between thrust and power while Hall Effect thrusters can support interplanetary transfers due to their higher nominal thrust with respect to the other options.

Trajectory correction maneuvers or ACS maneuvering for flybys or small operations (constellation phasing or swarm maintenance for instance) can benefit from the high TRL and simplicity of cold gas systems. For increased specific impulse performance, warm gas systems or resistojets can be a good alternative.

High impulse chemical systems for small spacecraft are divided in two main categories: hydrazine and non-toxic propellants. These can provide enough thrust and specific impulse for a small spacecraft to perform orbit transfers within the same planetary system or gravity well on their own. Hydrazine systems may present a problem since primary missions may not allow to have a toxic propellant on board while ADN or HAN based propellants may avoid that issue while providing more density and specific impulse. Various companies are already testing non-toxic propellant propulsion systems in space and the demand is increasing.