Computational and Experimental Efforts in Gravity Probe B Microthruster Analysis

Gravity Probe B, an experiment to test the theory of relativity, will be launched near the turn of the millennium. Due to the precise pointing requirements needed to successfully carry out this experiment, the satellite will use sixteen proportionally controlled microthrusters as a main component of the attitude control system. These microthrusters use the helium boil-off from the on-board dewar as propellant.

Marshall Space Flight Center, overseeing the project, verified the design of the thruster flow path by both computational and experimental methods. The flow performance of the thruster has been adequately characterized. Graphs show specific impulse, thrust coefficient, discharge coefficient, and mass flow rate trends. Value was added to the program through gained confidence in the design of the thruster and through evaluation of some design trade-offs.

This work may be valuable in the future due to the possible need of small thrusters on spacecraft that have precise pointing requirements.

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Background

- **Gravity Probe B (GPB)**
  - A satellite borne relativity experiment
  - Requires precise pointing control and acceleration free environment to be provided by attitude control system

- **Microthrusters**
  - Helium gas from dewar boiloff used as propellant
  - Sixteen microthrusters on spacecraft; used for orbit trim, spin-up, spin-down, and attitude control
  - Concerns about mission lifetime and control saturation

Objectives

- **Verify design of microthruster**
  - Thrust
  - Specific Impulse

- **Gain knowledge about the physics of rarefied thruster flows**
  - In the future, this size of thruster may become more common on spacecraft, due to:
    - » extremely tight spacecraft attitude control requirements
    - » use of large liquid helium dewars

Method

Direct Simulation Monte Carlo (DSMC):

Limits on areas of application

Slow - not useful for large parametric studies

Works well for low Reynolds number flows, costly to use for higher Reynolds number flows

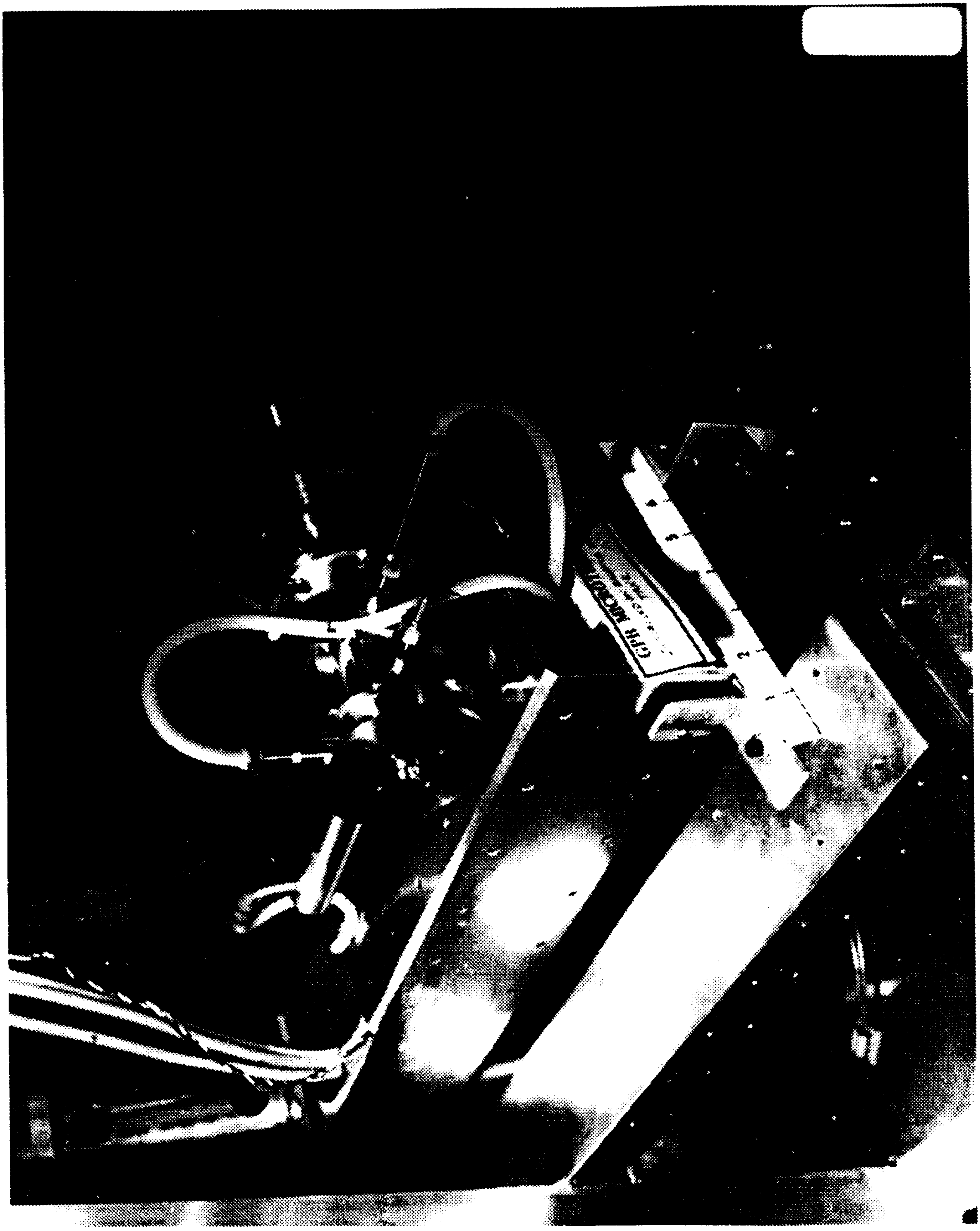
Gives good characterization of the flowfield

Experiment:

Covers all of the flowfield

Very fast once hardware is in place useful for parametric studies, useful for assessment of configuration change

Possible data scatter at low Reynolds numbers, but works well for higher Reynolds number flows



Results

- **Requirements:**
  - Thrust ≥ 8 mN at $P_{inlet} \geq$ 9.7torr and mass flow ≤ 1.52E-05 lbm/s
  - Thrust ≤ 0.05 mN at $P_{inlet} \leq$ 12.5 torr and mass flow ≤ 9.48E-07 lbm/s
  - Thrust ≥ 2.55 mN at $P_{inlet} \geq$ 4.2 torr and mass flow ≤ 4.85E-06 lbm/s
- **Microthruster Characterization**
  - Thrust
  - I_{sp}
- **Added Value**
  - Conical Nozzle vs. Sharp Edged Orifice
  - Analysis of change in piston and valve seat design

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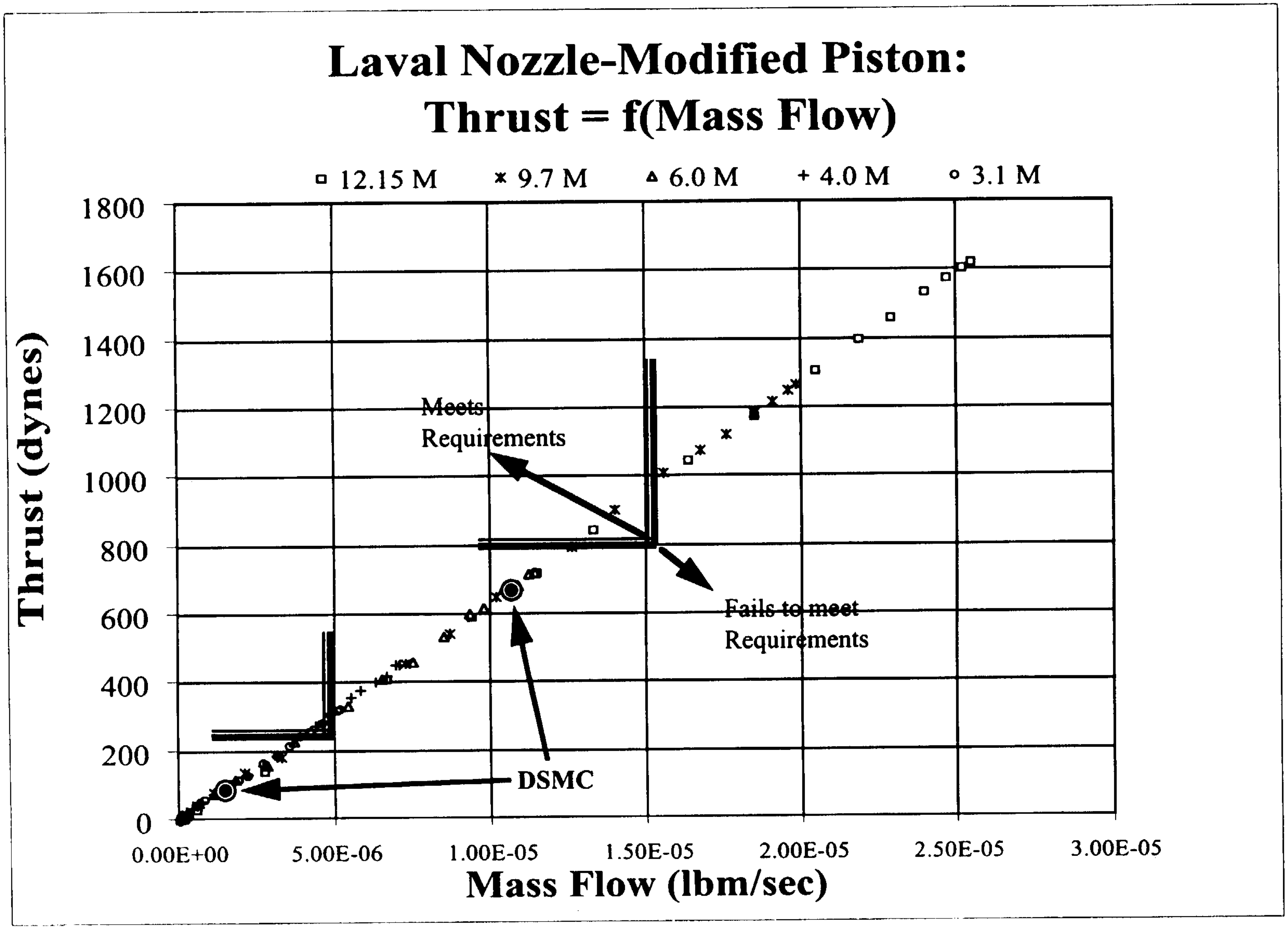

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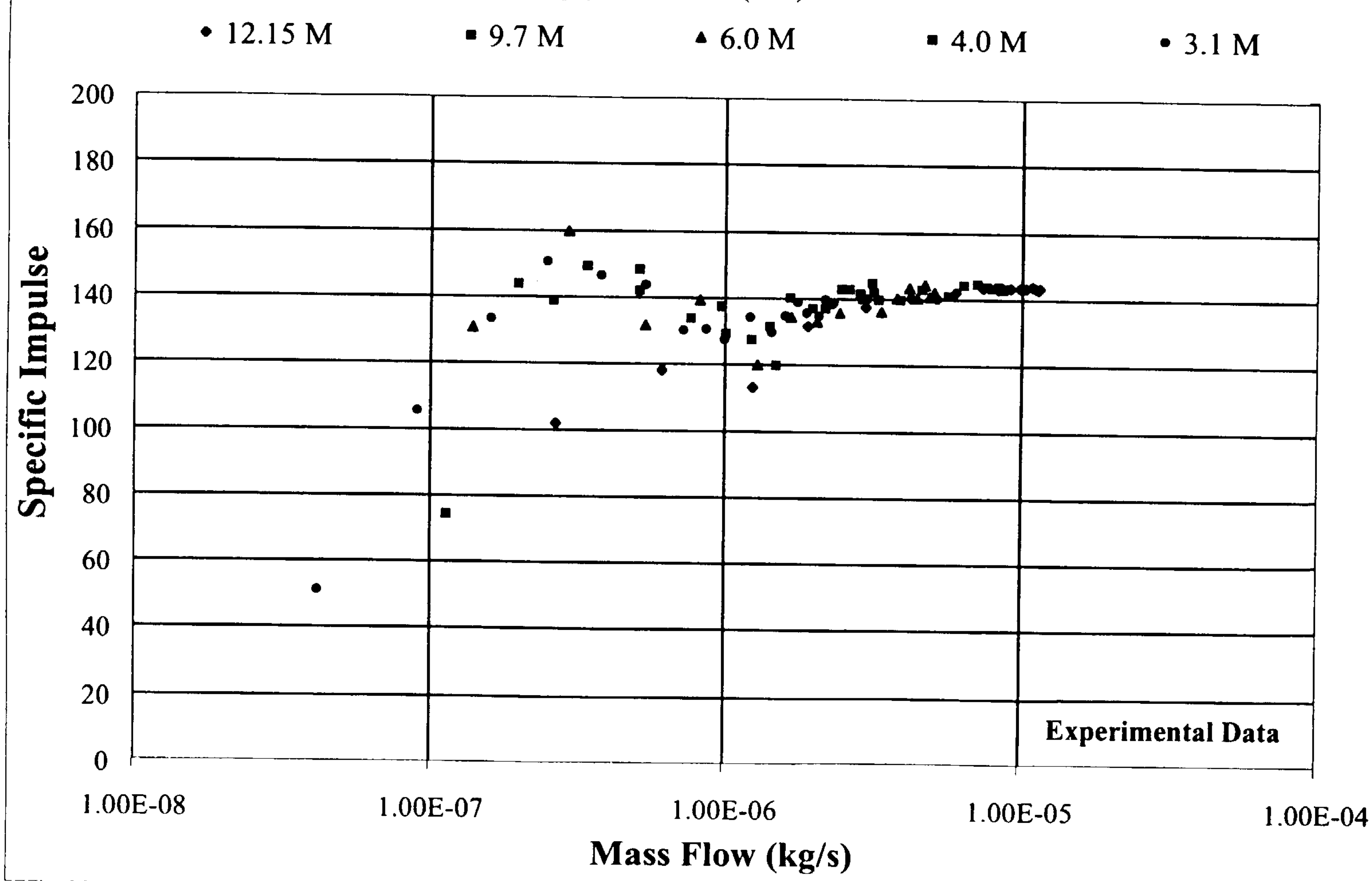
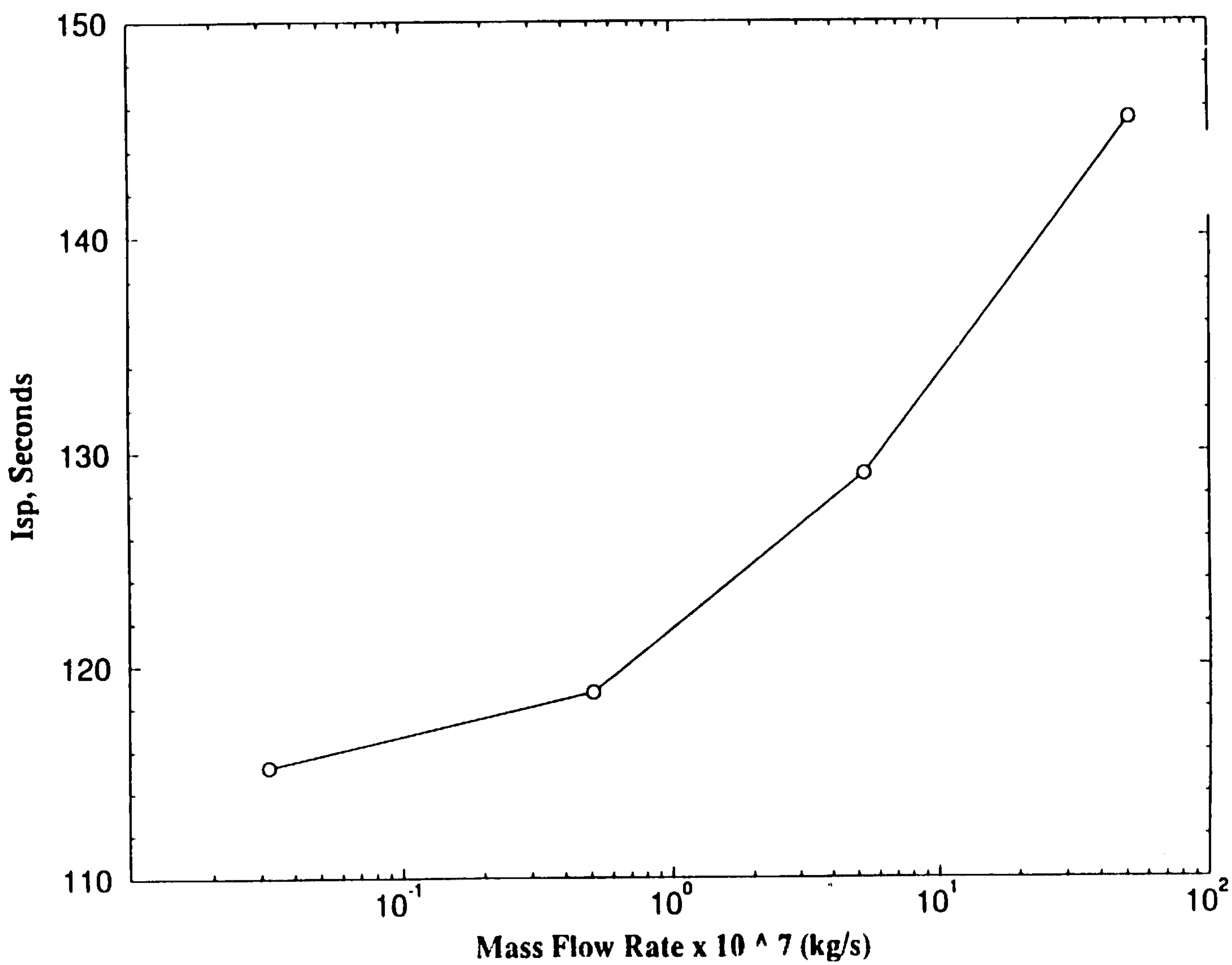
Nozzle - Modified Piston: Isp = f(Mass Flow)



DSMC Calculation of Specific Impulse



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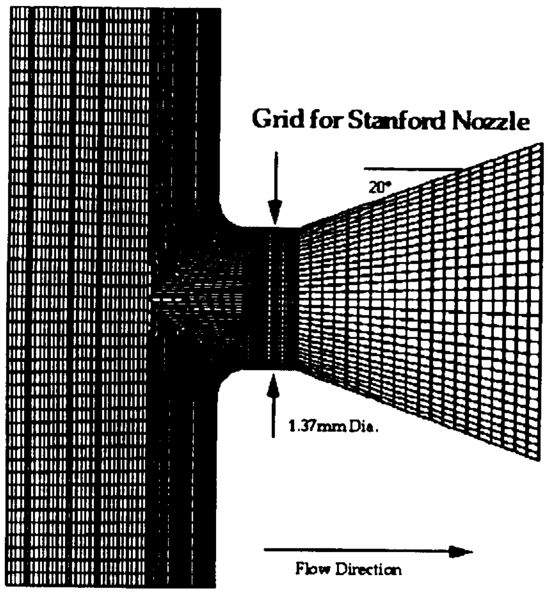
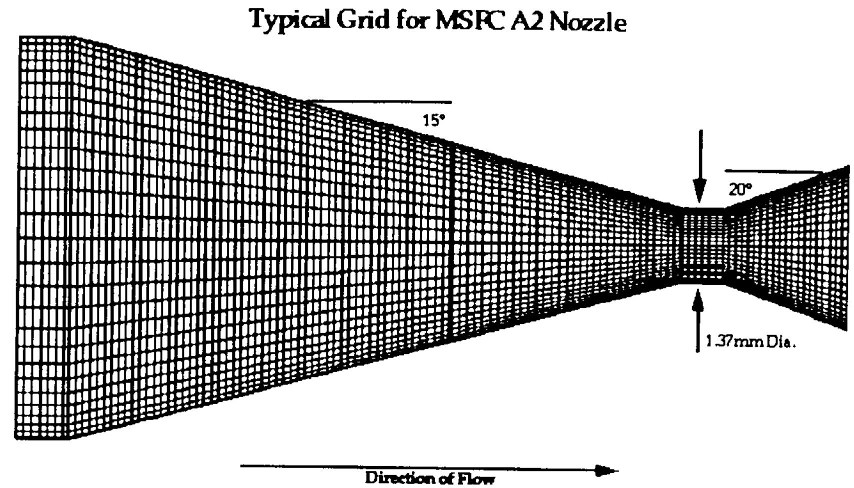
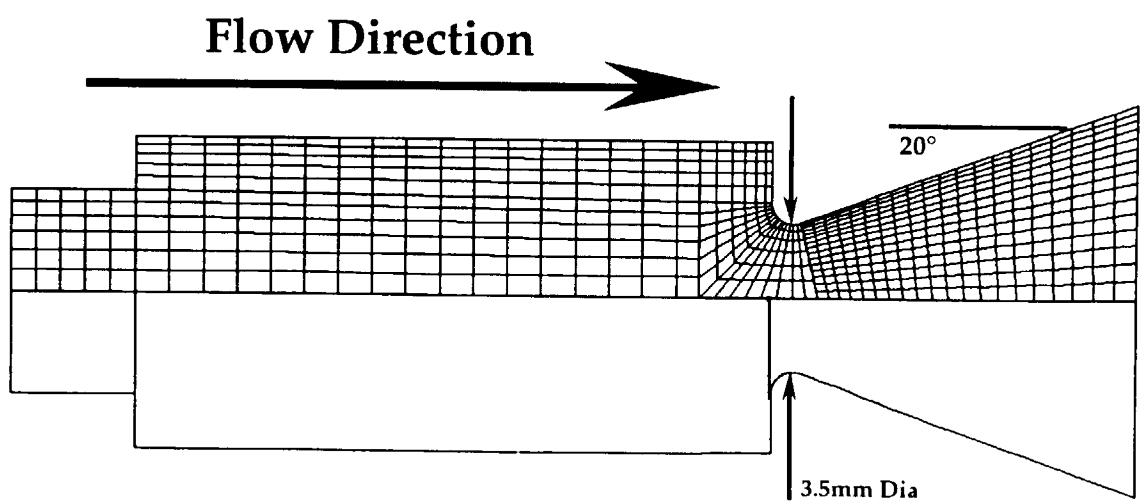


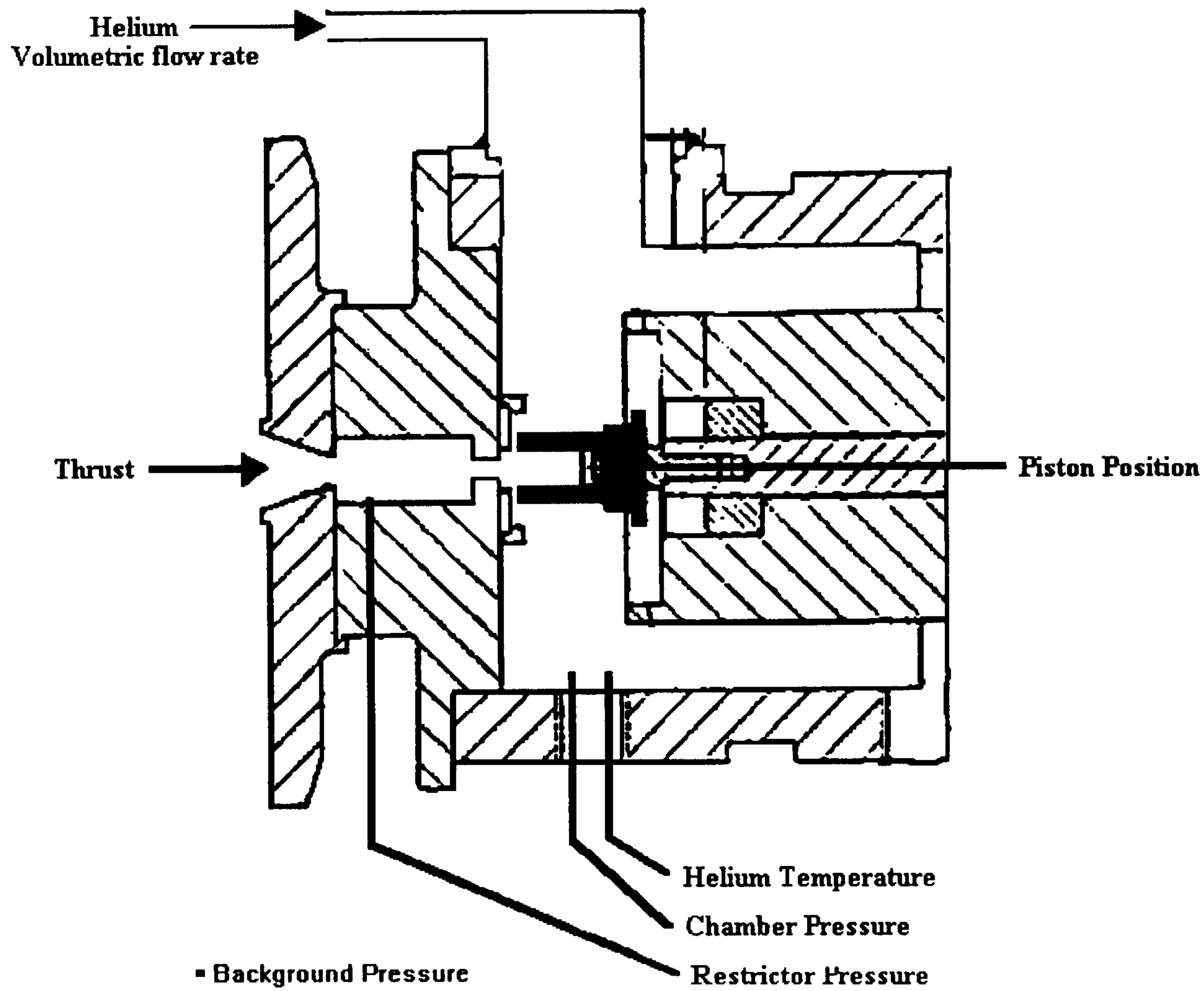


Note: Grids are not on the same scale



Grid / Geometry for Flight Nozzle

GP-B MODEL INSTRUMENTATION



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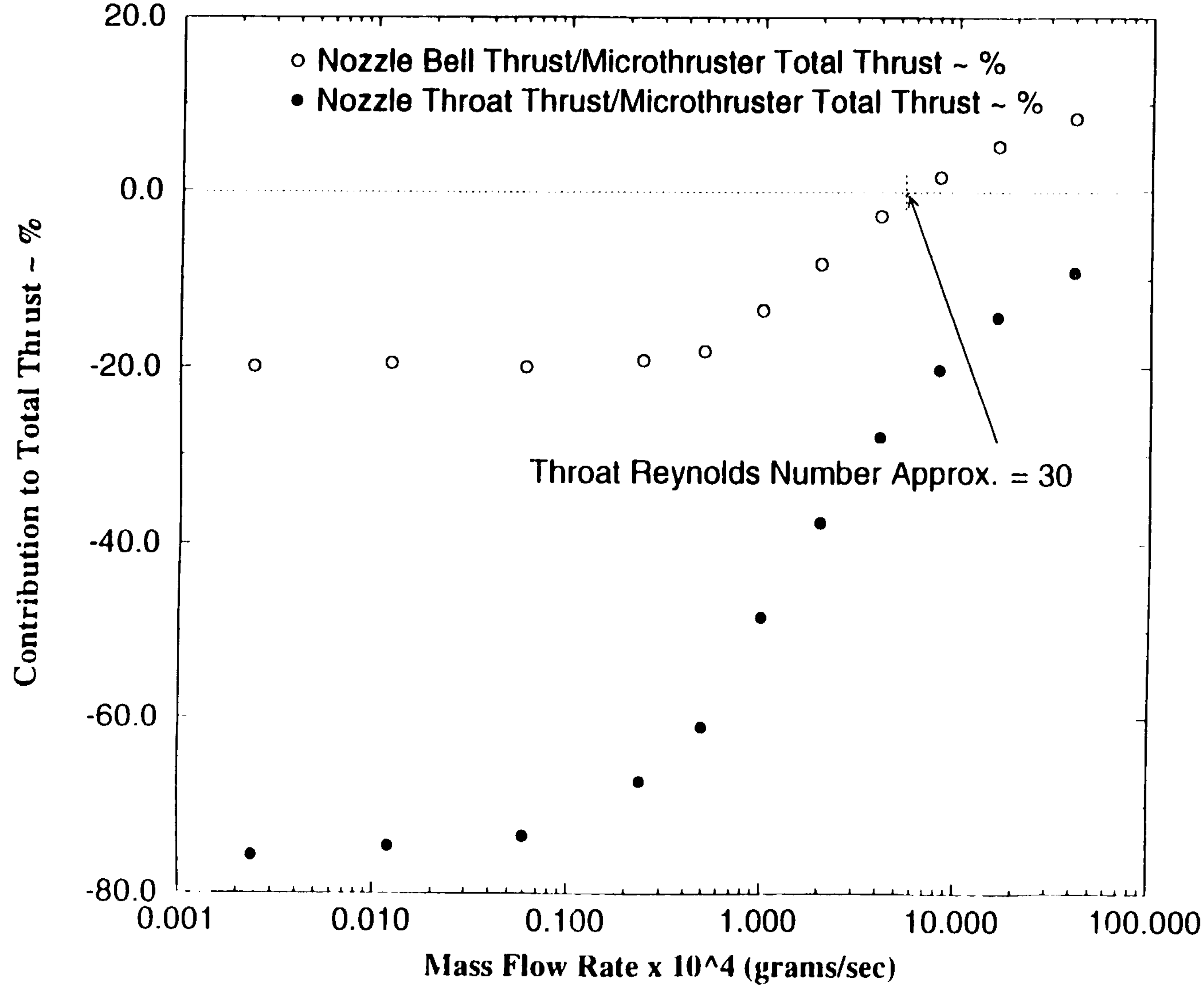
Contributions of the Nozzle Bell and the Cylindrical Throat to the MSFC A2 Configuration Total Thrust



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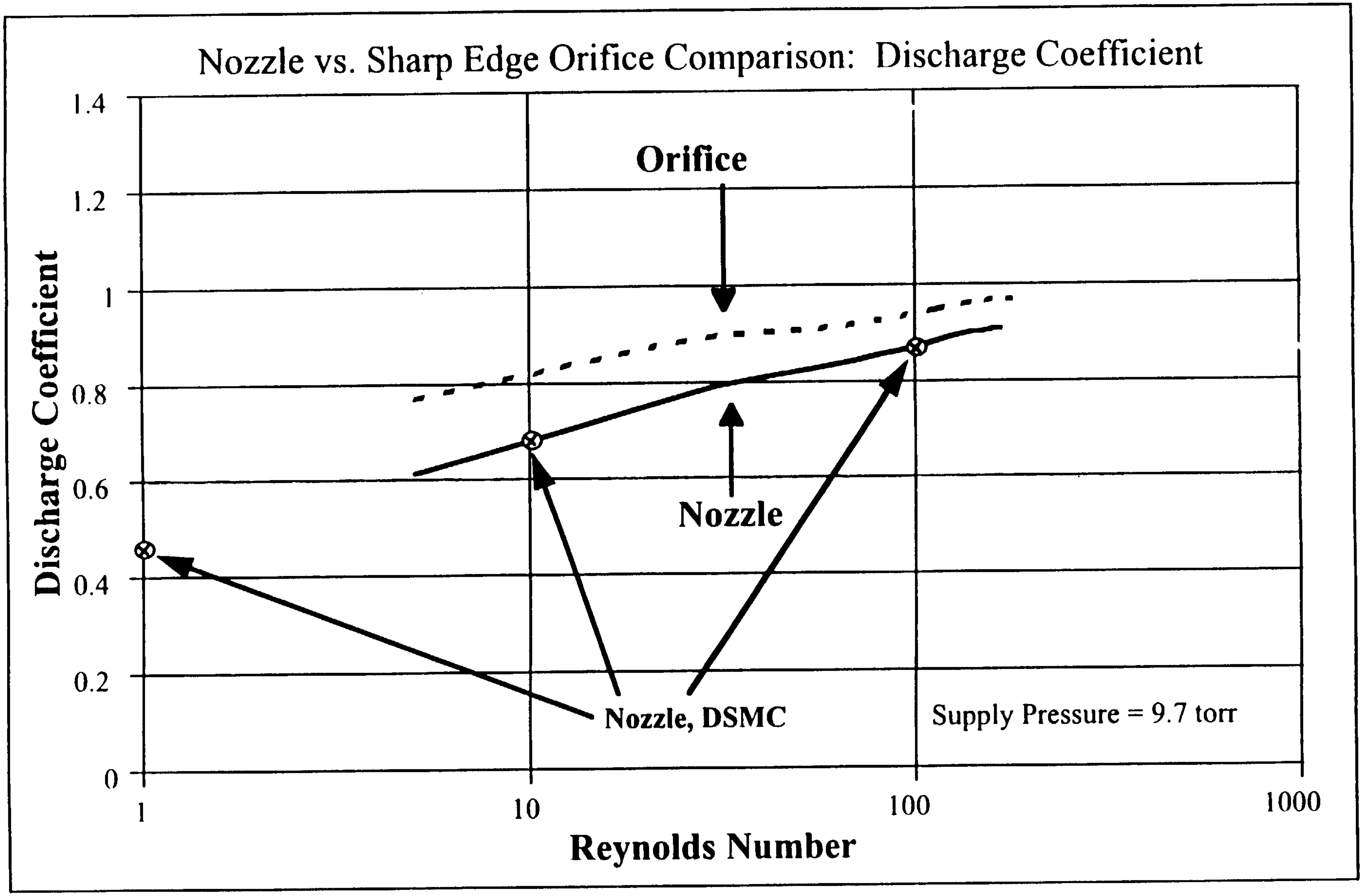
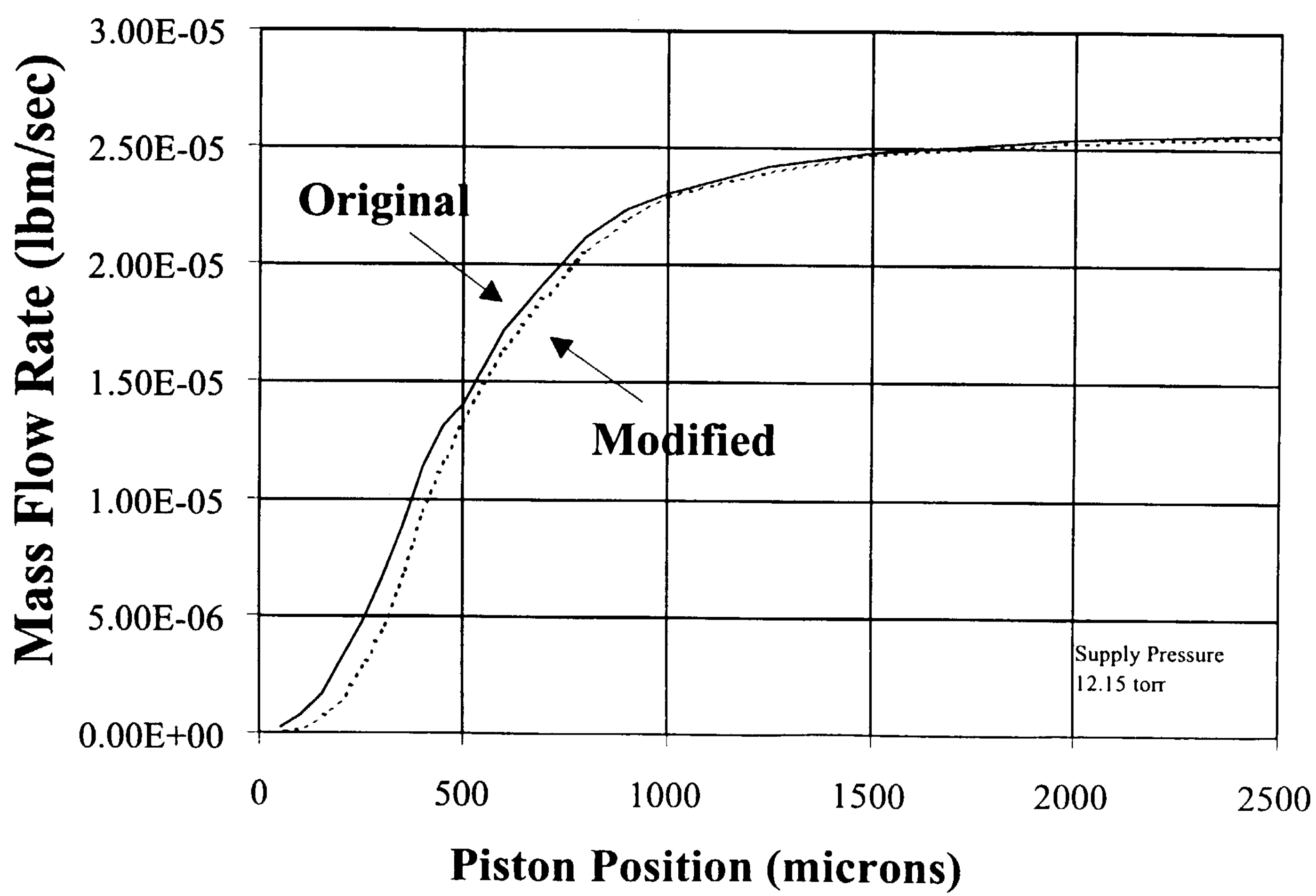


Laval Nozzle - Original vs Modified Piston: Mass Flow vs Piston Position



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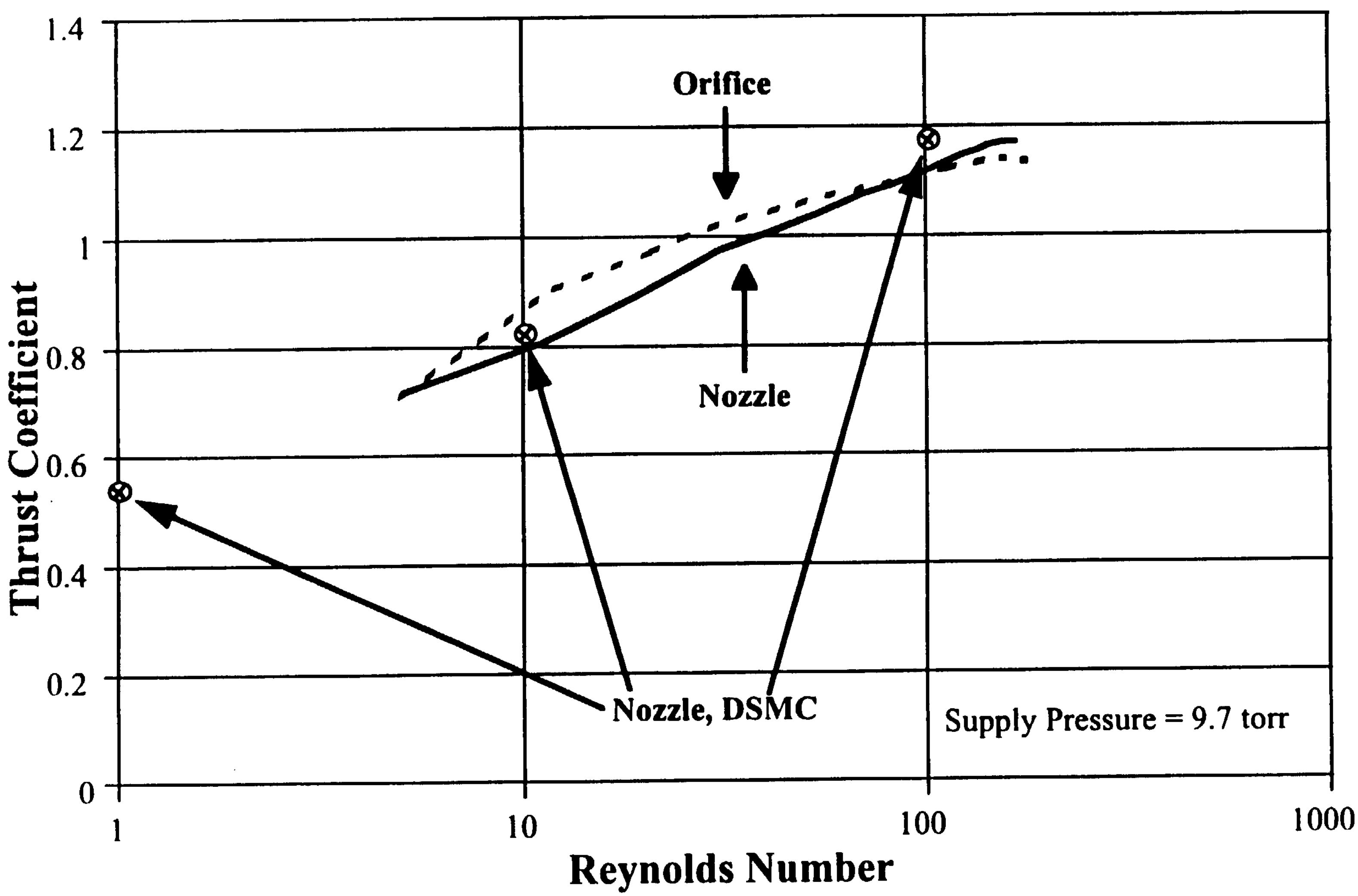
Nozzle vs. Sharp Edge Orifice Comparison: Thrust Coefficient



Conclusions

- Thruster meets or exceeds requirements
- Specific Impulse varies over operating range
- Current nozzle design is adequate throughout operating range
- Change in piston/valve seat increased flow resistance through the thruster

Future Work

- **DSMC**
  - Plume characterization and comparison with experiment
  - Plume impingement on spacecraft

- **Experimental**
  - Possible re-run of experiment with highly sensitive force balance in order to eliminate data scatter at low Reynolds numbers

- **Both**
  - Write detailed NASA Tecnical Memos or Technical Papers