VACCO ChEMS™

Micro Propulsion Systems

14 Flight Systems and Counting...
Heritage MEPSI Micro Propulsion System

Provided to AFRL for the Aerospace Corporation MEMS Pico-Satellite Inspector (MEPSI).

(1) Unit Delivered 22 March 2004.
MEPSI MiPS Schematic

Complete System:
(1) Storage Tank
(2) Pressure Transducers
(2) Temperature Sensors
(4) 5μ Filters
(1) Isolation Valve
(1) Heat Exchanger
(1) Gasification Plenum
(5) 55mN Thrusters
MEPSI MiPS Capability

Thrust:
- 55 mN (40 psia Plenum Pressure)

Propulsion System Mass: 509 g
- Dry Mass: 456 g
- Propellant Mass: 53 g (liquid butane)

Thrust / Propulsion Densities:
- 0.108 to 0.120 N/Kg
- 66 N-Sec/Kg

Number of thrust cycles:
- Up to 61,000 Minimum Impulse Bit Firings

Total Impulse: 34 N-Sec

114 N-sec/Liter Performance Density

MEPSI Mass: 1.0 Kg

Total ΔV: 34 m/s
- 26 m/s (–Z)
- 1 m/s (+Z)
- 3 m/s Pitch/Yaw
- 4 m/s Roll
Heritage Boeing *Palomar* Micro Propulsion System

Provided to Boeing Satellite Systems for Ground Test and Evaluation.

(1) Unit Delivered September 2006.
Palomar MiPS Summary

AFRL Conclusions:
- Highly Reliable Source for Thrust
- Compact Combination of Fuel Storage, Sensor Feedback, Communication, Fire Control and Multiple Axis Thrust in a Robust Package
- Average Single Thruster Values of 51±6mN Agreed Well with Predicted Values
- Propellant Temperature Affects Thrust

Fully Enclosed Design:
- Isobutane Propellant
- All-Welded Against External Leakage
- Redundant Interrupts Against Internal Leakage
- Reliable “Frictionless”, Soft-Seat, NC Valves
- Simple, Self-Pressurizing Design
- (8) 55mN Cold Gas Thrusters
- Integral Controller, Press and Temp Sensors
- Extensively Tested by VACCO & AFRL
- **100 N-sec/L Performance Density**
AFRL Propulsion Unit for Cubesats (PUC)

Jointly developed by VACCO & CU Aerospace Smart, Self-Contained Propulsion System:
- (9) Flight Systems Delivered

Design Includes:
- Propellant Storage & Feed System
- Axial Thruster
- Controller/PPU

Two Interrupts Against Leakage

Low Power Continuous Power (<15 watts)

All-Welded Titanium Construction

Microcontroller Driven:
- RS422 Digital Interface
- Controls Burn Type & Duration
- Closed-Loop, Variable Thrust Control
- (2) Settable Thermal Control Zones
- 1500 volt PPU
- (3) Power Supplies, (2) Valve Drivers

514 to 618 N-sec/Liter Performance Density
AFRL Propulsion Unit for Cubesats (PUC)

Modular & Expandable:
- Tank Expandable into Available Volume
- Auxiliary Tanks Easily Accommodated

Self-Pressurizing SO₂ Green Propellant:
- High Liquid Density
- Critical temperature > 150°C
- Freezing point < -75°C
- Manageable toxicity

Micro Cavity Discharge (MCD) Thruster:
- 4.5 mN Thrust
- Two Modes: Warm Gas & Cold Gas

Uses 0.25 U of internal cubesat volume to deliver 184 N-Sec or 48 m/s delta-V for 4 kg CubeSat

[Courtesy of CU Aerospace]
NASA/Tyvak CPOD Micro Propulsion System

- Contract with Tyvak Nano-Satellite Systems LLC
- CPOD: NASA Cubesat Proximity Operations Demonstration
- (2) Flight Systems Delivered
- Occupies Center 0.8U of 3U Cubesat
- Provides Attitude Control & Delta-V
CPOD MiPS Overview

System Overview
- All-Welded Aluminum Construction
- Eight 25mN Cold Gas Thrusters
- 0.20 mN-S Minimum Impulse Bit @ 3 mS Pulse Width
- 0.8U Center Manifold, Clamshell Configuration
- 484 grams Self-Pressurizing R134a Green Propellant
- Smart System with Integral Microcontroller
- RS422 Digital Interface
- Integral Sensor Suite
- Total “Wet” Mass: 1244 grams
- **186 N-S Total Impulse, 33 M/S Delta-V @ 40 sec Isp**
- 135 N-sec/Liter Performance Density

Program Complete
- Propellant Trade Study Complete (R134a Selected)
- Propulsion System “Flat Sat” Simulator
- (2) Flight Units Tested & Delivered
- Flight Expected in 2016


JPL MarCO Micro Propulsion System

First Interplanetary Cubesat
Smart, Self-Contained Propulsion System:
  ✤ Contract for (2) Flight Systems
  ✤ 755 N-Sec Total Impulse
  ✤ 3490 gram Wet Mass
  ✤ **354 N·sec/Liter Performance Density**

System-in-a-Tank Design Including:
  ✤ Propellant Storage & Feed System
  ✤ (4) Axial & (4) RCS 25mN Thrusters
  ✤ Controller & Sensor Suite

Two Interrupts Against Leakage
0.5 Watt Standby Power
All-Welded Aluminum Construction

Microcontroller Driven:
  ✤ RS422 Digital Interface
  ✤ Controls Burn Type & Duration
  ✤ Closed-Loop, Variable Thrust Control
  ✤ (3) Settable Thermal Control Zones
  ✤ (3) Power Supplies, (9) Valve Drivers
Low Cost, 0.25U Propulsion Module:
- Green R236fa Propellant
- Smart Module:
  - Controlled via RS422 Bus
  - Integral Sensor Suite
  - Closed-loop Vector Pointing
  - Closed-loop Thrust Vector Control
- (5) 10mN Cold Gas Thrusters (Isp=40s)
- Min Impulse Bit: 0.05 mN-Sec.
- Cold Gas Total Impulse: 103 N-Sec.
- Delta-V: 21.1 M/Sec (4.5 Kg Cubesat)
- 291 N-sec/Liter Cold Gas Performance Density
- Module Provides Delta-V and Reaction Control
- Module Depth can be Increased from 0.25U to 1U to Maximize Total Impulse
- Warm Gas Option: Total Impulse: 176 N-Sec
- Delta-V: 40.4 M/Sec (4.5 Kg Cubesat)
- 497 N-sec/Liter Warm Gas Performance Density
VACCO ChEMS™

High Performance Micro Propulsion Systems

100mN / 1U Hybrid ADN MiPS

120mN / 1U Hybrid ADN MiPS
VACCO Hybrid ADN MiPS Schematic

- Pressurant Tank w/Press & Temp Sensors
- Pressurant Fill & Drain Valve
- 10 micron Pressurant Filter
- Heater Exchanger w/Temp Sensor
- Pressurant Control Valve
- Vapor Tank w/Press & Temp Sensors

- (4) Isobutane Cold Gas Thrusters
- Check Valve
- ADN Propellant Storage Tank w/PMD
- Normally-Closed Isolation Valve
- Normally-Closed Thruster Valve
- Axial ADN Thruster
- 100mN thru 22N Versions Available
VACCO 100mN /1U Hybrid ADN MiPS
(Using New ECAPS Thruster)

Complete, Self-Contained Propulsion System.
Hybrid Delta-V and Attitude Control:
  (1) 100mN ADN Axial Delta-V Thruster
  (4) 10mN Butane Cold Gas ACS Thrusters
  1070 N-sec/Liter Performance Density
High 100mN Thrust:
  Derivative of 0.5N ADN Thruster
  Hot-Fire Tested by ECAPS
Range Safety Features:
  “Green” ADN and Isobutane Propellants
  All-Welded against ADN External Leakage
  (2) Interrupts against ADN Leakage
  Low (309 psia) Max Operating Pressure
  Safe & Arm Circuit

<table>
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<th>Cubesat Size</th>
<th>Cubesat Initial Mass (Kg)</th>
<th>MiPS Size</th>
<th>MiPS Dry Mass (Kg)</th>
<th>Prop Volume (CC)</th>
<th>Prop Mass (Kg)</th>
<th>MiPS Wet Mass (Kg)</th>
<th>Thruster Size (N)</th>
<th>Isp (sec)</th>
<th>Delta-V (M/s)</th>
<th>Total Impulse (N-sec)</th>
<th>Available Volume (cc)</th>
<th>Specific Impulse (N-sec/cc)</th>
<th>Total Burn Time (sec)</th>
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100mN / 1U Hybrid ADN MiPS
Summary

VACCO has a Variety of Micro Propulsion Solutions for ACS and Delta-V:

- (1) Development MEPSI MiPS,
- (1) Development Boeing Palomar MiPS
- (9) Flight AFRL Propulsion Unit for Cubesats
- (3) Flight Tyvak CPOD MiPS
- (2) Flight JPL MarCO MiPS
- (Future) ADN Hybrid MiPS

Self-Contained Systems
Smart & Versatile

- Wide variety of Performance Densities possible depending on available envelope and options

Various Propellants:
- Isobutane, SO2, R-134a, R236fa
- ADN, AF315

Materials of Construction:
- Titanium
- Aluminum