Characterization of a Fixed-Volume Release System for Initiating an Arc Discharge in a Heaterless Hollow Cathode

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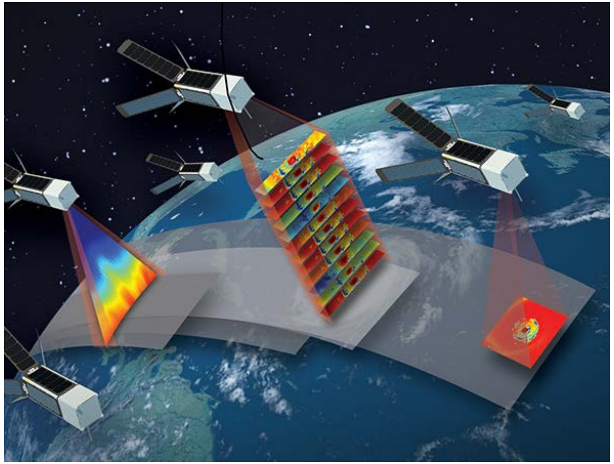
Agenda

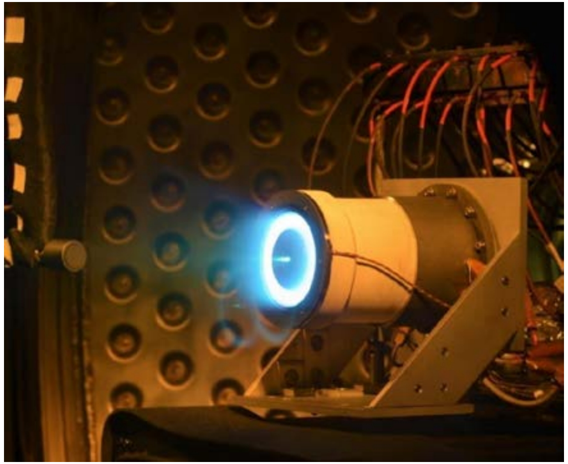
1) Background & Motivation
2) Heaterless Hollow Cathode Test Article
3) Fixed-Volume Release System Description
4) Fixed-Volume Release Propellant Flow Model
5) Results
6) Conclusion
7) Questions

Background & Motivation: Growing Small-Satellite Market



(Source: https://climate.nasa.gov/news/2512/nasa-small-satellites-will-take-a-fresh-look-at-earth/)

(Source: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190001454.pdf)

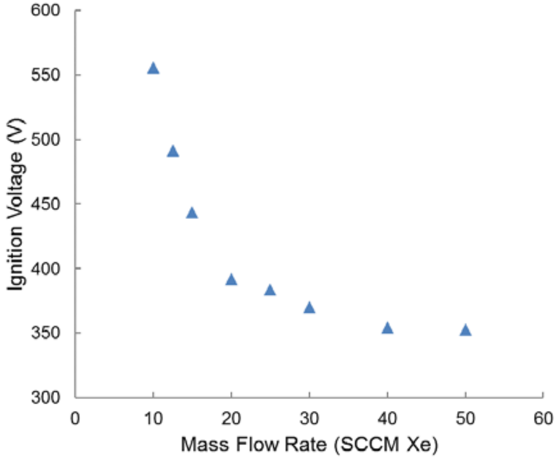


(Source: “Development and Initial Performance Testing of a Low-Power Magnetically Shielded Hall Thruster with an Internally-Mounted Hollow Cathode,” IEPC-2017-64)

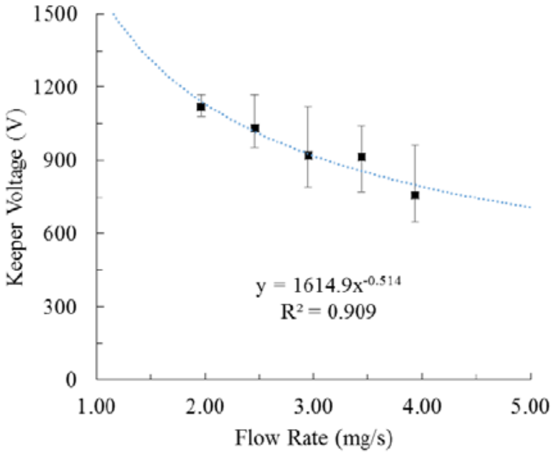
Advantages of using heaterless hollow cathodes in low-power Hall-effect thrusters

- Significantly lower cost (attractive in small-satellite applications).
- Elimination of the heater power module from a power processing unit (PPU).
- Reduced size provides greater design flexibility.

Background & Motivation: Heaterless Hollow Cathode Ignition



(Source: "Characterization of Propellant Flow and Bias Required to Initiate an Arc Discharge in a Heaterless Hollow Cathode," AIAA 2019-4247)



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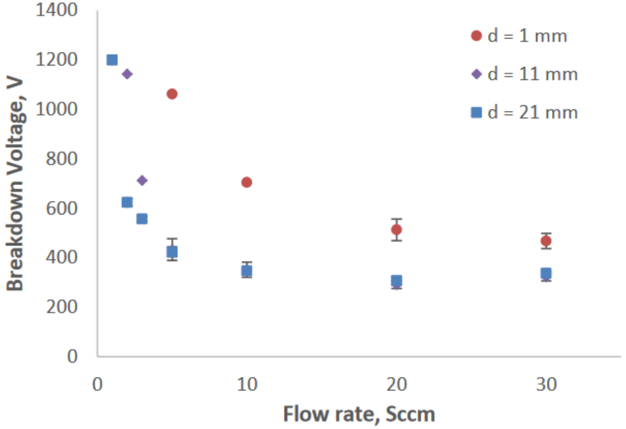
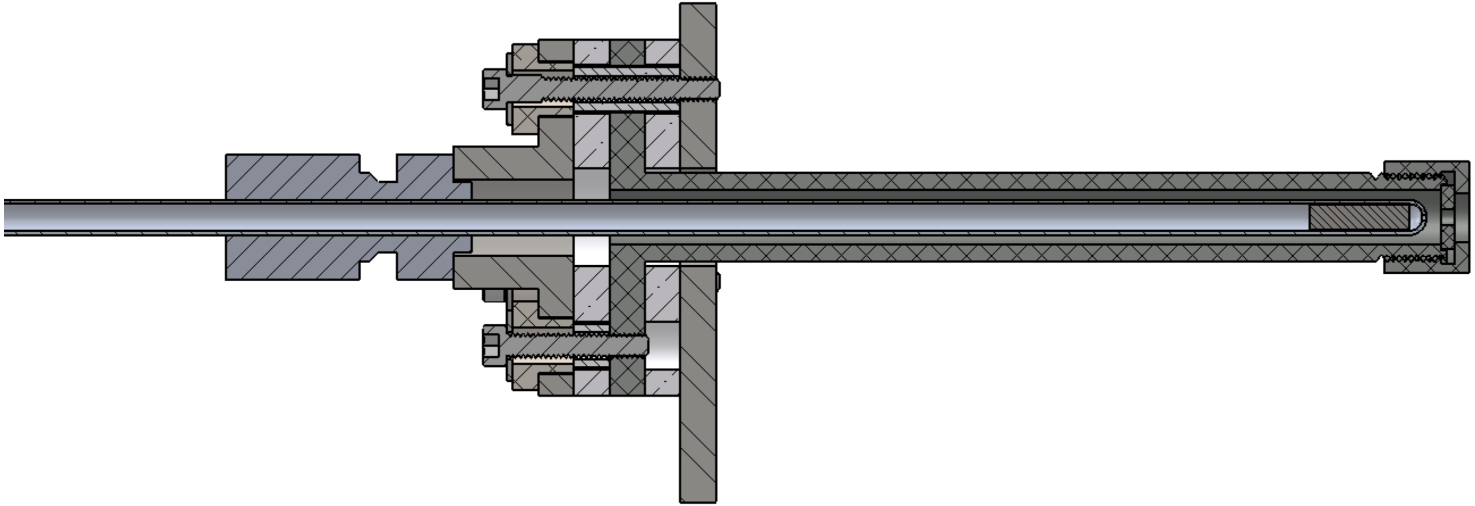


(Source: "Investigation of Heaterless Hollow Cathode Breakdown," IEPC-2015-193)

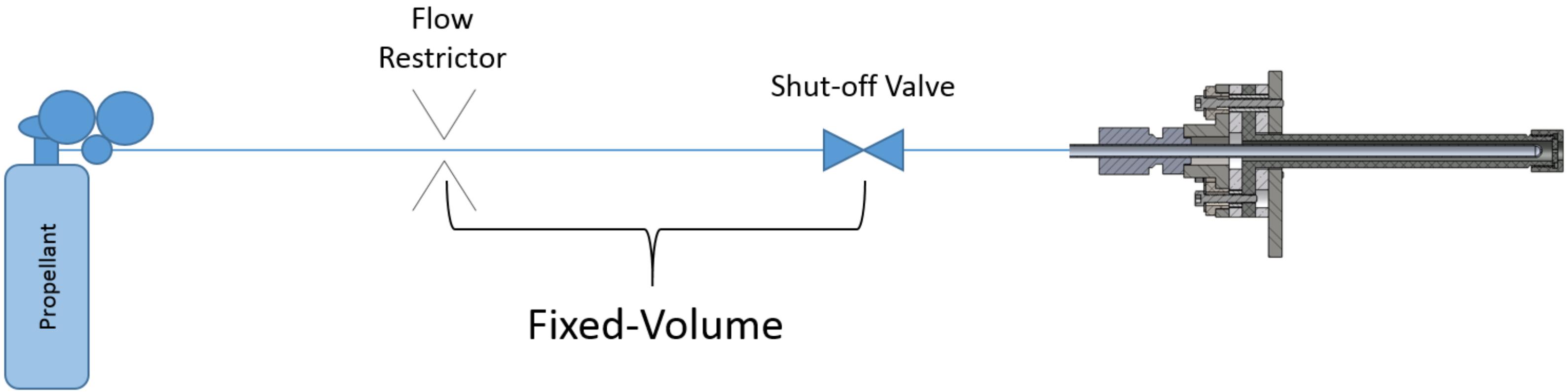
- To ignite a heaterless hollow cathode, one or both of the following are necessary:
  - A high bias voltage between the cathode and keeper
  - A significantly elevated propellant mass flow rate
- System-level implications are not yet well defined.

Heaterless Hollow Cathode Test Article



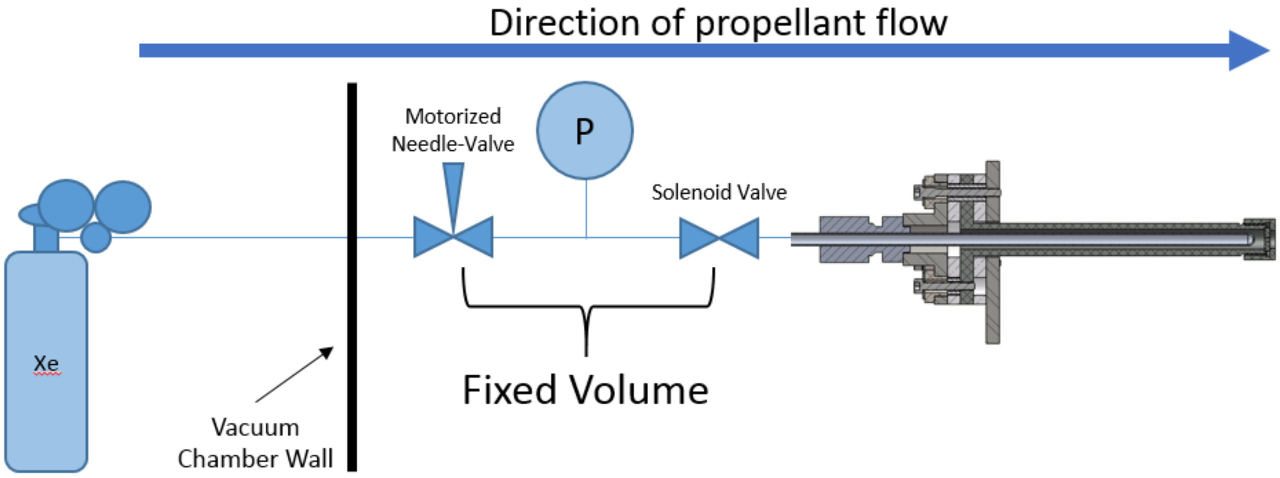
- Cathode Tube Diameter: 3.2 mm
- Cathode Orifice Diameter: 0.5 mm
- Keeper Orifice Diameter: 1.4 mm
- Cathode-Keeper Spacing: 1.3mm

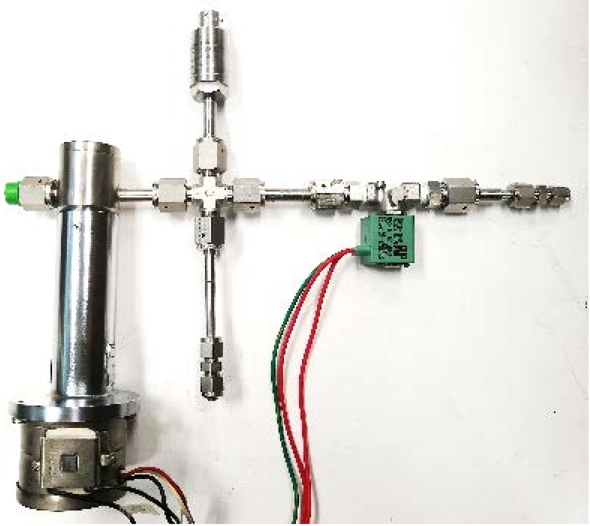
Fixed-Volume Release System Description



- With shut-off valve closed, the propellant pressure in the fixed-volume rises to the supply pressure (e.g. 40 psi).
- Elevated flow rate achieved by opening valve and releasing pressurized propellant.
- Simple, low-risk components: Flow Restrictor, Shut-off Valve
- Flow restrictor maintains nominal flow rate during steady-state cathode operation.

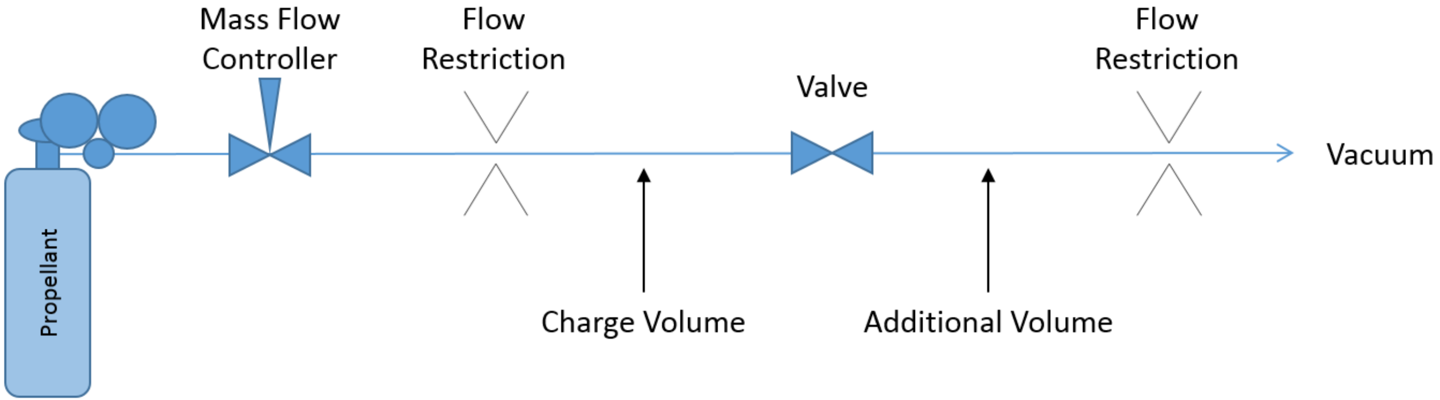
Experimental Apparatus





- Experimental apparatus operated in vacuum to minimize downstream flow path.
- Motorized needle-valve used, rather than a fixed flow restrictor.
- Pressure transducer added to enable additional performance evaluation.

Fixed-Volume Release Propellant Flow Model



Modelling Flow Rate

$$\dot{m}_{out} = \frac{A * P}{\sqrt{T}} \sqrt{\frac{\gamma}{R}} \left(\frac{\gamma + 1}{2}\right)^{-\frac{\gamma+1}{2(\gamma-1)}}$$

Assumption: Room Temperature Gas

Measuring Flow Rate

$$\dot{m}_{out} = \frac{-\dot{P}V}{RT} + \dot{m}_{in}$$

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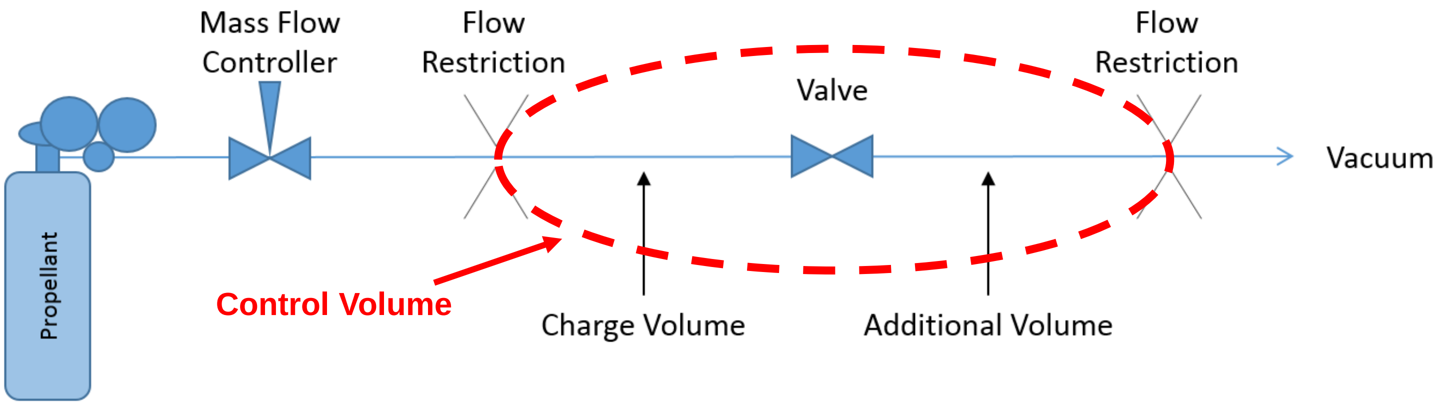
Fixed-Volume Release Propellant Flow Model



Modelling Flow Rate

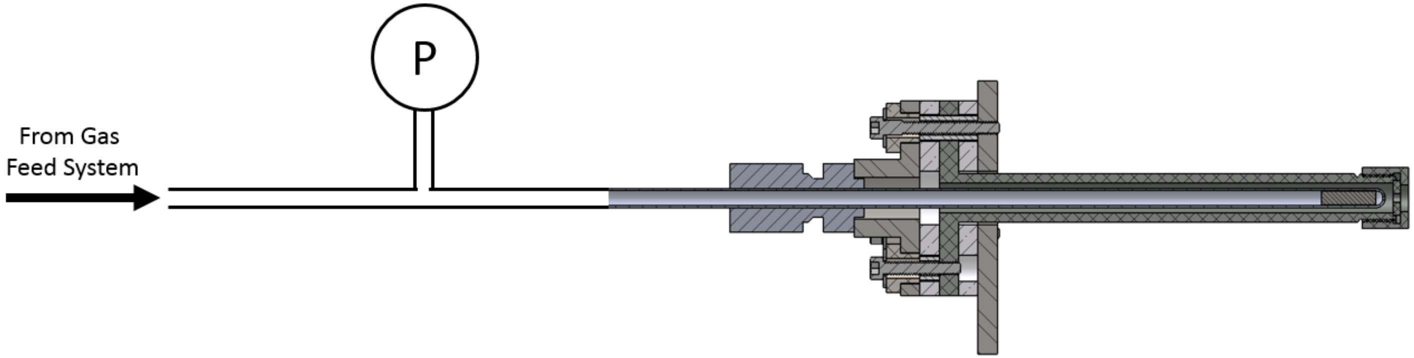
$$\dot{m}_{out} = \frac{A * P}{\sqrt{T}} \sqrt{\frac{\gamma}{R}} \left(\frac{\gamma + 1}{2}\right)^{-\frac{\gamma+1}{2(\gamma-1)}}$$

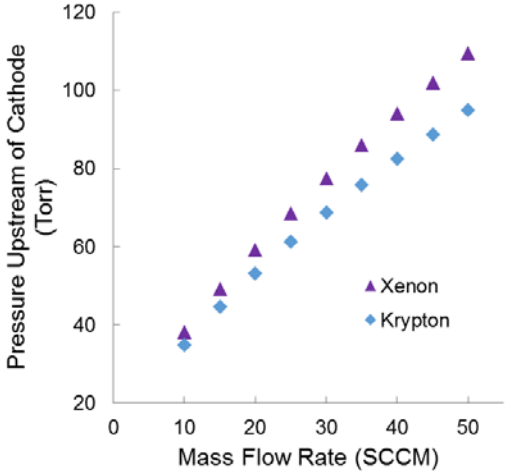
Assumption: Room Temperature Gas

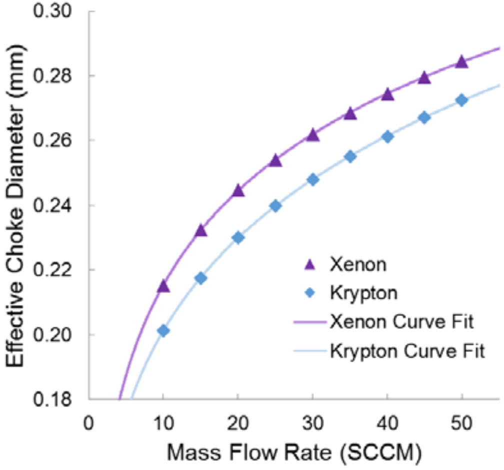
Measuring Flow Rate

$$\dot{m}_{out} = \frac{-\dot{P}V}{RT} + \dot{m}_{in}$$

Quantifying Flow Impedance of Hollow Cathode Assembly







$$\dot{m} = \frac{\pi d^2 P}{4\sqrt{T}} \sqrt{\frac{\gamma}{R}} \left(\frac{\gamma + 1}{2}\right)^{-\frac{\gamma+1}{2(\gamma-1)}}$$

Assumption: Room Temperature Gas

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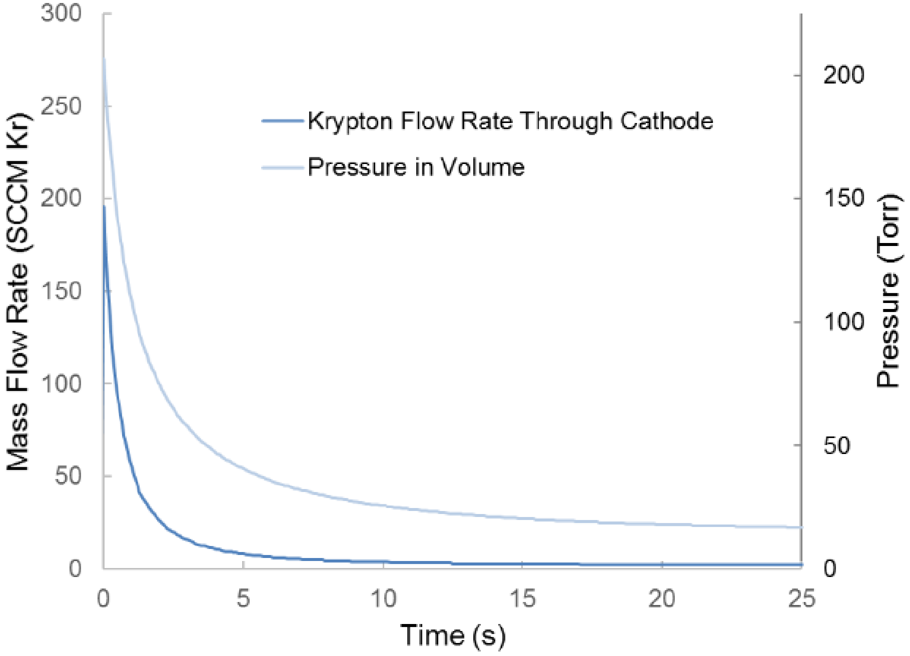
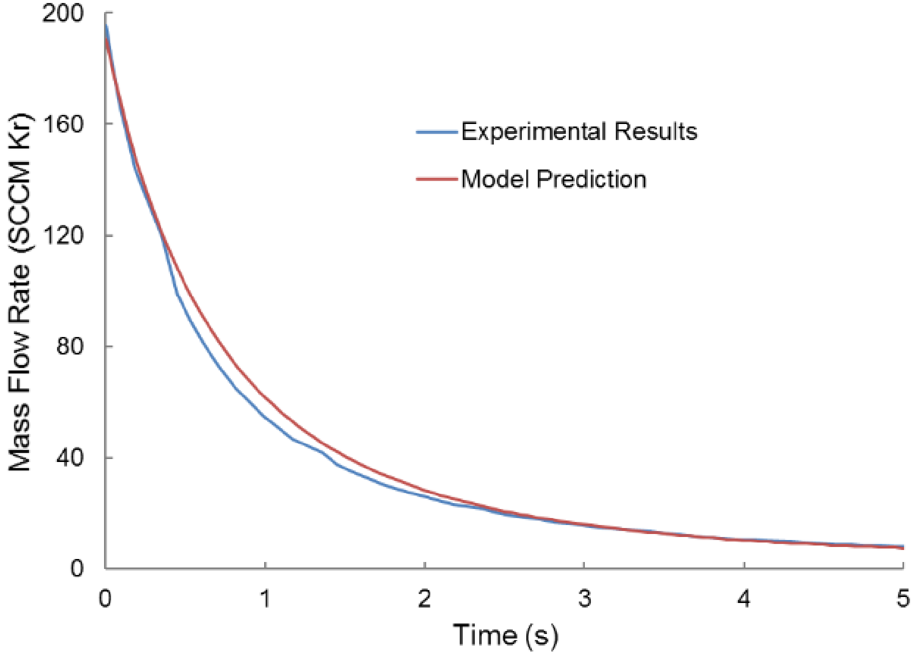
Modeled and Measured Propellant Flow Rate Through Hollow Cathode

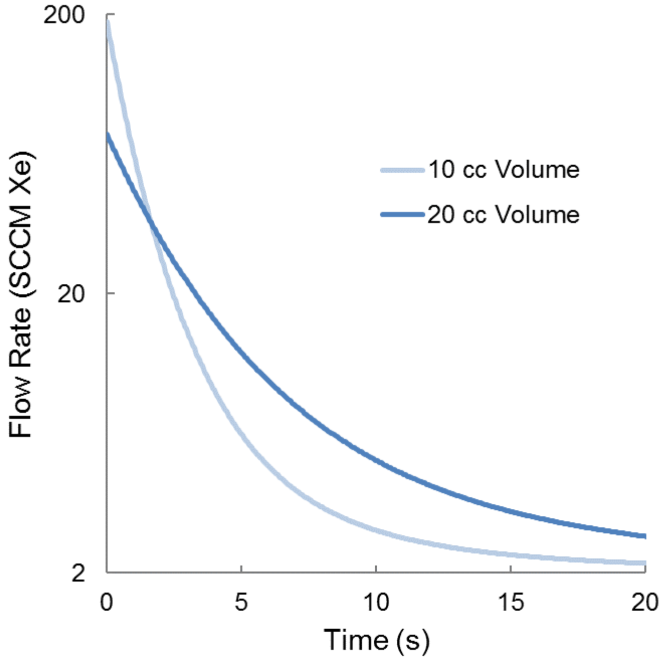


Graph showing experimentally measured pressure within the fixed-volume. These data were then used to calculate the propellant flow through the hollow cathode.

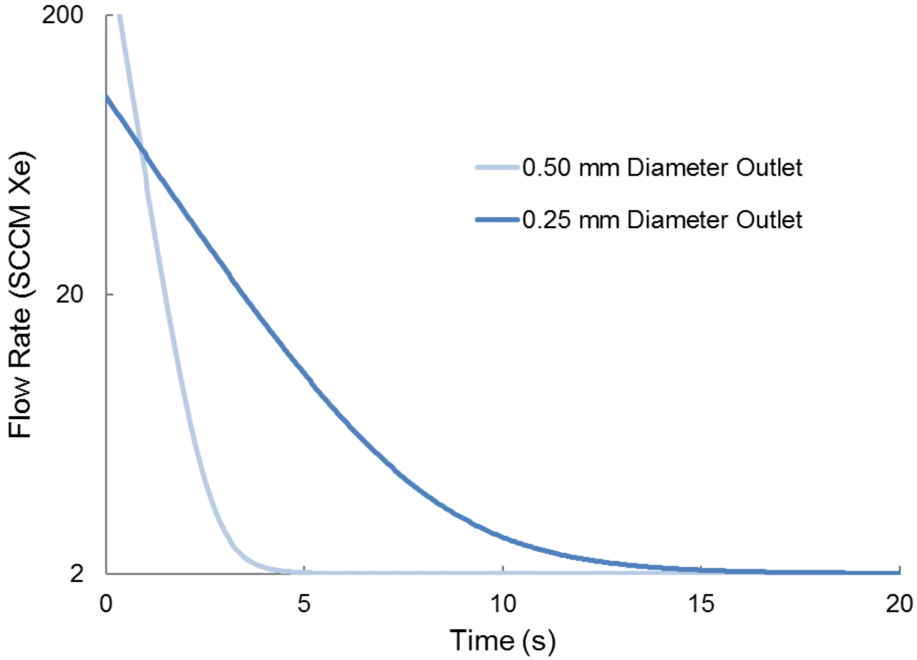


Comparison of the model prediction and experimental results.

Modeled Flow Rate Through Hollow Cathode

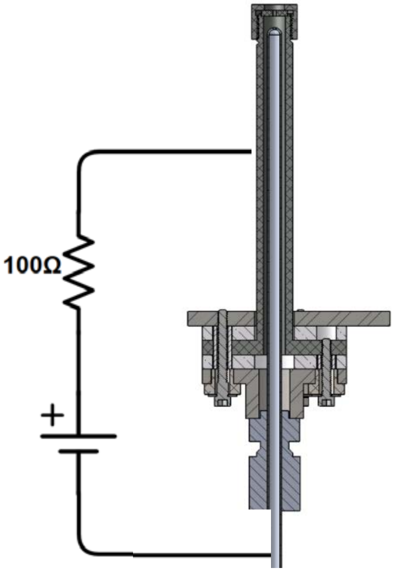


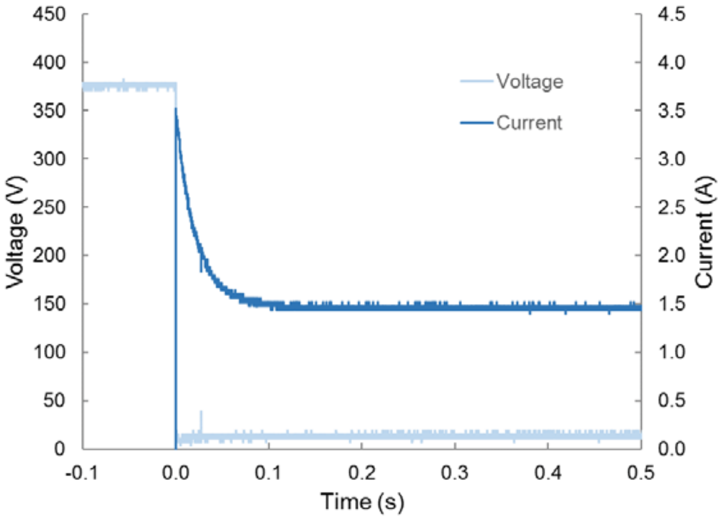
Comparison of flow rate behavior produced by two different size volumes, modeled using 20 mg of xenon propellant.

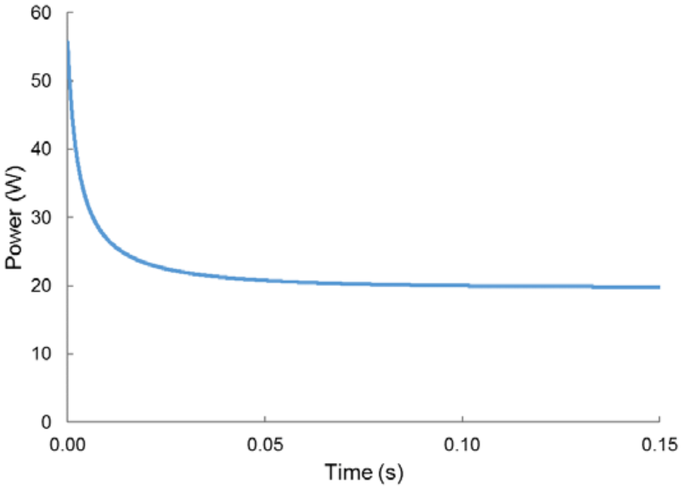


Comparison of flow rate behavior produced by two different outlet flow restrictions, modeled using 20 mg of xenon propellant.

Results: Ignition Behavior







Ignition Parameters:

- Cathode-Keeper Bias Voltage: 375 V
- Propellant charge mass: 17.3 mg (xenon)
- Fixed-Volume: 13 cm^3

Conclusion

- A fixed-volume release system was demonstrated.
- Repeatable ignition behavior was achieved in a 3.2 mm heaterless hollow cathode using a 13 cm^3 fixed-volume release system with the following parameters:
  - 375 V cathode-keeper bias voltage, and 17 mg of xenon propellant.
  - 300 V cathode-keeper bias voltage, and 13 mg of krypton propellant.
- In either case, over 10,000 ignition cycles could be performed with 200 g of propellant.

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Questions