A Miniaturized Hydrogen Peroxide/ABS Based Hybrid Propulsion Systems for CubeSats

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Paper: SSC22-X-02

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Agenda

1. Background
2. Theoretical Evaluation
3. Test Setup
4. Test Results
5. Conclusion

Background

Research Goals

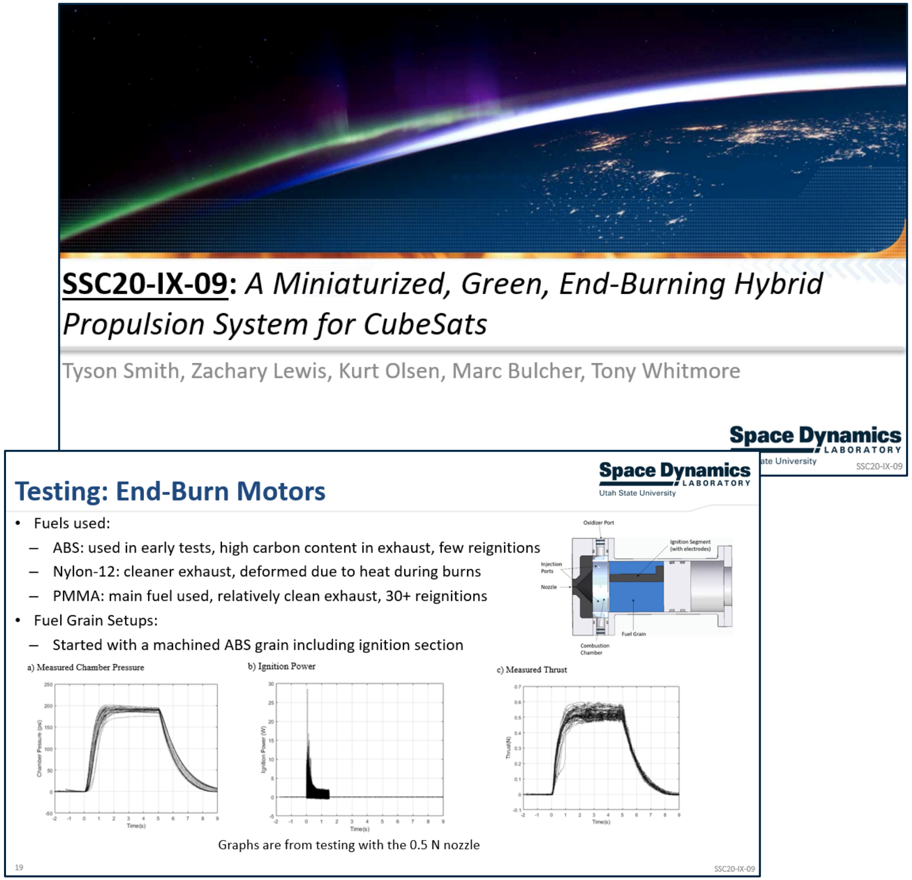
- Development of a non-toxic or "green" replacement for hydrazine
  - Cost effective using COTS components
  - Incorporate benign fuel and oxidizers

- Develop a sub-Newton hybrid propulsion system for Small/Cube Sats, enabling:
  - Satellite attitude control
  - Station keeping
  - Rendezvous proximity operations
  - Deorbiting

Need for Higher Density Oxidizer

- At SmallSat 2020 a presentation on a Gox/ ABS solution was given
  - GOX has a low specific gravity and is a volumetrically inefficient propellant

- H_2O_2 has a much higher density and can be stored at lower pressures
  - GOX would need to be stored at pressures above 10,000 psi to achieve comparable density



Smith, T. K., Lewis, Z. Olsen, K., Bulcher, M. A., and Whitmore, S. A., "A Miniaturized, Green, End-Burning, and Sandwich Hybrid Propulsion System," J. Prop. and Power, Published Online, May 2022, https://doi.org/10.2514/1.B38623

Comparison of Performance Characteristics

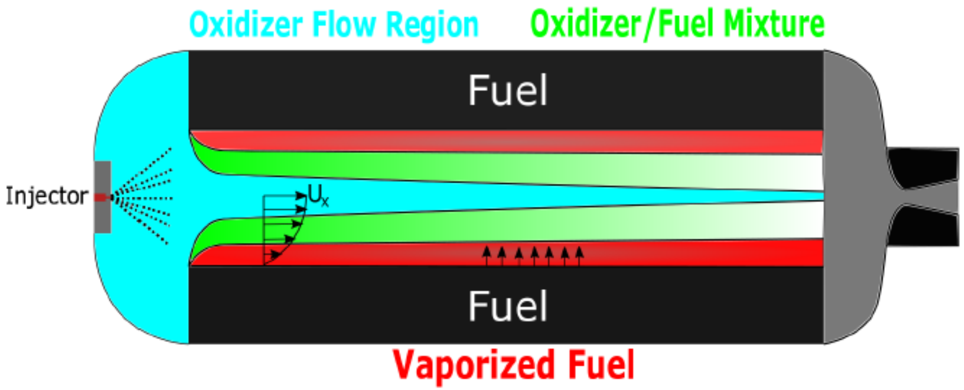
Propellant	Hydrazine	LMP-103S	AF-M315E	H_2O_2/ABS Hybrid
Flame Temperature	600-750^{o}C	1600 ^{o}C	1900^{o}C	2900 ^{o}C
I_{sp}, *sec*	220-225	252 (theory), 235 (delivered)	266 (theory) 245 (delivered)	324 (theory) 302 (delivered)
Specific Gravity	1.01	1.24	1.465	1.392 (90% H_2O_2)
Density Impulse, *N-sec/liter*	22705	3125 (theory) 2915 (delivered)	3900 (theory) 3650 (delivered)	4450 (theory) 4002 (delivered)
Preheat Temperature	315^{o}C, cold-start capable	300^{o}C	370 ^{o}C	N/A none-required
Required Ignition Input Energy, *Joules*	N/A	18,000 J (10 Watts @ 1800 seconds)	27,000 J (15 Watts @ 1800 seconds)	2-8 J (8-16 Watts for 250-500 msec)
Propellant Freezing Temperature	1-2^{o}C	-7^{o}C	< 0^{o}C *(forms glass, no freezing point)*	-10^{o}C *(90% concentration)*
Cost	$	$$$	$$$$	$
Availability	Readily Available	Restricted Access	Limited Access	Very Widely Available[i]
NFPA 704 Hazard Class			 	

Hawkins, T. W., Brand, A. J., McKay, M. B., and Tinnirello, M., "Reduced Toxicity, High Performance Monopropellant at the U.S. Air Force Research Laboratory," AFRL-RZ-ED-TP-2010-219,

H_2O_2 Ignition Concern

- A bi-product of peroxide is water.
  - Can lead to a “wet” burn
- As the oxidizer plume exits the injector and enters the hybrid combustion chamber, it rapidly expands and super-cools to well below the evaporation temperature of water.
- As a result, liquid water re-condenses and the "soaked" fuel grain will simply not ignite.

Hydrogen Peroxide Decomposition Reaction.



How do we get this thing to ignite?

Catalyst Bed Concerns

- A catalyst bed is commonly used to initiate decomposition of propellants.
  - Including high test peroxide (HTP) monoprops
- Issues with Peroxide and catbeds
  - “smoldering” = very long rise times
    - chamber pressure takes more than 2 seconds [ii]
  - Catbeds don’t alleviate the “wet motor” issue [iii]
    - Causing insufficient combustion
    - Longer rise times
  - Catbeds are heavy and volumetrically inefficient.
  - Catalyst beds must be externally heated to high temperatures
    - Pre-heat presents requires significant power.
  - Catbeds often self-consume and become less efficient over time
  - Catalyst beds can be "poisoned" and rendered ineffective in the presence of common stabilizers in HTP.

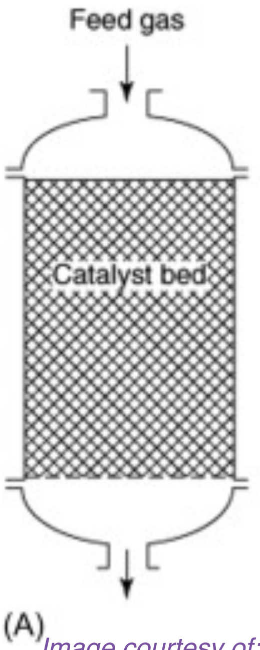


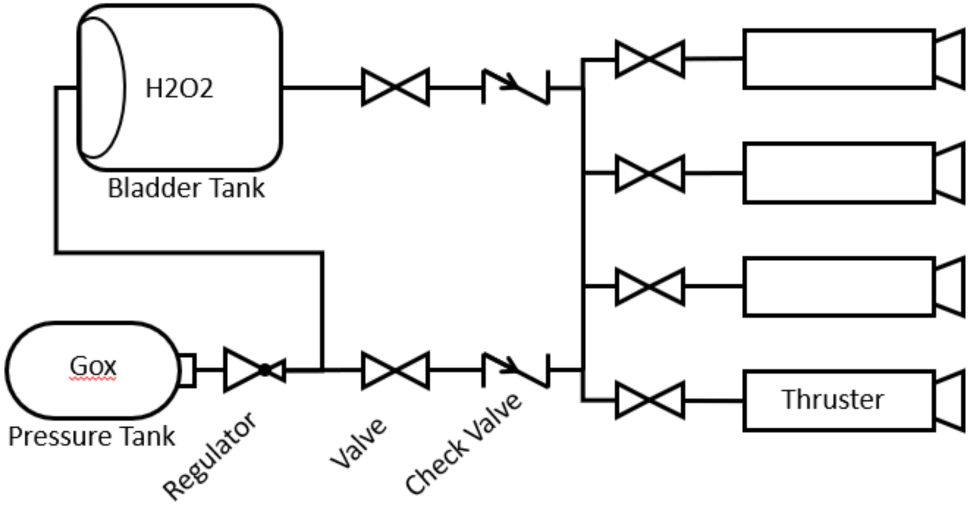
Image courtesy of: Advances in Clean Hydrocarbon Fuel Processing, Science and Technology

[ii] Rommingen, J. E., and Husdal J., *"Nammo Hybrid Rocket Propulsion TRL Improvement Program,"* AIAA-2012-4311 https://doi.org/10.2514/6.2012-4311

[iii] Whitmore S. A., Merkley D. P., "Arc-Ignition of an 80% Hydrogen Peroxide/ ABS Hybrid Rocket System," https://doi.org/10.2514/6.2017-5047

Ignition Solution

- Gox pre-lead
  - Gox ignition is a proven technology. [iv]
- ConOps:
  - Initially Inject Gox into the combustion chamber < 1 sec, once combustion has occurred inject the motor with HTP.



[iv] Smith, T. K., Lewis, Z. Olsen, K., Bulcher, M. A., and Whitmore, S. A., "A Miniaturized, Green, End-Burning, and Sandwich Hybrid Propulsion System," https://doi.org/10.2514/1.B38623

Theoretical Evaluation

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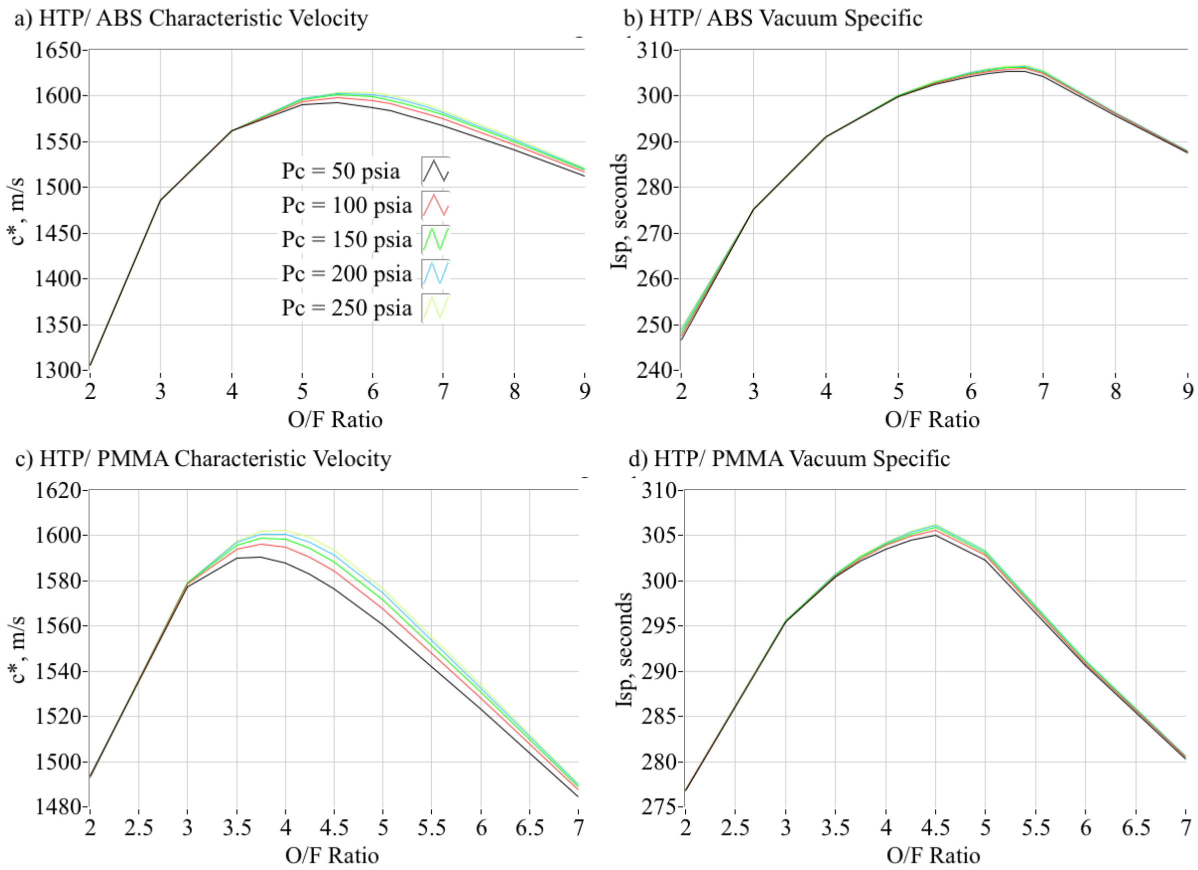
Hybrid Rocket systems generally favor a narrow range of Oxidizer/Fuel ratios where the system performance is near optimal



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Test Setup

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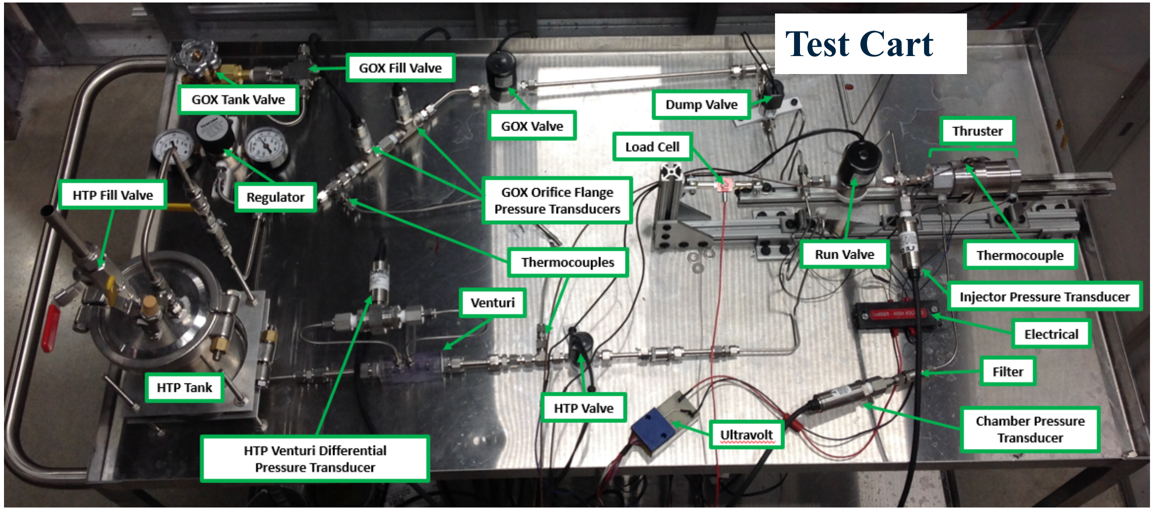
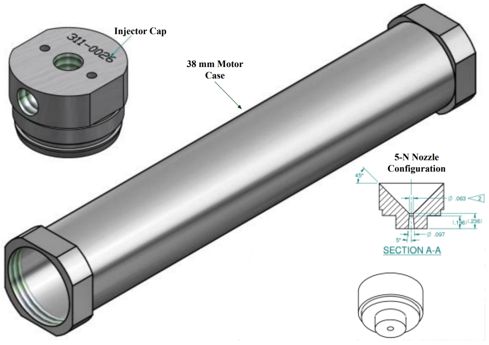
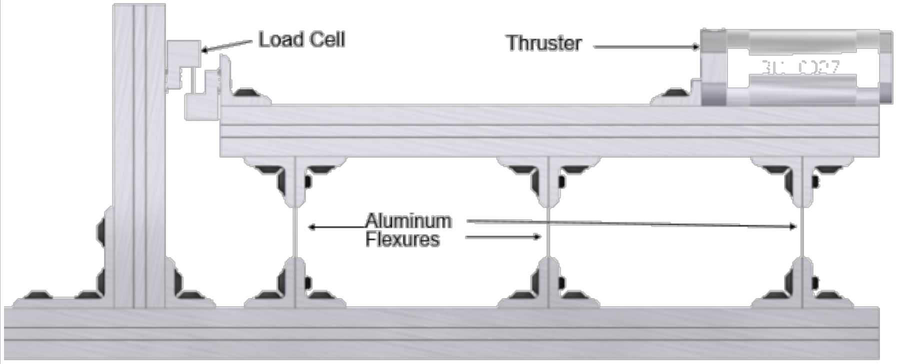
Motor Specifications

Parameter		1 N Thruster	5 N Thruster
Fuel Material		ABS	PMMA
Fuel Grain Dimensions	Grain Length	Long: 205.7 mm Short: 40.6 mm	
	Outer Grain Diameter	34.3 mm	
	Initial Fuel Port Diameter	5.33 mm	
Injector	Atomizing 45° Cone	Eff. Port Diameter: 0.19 mm, 0.30 mm	
	Straight Port	Port Diameter: 0.41 mm	
Nozzle	Throat Diameter	0.91 mm	1.60 mm
	Expansion Ratio	2.42	2.37
	Nozzle Exit Angle	5°	5°
Chamber Pressure		215 psia	





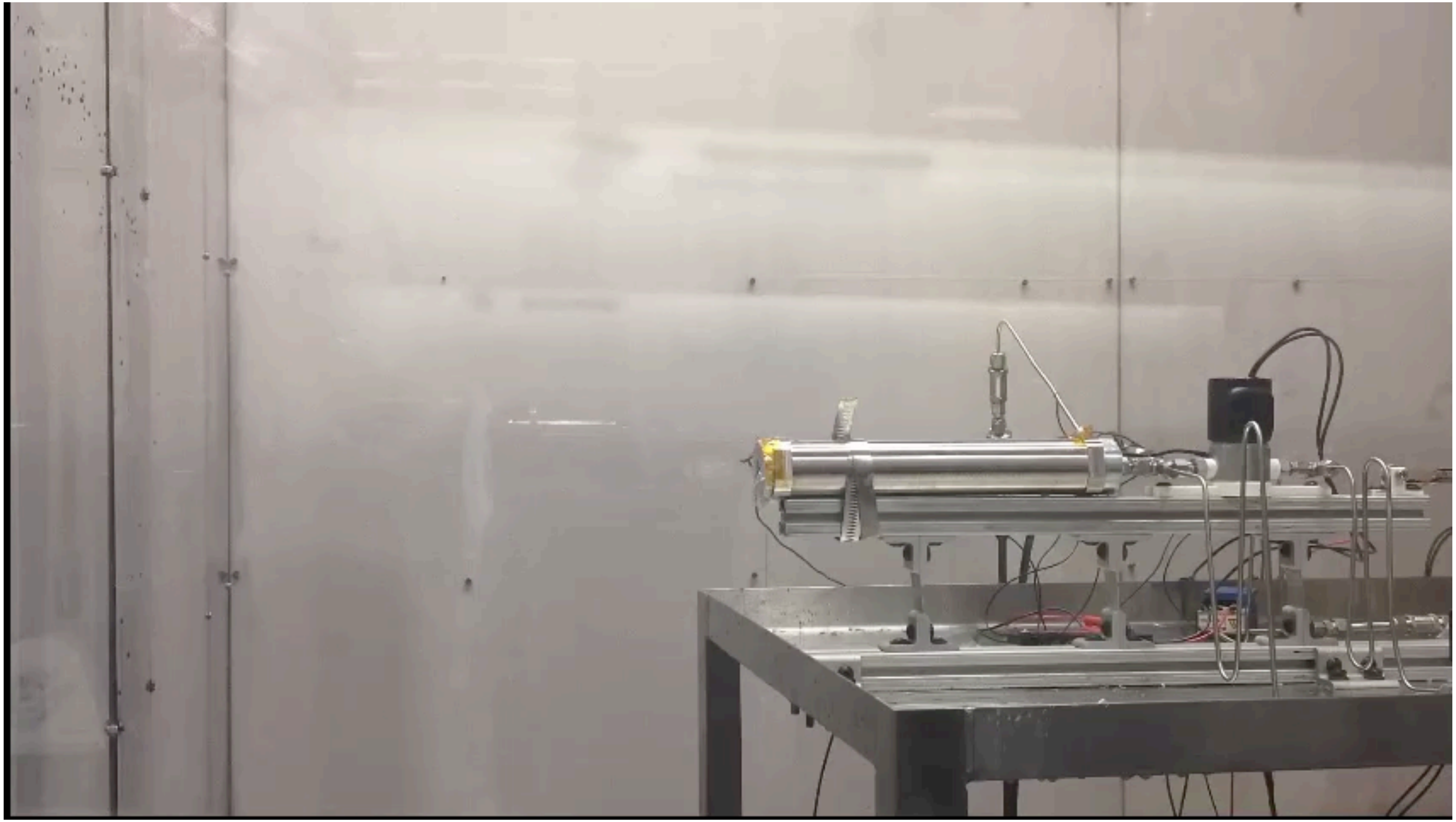
Motor Case Layout



Motor Sled with Mounted Thrust Chamber and Load Cell.

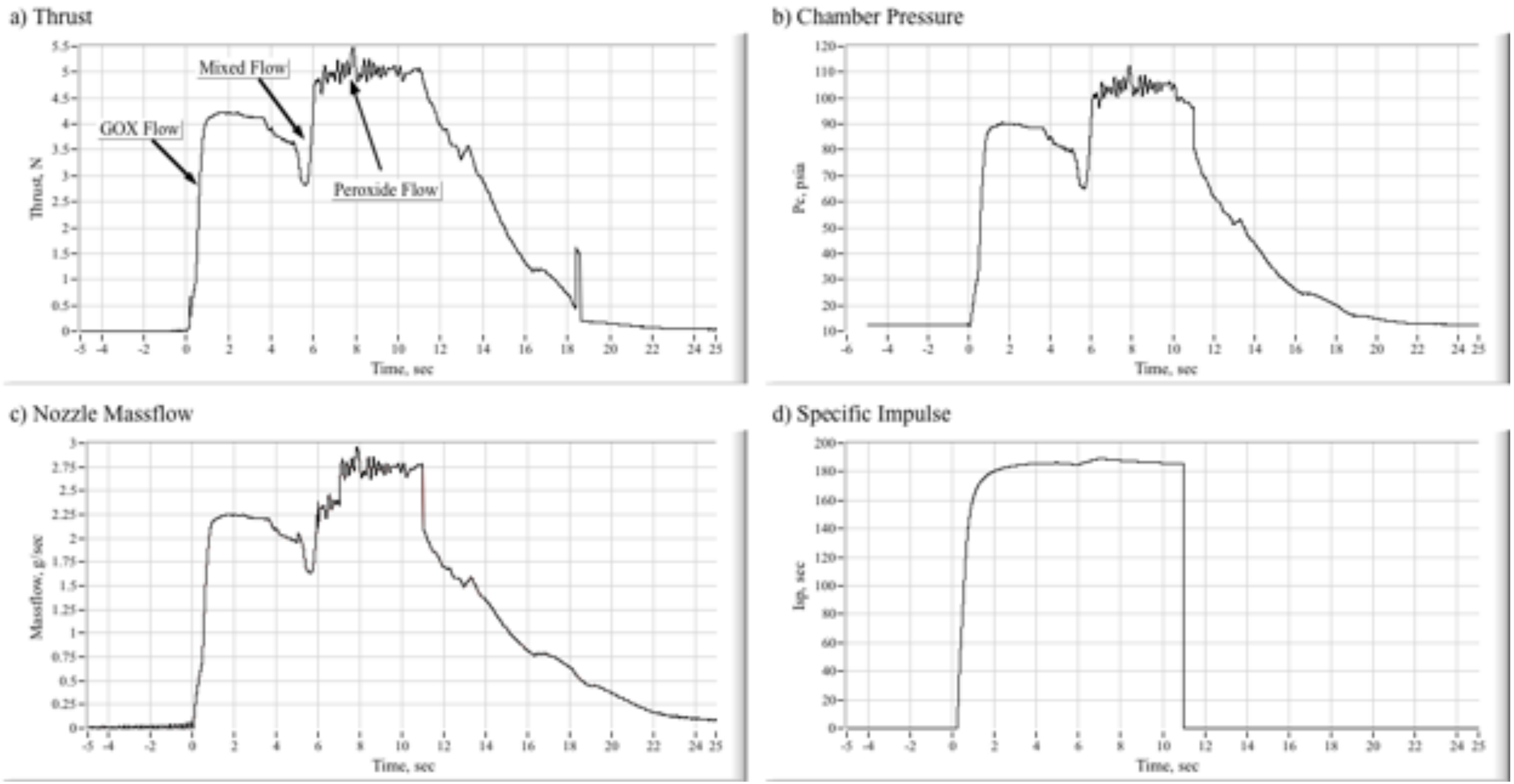
Test Results

Test Video



Test Results

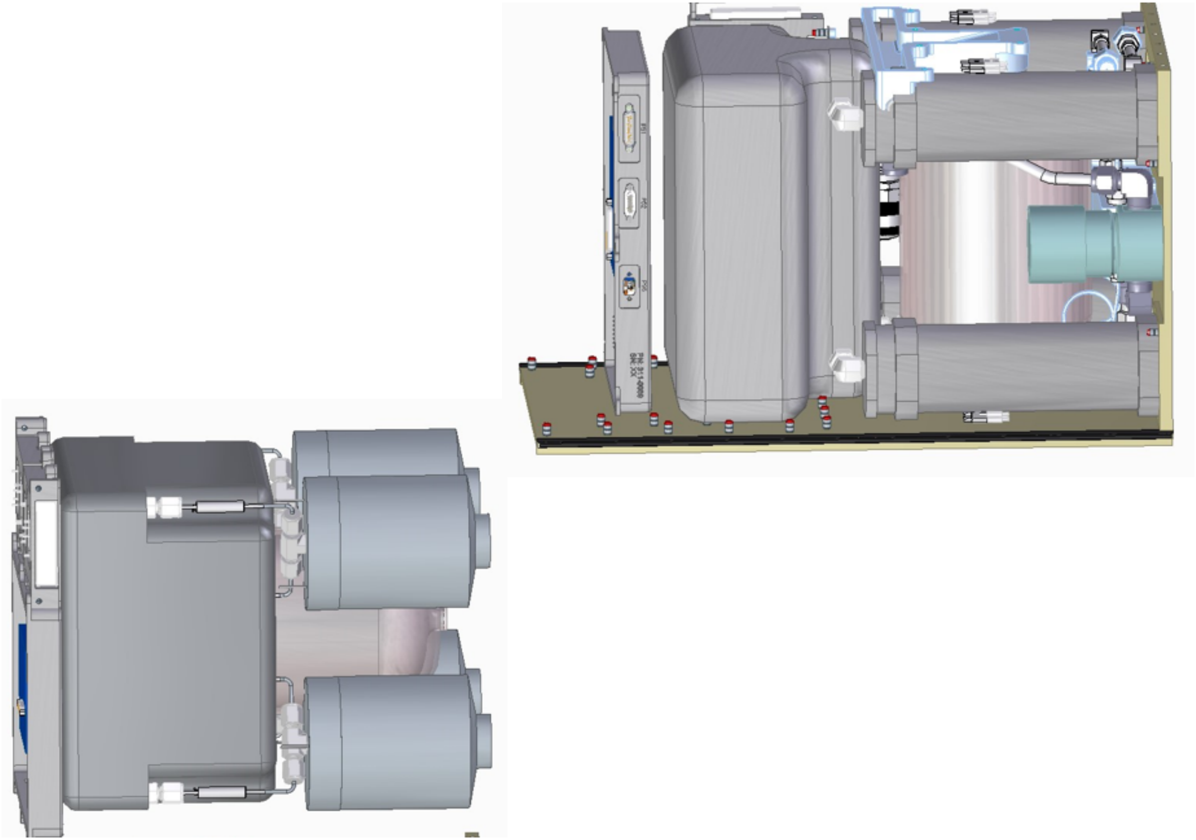
Data at ambient pressure



Flight System

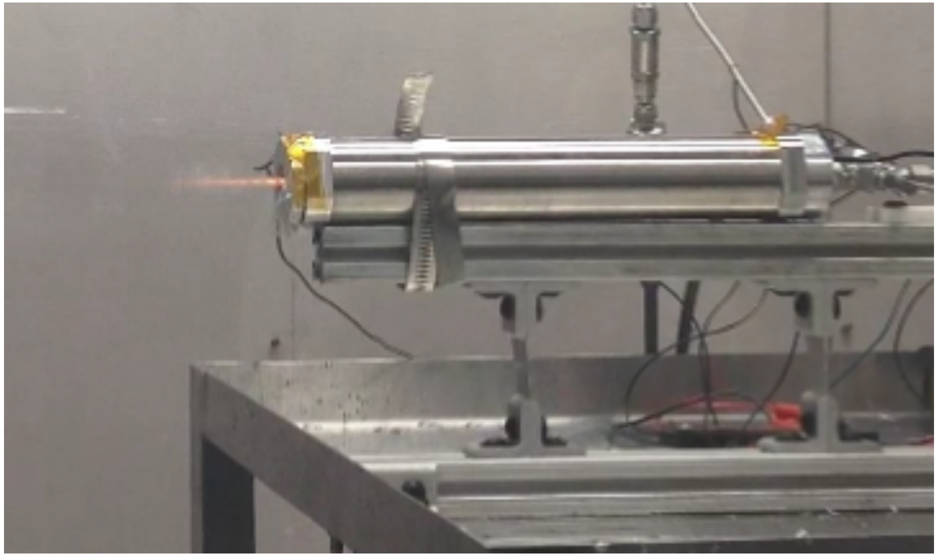
Parameters	Value
Thrust levels	0.5, 1, 5 N
Total Impulse	11,000 Ns
Volume	< 8U
Mass	< 8 kg
Power	8 W
Min I-bit	0.25 Ns
Rise Time	< 25 ms
Demonstrated Vac Isp	250 sec

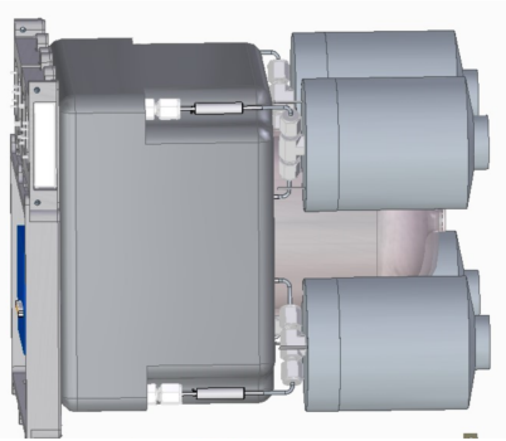
Flight Propulsion System Configurations



Conclusion

- SDL/USU have develop a non-toxic hybrid prototype propulsion system for Small/Cube Sats using HTP/ABS
- Ignition system uses a Gox pre-lead
- Lab testing has demonstrated
  - Thrust: 0.5, 1, 5 N
  - Vac Isp: 250 sec





Questions?

Thank you for your attention

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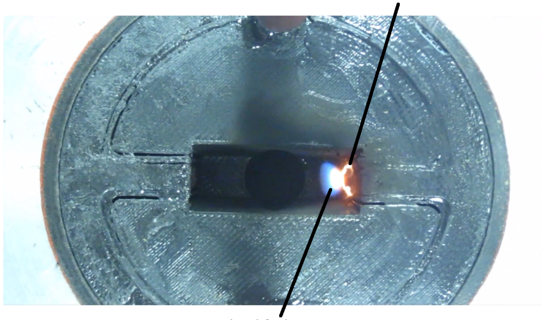
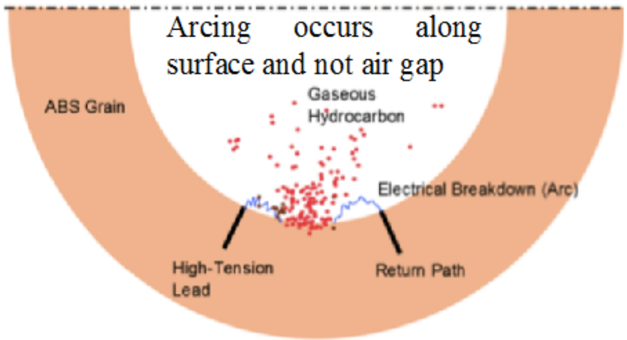
Back-up

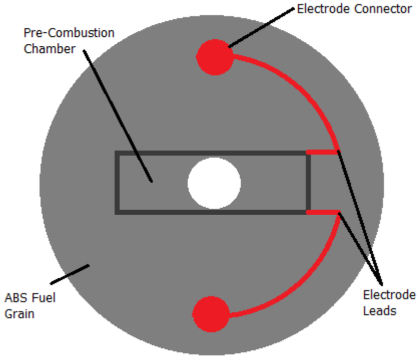
Arc Ignition Technology

- High-voltage arc vaporizes solid fuel
  - Replaces catalyst bed heaters
  - Low-power and reliable option

- 3-D printed fuel is a unique feature
- Enables multiple hybrid rocket restarts







Whitmore, S. A, Inkley, Nathan, and Merkley, Daniel P., "Development of a Power-Efficient, Restart-Capable Arc Ignitor for Hybrid Rockets", *Journal of Propulsion and Power*, Vol. 31, No. 6, 2015, pp. 1739-1749