

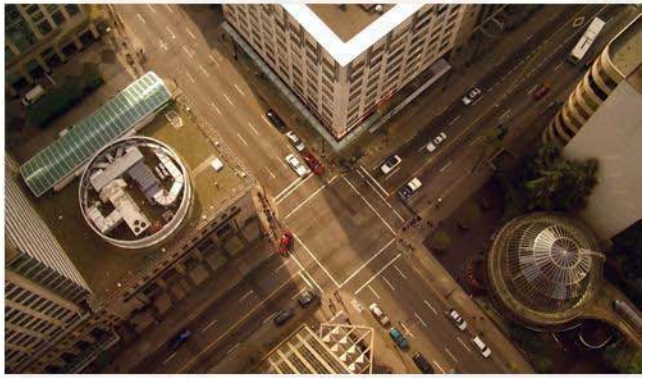

Moog CSA Engineering

CubeSat Payload Accommodations and Propulsive Adapters

11th Annual
CubeSat Developer's Workshop
25 April 2014

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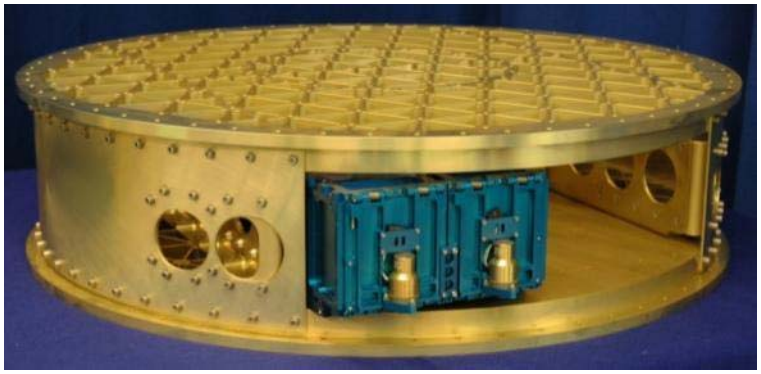
MOOG
CSA Engineering

Agenda

- CubeSat “Wafer” adapters for small launch vehicles
  - CubeStack launched on Minotaur I ORS-3
  - NASA NLAS adapter manifested on Super Strypi ORS-4
- FANTM-RiDE CubeSat rideshares
- ESPA 6U Mount
- CubeSat deployment sequencer
- CubeSat propulsion
  - Controlled re-startable solids from DSSP
- Propulsive adapters
  - CubeSat delivery stages built on CubeStack and ESPA

CubeSat “Wafer” Adapters

- Steve Buckley “wafer” configuration pioneered by NASA Ames with NanoSat Launch Adapter System (NLAS)
  - 25.4 cm (10 inches) tall with 986-mm (38.81-inch) primary interface
  - Accommodates dispensers for up to eight 3U equivalent cubesats in combinations of 3U and 6U

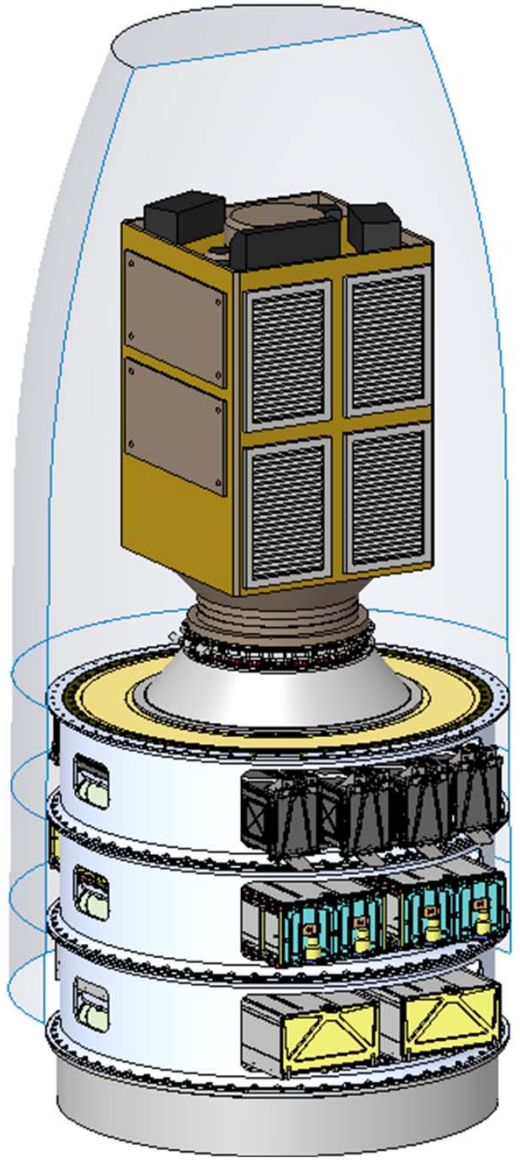


- Configured for cubesat deployments in two directions only
  - All deployed satellites remain in same orbit
  - Radial and anti-radial maneuvers coupled with out-of-plane maneuver allow clustering of payloads to reduce risk of re-contact with primary payload and rocket body

CubeStack

CubeSat adapter developed by LoadPath and Moog CSA under contract to AFRL Space Vehicles Directorate

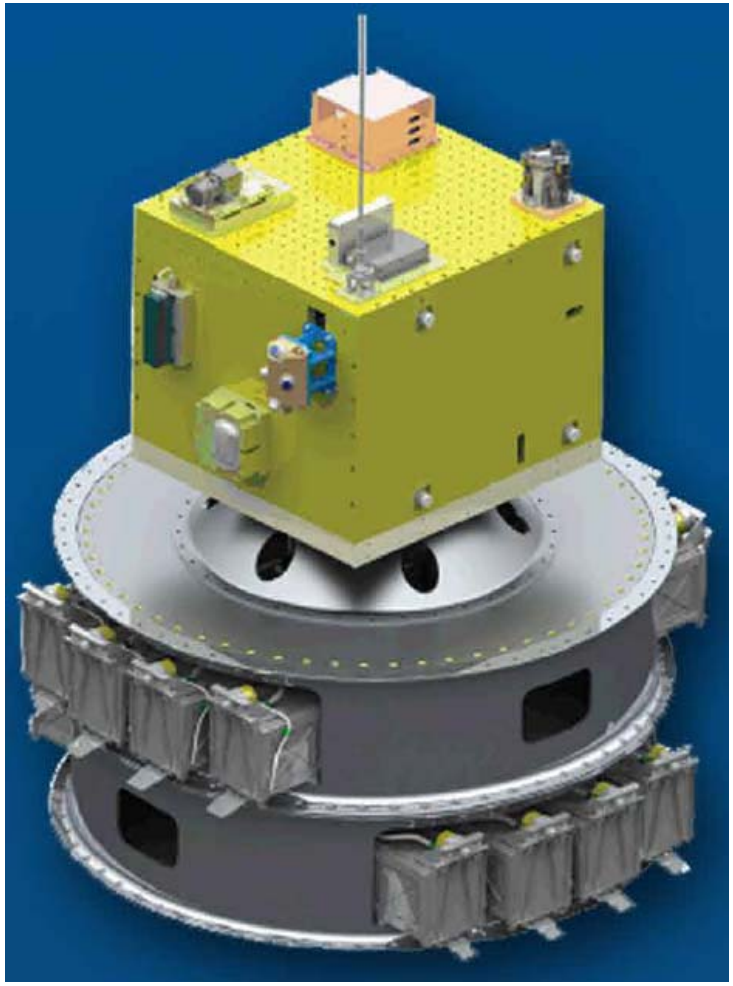
- Eight 3Us, or four 6Us, or combinations of 3Us and 6Us
- Qualified by test in 2011



CubeStack Maiden Launch

Dual CubeStack launched on ORS-3 November 19, 2013

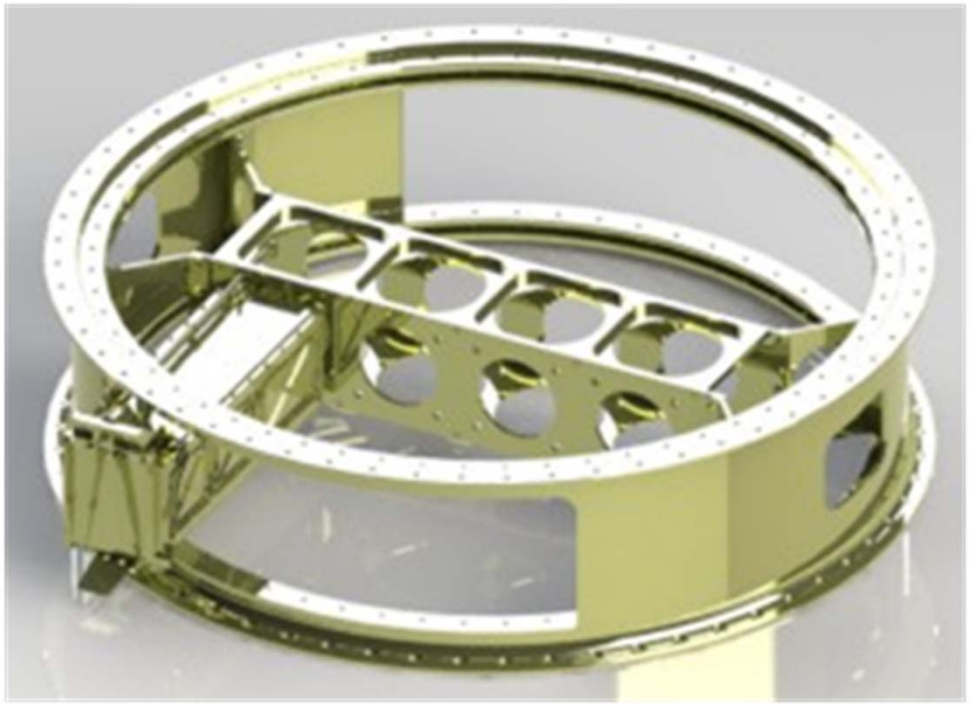
- "Enabler Mission" delivered payload stack consisting of STPSat-3, and 28 cubesats
- Air Force Minotaur 1 tested space-based rocket tracking technology and autonomous flight termination system



CubeStack Version 2

Second generation design

- Bulkhead design eliminates lower deck
- Weight reduced by 15%-20%
- Improved access for integration



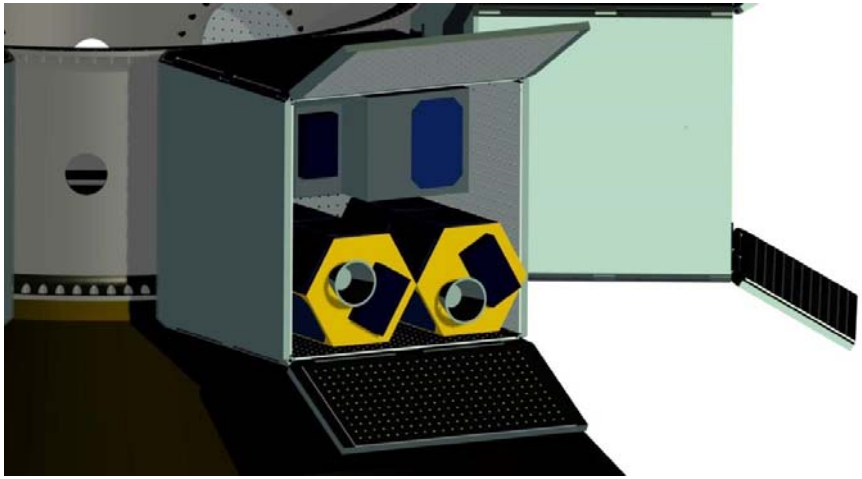
NLAS Adapter

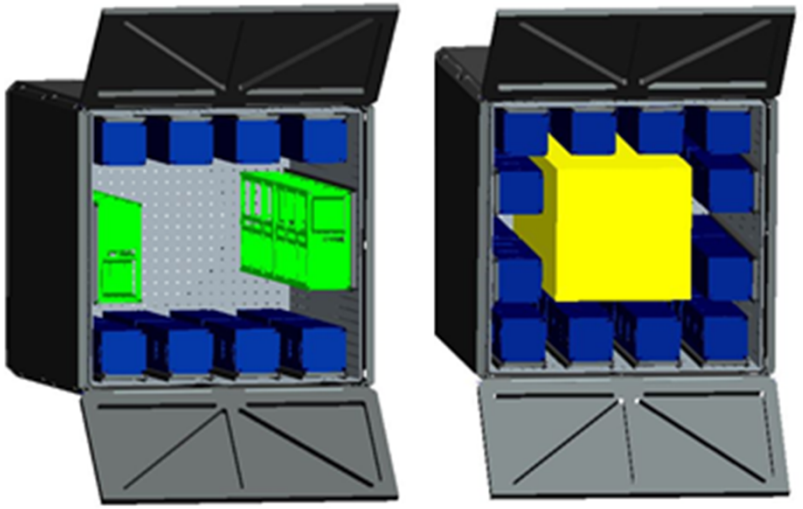
- NASA Nanosat Launch Adapter System (NLAS) includes adapter, 6U dispenser, and sequencer
- Adapter prototype design by NASA Ames Research Center
  - Final design, fabrication, and test by CSA in 2010
- Manifested on ORS 4
  - Super Strypi launch in 2014
  - University of Hawaii HiakaSat as primary payload
  - 13 CubeSat secondary payloads

FANTM-RiDE™

Configurable enclosure for multi-manifest missions

- Collaboration between TriSept Corporation and Moog CSA
- Mix and match CubeSats with microsats and other nanosats in ESPAsat-sized box (24”x24”x28”)
  - 3U and 6U spacecraft can be attached 2 deep along interior dispenser walls, leaving space for central microsat
  - Compatible with multiple launch options including ESPA
- Integration services provided by TriSept

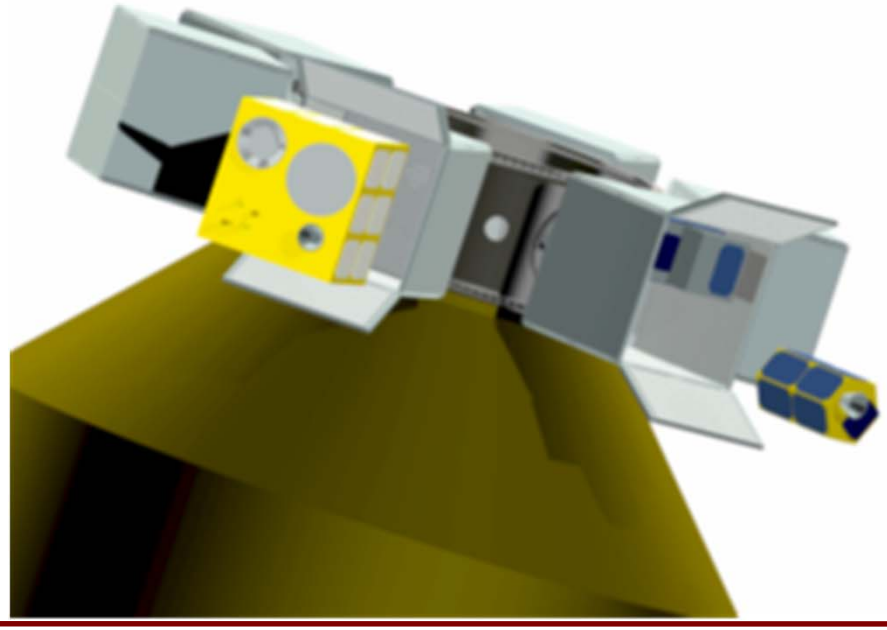


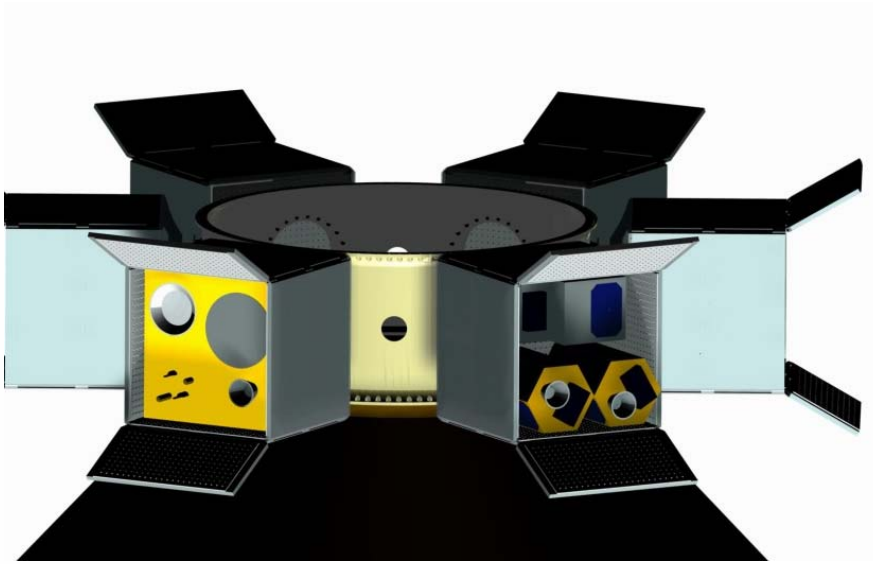


FANTM-RiDE™

Dispenser designed to be “mass tuned”

- Maintain same mass properties regardless of contents
- Allows for late schedule additions and/or removals from the launch schedule without affecting coupled loads analyses

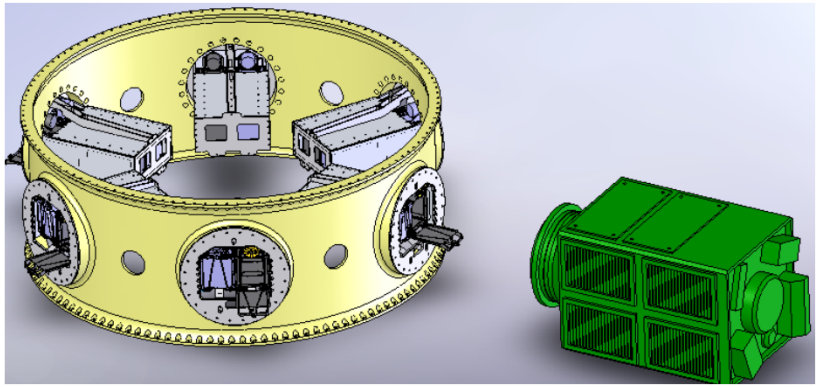


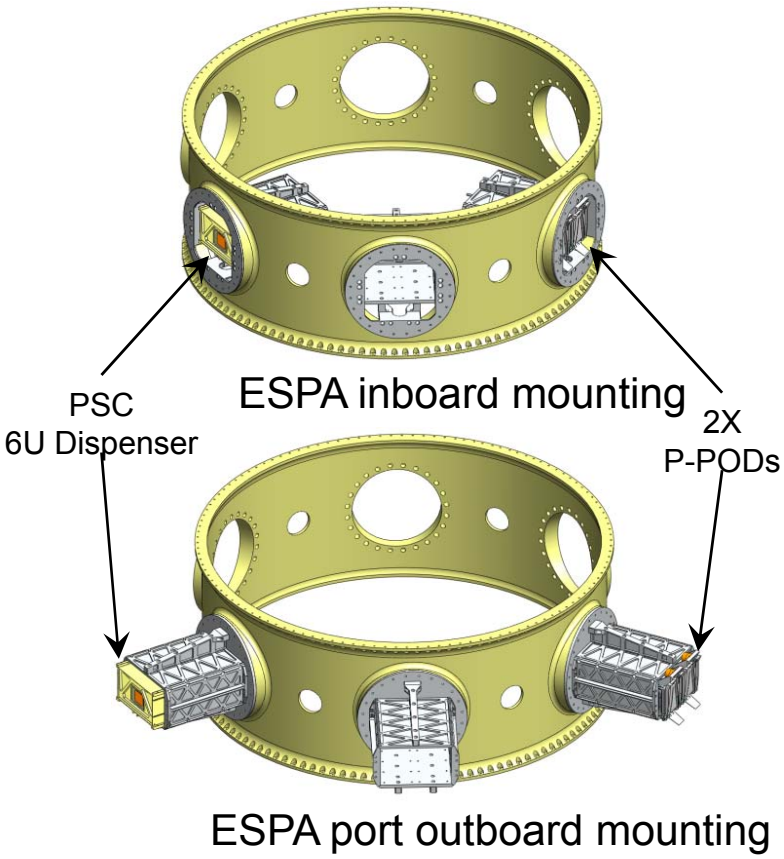


ESPA Six U Mount

SUM mounts on ESPA port

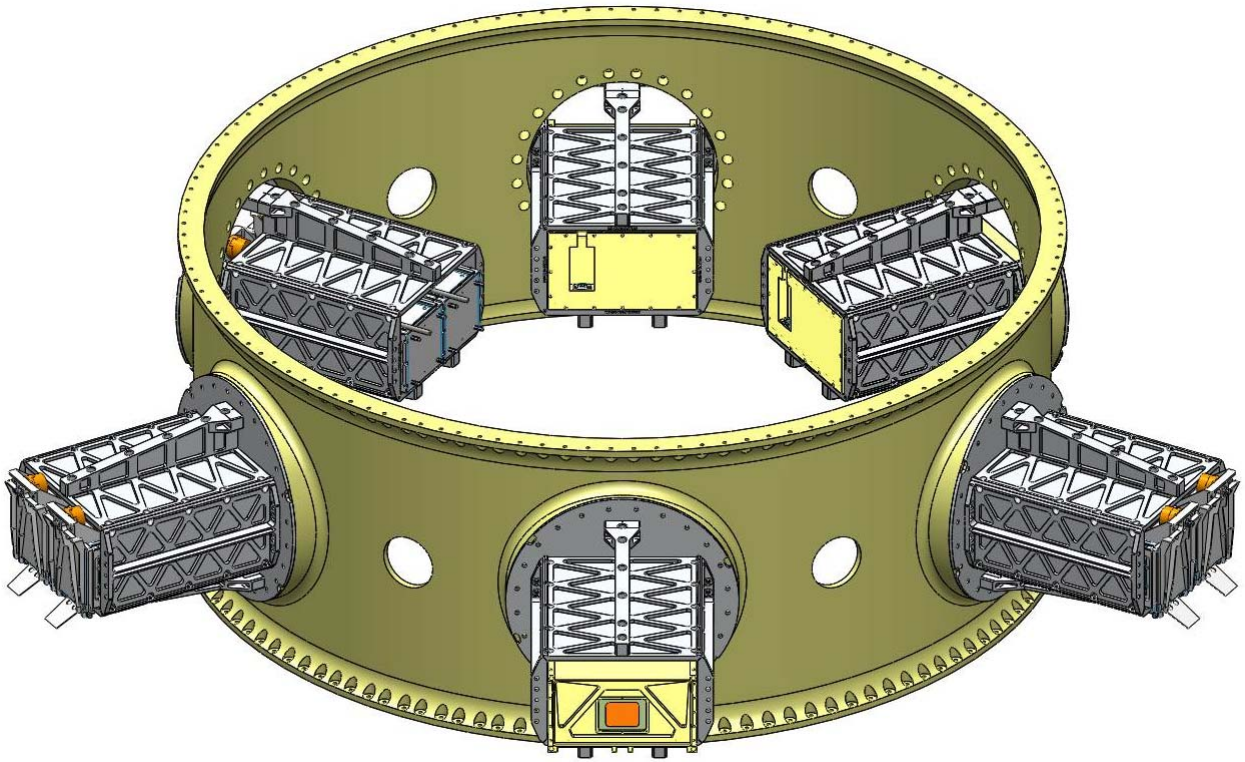
- Standard secondary interface 15” bolt circle
- Compatible with standard Athena II Rideshare Adapter, Atlas V Aft Bulkhead Carrier, CubeStack





ESPA with Six SUMs

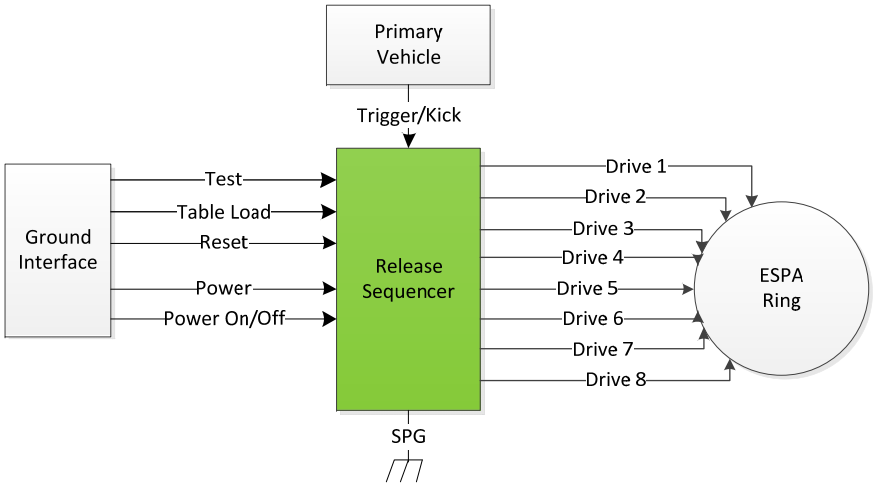
- Each SUM holds two P-PODs or one 6U dispenser
  - Inboard or outboard mounting on port
- Enables increased capacity for ESPA
  - Six 400-lb satellites and twelve 3U satellites



CubeSat Deployment Sequencer

- Moog IRAD multi-payload sequencer
  - Modular architecture
  - Compatible with P-POD, PSC, SNC, RUAG systems
- Redundant high-current output signals to drive multiple spacecraft release mechanisms

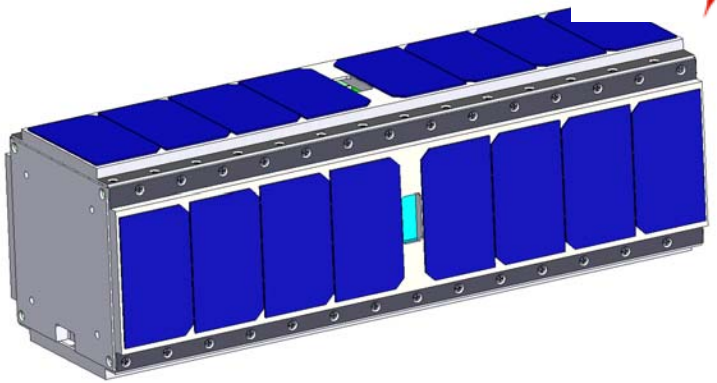
- Moog Broad Reach board set and architecture
  - Flight heritage
  - Modularity for addition of sensor and telemetry interfaces



CubeSat Agile Propulsion System (CAPS)

CAPS flight demonstrations

- 1U flight demo mission in work to demonstrate 3U system
  - Team of Morehead State, Sonoma State, DSSP, Moog, and Little H-Bar Ranch
- SpinSat mission by NRL and DSSP to characterize on-orbit performance of electrically controlled solid propellant technology
  - Scheduled for Station deployment this year



CAPS Summary

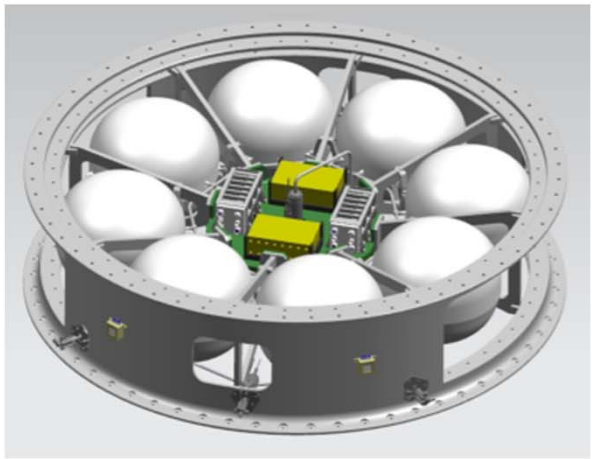
Flexible modular CubeSat propulsion system with DSSP electric solid propellant technology

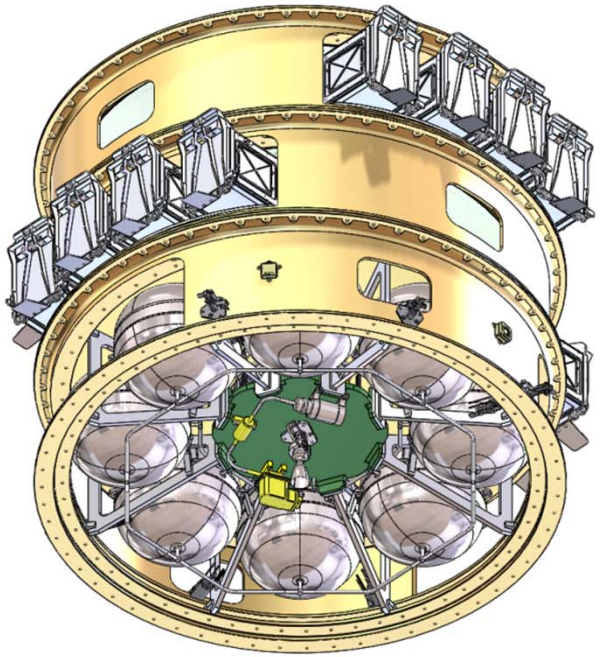
- Can fire up to 12 different micro-thruster elements, each with lifetime exceeding 250 pulses
  - Ignition power delivered via capacitor discharge → extremely high power, short duration impulse
  - Pulse frequency dependent on power input, can reach 0.04 Hertz
- Controller is miniature bi-level PCB stack < 2¼" in height
  - Thrusters can be board-mounted or installed in modular housings that wire to controller
  - CAPS accepts a 5V to 12V DC supply and has a simple SPI communications interface
  - Power consumption (1-3 W) is dependent on user-programmable arm rate

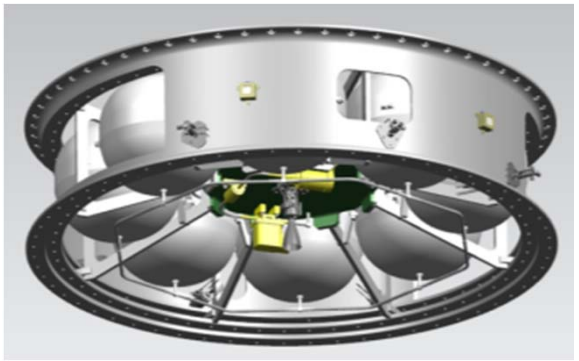
Propulsive CubeStack

Wafer adapter (CubeStack or NLAS) augmented with propulsive “stage” for CubeSat delivery

- Adapter functions as Orbital Maneuvering Vehicle
- One or more wafers added to propulsive stage with Cubesat payloads
- Concept development for lunar cubesat deployment





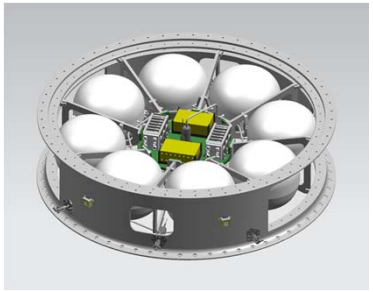


CubeStack Delivery Stage

LoadPath
Aerospace Structures | Design, Test, and Materials

Spacecraft Avionics – Mission Control

- C&DH Integrated and Redundant Systems
  - Processor Boards
  - Digital & Analog I/O storage and GPS
  - Solar Array Interface
  - Torque Rod Drivers
  - Power Switching
- IMU MEMS w/GPS / Antenna
- EPS - rechargeable LI battery packs
- Sun Sensors - coarse and fine
- ACS Reaction Wheels
- Comm Ka/Ku band

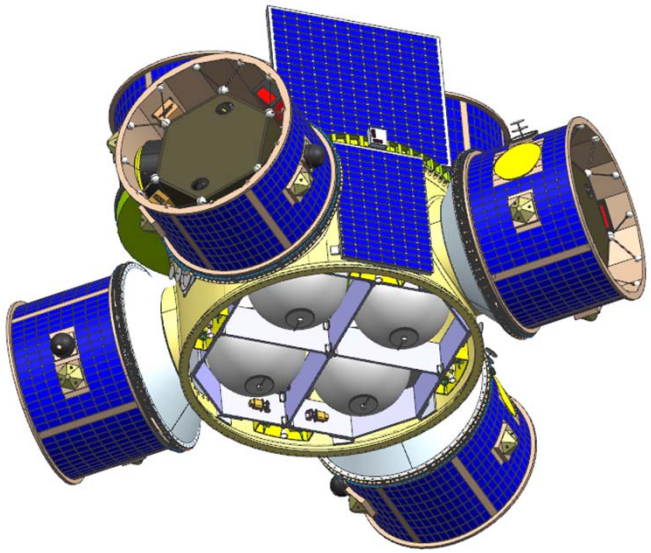


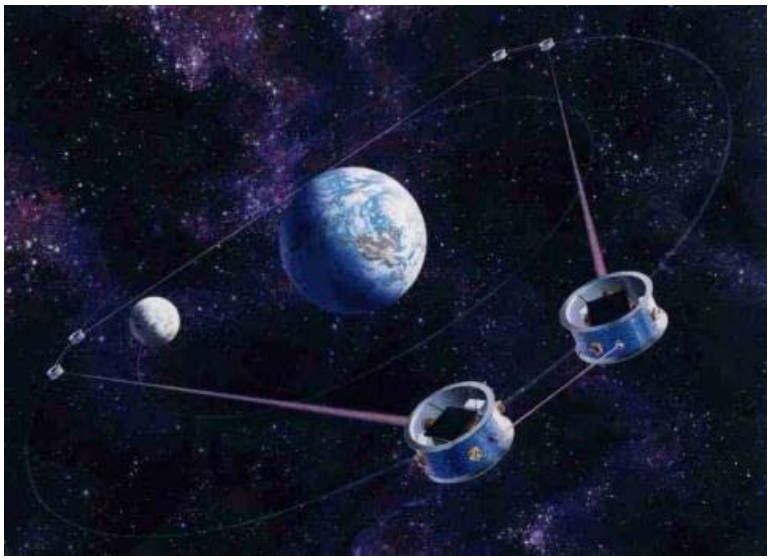
Propulsion

- Monopropellant High Performance Thrusters
  - MONARC 1N, 5N, 22N vast flight heritage
  - N_2H_4 $I_{sp(ave)}$ = 230 sec
  - ref….I ~ 19,780 kg-sec (86 kg propellant)
  - ref….ΔV ~ 415 m/sec (230kg wet mass)
- Bipropellant option MMH/NTO
- Green propellant option (AF-M315E or LMP-103S)
- Rolling Metal Diaphragm Tanks
  - Supplied prefilled unpressurized
  - Zero Slosh
  - 99.9% expulsion efficiency

ESPA Delivery Stage

- Orbiting Medium Explorer for Gravitational Astronomy (OMEGA) proposal to NASA used ESPA delivery stage
  - Allowed spacecraft to be simplified, reducing cost and weight
  - Each spacecraft required very small μN thruster for precise stationkeeping instead of large, complex propulsion module to establish orbit
- Configurations in work for CubeSats





MONTANA STATE UNIVERSITY · UtahState University · Space Dynamics Laboratory, Utah State University Research Foundation · SURREY SATELLITE TECHNOLOGY US LLC · MOOG SPACE AND DEFENSE GROUP

Summary

- CubeSat “Wafer” adapters for small launchers
- FANTM-RiDE CubeSat rideshares
- ESPA SUM for EELV and Falcon 9 CubeSats
- CubeSat deployment sequencer
- CubeSat electric solid propulsion
- Propulsive adapters and CubeSat delivery stages