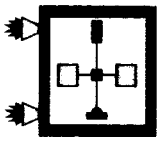


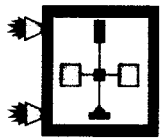
ST7 - DRS

The Space Technology 7 Disturbance Reduction System

W. Folkner

Jet Propulsion Laboratory

California Institute of Technology



Team Members

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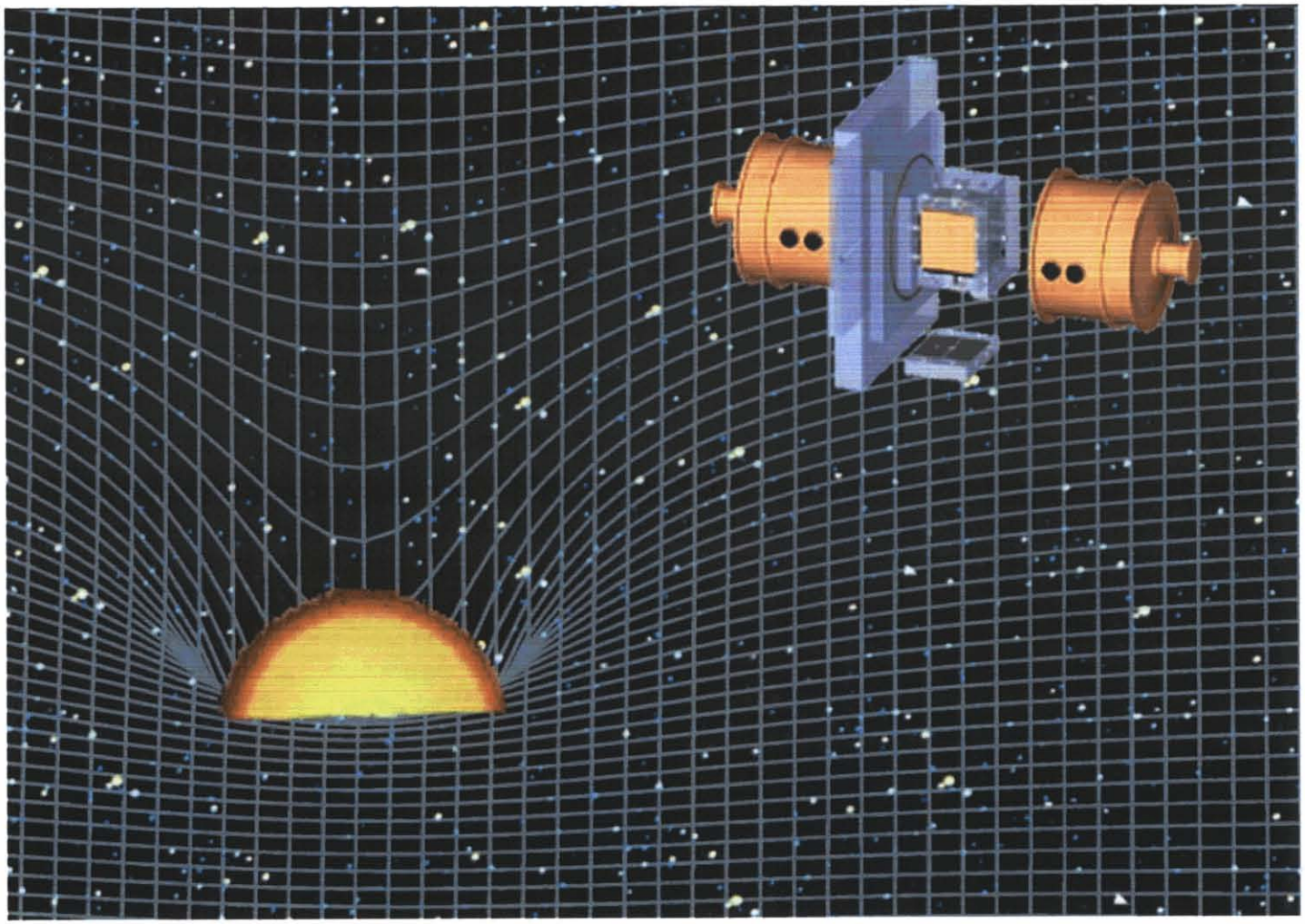
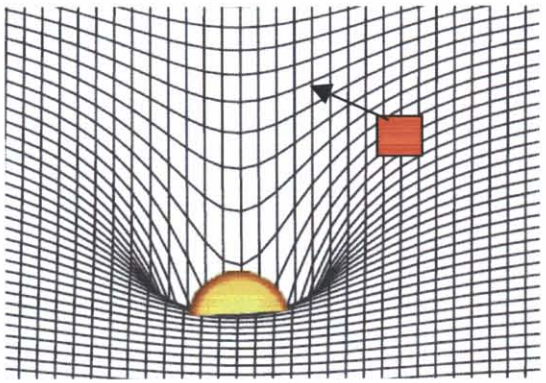
Disturbance Reduction System

ST7 - DRS

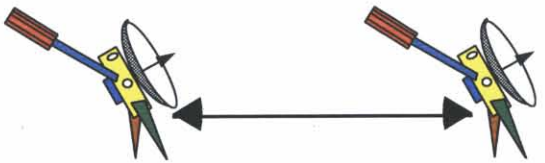


DRS Objectives

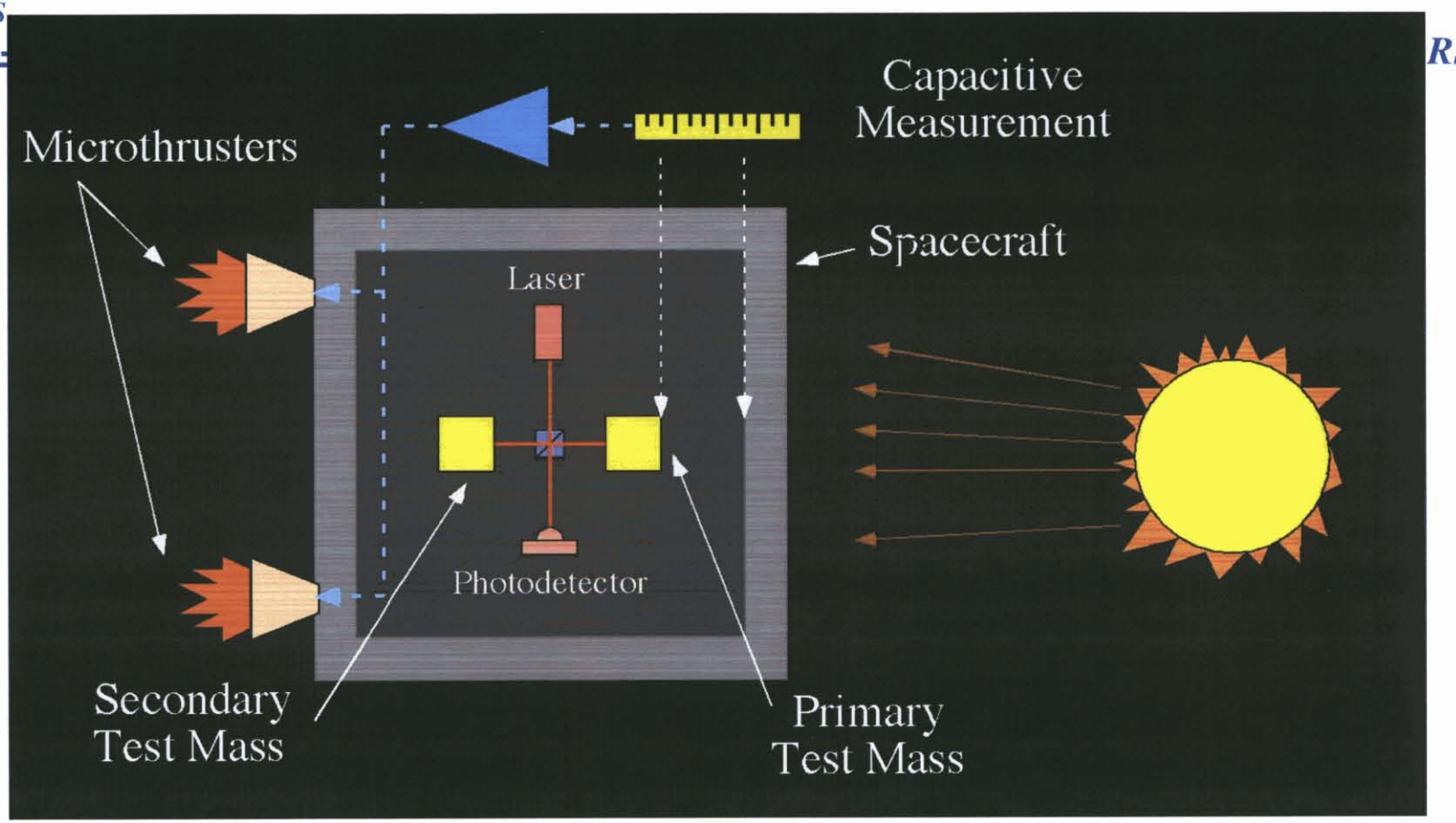
- **Validate that a test mass follows a trajectory determined by gravitational forces only within 3×10^{-14} m/s^2/√Hz**
  - Low acceleration noise is needed for study of general relativity, planetary gravity, gravitational waves



- **Validate spacecraft position control to an accuracy of <10 nm/√Hz**
  - Spacecraft position control is required for separated-spacecraft interferometers which do not use internal delay lines

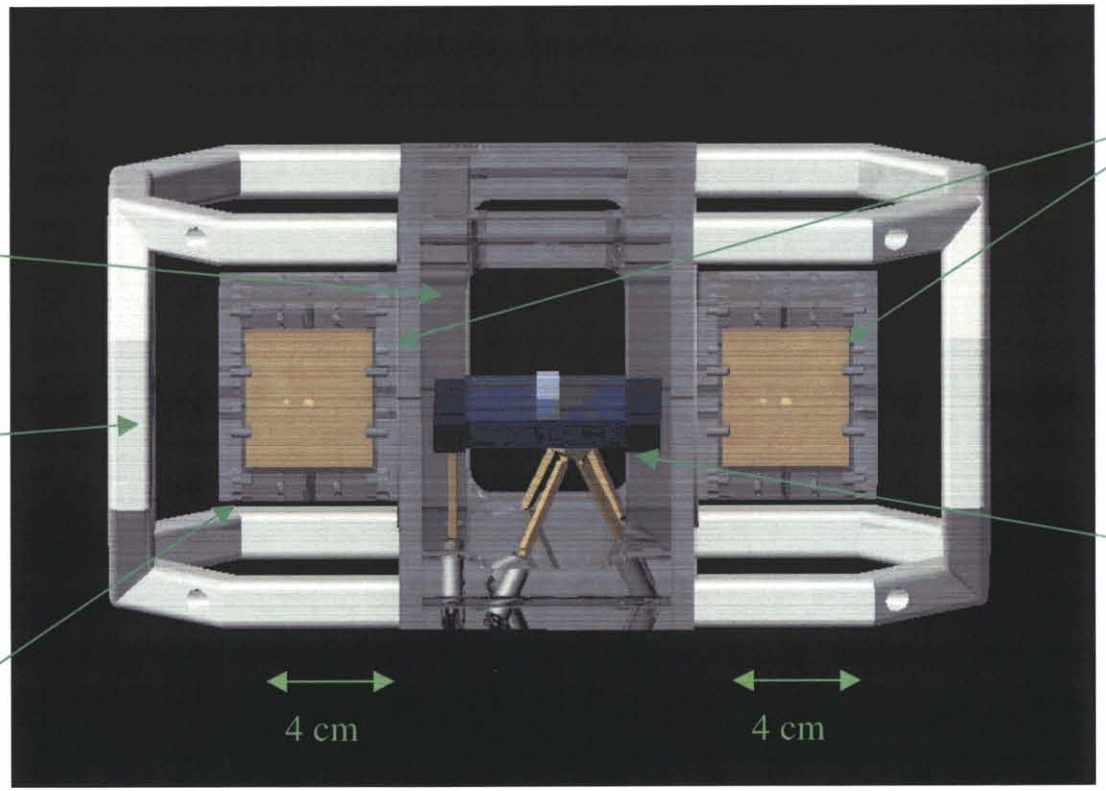


DRS Concept



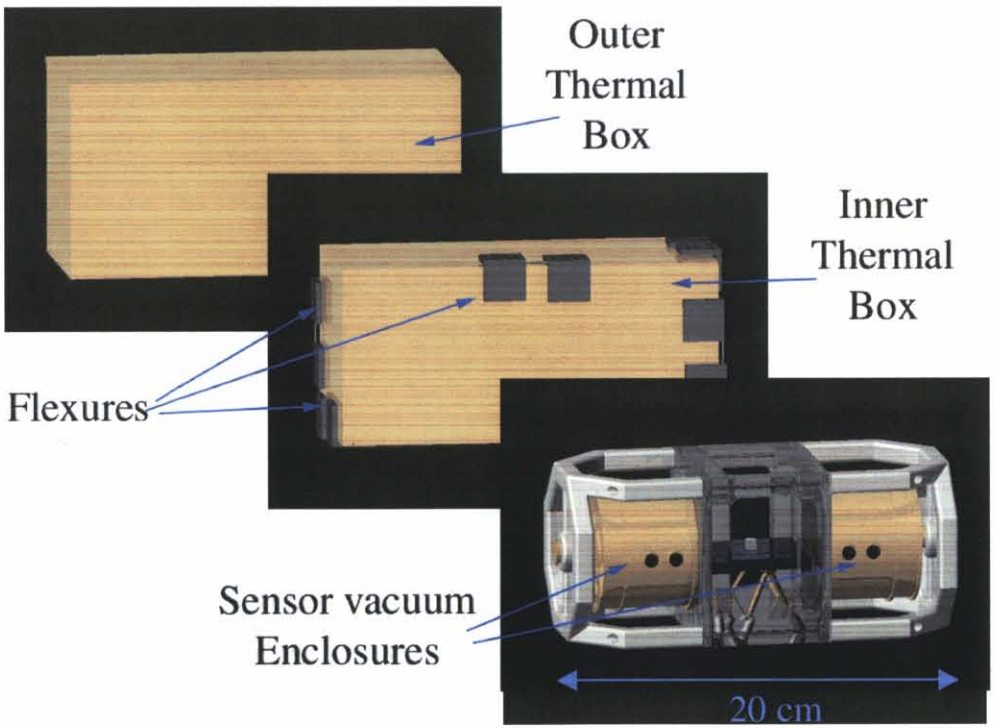
- **The DRS instrument package consists of**
  - Two gravitational reference sensors
  - Microthrusters for spacecraft position control
  - Interferometer to measure the distance between the two test masses.

Instrument Configuration



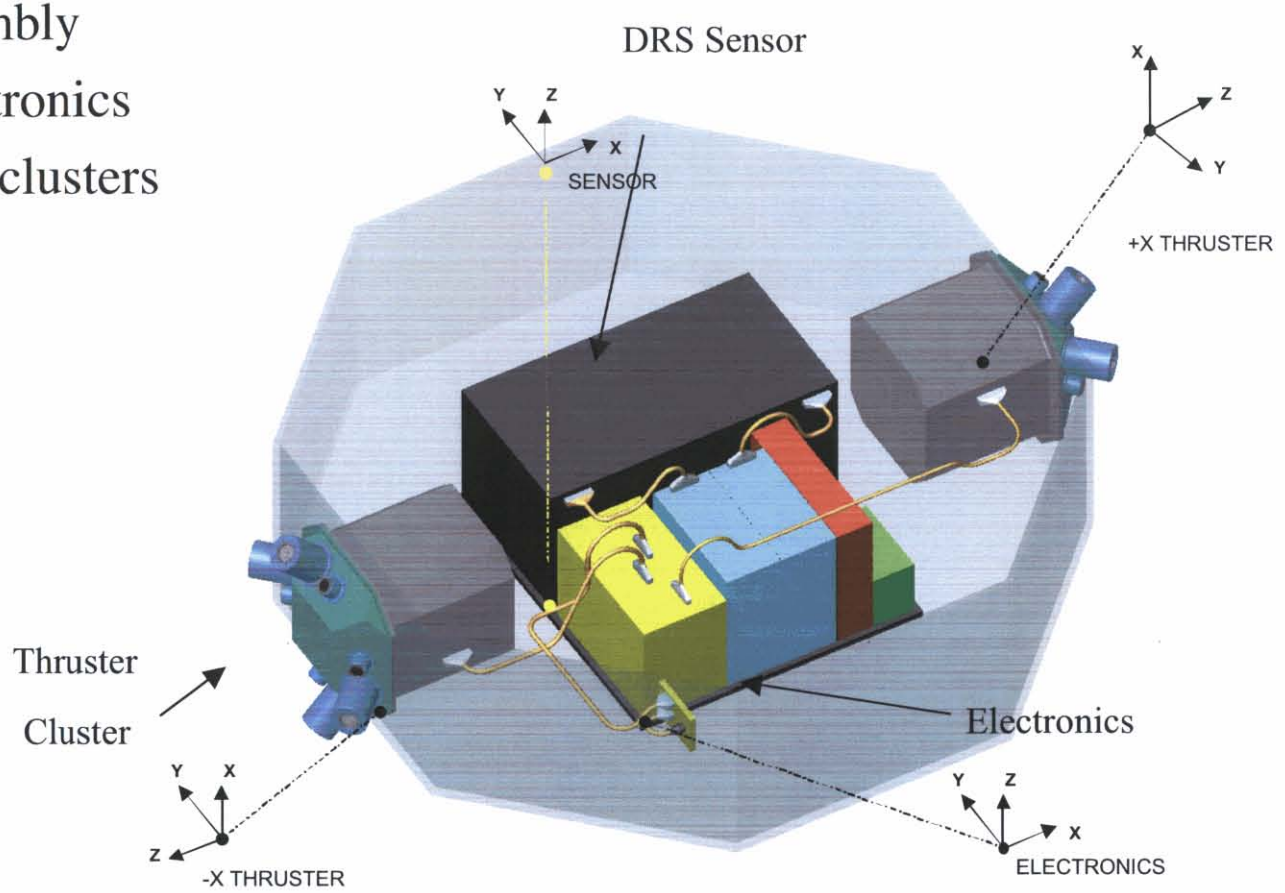
Instrument Configuration (2)

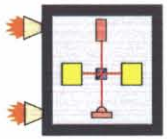
- **GRS and interferometer are in double-wall insulation box**
  - Thermal requirements set by GRS thermal force noise
    - Thermal stability eases interferometer design
  - Maintain temperature constant to ~1μK over 1000 seconds
    - No active control no particular average temperature



Instrument Configuration (3)

- **DRS will be attached to ESA's SMART-2 spacecraft**
  - Sensor Assembly
  - Support Electronics
  - Two thruster clusters





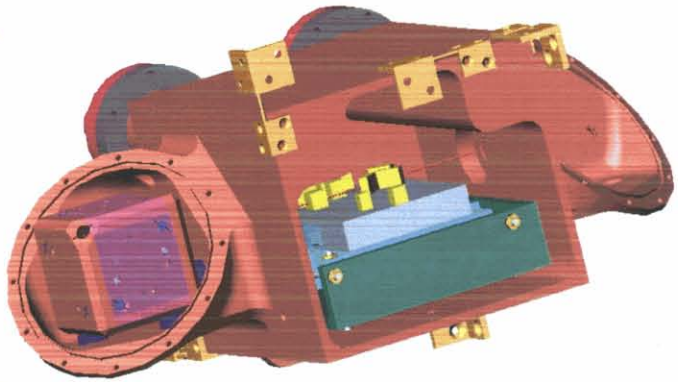
ST7 - DRS

Gravitational Reference Sensor (GRS)

ST7 - DRS

Salient Features

- Test mass noise < 3×10^{-14} m/s^2/√Hz, 1 mHz to 10 mHz
- Position measurement to < 3 nm/√Hz, 1 mHz to 10 mHz
- Accelerometer mode
- Validation of thruster performance
- Force noise diagnostics
- Validation of drag free environment models

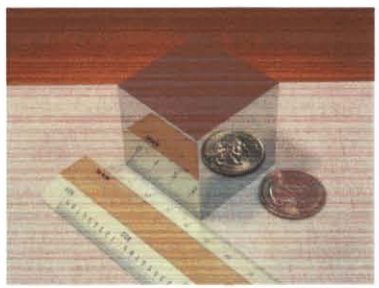


DRS chassis showing interferometer

Caging System

Gravitational Reference Sensor Technologies

- Test mass is 4-cm cube of Au/Pt alloy
- Beryllia housing with plated Au electrodes
- Caging system capable of supporting launch loads and re-caging on-orbit
- Capacitive sensing system providing < 3 nm/√Hz measurement
- Electrostatic forcing system providing 4×10^{-8} m/s^2 peak acceleration

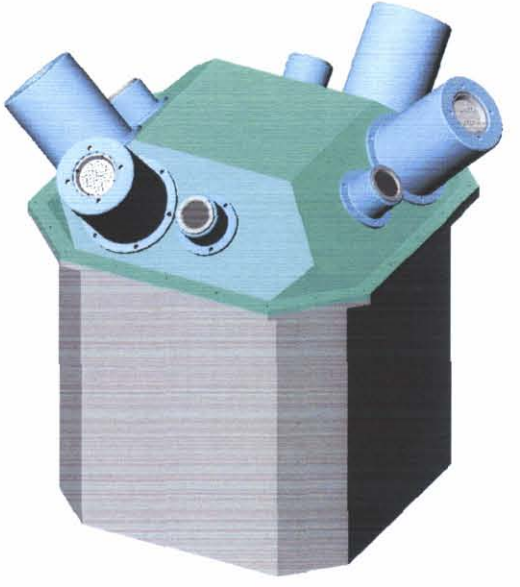


GRS Proof Mass Prototype

Micro Newton Thrusters

Salient Features

- Colloid μN thrusters delivering 1 to 20 μN each
- Thrust controllability and resolution 0.1 μN
- Thrust noise 0.1 μN /√Hz from 1 to 10 mHz
- 4 thrusters/cluster, 2 clusters
- Operational life: 90 days

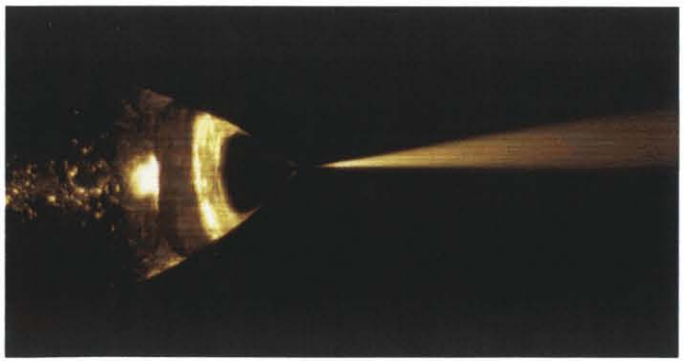


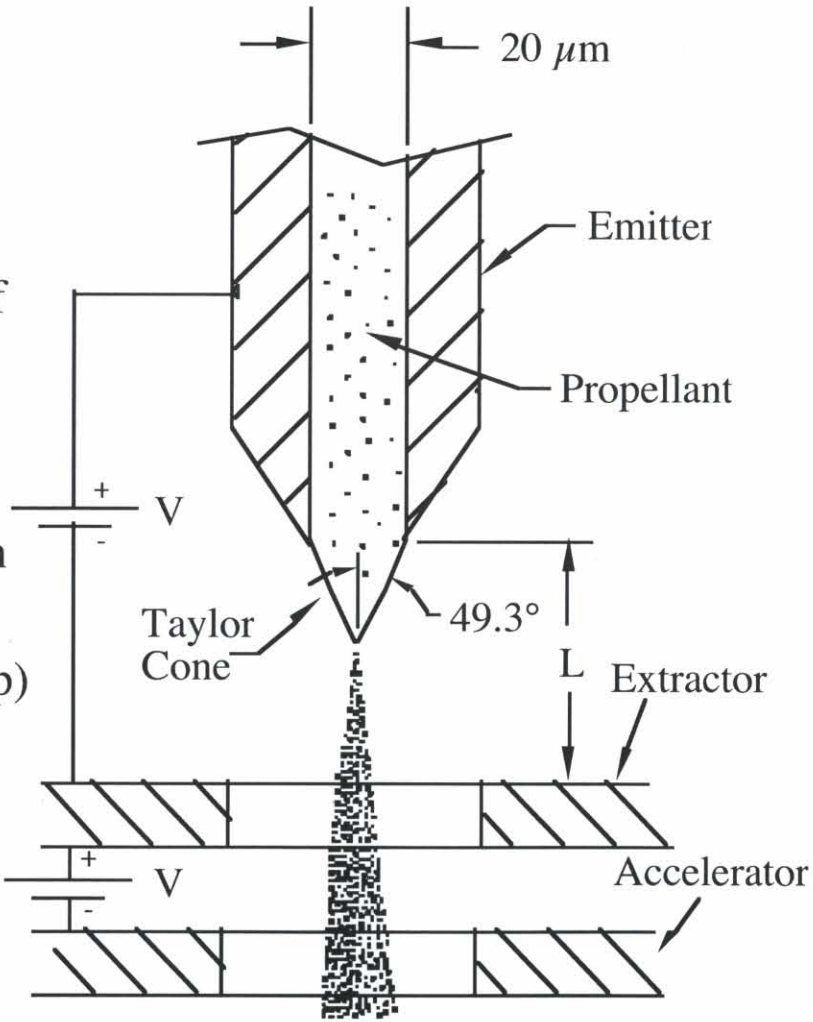
Micro Newton Thruster Technologies

- High stability dual electrode thruster/electrospray
- High stability propellant feed system (1 x 10^{-7} ml/min target)
- Carbon nanotube field emission cathode/neutralizer
- High voltage (≤ 10 kV) DC to DC converters/H.V. generation and control in small volume

Colloidal Thrusters

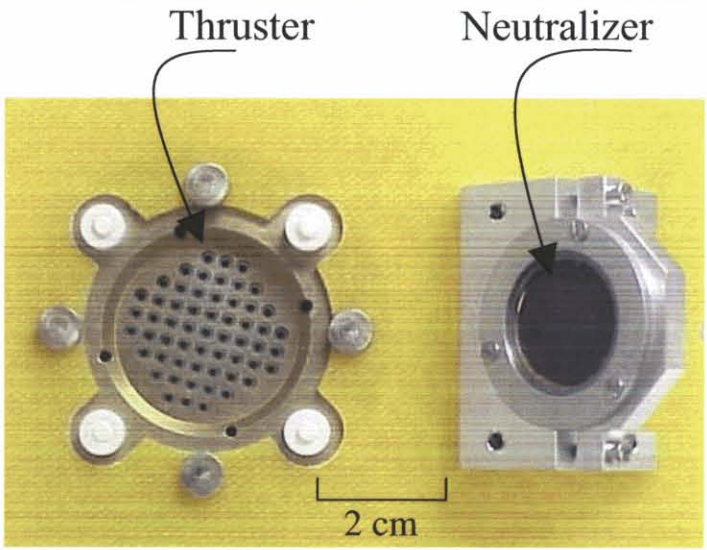
- **Colloidal thrusters**
  - Fluid fed through fine needle
  - High voltage extracts charged droplets
  - Droplets accelerated by high voltage
  - Thrust control of 0.1 μN through change of voltage or flow rate
  - Many needles can be combined to develop necessary thrust
  - Proportional thrust control allows precision position control
    - (displacement to thrust feedback loop)





DRS Thruster Configuration

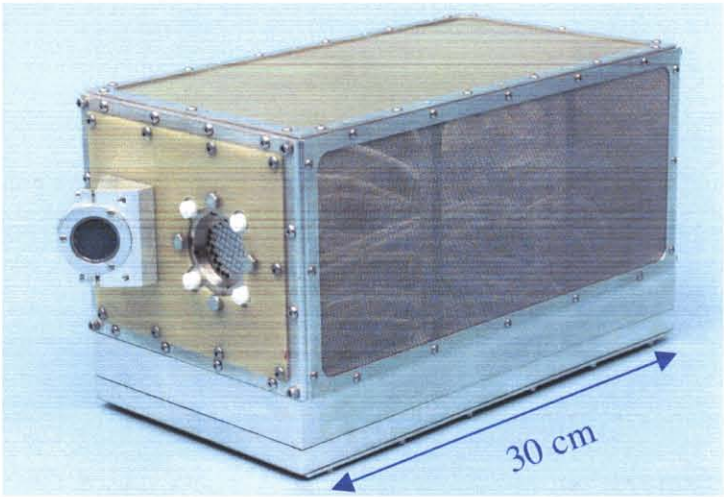
- **Dynamic Range**
  - Smooth operation of single needle is limited (by onset of turbulence at higher propellant flow rates)
  - For smooth operation at levels needed to counter solar pressure, an array of ~50 emitter needles has been developed
  - Small (20%) changes in thrust can be achieved quickly, by change in voltage
  - Large (x10) changes in thrust require change in fluid flow rate

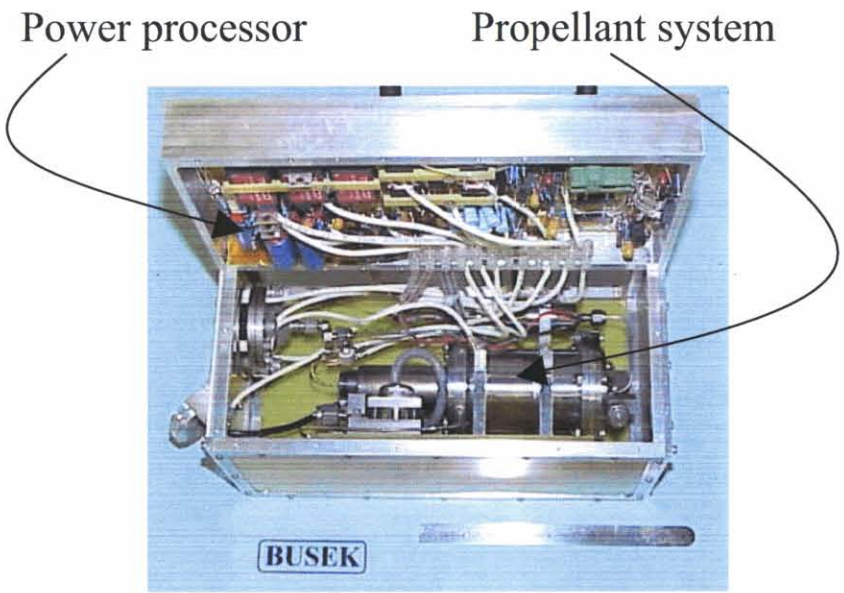


- **Neutralizer**
  - Carbon nanotube cathode used to emit electrons to keep spacecraft from building positive charge

Thruster Configuration (2)

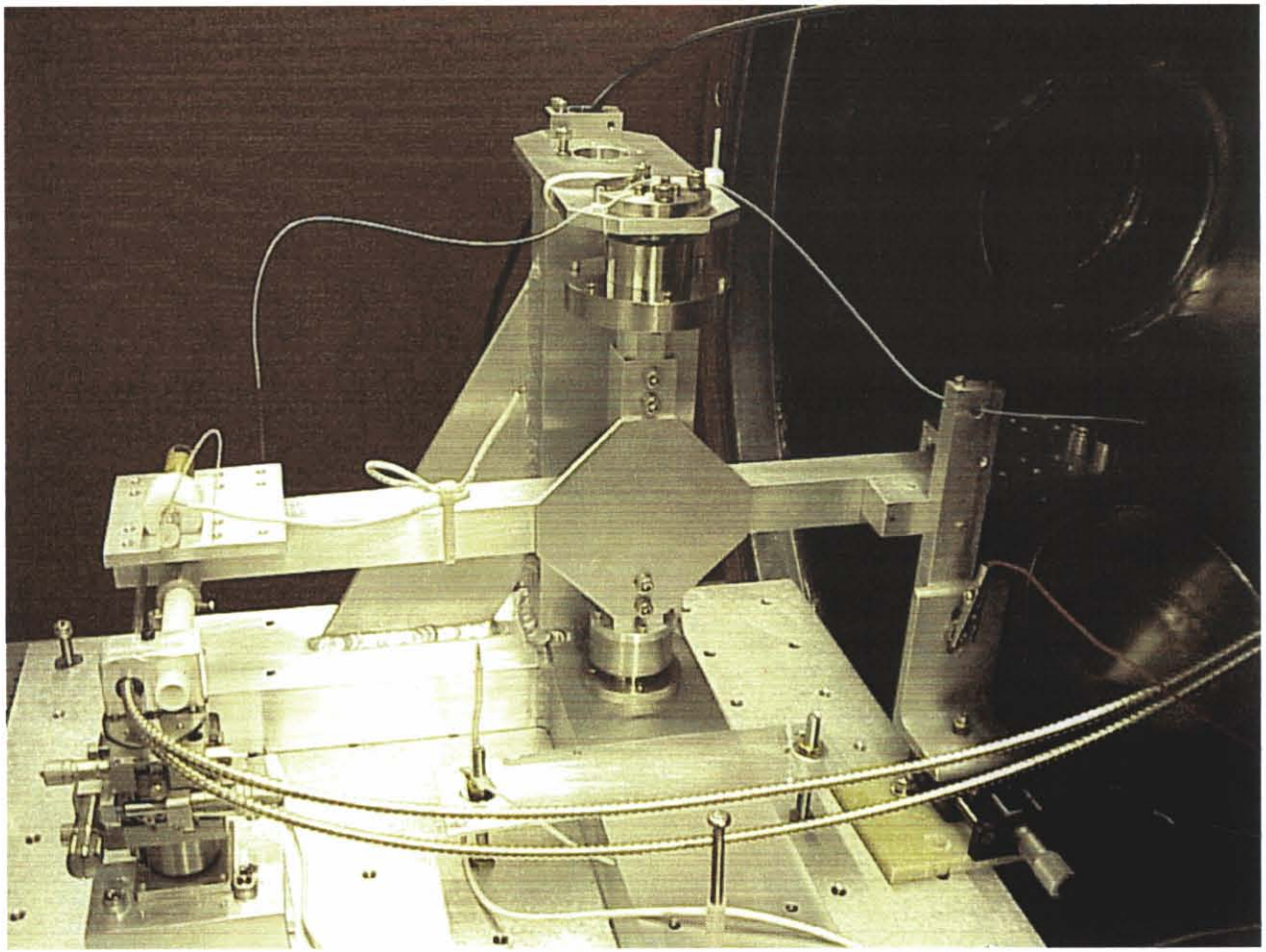
- **Prototype thruster developed**
  - Using variable gas pressure to drive propellant
- **Evolved thruster under development**
  - Improved emmitters
  - Smaller, lower power package



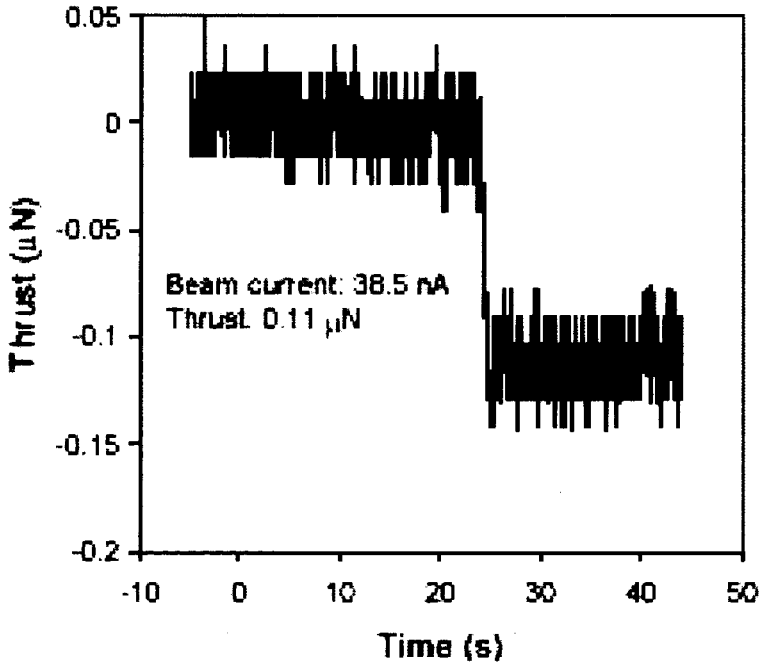


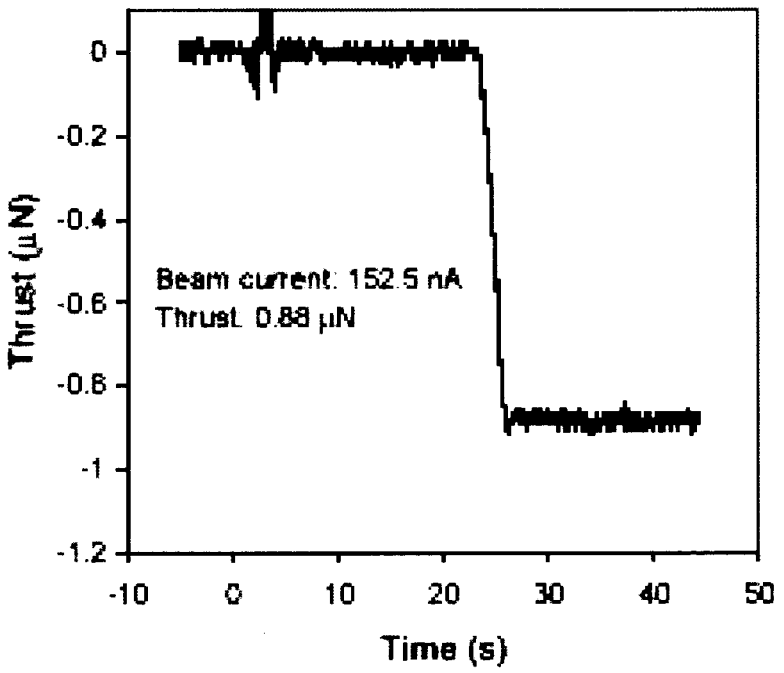
Thruster Measurement Facility

- **Thrust Stand**
  - Torsional thrust stand completed, 0.01 μN resolution verified (IEPC-01-235)

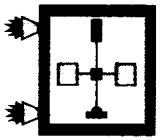


Thrust Measurement Results





M Gamero-Castano and V. Hruby, IEPC-01-235, 2001



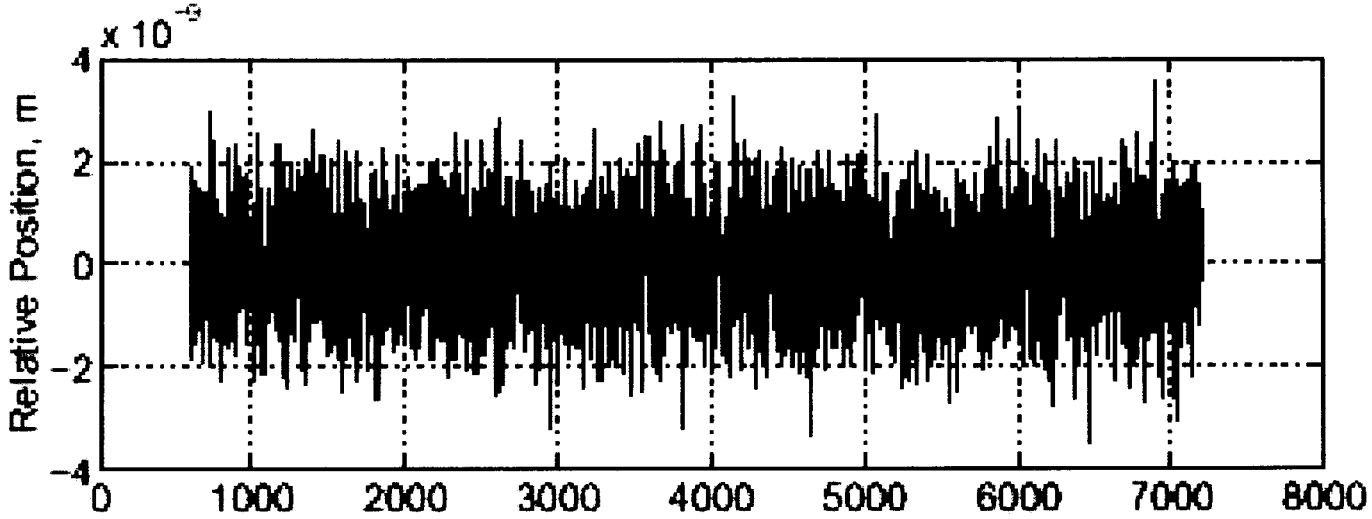
Spacecraft Control Simulations

- **1 degree-of-freedom simulations**
  - Thruster counter solar pressure
  - Nominal noise from sensor, thruster, solar pressure
  - Examined position noise versus control bandwidth
  - 4 Hz control loop performance significantly worse than 10 Hz loop

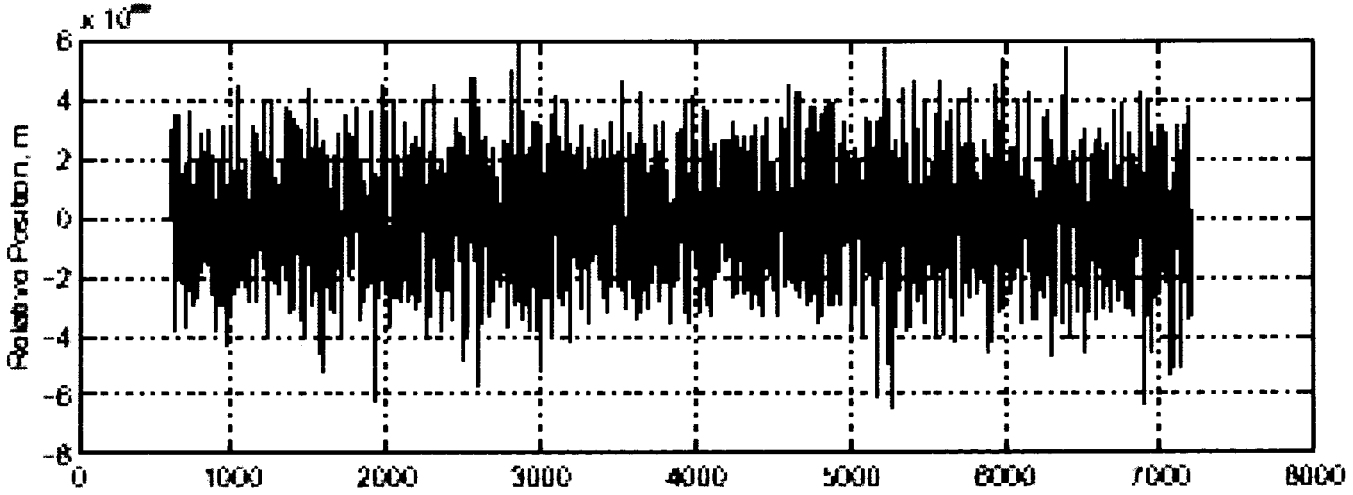
ST7 - DRS

S/C Position vs Time

ST7 - DRS

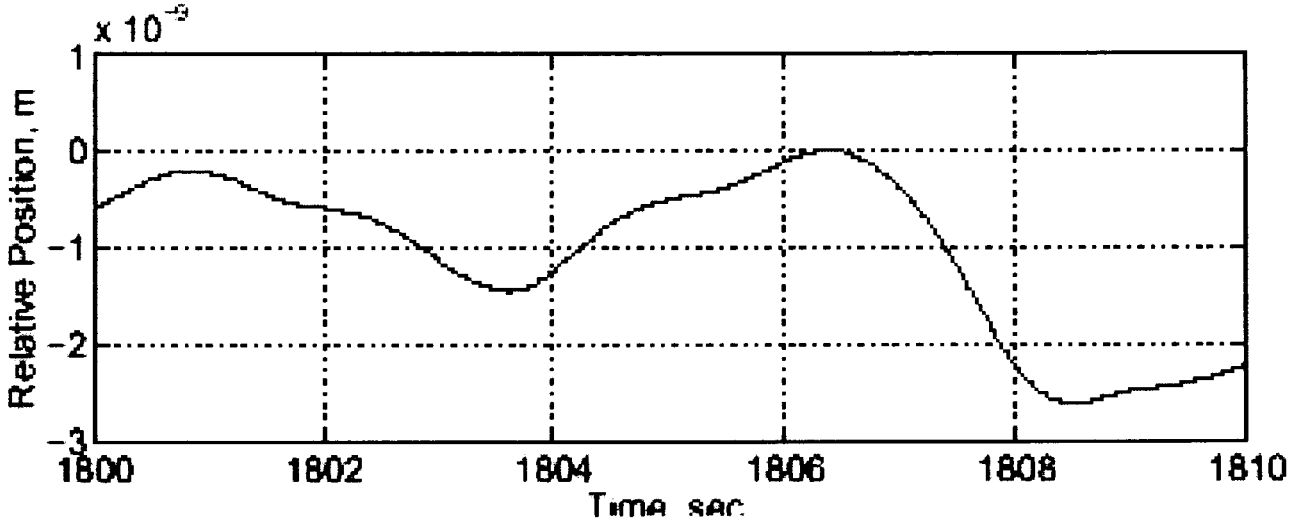


10 Hz loop

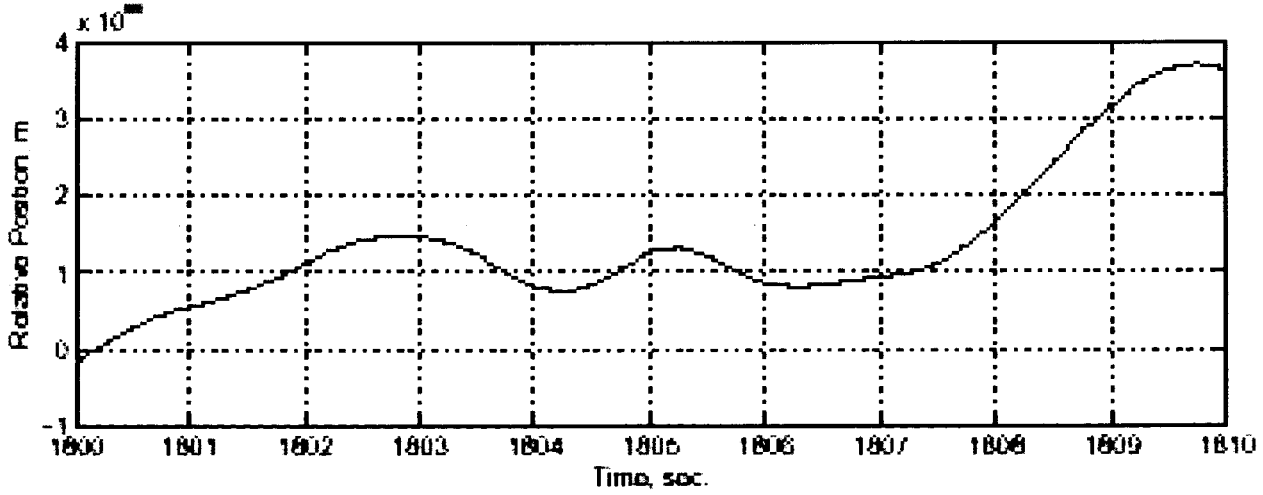


4 Hz loop

S/C Position vs time

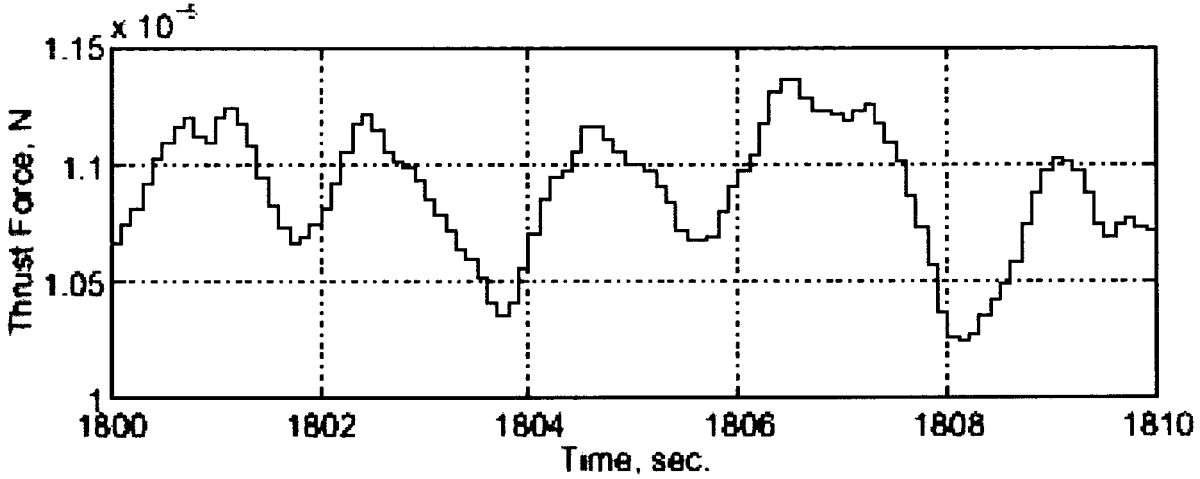


10 Hz loop

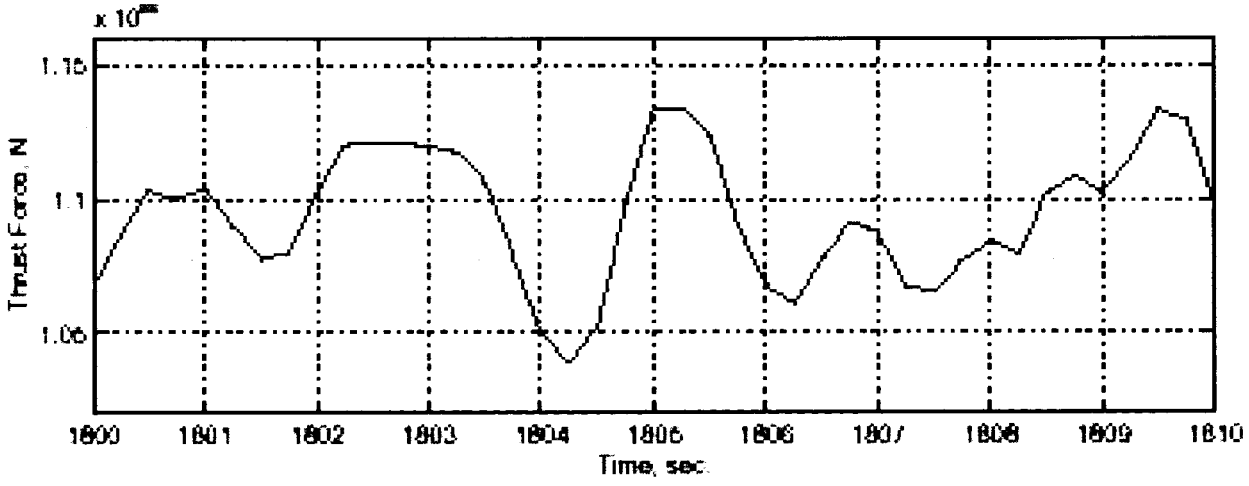


4 Hz loop

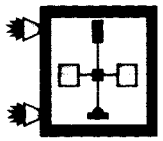
Thrust Command vs time



10 Hz loop



4 Hz loop



Summary

- **DRS will be rapidly developed for launch in 2006**
- **Colloidal microthrusters will allow for precise, quiet spacecraft position and attitude control**
- **Technology is intended to be useful for many future missions**
- **Some additional range of demonstration could be accommodated if helpful to specific mission concepts**