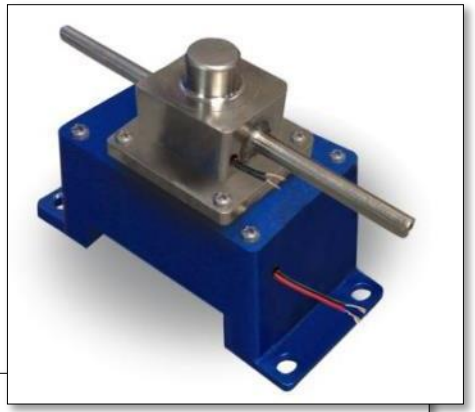
VACCO ChEMS™ Micro Propulsion Systems

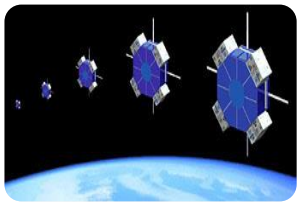
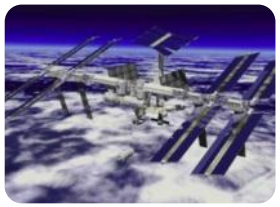
Advances and Experience in CubeSat Propulsion System Technologies



May 1st, 2018

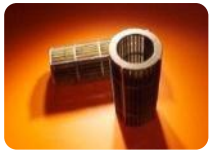
VACCO

VACCO *Industries*

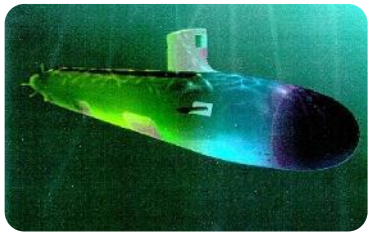












Tyvak NanoACE Micro Propulsion System

- ***NanoACE Launched 7 July 2017***
- Contract with Tyvak Nano-Satellite Systems Inc.
- Occupies Center 1U of 3U Cubesat
- Provides Attitude Control, Divert & Delta-V

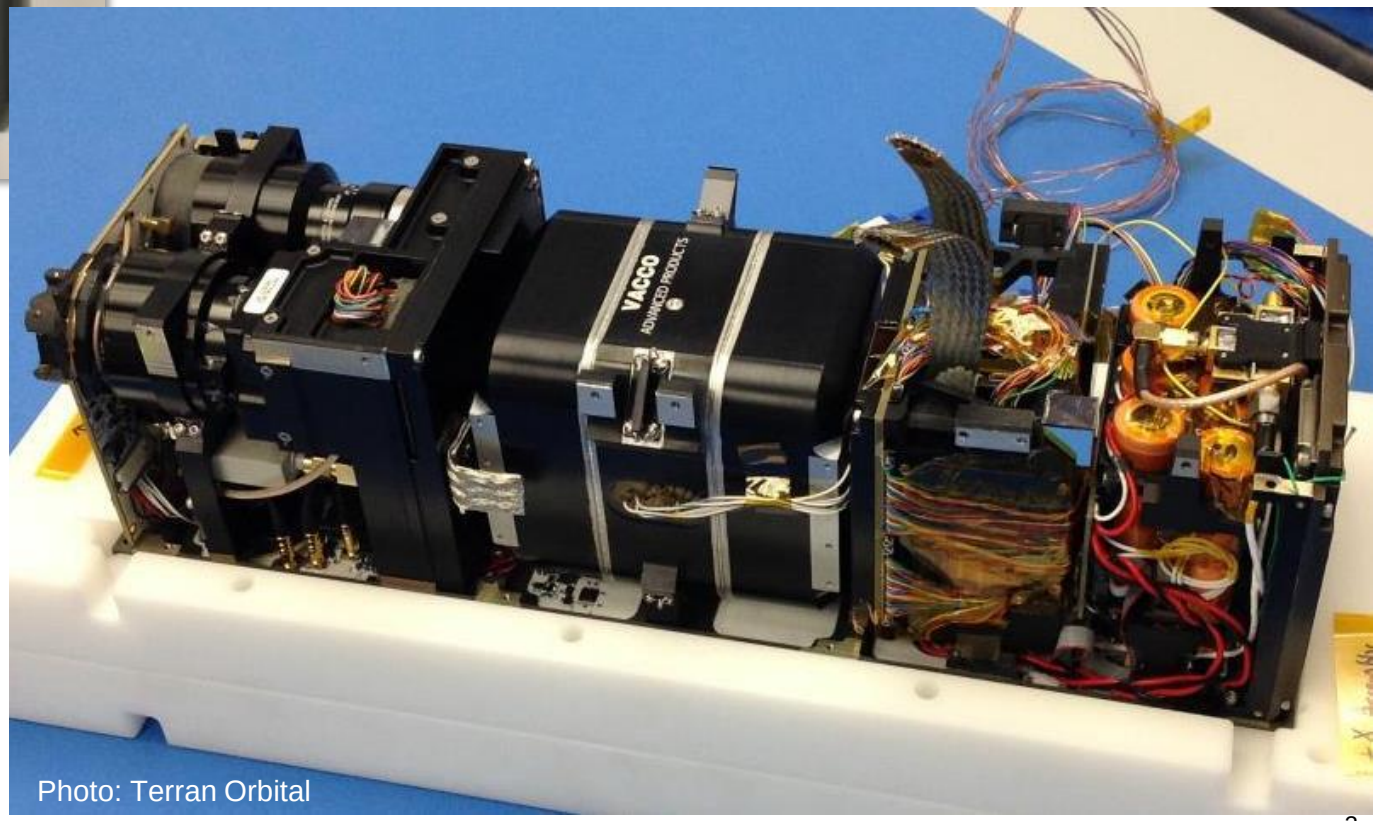


Photo: Terran Orbital

NASA/Tyvak CPOD Micro Propulsion System

- Contract with Tyvak Nano-Satellite Systems Inc.
- CPOD: NASA Cubesat Proximity Operations Demonstration
- (2) Flight Systems Delivered
- Occupies Center 1U of 3U Cubesat

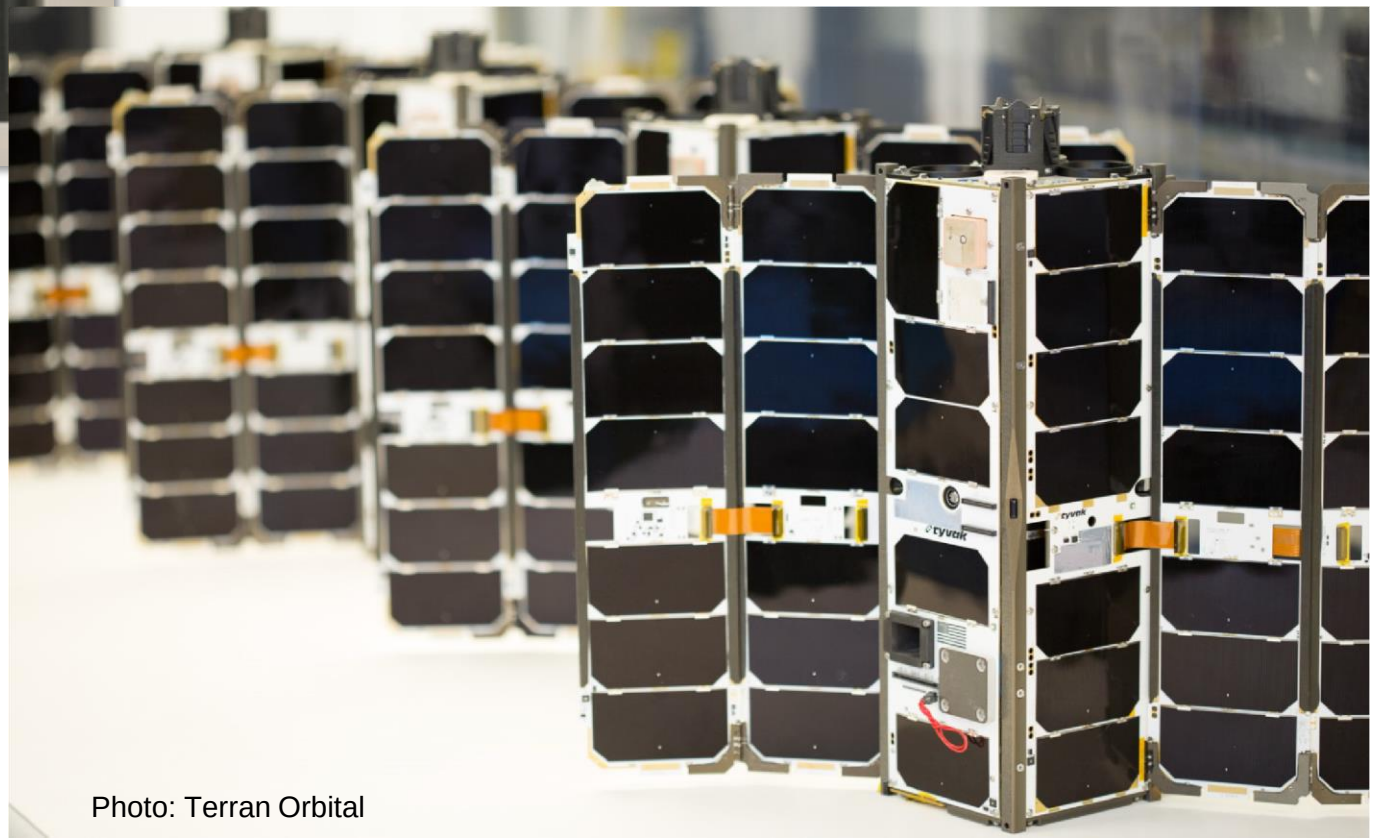
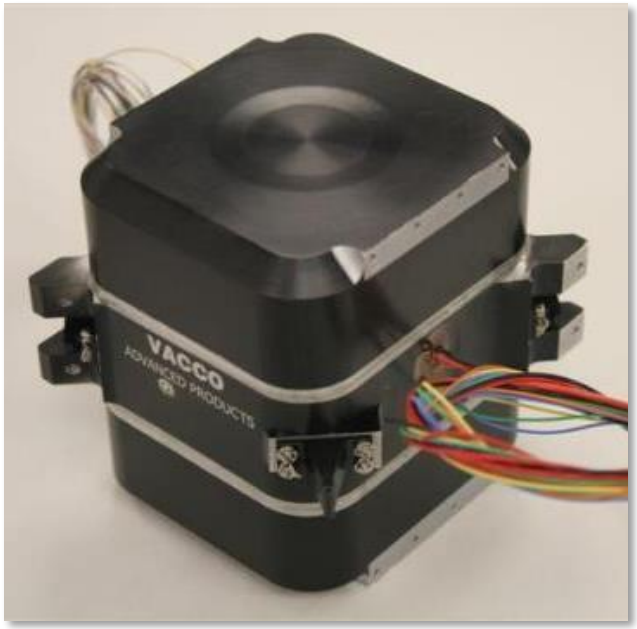
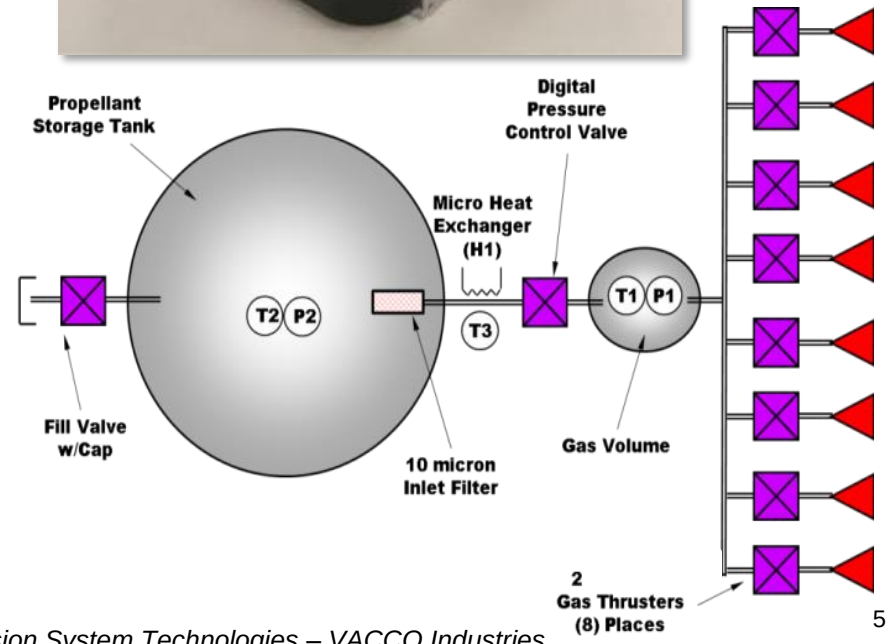


Photo: Terran Orbital

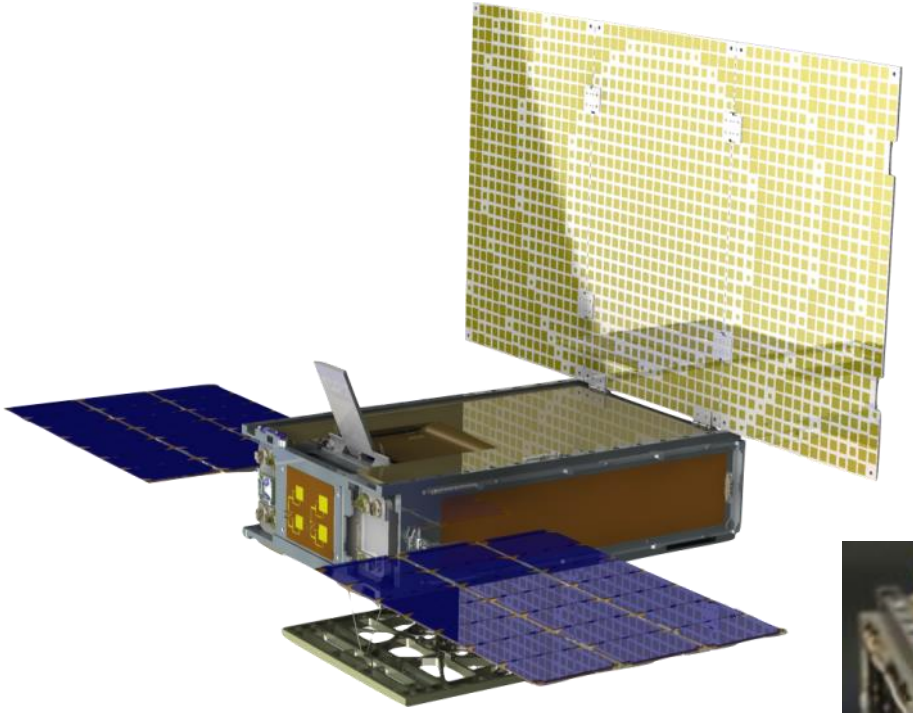
CPOD Micro Propulsion System Overview

System Overview
All-Welded Aluminum Alloy Construction
Eight 10mN Cold Gas Thrusters
174 N-S Total Impulse, 31 m/s Delta-V
0.10 mN-S Minimum Impulse Bit
1U Center Manifold, Clamshell Configuration
510 grams Self-Pressurizing R236fa Green Propellant
Smart System with Integral Microcontroller
RS422 Digital Interface
Integral Sensor Suite
Total “Wet” Mass: 1270 grams



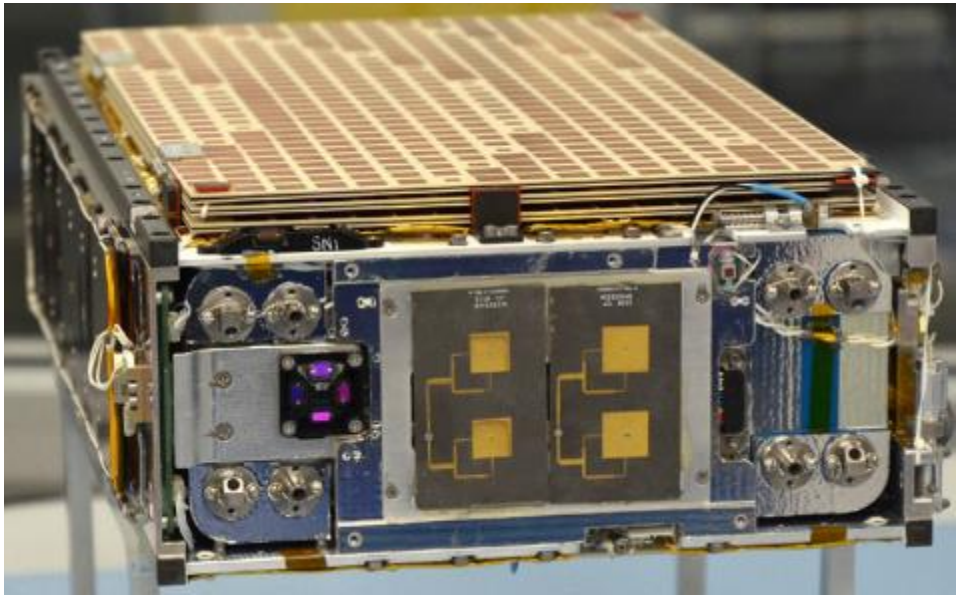


JPL Mars Cube One (MarCO) Mission



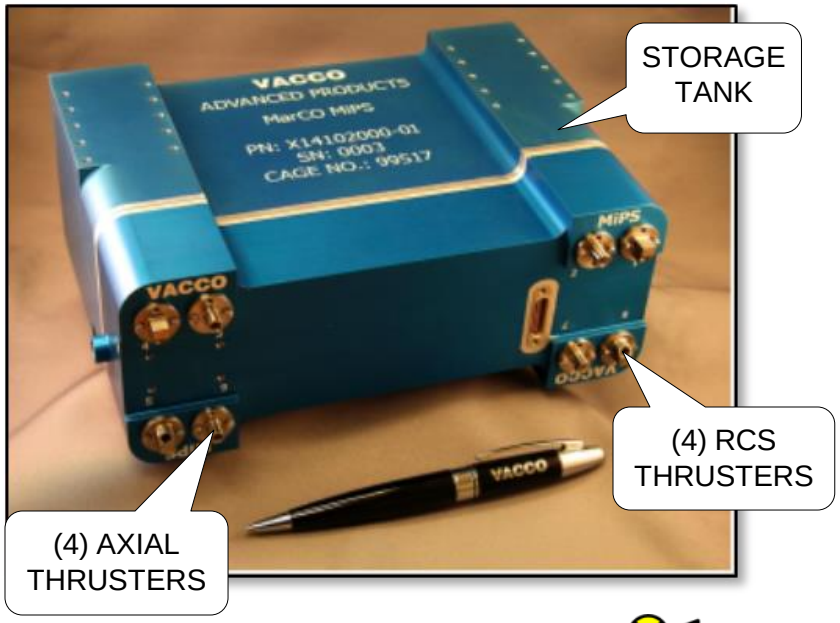
Mission Objective:

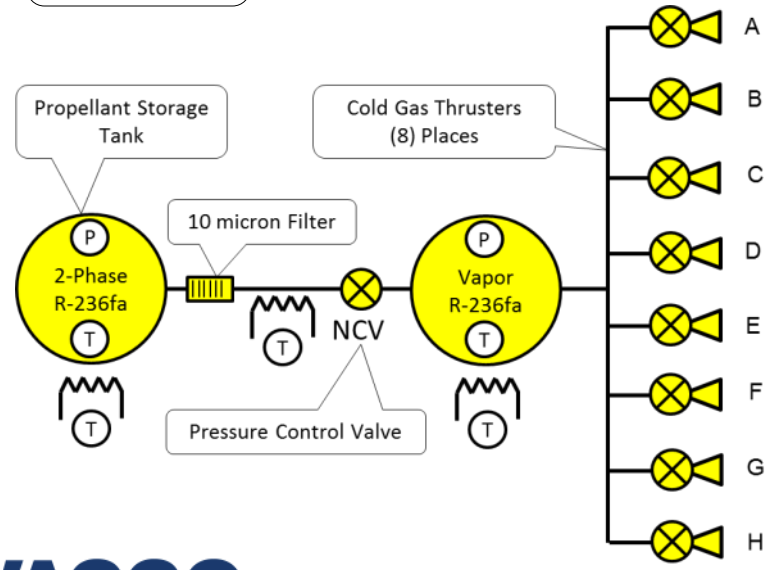
Provide an 8kbps real-time relay for InSight's Entry, Descent and Landing at Mars



Two Units will be Launched with the InSight Mission May 2018

JPL MarCO Micro Propulsion System





First Interplanetary Cubesat

Launch with InSight Lander, May 2018

Smart, Self-Contained Propulsion System:

- Contract for (2) Flight Systems
- **755 N-Sec Total Impulse**
- 3490 gram Wet Mass

System-in-a-Tank Design Including:

- Propellant Storage & Feed System
- (4) Axial & (4) RCS 25mN Thrusters
- Controller & Sensor Suite

Two Interrupts Against Leakage

Low Power Continuous Power (<15 watts)

All-Welded Aluminum Alloy Construction

Microcontroller Driven:

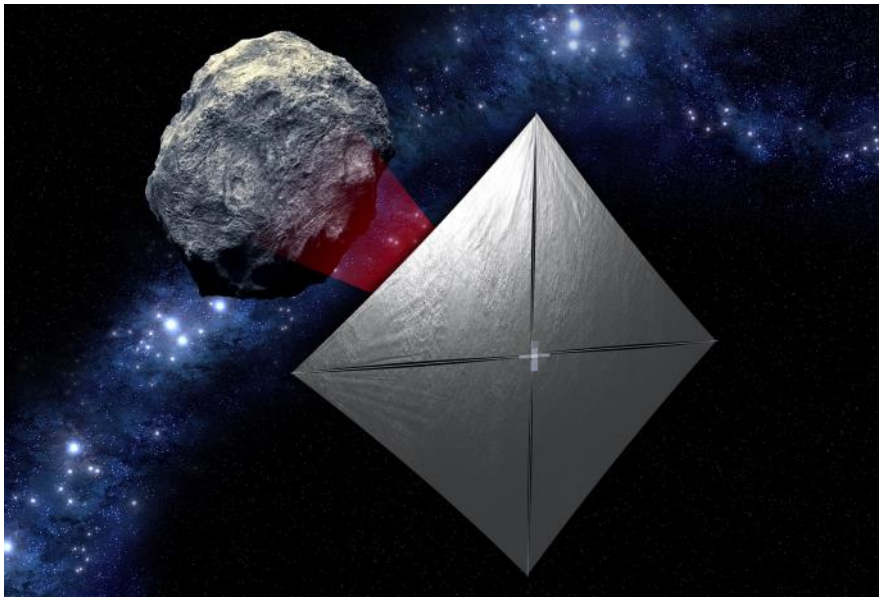
- RS422 Digital Interface
- Controls Burn Type & Duration
- Closed-Loop, Variable Thrust Control
- (3) Settable Thermal Control Zones
- (3) Power Supplies, (9) Valve Drivers

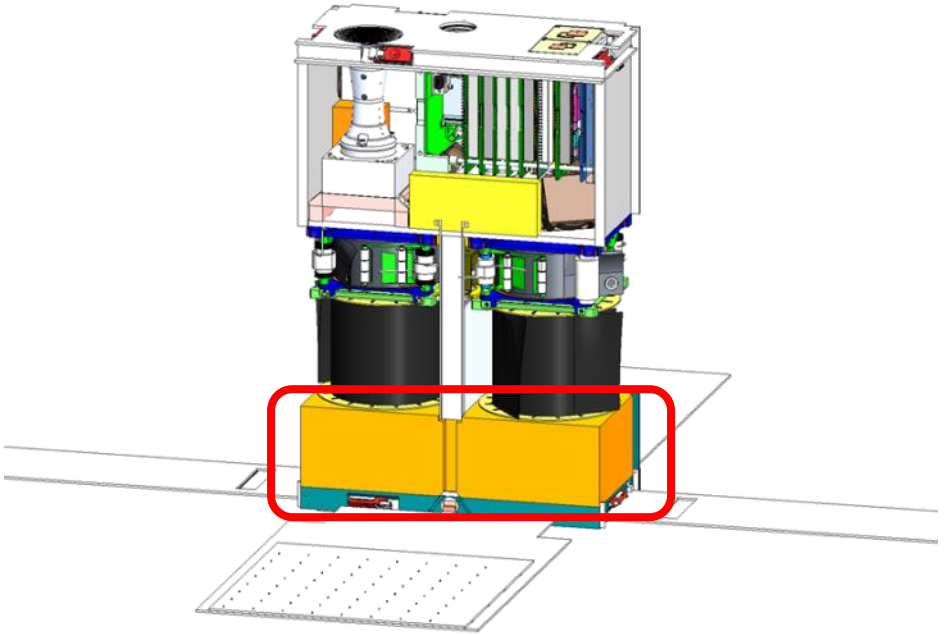
JPL/MSFC Near Earth Asteroid Scout Mission

Mission Objectives:

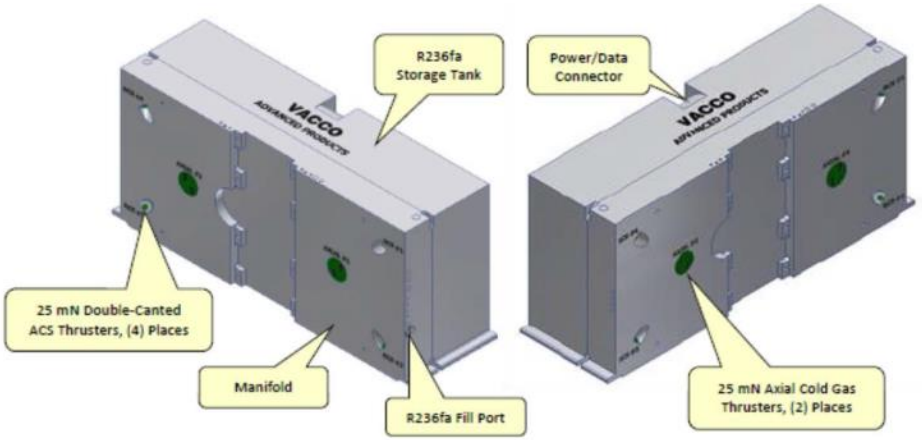
- Detect, rendezvous with and flyby a Near Earth Asteroid (NEA) target
- Characterize physical properties: volume, spectral type, spin mode and orbit
- ≥80% coverage imaging at ≤50 cm/px
- ≥30% coverage imaging at ≤10 cm/px

Main Propulsion: ~80m² Solar Sail





NEA Scout Micro Propulsion System



Smart, Self-Contained Cold Gas Propulsion System based on MarCO:

- Contract for (1) Flight System
- **500 N-Sec Total Impulse**
- 2600 gram Wet Mass

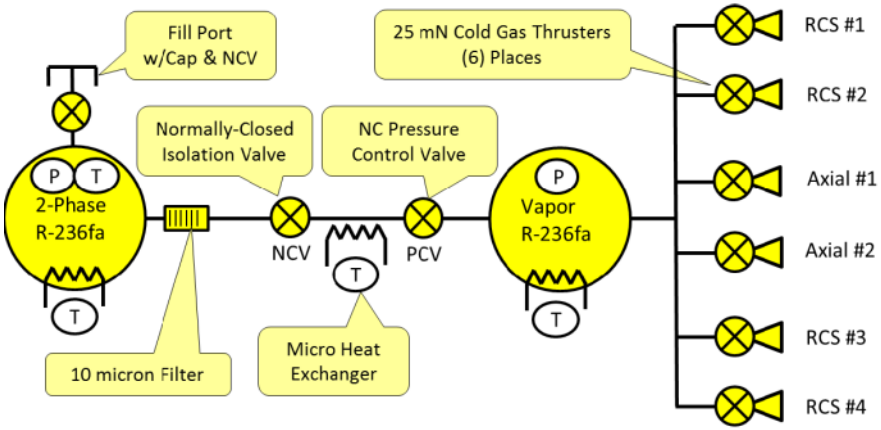
System-in-a-Tank Design Including:

- Propellant Storage & Feed System
- (2) Axial & (4) RCS 25mN Thrusters
- Controller & Sensor Suite

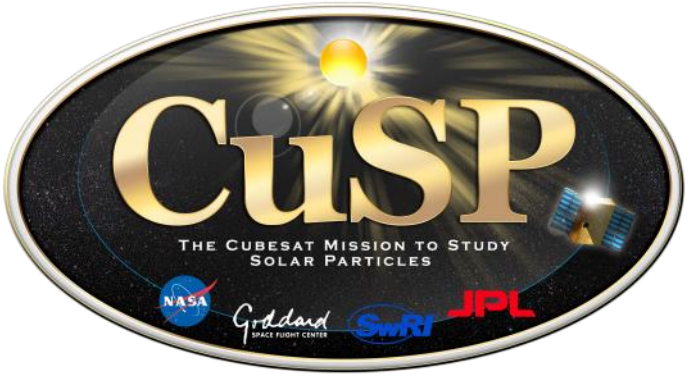
Three Interrupts Against Leakage

Power: <9 watts while Firing

All-Welded Aluminum Alloy Construction



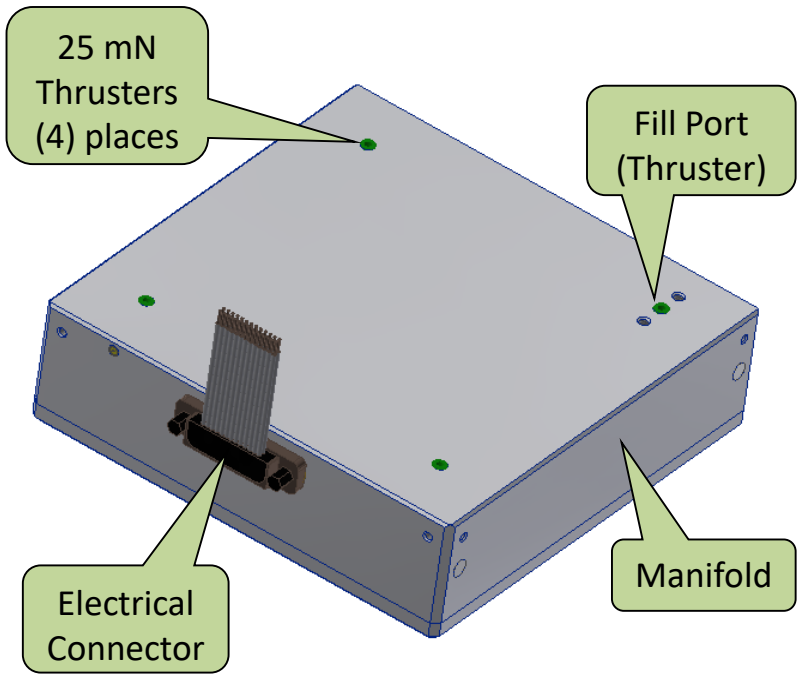
SWRI CubeSat Mission to Study Solar Particles (CuSP)



CuSP Mission Objectives:

1. Study Solar Particles in interplanetary space
2. Be a Pathfinder for creating a network of “Space Weather Stations”
3. Strengthen the case for CubeSats as a viable platform for performing ‘High Value’ Science
4. Raise the TRL of the SIS instrument for future missions

CuSP Micro Propulsion System



Smart, Self-Contained Cold Gas Propulsion System based on MarCO:

- Contract for (1) Flight System

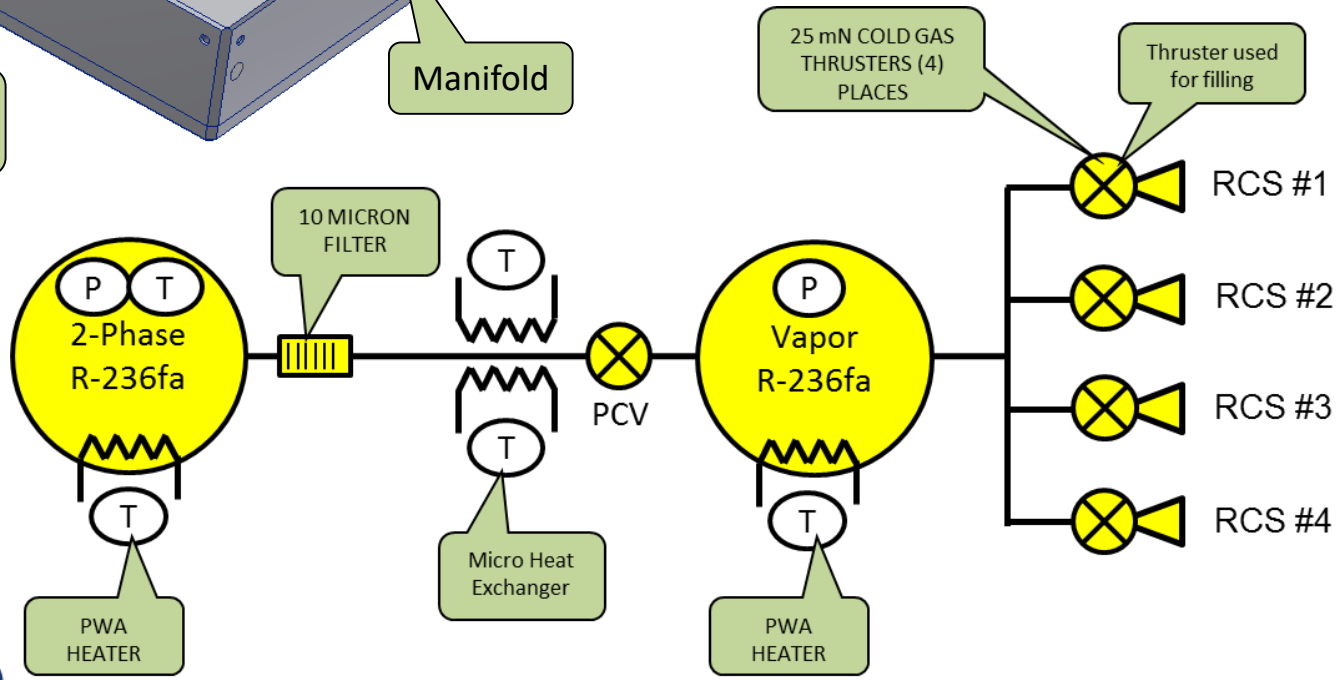
System-in-a-Tank Design Including:

- Propellant Storage & Feed System
- (4) RCS 25mN Thrusters
- Controller & Sensor Suite

Two Interrupts Against Leakage

Power: <12 watts while Firing

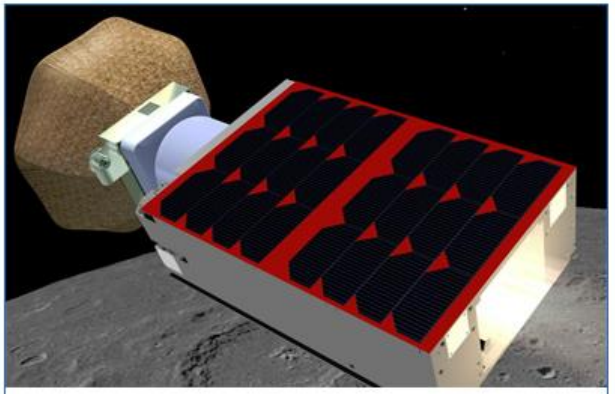
All-Welded Aluminum Alloy Construction



JAXA Nano Impactor (Omotenashi) CubeSat

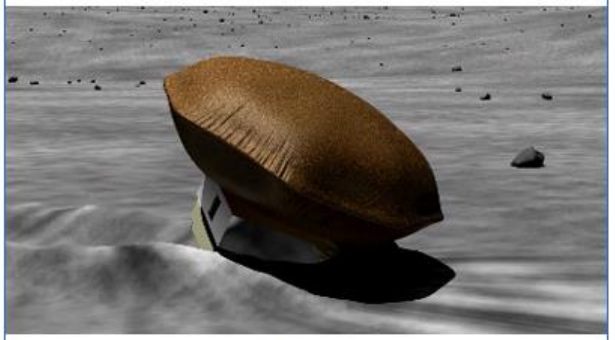
OMOTENASHI:

- Lunar mission designed jointly by the Japan Aerospace Exploration Agency (JAXA) and the University of Tokyo.
- Will demonstrate low-cost exploration of the lunar surface.
- 6U CubeSat to be put onto a course to the moon. The probe performs a semi-hard landing at a velocity of about 30 m/s.



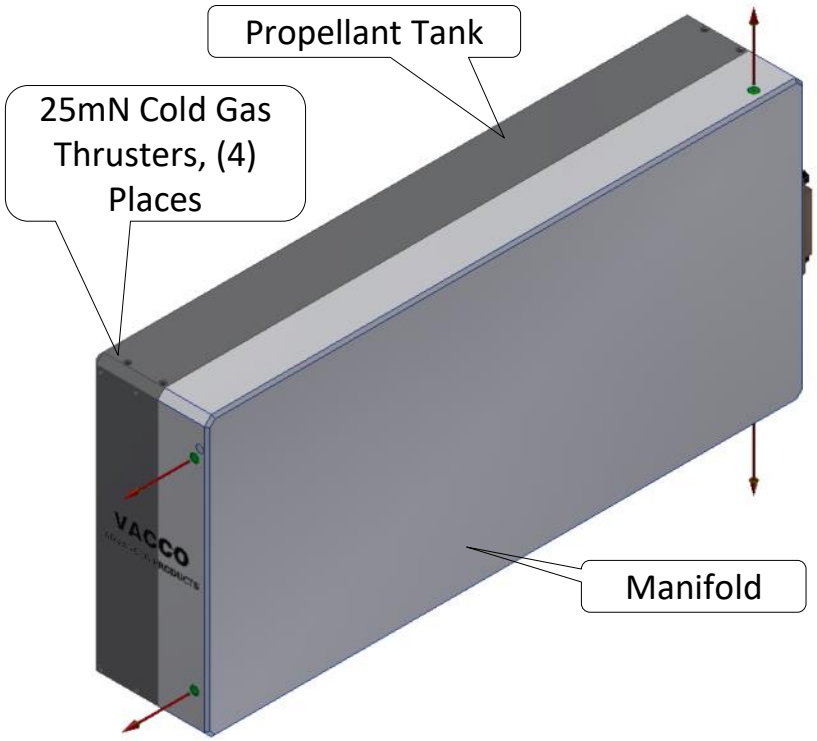
OMOTENASHI *[JAXA]*

OMOTENASHI *[JAXA]*



OMOTENASHI *[JAXA]*

Omotenashi MiPS

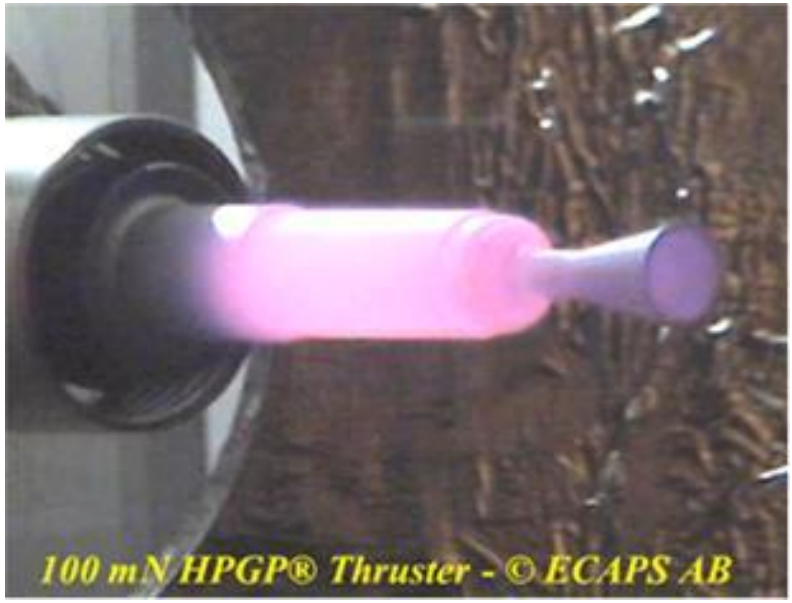


(2) Identical RCS Assemblies (left & right):
- Self-Contained Delta-V / RCS Systems
- (4) 25mN Cold Gas Thrusters in Each:
  - (2) Axial, Pitch / Yaw
  - (2) Roll Control
- All-Welded Aluminum Alloy Construction
- Normally-Closed Frictionless Valves
- Built-In, Shielded Control Electronics
- 9V to 12.6V Unregulated Input Voltage
- RS422 Data Bus Interface
- Integral Pressure & Temperature Sensors
- Minimum Impulse Bit: <4.0mN-Sec

Range Safety Features:
- Green R236fa Propellant:
  - Benign Fire Extinguisher Material
  - Max Pressure <0.69MPa (<100 psi)
- (3) Interrupts Against Propellant Leakage

Green Monopropellant Micro Propulsion Systems

ECAPS 1N ADN Thruster on PRISMA

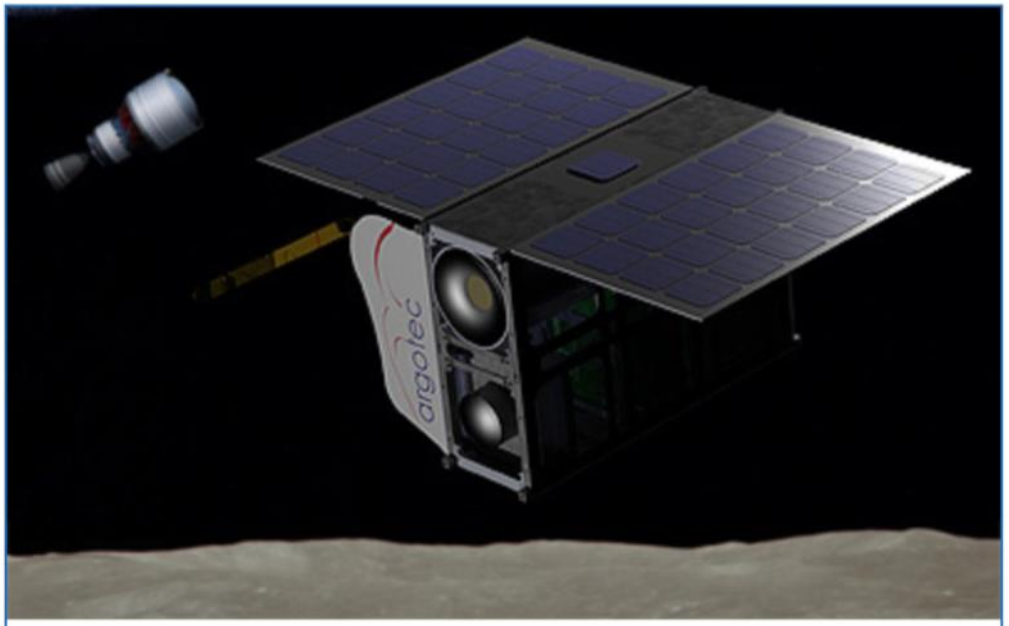


ECAPS 100mN ADN Hot Fire Test

ArgoMoon Hybrid Micro Propulsion System

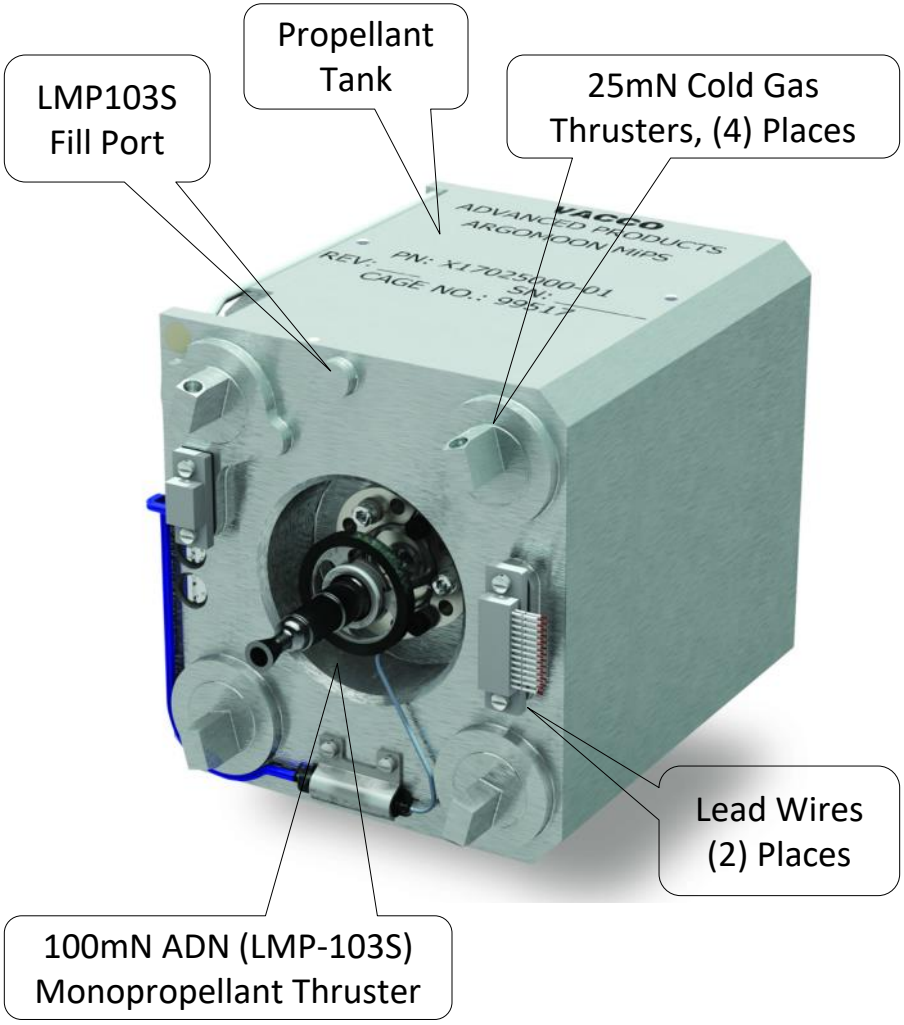
ArgoMoon

- Lunar mission designed by the Italian company Argotec for the Italian Space Agency (ASI)
- Will demonstrate proximity operations with the Interim Cryogenic Propulsion Stage (ICPS)
- Record images of the ICPS for historical documentation
- Test optical communication capabilities between the CubeSat and Earth.



ArgoMoon *[Argotec]*

ArgoMoon Hybrid Micro Propulsion System



Customer is Argotec in Italy

EM-1 CubeSat

Self-Contained Propulsion System:

- (1) Axial 100mN LMP-103S Delta-V Thruster
- (4) 25mN Cold Gas ACS Thrusters:
  - Double Canted 15° in Pairs
- All-Welded Titanium Alloy Construction
- Normally-Closed Frictionless Valves
- Built-In, Shielded Controller
- Sensor Suite
- 9V to 12.6V Input Voltage
- RS422 Data Bus Interface
- ACS Minimum Impulse Bit: <1.25mN-Sec

Green LMP-130S Monopropellant:

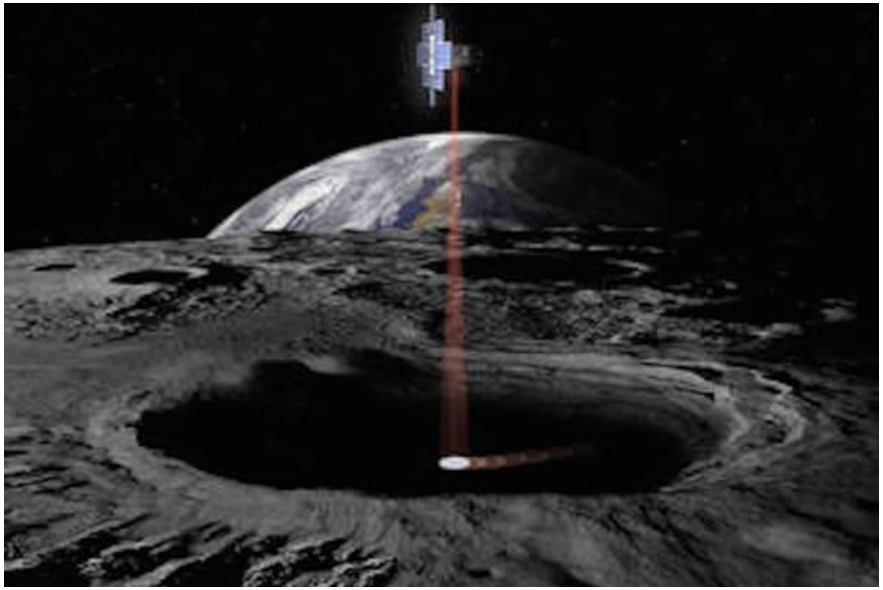
- Flight Proven on PRISMA
- Qualified for Skybox
- UN / US 1.4S (Commercial Aircraft)

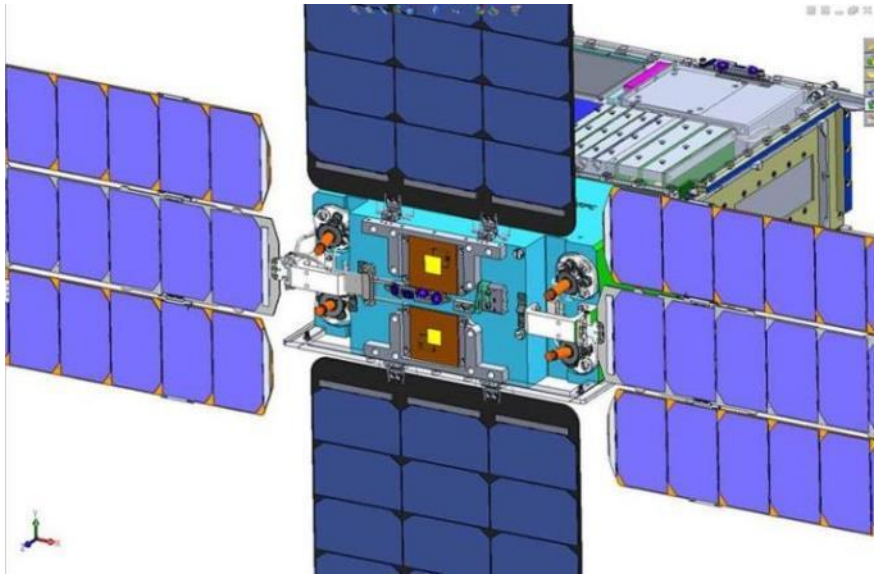
R134a Pressurant / ACS Propellant

(3) Interrupts Against LMP-103S Leakage

(3) Interrupts Against R-134a Leakage

JPL/MSFC Lunar Flashlight Mission





Mission Objectives:

- Map surficial lunar water ice in permanently-shadowed regions

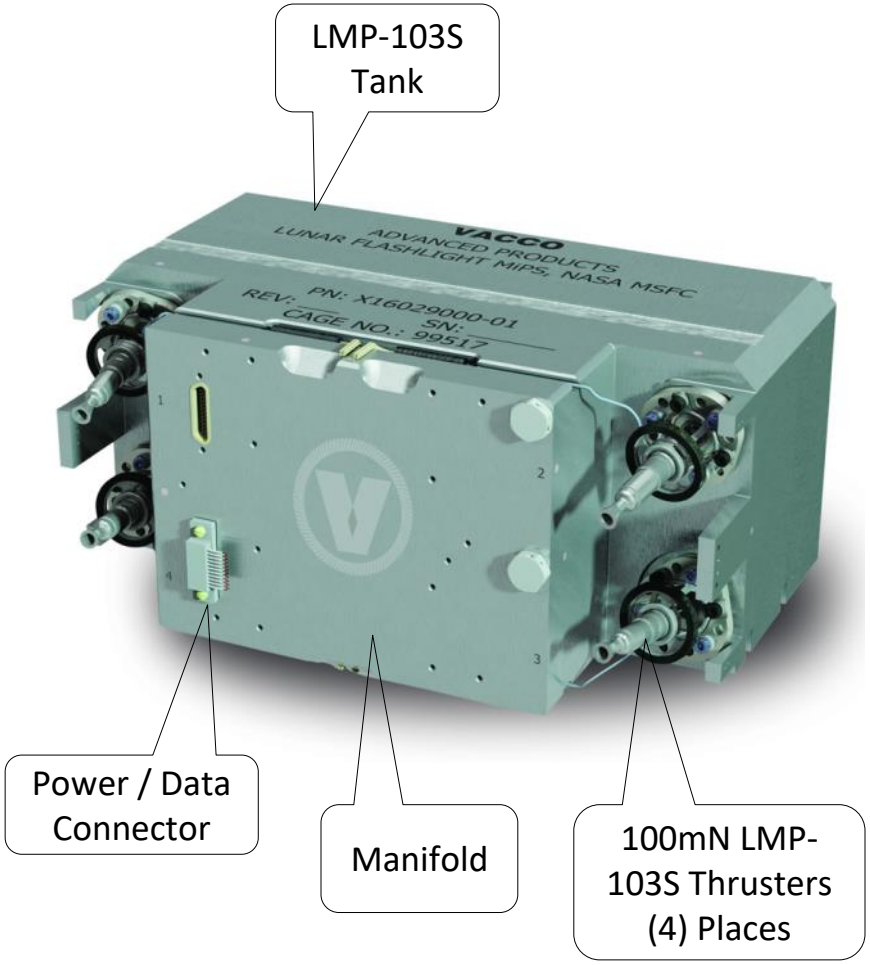
Measurements:

- Using the difference in reflected laser light ratios to indicate the presence and quantity of water ice
- Multiple passes over lunar south polar region with potential ice deposits.

Key Technical Constraints:

- 30 month maximum mission duration
- Surface illumination strategies

VACCO Lunar Flashlight Micro Propulsion System



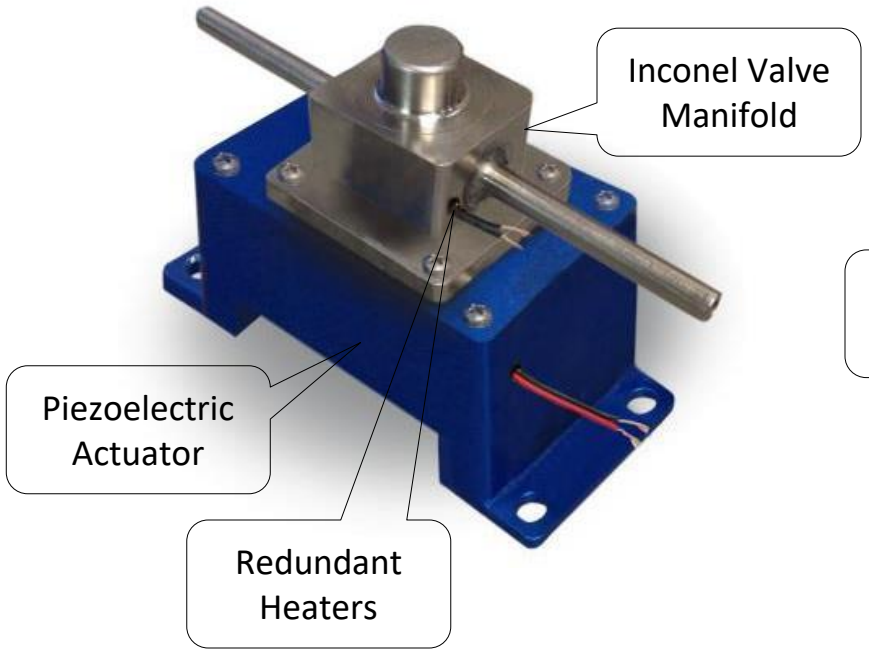
Self-Contained Delta-V Propulsion System:

- (4) 100mN ADN Thrusters
- Provides Pitch, Yaw, Roll and Delta-V
- All-Welded Titanium Alloy Construction
- Normally-Closed Frictionless Valves
- Built-In, Shielded Controller
- 5V & 28V Input Voltage
- 15 watts while firing
- RS422 Data Bus Interface
- Full Sensor Suite
- Minimum Impulse Bit: <5mN-Sec

Range Safety Features:

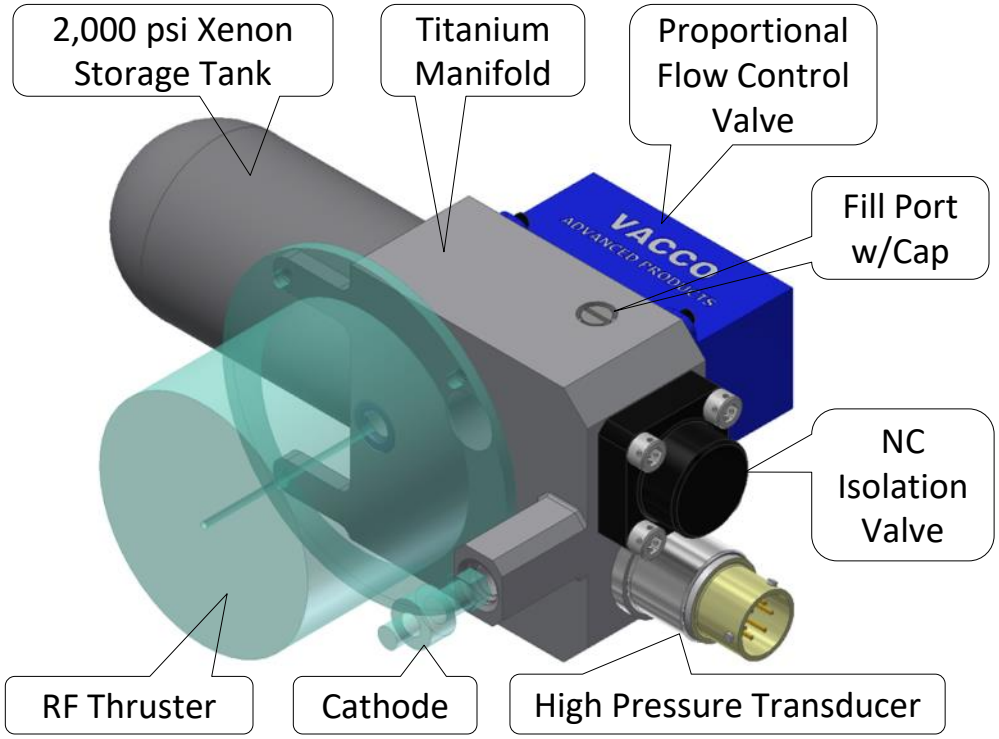
- Green ADN Monopropellant:
  - Flight Proven on PRISMA
  - Qualified for Skybox
  - UN / US 1.4S (Commercial Aircraft)
- (3) Interrupts Against Leakage
- Benign GHe Pressurant
- Safe and Arm Circuit

NASA MSFC ISAT Iodine Propulsion Flight Experiment



- Valves proportionately control iodine vapor flow to anode and cathode.
- VACCO supplied (2) development units hot fire tested at both GRC and MSFC.
- VACCO currently under contract for (5) flight units (4 delivered to-date).

6U Xenon Propellant Management System (PMS)



The VACCO PMS is a Highly-Integrated Xenon Storage and Feed System.

3W RF Thruster and Cathode Mounts to the Front Face of the PMS.

All-Welded Titanium Assembly.

Fully Qualified Components.

Storage Capacity: 71 cm3 @ 2,000 psi.

10 micron System Filter.

High Pressure Transducer.

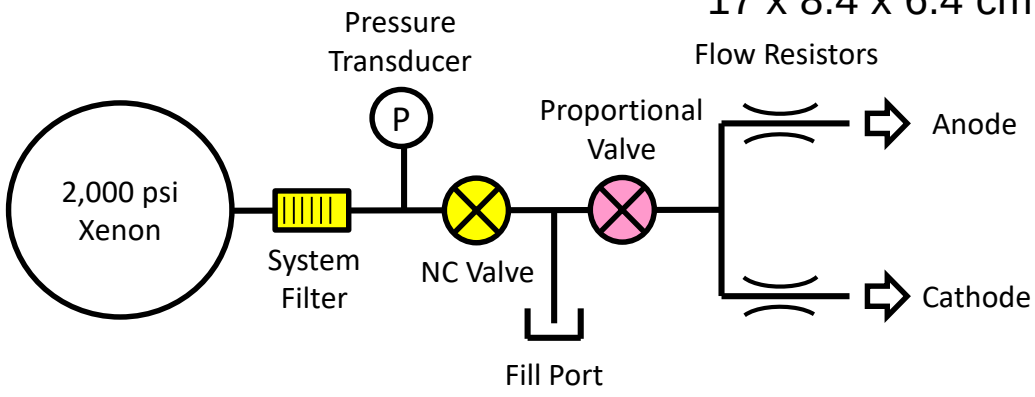
High Pressure Normally-Closed Valve.

Fill Port with Cap.

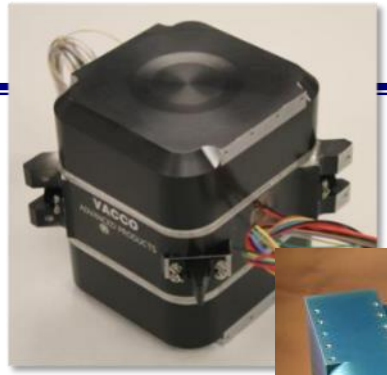
High Pressure Proportional Valve.

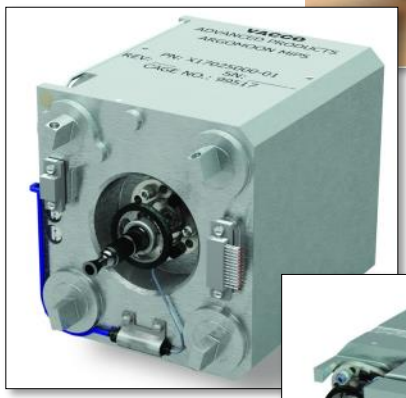
Flow Resistors for Fixed Flow Ratio.

17 x 8.4 x 6.4 cm envelope



Summary





Flight Proven on Tyvak NanoACE

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

- Tyvak NanoACE
- NASA/Tyvak CPOD MiPS
- JPL MarCO MiPS
- JPL/NASA Lunar Flashlight EM-1 MiPS
- JPL/NASA NEAScout EM-1 MiPS
- SwRI CuSP EM-1 MiPS
- JAXA Omotenashi EM-1 MiPS
- Argotec ArgoMoon Hybrid EM-1 MiPS
- Xenon & Iodine EP Feed Systems

Self-Contained Systems

Smart & Versatile

Various Propellants:

- R236fa, R134a, Isobutane
- LMP-103S, AF-M315E, Xenon & Iodine

Materials of Construction:

- Titanium
- Aluminum
- Inconel