Design and Optimization of a MEMS Monopropellant Micro-Thruster

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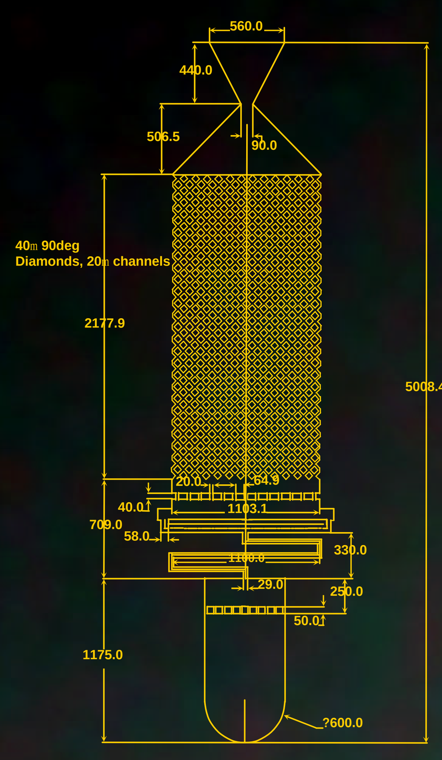


Micro-Thruster

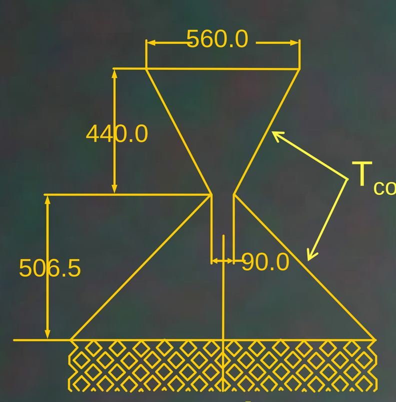
"Nanosats," or satellites featuring a mass of approximately 1-10 kg, are being considered for a wide range of advanced missions such as precision formation flying. Unique thrust requirements accompanying the nanosats have initiated a design concept for a MEMS based micro-thruster. Due to the complexity of the fluid dynamics inherent on the micrometer scale, experimental and numerical studies have been proposed to better understand the flow properties as well as optimize the design.

Computational Analysis of the Supersonic Nozzle

Why study the nozzle?

The nozzle is a key component in the overall performance of the thruster. Computational fluid dynamics is used to analyze the operation and then optimize the nozzle design.

Areas of interest include:



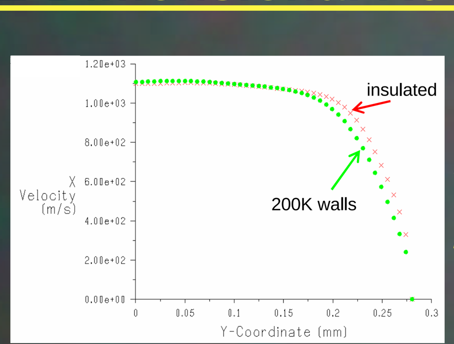
Nozzle

- Viscous effects/boundary layer growth
- Impact on thrust vector
- Optimization of divergence angle
- Impact of heat transfer through the nozzle
  - adiabatic vs. isothermal walls

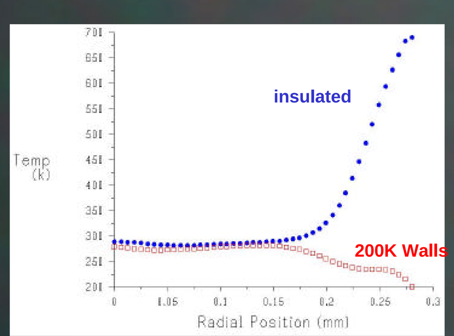
Computational Methodology:

- FLUENT 6® was used for all calculations
- Continuum modeling using a mixture of the product gases
- Constant mass flow rate and adiabatic flame temperature defined at inlet, far field set as pressure outlet
- Convergence was determined via residuals, monitors, and mass conservation

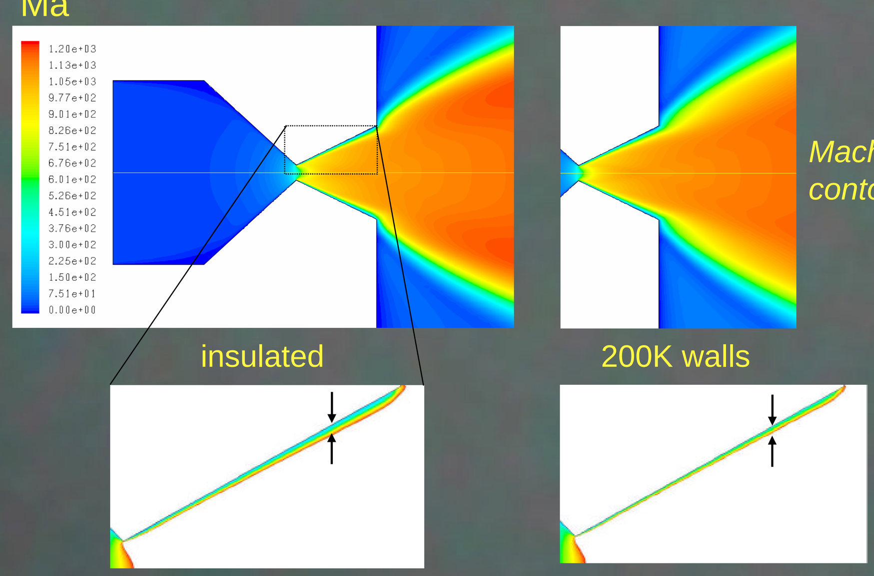
2-Dimensional Results Including Heat Transfer:



Exit velocity for ½ of the nozzle geometry



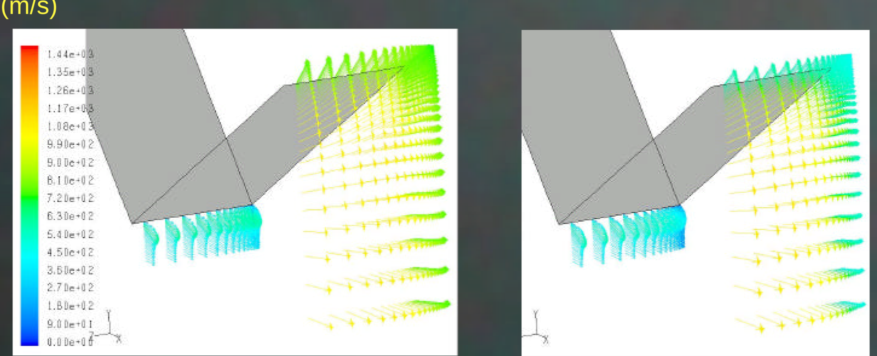
Exit temperature for ½ of the nozzle geometry



Mach contours

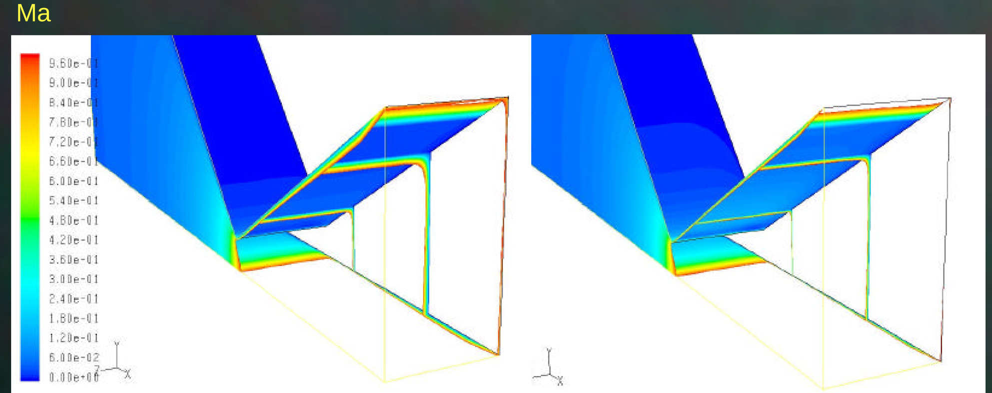
Subsonic region near the wall

3-Dimensional Results Including Heat Transfer:



Velocity vectors for ¼ of the nozzle

3-D subsonic regions



Experimental Study of the Catalyst Bed

Introduction:

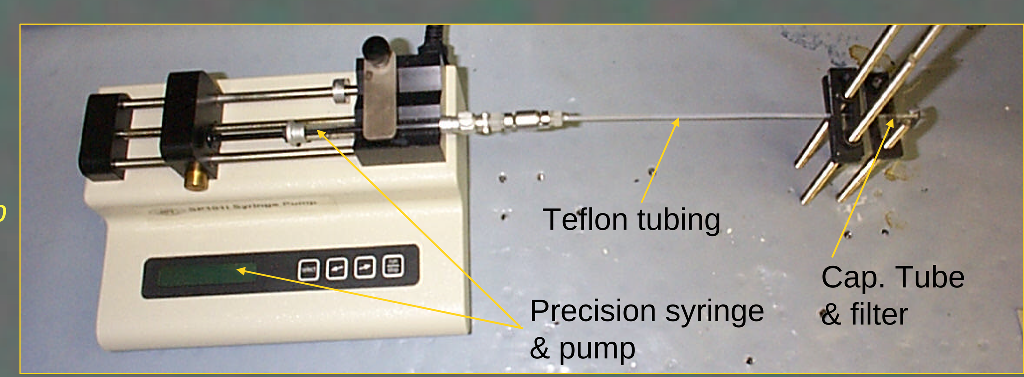
Incomplete decomposition of the monopropellant is severely hindering the thruster's performance. The resulting 2-phase flow gives rise to an empirical study of the catalyst bed to determine the required decomposition length as well as the feasibility of using silver powder as the catalyst.

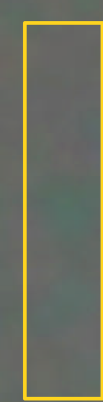
Experimental Setup:

The setup being considered is designed to pass high test hydrogen peroxide (HTP) through a silver powder test bed. The catalyst is located inside a glass capillary tube fitted on one end with a 24 μm steel mesh/filter.

- Capillary catalyst bed – Kimax® capillary tube (I.D. ≈ 1.24mm)
- Silver powder (diameter ≈ 44 μm) used as the catalyst
- Hamilton® precision syringe and precision syringe pump produce a pre-defined mass flow rate

Test setup





Kimax® capillary tube with filter

Experimental Methodology:

The decomposition length is determined based on the exhausting products and the % of remaining HTP:

$$H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g) + \text{heat}$$

Methods of measurement include:

1. % HTP measured using a Brix refractometer
2. visual inspection for 2-phase flow

Conclusions:

To date, 2-D and 3-D numerical models have been successfully completed and are in good agreement.

- The flow in the diverging region of the nozzle is underexpanded, supporting a larger divergence angle.
- The 3-D case shows approximately a 10% reduction in thrust when considering isothermal walls as opposed to adiabatic conditions.
- The subsonic region found near the wall seems to be intimately linked to the efficiency of the nozzle.

Experimental tests are currently underway to characterize the catalyst bed length for a silver powder catalyst.

Acknowledgements:

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