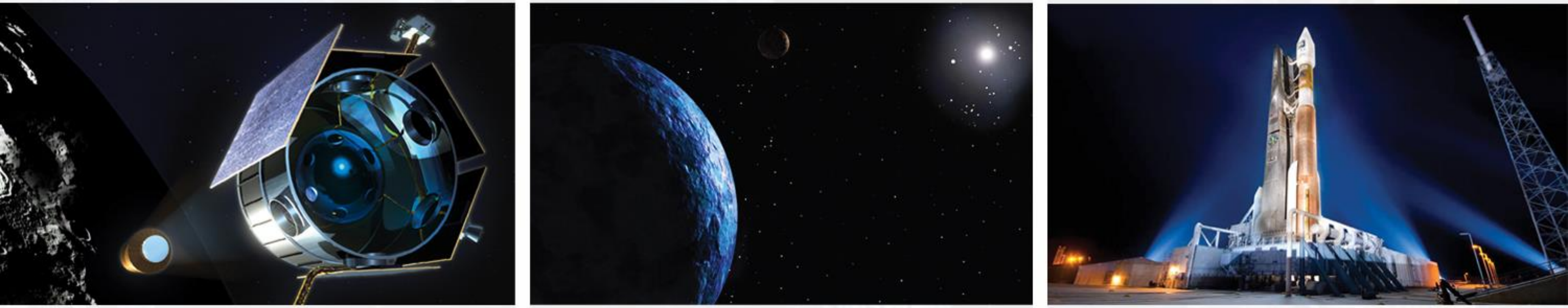


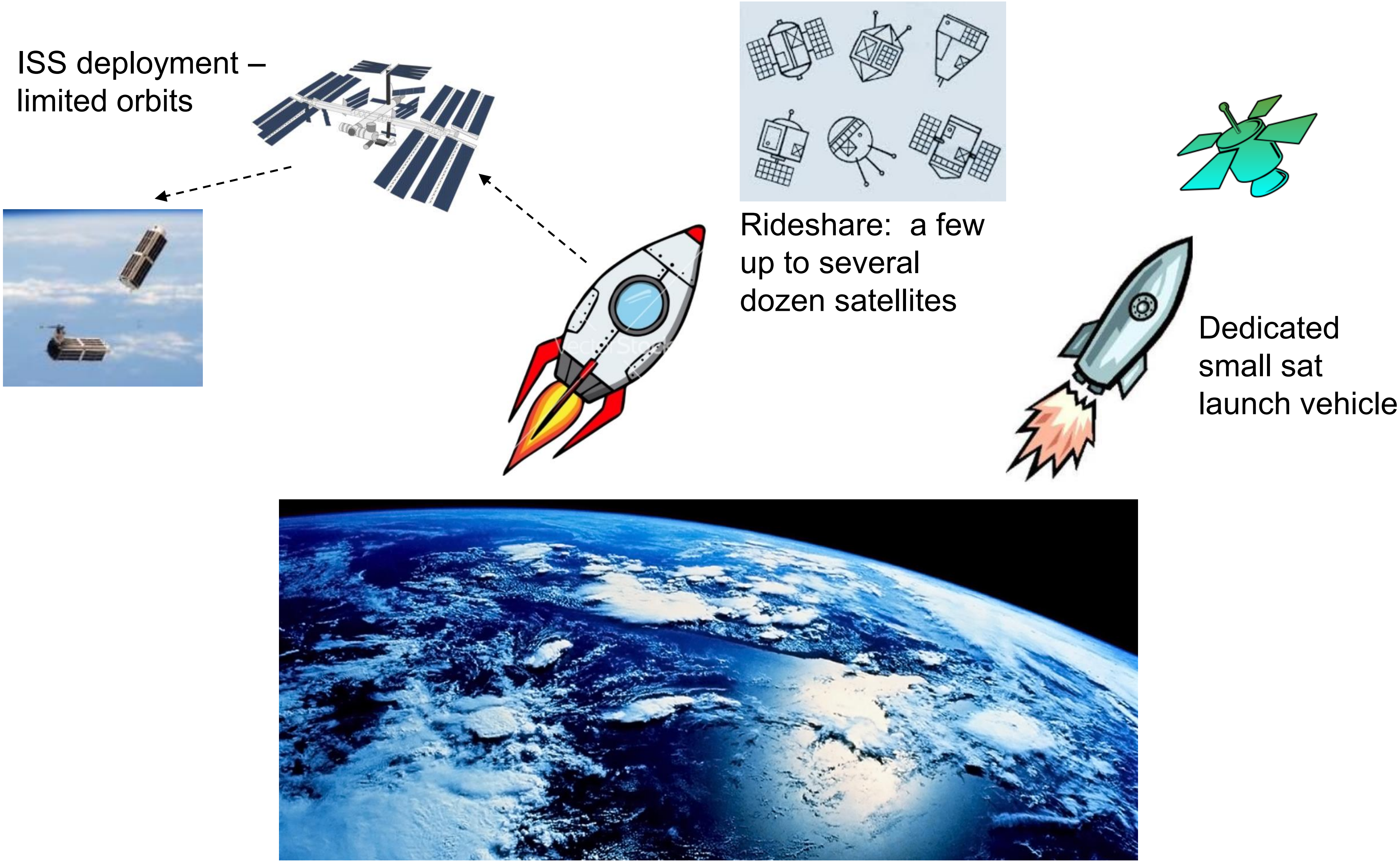
CubeSat Launch and Deployment Accommodations

April 23, 2015

Marissa Stender, Chris Loghry, Chris Pearson, Joe Maly
Moog Space Access and Integrated Systems
jmaly@moog.com

MOOG
SPACE AND DEFENSE GROUP

Getting Small Satellites into Orbit



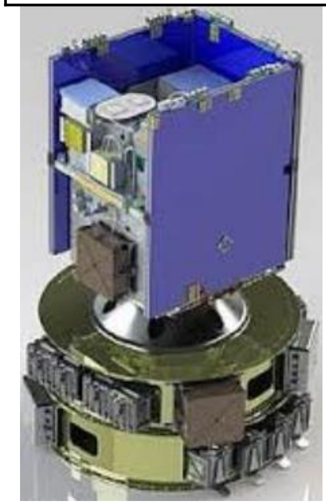
ISS deployment – limited orbits

Rideshare: a few up to several dozen satellites

Dedicated small sat launch vehicle

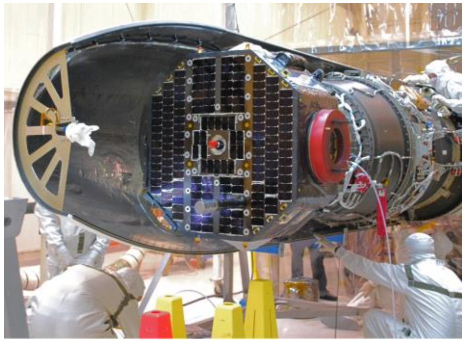
Comparing the Options

	PROS	CONS
Rideshare	Established and developing infrastructure	Orbits tied to primary sat; primary imposes other constraints
Dedicated Rideshare (No Primary)	More control over orbits, Upper Stage restart capability	Costs could be higher, large constellations with many different payloads are difficult for launch providers
ISS Deployment	Low cost and subsidized	Low, restricted and limited life orbits, payload limitations
Dedicated Launch	Complete control over orbit	Not much market capacity (yet)


Rideshare


Dedicated rideshare (no primary)

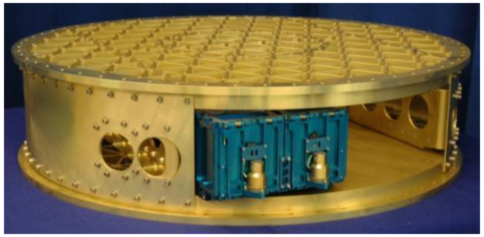

Space Station


Dedicated launcher

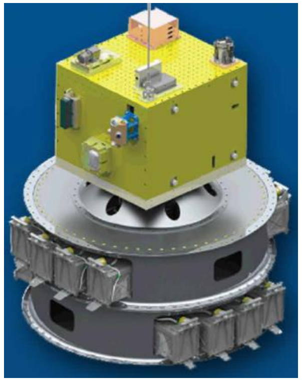
"Wafer" CubeSat Adapters

Steve Buckley's wafer adapter (Φ38.8" x 10" tall) for eight 3Us, four 6Us, or combinations of 3U and 6U dispensers

- Wafer prototype, Nanosat Launch Adapter System (NLAS) by NASA Ames
  - Final design and fab by Moog CSA
  - ORS 4 Super Strypi launch late 2015 with HiakaSat primary and 13 CubeSats
  - NLAS also includes sequencer and 6U dispenser



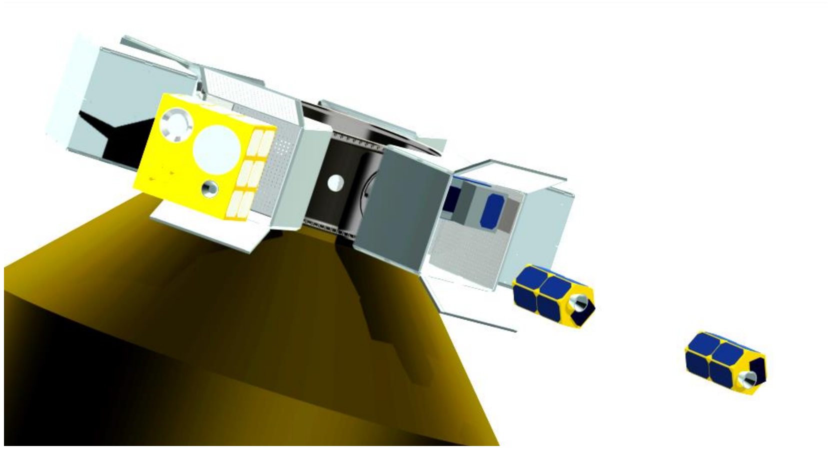
- CubeStack by LoadPath and Moog CSA
  - Developed for ORS under contract to AFRL Space Vehicles Directorate
  - ORS 3 November 2013 dual CubeStack launch
  - 2015 second generation design: reduced weight and improved integration access

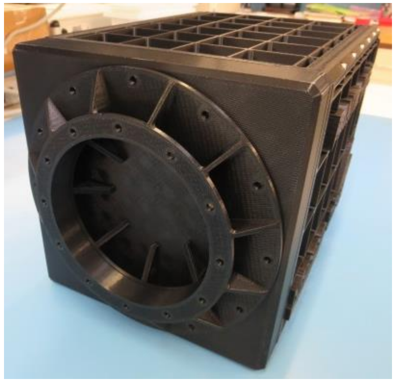


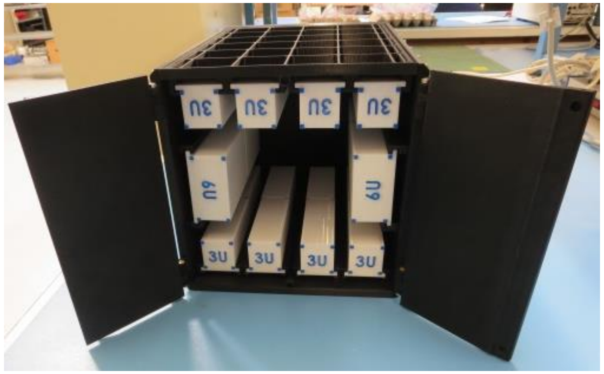
FANTM-RiDE™

Satellite dispenser for multi-manifest missions

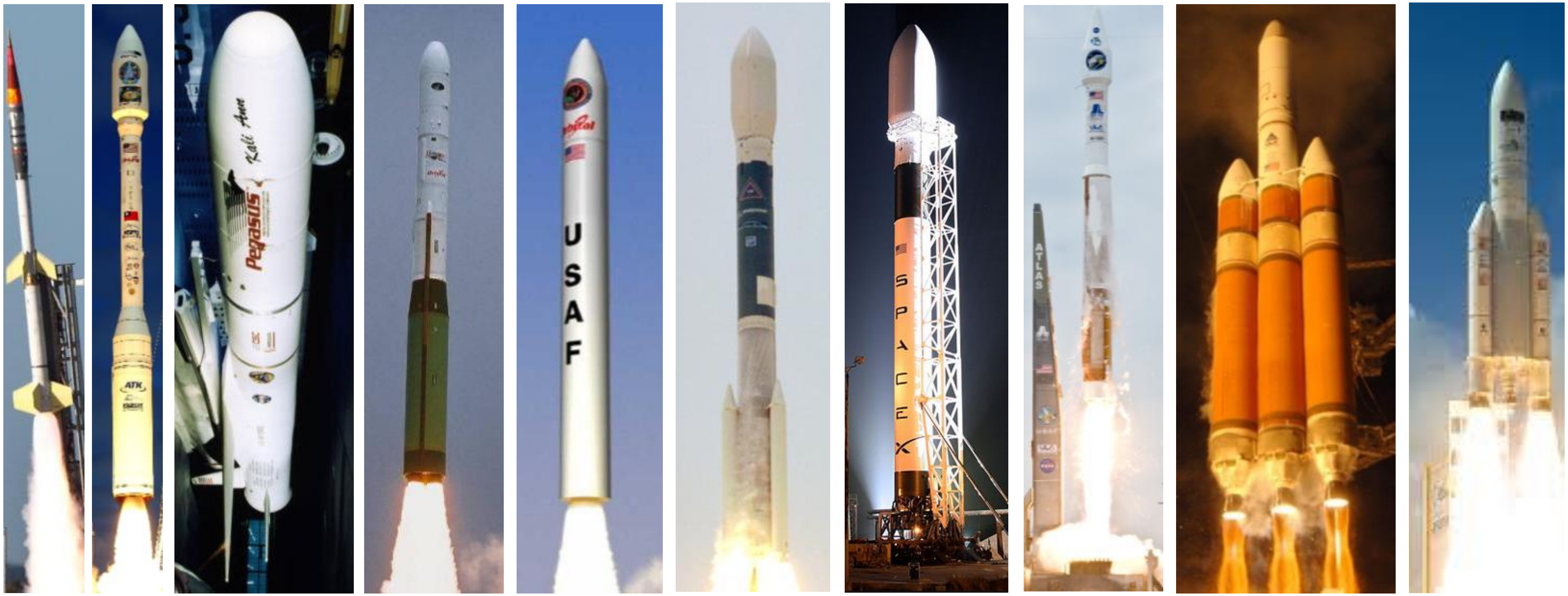
- Collaboration between TriSept Corporation and Moog CSA
- Mix and match CubeSats with microsats in ESPAsat-sized box, i.e., 24”x24”x32”
  - 3U and 6U attached 2 deep along dispenser walls, leaving space for central microsat
  - Compatible with multiple launch options including ESPA
- Integration services provided by TriSept







SoftRide Launch Vehicle Heritage



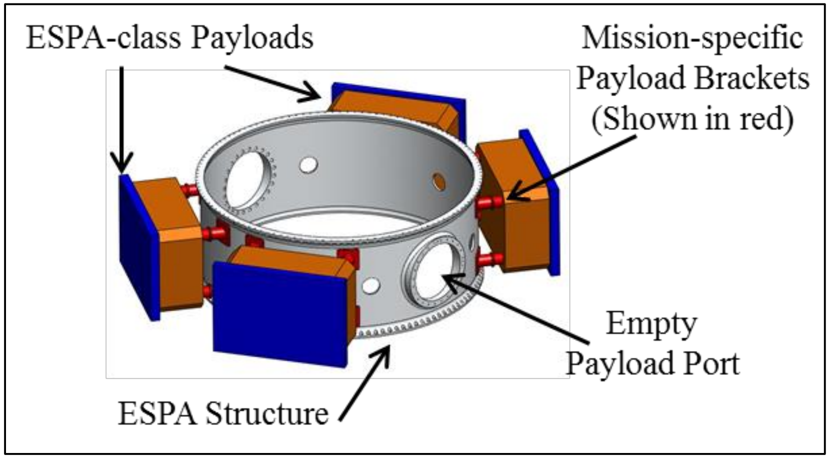
Terrier/ Orion	Taurus	Pegasus	Minotaur I, IV, V		Delta II	Falcon 1, 9	Atlas V	Delta IV, IV Heavy	Ariane 5 ECA
2	6	4	7	2	4	3	1	4	1

SoftRide has flown 34 times on 9 Launch Vehicles
Additional SoftRide systems delivered increasing launch vehicle heritage

EELV Secondary Payload Adapter (ESPA)

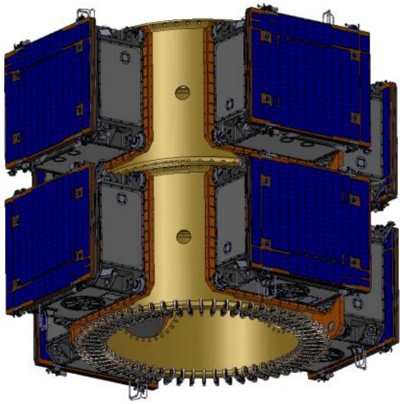
- Multi-payload adapter for large primary spacecraft and six auxiliary spacecraft (up to 180 kg/400 lb)
  - 24-inch port enables 320 kg/700lb
- Multiple ring heights and increased carrying capability are also options for alternate launch configurations
- Multiple mounting options
  - Standard or custom ESPA ports
  - External brackets
  - Internal mounting features
  - Multiple deployment devices per port
- Heritage:
  - STP-1 (2007)
  - NASA's LRO/LCROSS (2009)
  - OG2 Mission 1 Constellation (2014)
  - AFSPC-4 (2014)
- Upcoming missions:
  - OG2 Mission 2 – Launches Summer 2015
  - Spaceflight SHERPA
  - AFRL's DSX
  - U.S. Air Force's EAGLE
  - AFSPC-6

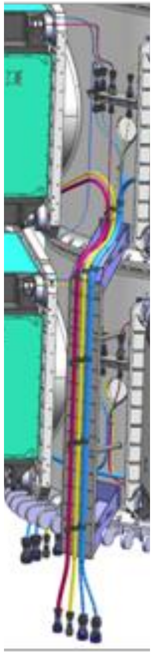
OG2 Constellation of eight spacecraft on two stacked ESPA rings with SoftRide vibration isolation for launch on SpaceX Falcon 9
(Photo credit Sierra Nevada Corporation and ORBCOMM)

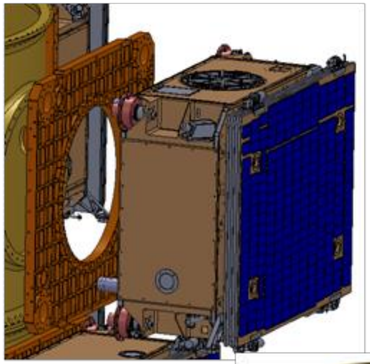


ESPA Grande

	Port Diameter	Payload at 20-in CG
ESPA Grande	24 in	700 lbm / 318 kg
Standard ESPA	15 in	400 lbm / 181 kg





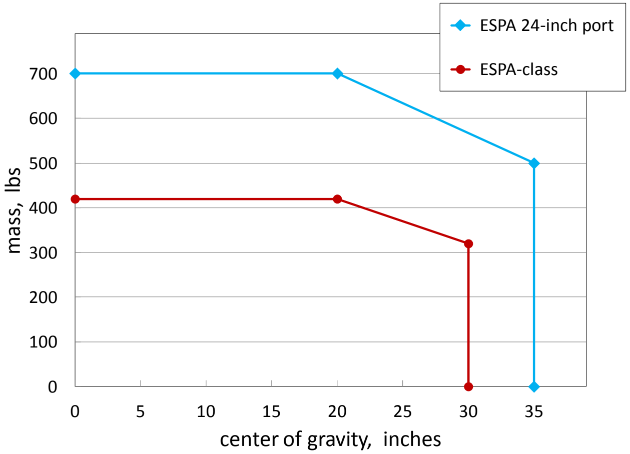


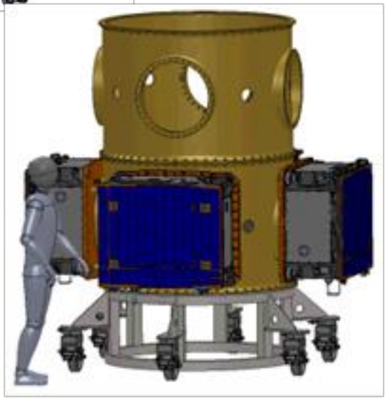
ORBCOMM (OG2) Mission 1 (July 2014) was first use of ESPA for constellation deployment

Two 4-port ESPA rings with SoftRide and harness integrated by Moog at SpaceX SLC-40

OG2 Mission 2 (Summer 2015)

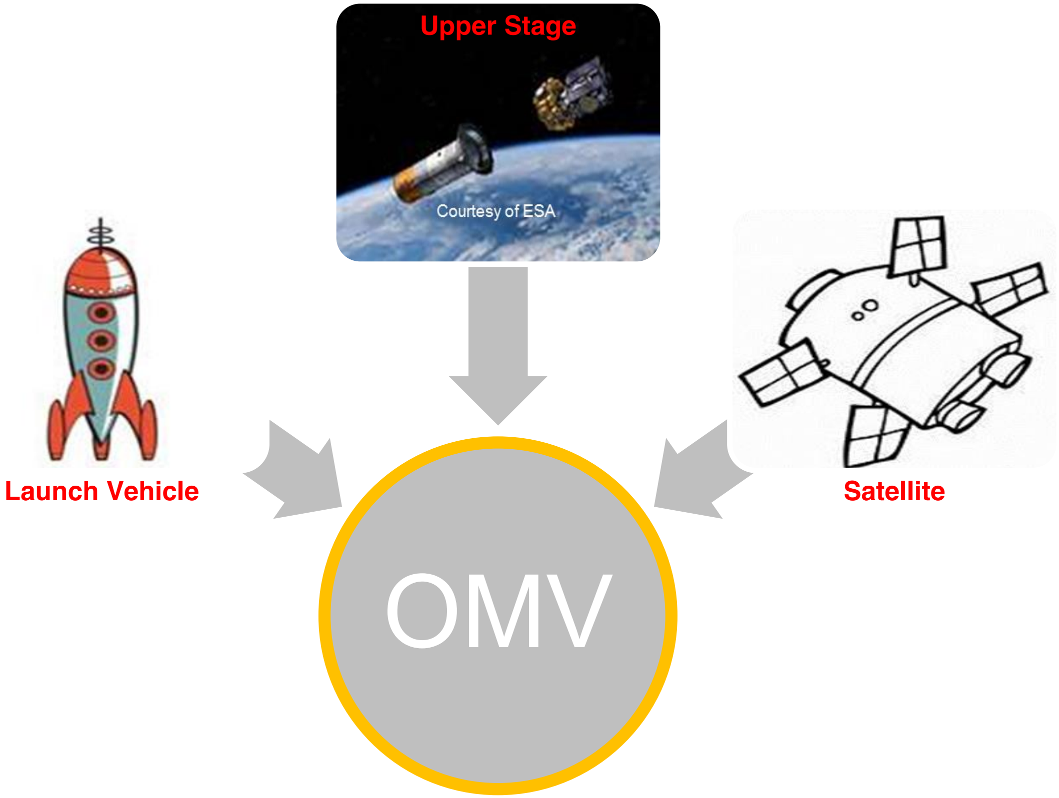
Launching 11 satellites on Three 4-port ESPA rings with SoftRide and harness integrated by Moog at SpaceX SLC-40





What Is an Orbital Maneuvering Vehicle (OMV)?

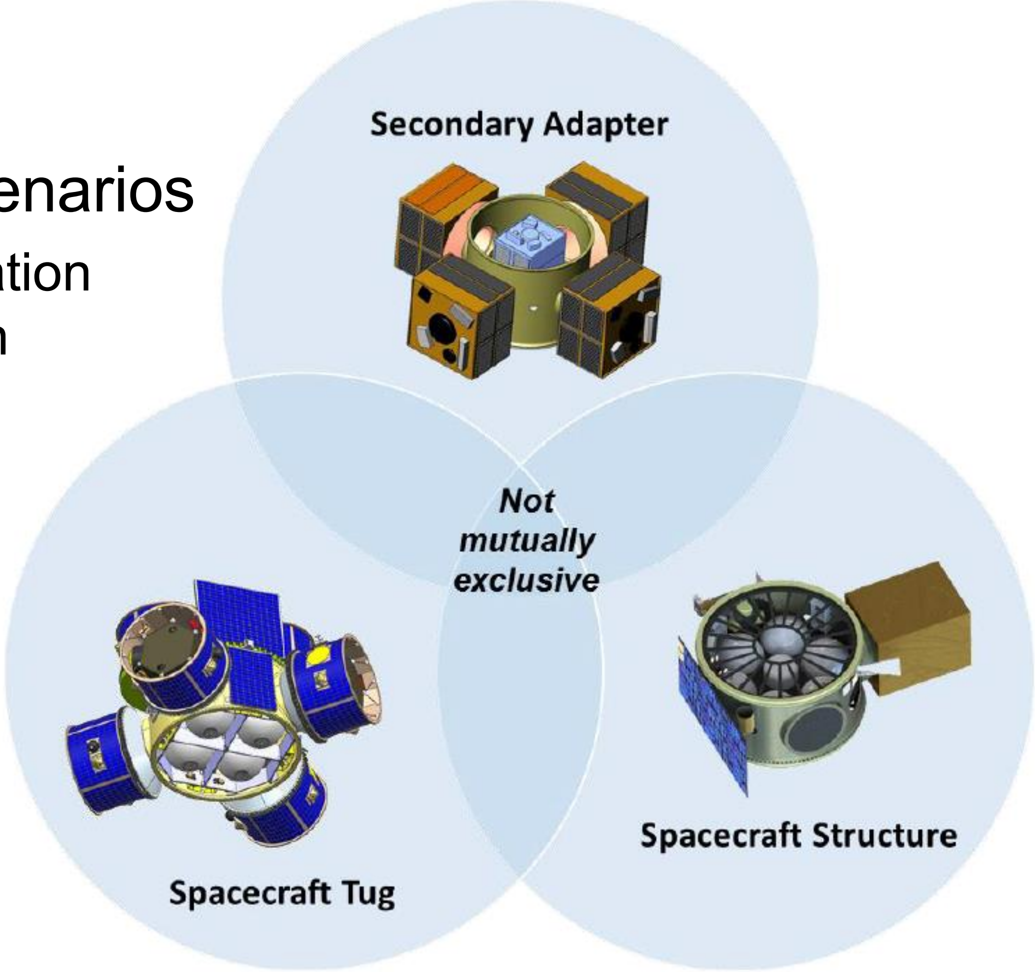
- An OMV is an intermediate vehicle somewhere between Launch Vehicle and Satellite and a close cousin to Upper Stages
  - Provides delta-v & maneuvering within space, typically within Earth’s orbit but not always



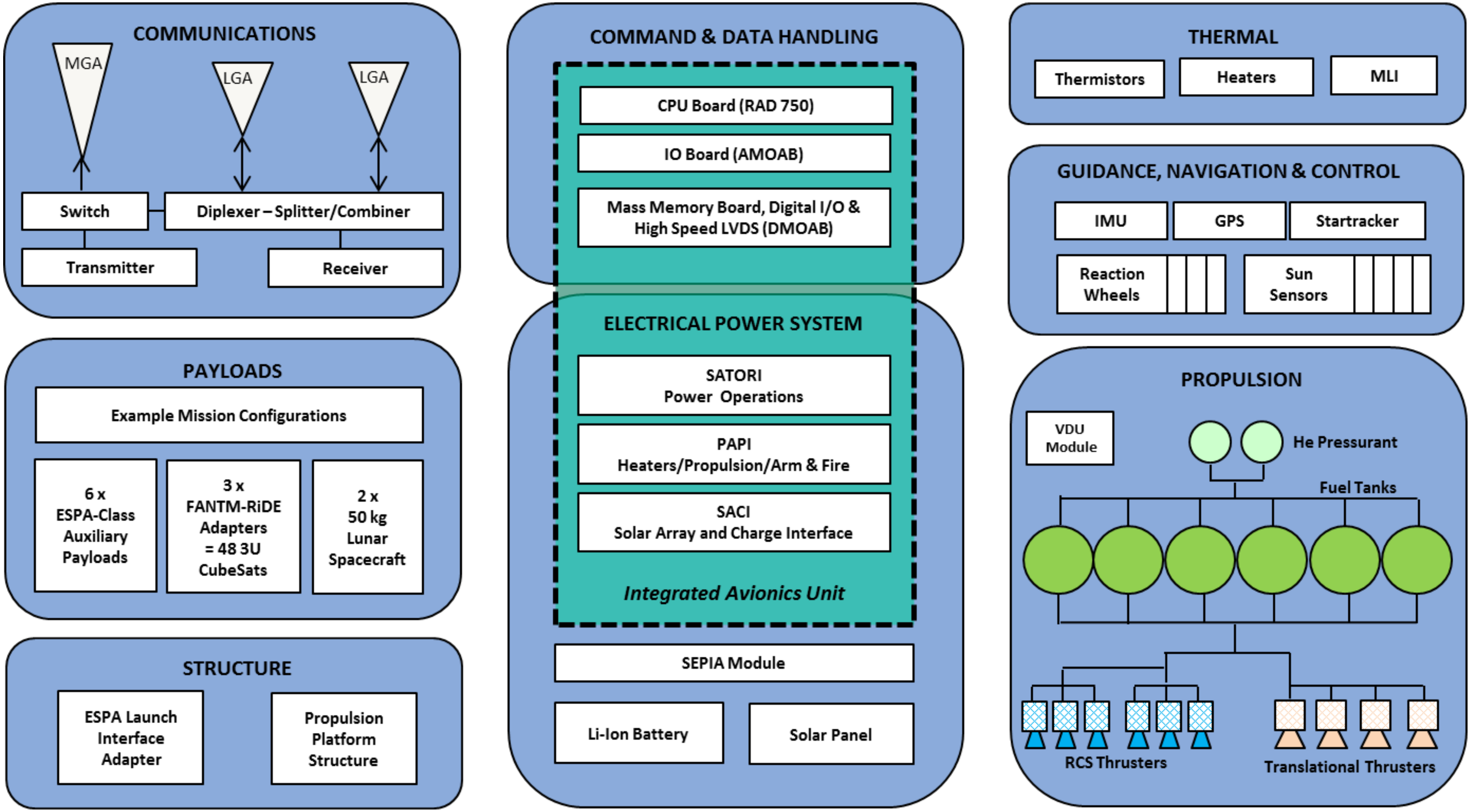
- How can an OMV address limitations of other options for getting small satellites to their desired orbits?
  - Addressed here with example cases

OMV Topics

- Orbital maneuvering vehicle overview
  - ESPA-based vehicle
  - Block diagram
  - Capability summary
- Case studies of typical scenarios
  - Low altitude, Earth Observation (EO), CubeSat constellation
  - Ferry to Low Lunar Orbit
- OMV applications for shared launch opportunities



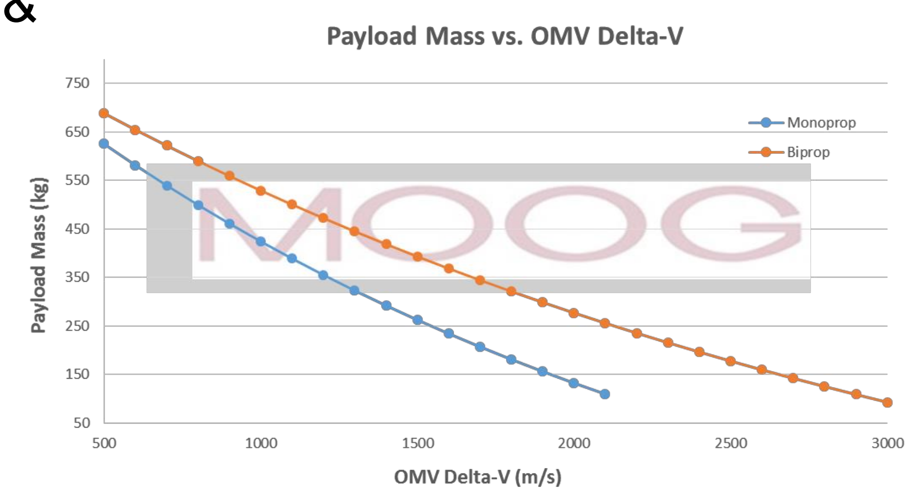
Typical OMV Block Diagram



Each OMV is specifically tailored for the mission requirements.

Demonstrative OMV Capability

- Example point design of modular & scalable OMV architecture
  - Power >200 Watts
  - Mass: variable, example:
    - Wet Mass: 1191 kg
    - Payload: 540 kg
    - Delta-V: 535 m/s
  - Delta-V
    - Cases analyzed from 500 to 1100 m/s
    - Expanded capability via taller ESPA ring and 4 cylindrical fuel tanks
      - All other propulsion hardware would remain the same



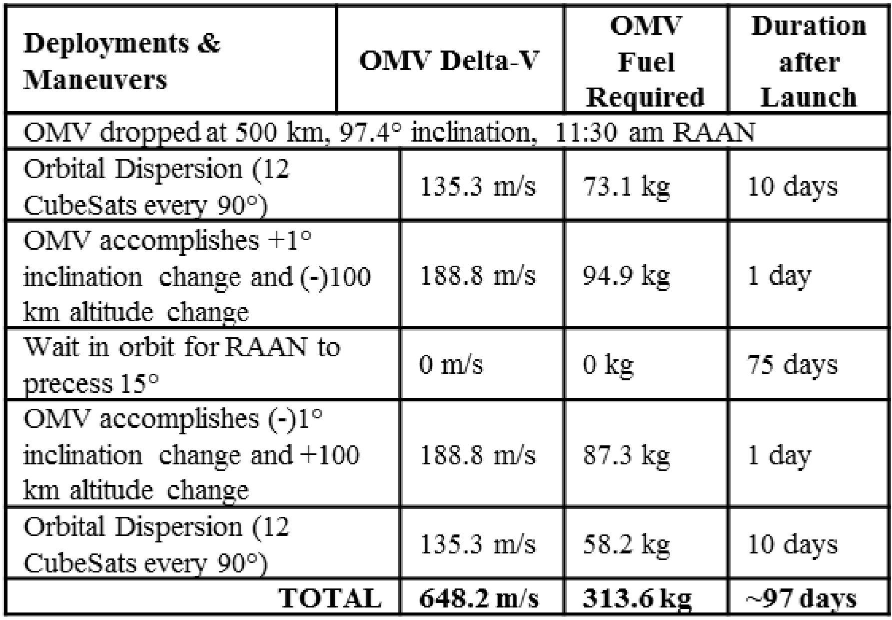
OMV Mass Budget		
Subsystem	**Mass**	
Avionics	7.3	kg
Communications	8.8	kg
Power	32.0	kg
ADCS	25.6	kg
Structure	207.8	kg
Propulsion	66.9	kg
Thermal	10.0	kg
Harness	17.3	kg
Payload	540	kg
Sub-Total	915.7	kg
Hydrazine Propellant	275.4	kg
Total	1191.1	kg

OMV System	Total OMV Mass	Payload Mass	Propellant Mass	Propellant Isp	Delta-V*
360 L Blow-down Hydrazine System	1200 kg	545 kg	275.4 kg	218 s	535 m/s
360 L Pressurized Hydrazine System	1200 kg	450 kg	367.2 kg	235 s	810 m/s
360 L Blow-down HPGP** System	1200 kg	485 kg	334.8 kg	230 s	710 m/s
360 L Pressurized HPGP System	1200 kg	375 kg	446.4 kg	250 s	1090 m/s

*Delta-V values assume a 3% margin included in the propellant mass.
**HPGP = High Performance Green Propellant

Case 1: Earth Observation CubeSat Constellation

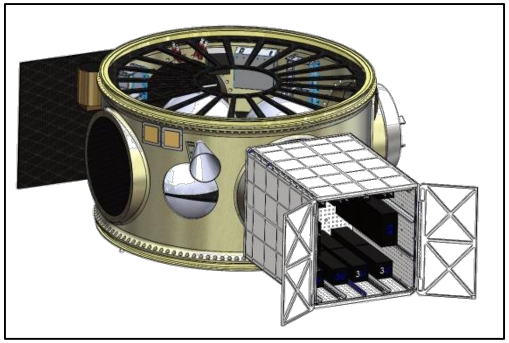
- Baseline parameters:
  - OMV delivers 48 CubeSats to two orbits from a single secondary launch
    - Deploy 24 CubeSats per orbit, dropped at 90° intervals around each orbital plane
- OMV Configuration:
  - 3 standardized deployment devices (16 CubeSats each)
    - FANTM-RiDE concept in conjunction TriSept Corporation
  - HPGP Blowdown System
- CONOPS
  - OMV drops-off 24 CubeSats in initial orbit → Multiple drop-offs around plane
  - OMV makes a 1° inclination change and 100 km altitude change to increase precession rate wrt to initial plane
  - OMV returns to initial inclination and altitude after RAAN precesses 15° → Multiple drop-offs to release remaining 24 CubeSats around plane
  - Total Time: 97 days



Deployments & Maneuvers	**OMV Delta-V**	**OMV Fuel Required**	**Duration after Launch**
OMV dropped at 500 km, 97.4° inclination, 11:30 am RAAN			
Orbital Dispersion (12 CubeSats every 90°)	135.3 m/s	73.1 kg	10 days
OMV accomplishes +1° inclination change and (-)100 km altitude change	188.8 m/s	94.9 kg	1 day
Wait in orbit for RAAN to precess 15°	0 m/s	0 kg	75 days
OMV accomplishes (-)1° inclination change and +100 km altitude change	188.8 m/s	87.3 kg	1 day
Orbital Dispersion (12 CubeSats every 90°)	135.3 m/s	58.2 kg	10 days
TOTAL	**648.2 m/s**	**313.6 kg**	**~97 days**

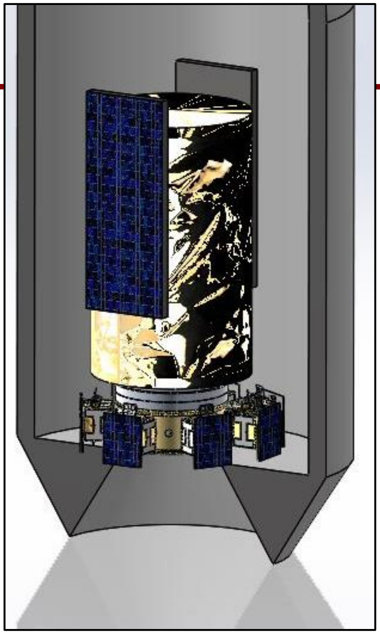
Case 2: CubeSat Carrier to Low Lunar Orbit

- Scenario influenced by the interest in sending CubeSats to lunar orbit and the challenges associated with that architecture
- Baseline parameters
  - OMV delivers CubeSats to Low Lunar Orbit (LLO)
  - OMV acts as a communication relay to Earth
- OMV Configuration
  - 1 FANTM-RiDE: 16 3U CubeSats
  - Pressurized HPGP propellant
- CONOPS
  - OMV dropped in GTO after primary separates from launch vehicle
  - OMV completes multiple burns to increase apogee
  - OMV completes final, large burn to enter Lunar Orbit
  - OMV releases CubeSats incrementally



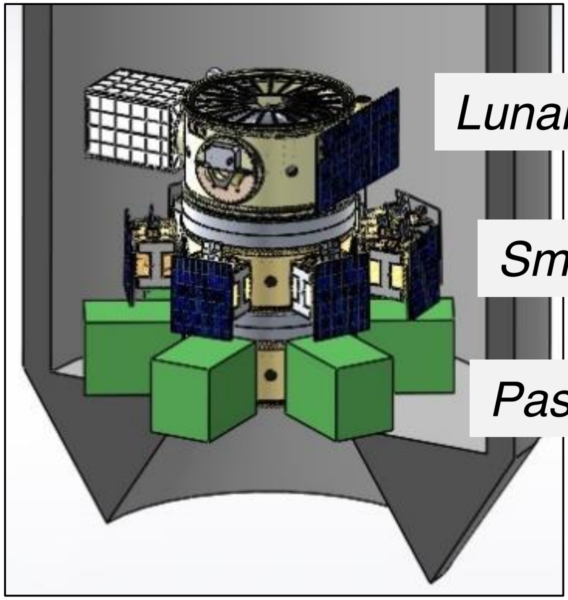
Deployments & Maneuvers	OMV Delta-V	OMV Fuel Required	Duration after Launch
OMV dropped in GTO	0 m/s	0 kg	
Translunar Orbit Injection (1)	240 m/s	102.2 kg	Day 1
Translunar Orbit Injection (2)	240 m/s	92.7 kg	Day 2
Translunar Orbit Injection (3)	240 m/s	84.1 kg	Day 4
Mid-course Maneuver	50 m/s	16.5 kg	
Lunar Capture (at 200 km)	810 m/s	225.3 kg	Day 8
TOTAL	**1580 m/s**	**520.8 kg**	**8 days**

Example Rideshare Configurations



- Primary Spacecraft + OMV to GTO
  - Throw mass more likely to constrain auxiliary payloads than volume
  - Launch to GTO could offer a staging orbit for an OMV's interplanetary or lunar trajectory

- Multiple OMVs to LEO
  - Three Example OMVs:
    - Lunar Tug
    - Smallsat Constellation
    - Passive ESPA Ring
  - Total Mass: 3,264 kg

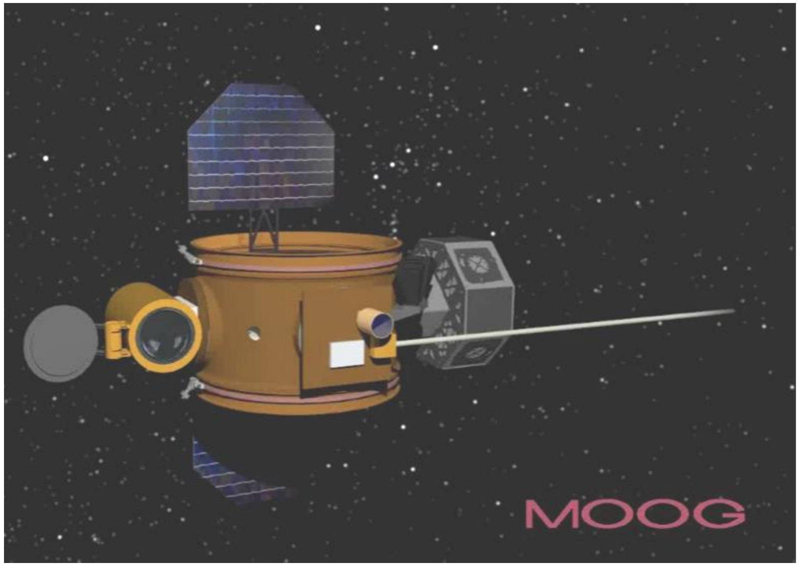


Lunar CubeSat Tug

Smallsat Constellation

Passive ESPA Ring

OMV Conclusions



- The OMV can offer small rideshare payloads:
  - Orbit Optimization
  - Accelerated Constellation Deployment
  - Non-standard Orbits
- An advantage of this propulsive ESPA concept is the vertical integration Moog can leverage. Sourcing components in-house creates a number of benefits, including:
  - Reduction in programmatic costs, lead time and risk
  - Heritage
  - Scalability for numerous applications
- The diverse and growing number of rideshare payloads can take advantage of a greater number of launch opportunities with the flexibility provided by an OMV

Conclusions

- Moog supports the CubeSat community in a variety of ways with solutions for space access
- CubeStack, NLAS, FANTM-RiDE, ESPA, and SoftRide support the growing CubeSat and Small Sat market
- Orbital Maneuvering Vehicle (OMV) provides a flexible and modular solution for a wide variety of space access issues
- OMV can support a range of missions from small to large