Development of Novel Propellant Feed Systems for the CubeSat Ambipolar Thruster

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Introduction

One of the technological obstacles impeding a wider use of nanosatellites is the dearth of proven micropropulsion systems [1]. The CubeSat Ambipolar Thruster (CAT) is designed to enable a broad array of missions by offering a high performance, low power electric thruster.

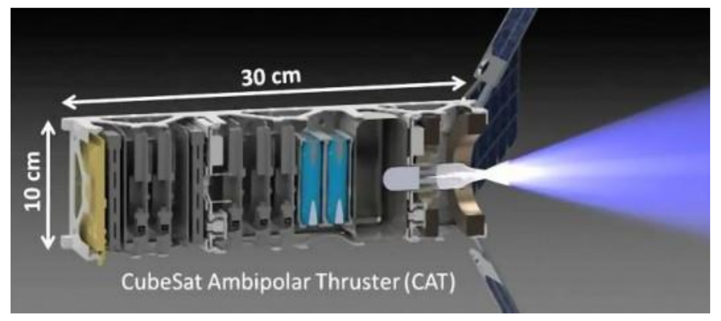

Figure 1: CAD concept drawing of CAT.

CAT operates by ionizing the propellant, which is delivered to the device via a propellant feed system. The type of feed system depends on how the propellant is stored. CAT can operate at 10 – 100 W with volume flow rates of 1 – 100 sccm and an inlet pressure of 1 Torr (1/760th of an atmosphere) [2].

Objectives

1. Identify alternative gas-, liquid-, or solid-storable propellants that provide suitable performance characteristics.
2. Develop propellant feed systems to deliver selected propellants to CAT.
3. Minimize mass, volume, cost, and risk associated with the propellant feed system.

Results and Discussion

Xenon is the standard high performance propellant for electric propulsion due to its high mass and low ionization potential. The cheaper propellants listed in Table 1 are similar. Iodine is the most similar.

Table 1: Properties of iodine, krypton, and xenon [3]. *14 MPa, 50 ºC (NIST Database)

Propellant	I_2	I	Kr	Xe
Atomic Mass	253.8	126.9	83.8	131.3
Cost, USD per 100 g	8.30	8.30	33.00	120.00
Storage density near room temp, g/cm^3	4.9	4.9	0.5*	1.6*
Ionization Properties				
Dissociation Energy, eV	1.54	N/A	N/A	N/A
First Ionization Potential, eV	9.4	10.5	14.0	12.1

Since iodine is stored as a solid it must be converted to a gas before being fed to CAT. As shown in Figure 2 suitable vapor pressures can be attained. On a space mission iodine can be thermally throttled to obtain variable operating conditions.

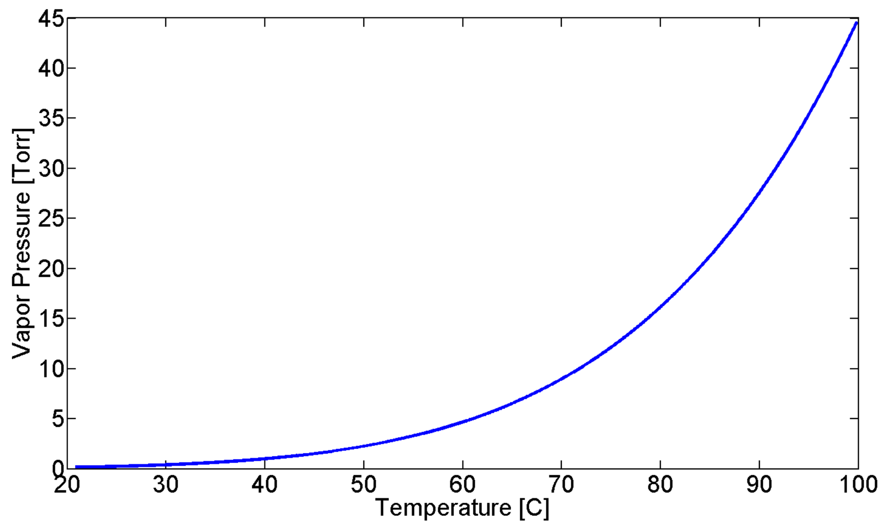

Figure 2: Vapor pressure curve for diatomic iodine.

Unfortunately, iodine is highly reactive with commonly used spacecraft materials. Figure 3 shows the level of corrosion for several materials after being dosed with iodine for 48 hours at STP.

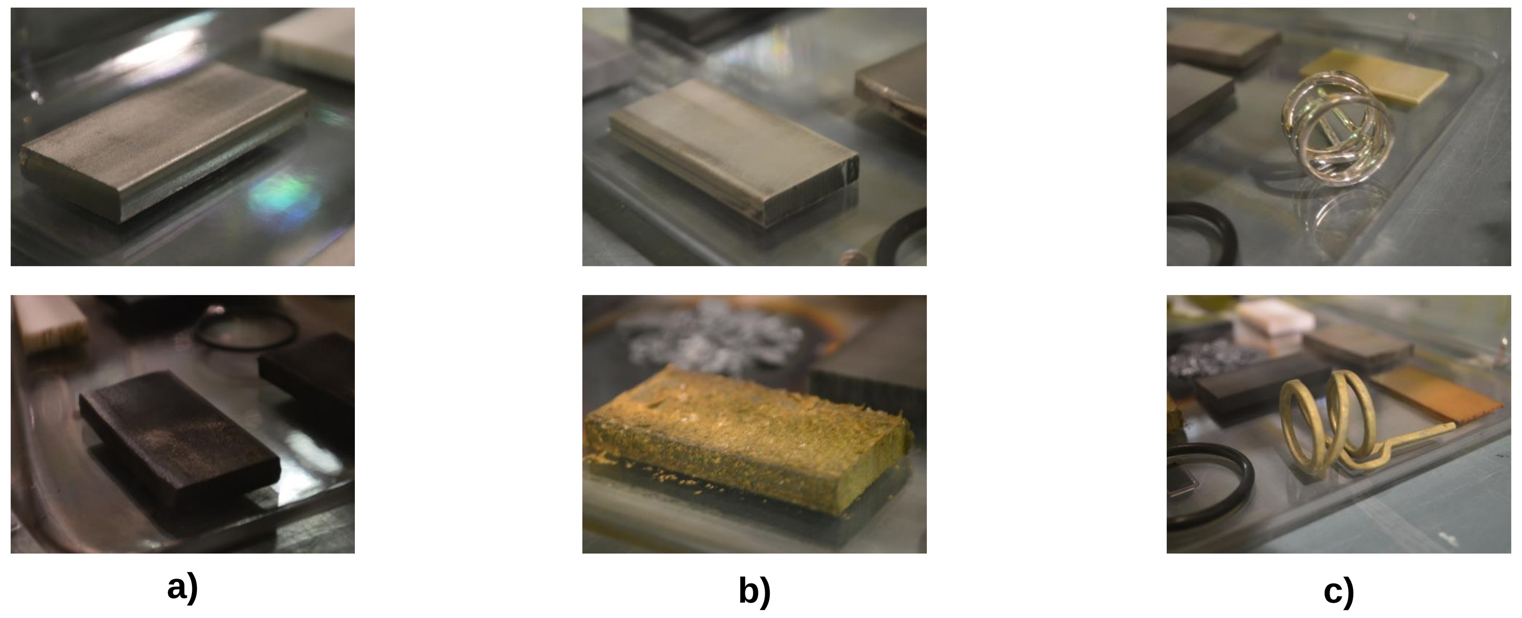

Figure 3: The top image is a control specimen; the bottom is a specimen that has been dosed at STP for 48 hours. a) 316 stainless steel, b) 7075 aluminum, c) silver RF antenna

In conjunction with the investigation of iodine, a pressurized gas-storable propellant feed system has been designed. A CAD assembly depicting the feed system is shown in Figure 4. This feed system is designed to provide flexible CAT operating conditions through adjustments of the Beswick pressure regulator and the static orifice. Possible flow conditions can be found in Figure 5. A custom titanium laser-sintered tank that can store propellant at up to 100 atm with a factor of safety of 4 is shown in Figure 6.


Figure 4: A CAD assembly of the gas-storable propellant feed system.

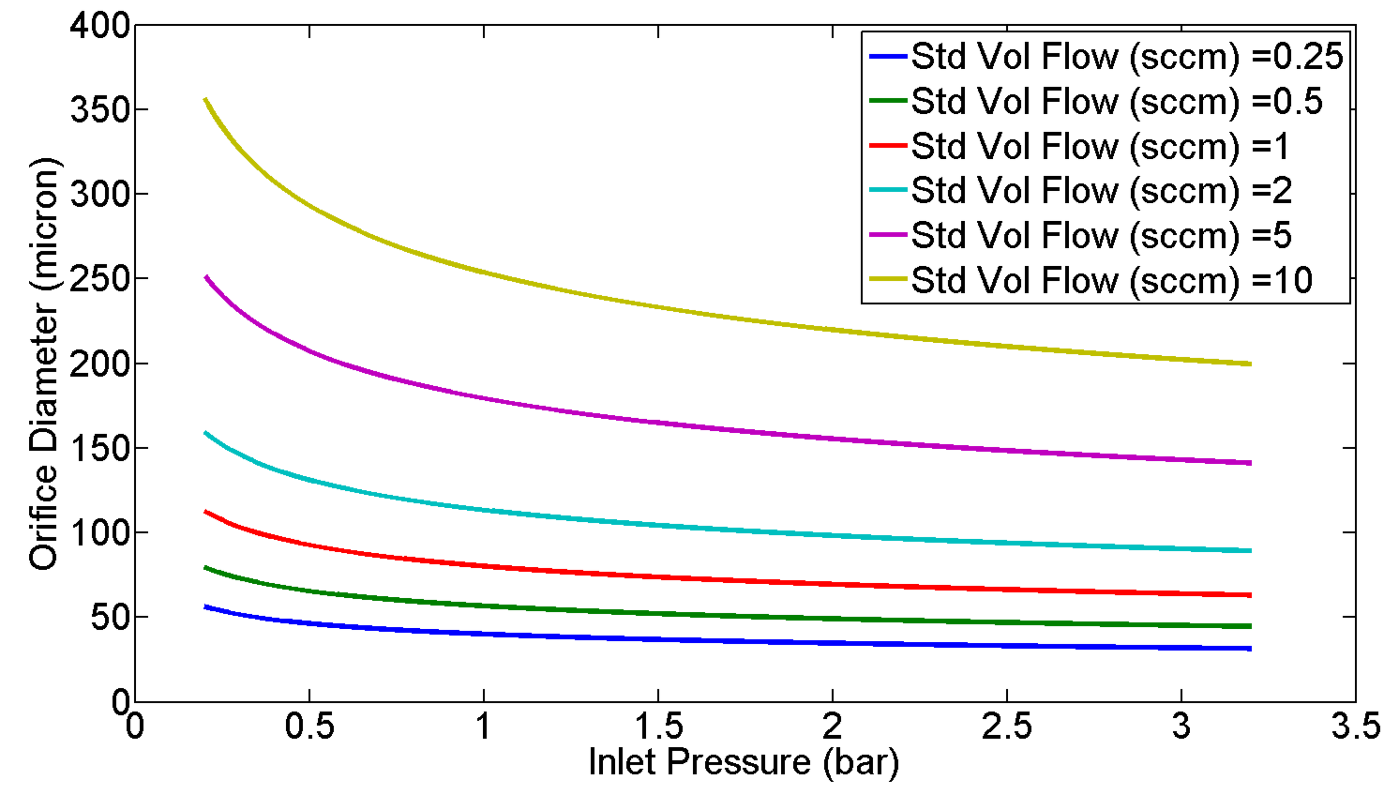

Figure 5: Possible flow conditions using standard static orifice sizes and adjusting the Beswick regulator setpoint.

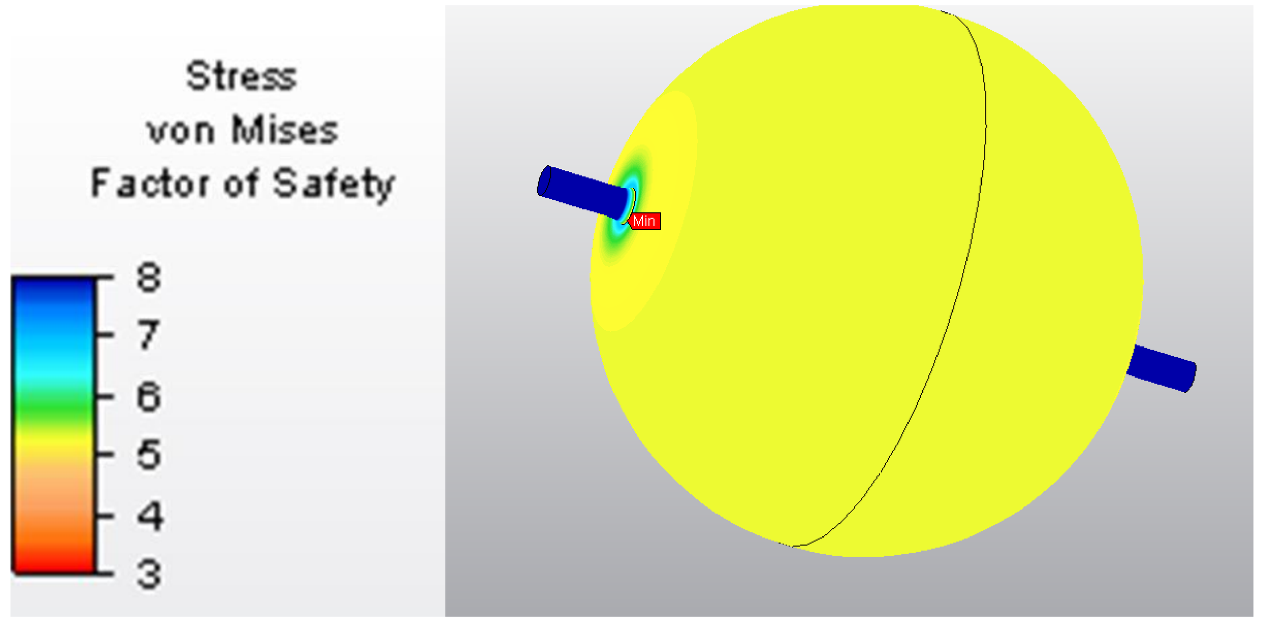

Figure 6: Stress analysis of the spherical titanium tank. The tank can store propellant at 100 atm. Safety factor is shown, but is increased with a rounded fillet at the tube stub juncture.

Conclusions

While iodine provides good performance characteristics it is highly corrosive. This will be addressed by managing the feed system temperatures and materials.
A pressurized inert gas-storable propellant feed system has been developed and is in the process of being tested. Theoretical optimal flow rates for desired CAT operating conditions have been identified and will be experimentally verified.

Acknowledgements

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References

[1] J. Mueller, R. Hofer, and J. Ziemer, "Survey of propulsion technologies applicable to cubesats," in Joint Army-Navy-NASA-Air Force (JANNAF), Colorado Springs, Colorado, 2010.
[2] J. P. Sheehan, T. Collard, B. W. Longmier, and I. Goglio, "New Low-Power Plasma Thruster for Nanosatellites," in 50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, ed: American Institute of Aeronautics and Astronautics, 2014.
[3] J. Szabo, B. Pote, S. Paintal, M. Robin, A. Hillier, R. D. Branam, et al., "Performance Evaluation of an Iodine-Vapor Hall Thruster," Journal of Propulsion and Power, vol. 28, pp. 848-857, 2012/07/01 2012.

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