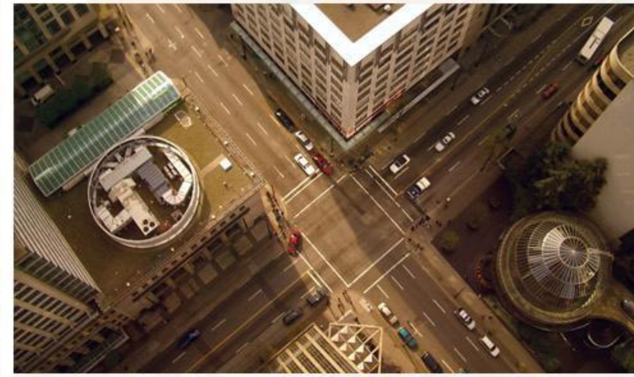




An Orbital Maneuvering Vehicle for Transport Beyond Earth Orbit

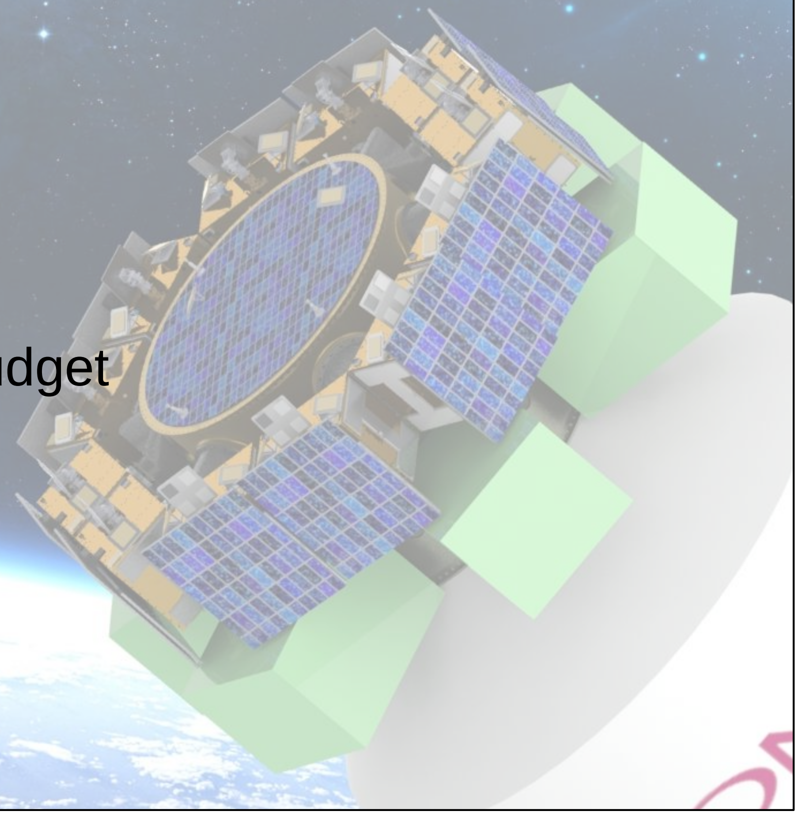
Interplanetary Small Satellite Conference

25 April 2016

MOOG
SPACE AND DEFENSE GROUP

Overview

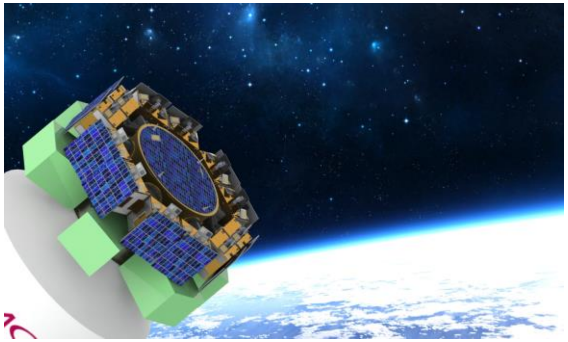
- Secondary Payload Adapters and Dispensers
- Orbital Maneuvering Vehicle
  - Moog's Vertical Integration
  - Beyond Earth Orbit heritage
- Example Lunar Mission
  - Architecture
  - Payload Capacity & Delta-V Budget
  - Mass Budget
- Conclusion

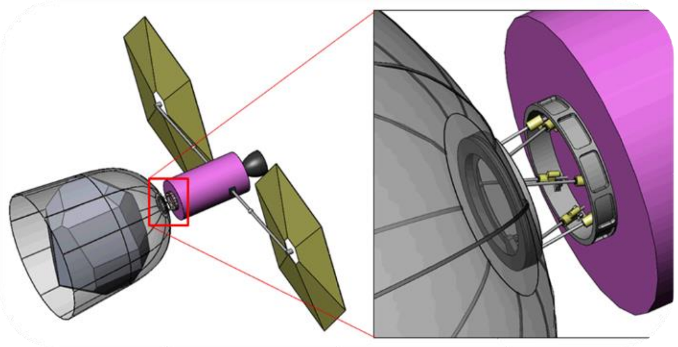


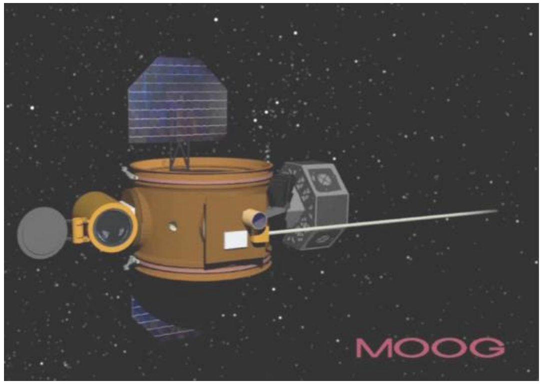
Moog Space Access and Integrated Systems

CubeSat and OMV work is mainly supported by Moog personnel in Golden, CO, Mountain View, CA and Chatsworth, CA

- Moog Integrated Systems provides a focal point to harness the breadth and depth of Moog capability
  - Mission architecture/design
  - Launch strategy
  - Spacecraft systems engineering
- The IS group works with customers at the initial stages to identify and optimize technical, cost, risk and programmatic trades
- Moog has supported trades and developed concepts for:
  - Commercial GPS-RO Weather constellation
  - Commercial Broadband Satellite Mega Constellation
  - NASA Asteroid Return Mission
  - Non-traditional Mars Mission
  - Numerous mission concepts based on an Orbital Maneuvering Vehicle (OMV)

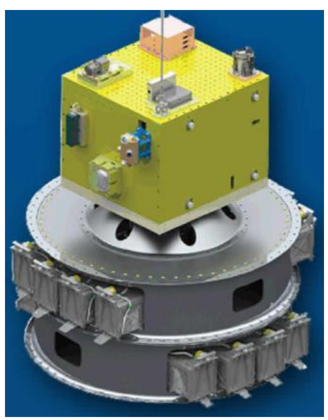


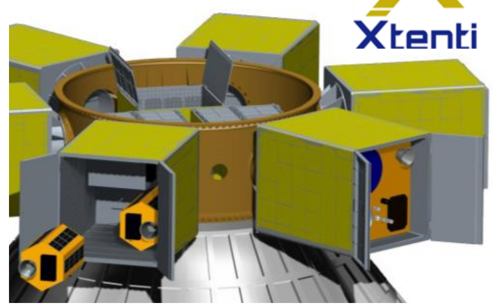


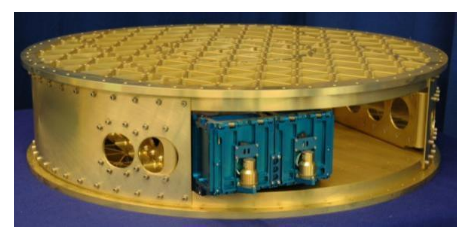


Moog Secondary Payload Adapters For Rideshare

- ESPA: Moog flagship adapter product (up to 300kg secondary payloads)
  - Atlas V, Delta IV, Falcon 9 heritage
- Moog has partnered on the development of nanosat deployers
  - Cubestack and NLAS Wafer adapters: 8x 3U, 4x 6U (or combinations)
  - FANTM-Ride: ESPAsat-sized box, 3U & 6U spacecraft with additional space for central microsat



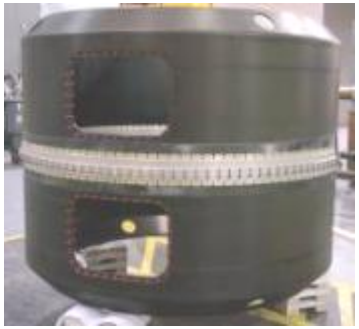




Moog Growing Family of Adapters

ESPA

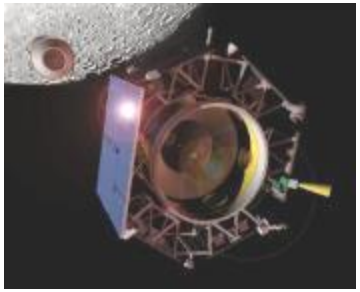
Flat Plate Adapters



CASPAR

CubeSat Wafer

ESPA SUM



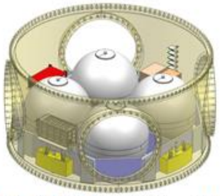
ESPA as Bus:
LCROSS

ESPA 6-15-24 LCROSS

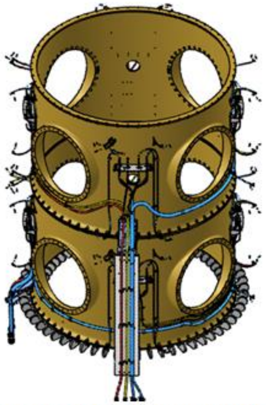
SL ESPA 15

SL ESPA 24

ESPA 4-15-24 DSX



ESPA 4-24-32 SPECIAL OMEGA

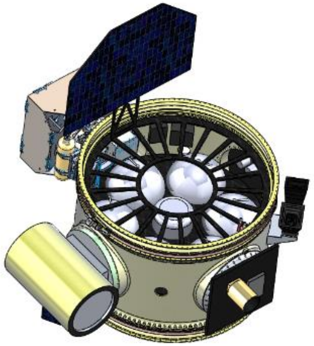


2x ESPA 4-24-42 ORBCOMM

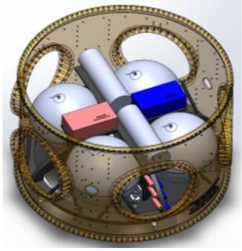
ESPA 2-15-24-4PT EAGLE

ESPA 5-24-42 SHERPA

ESPA n-d-h
n=number of ports, d=port diameter (inches), h=ring height (inches)



OMV



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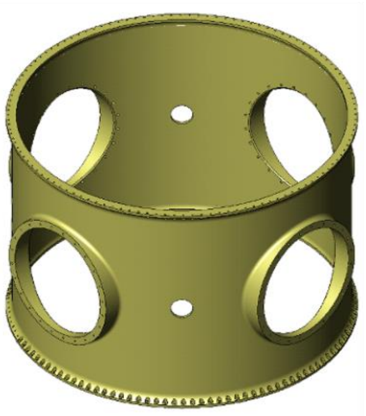
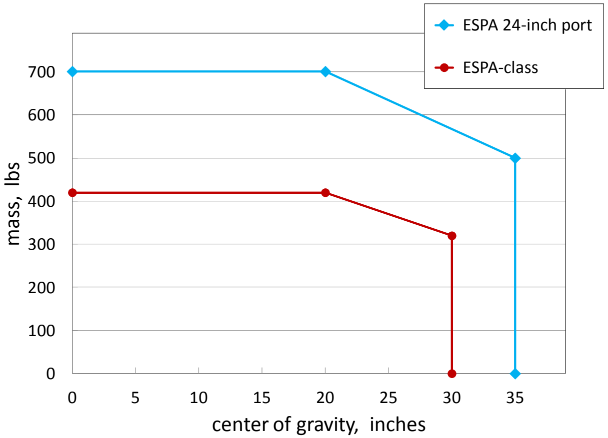
ESPA Grande

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

- OG2 Mission 1 (July 2014) was first use of ESPA for constellation deployment
- Mission 2 launched with 3 rings in December 2015
  - Three 4-port ESPA rings with SoftRide and harness integrated by Moog at SpaceX SLC-40



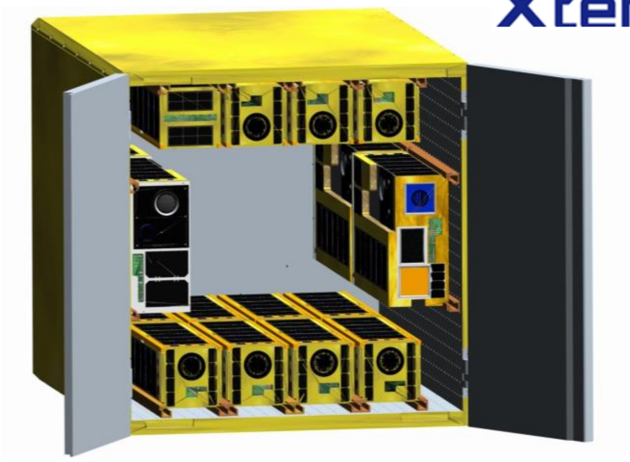


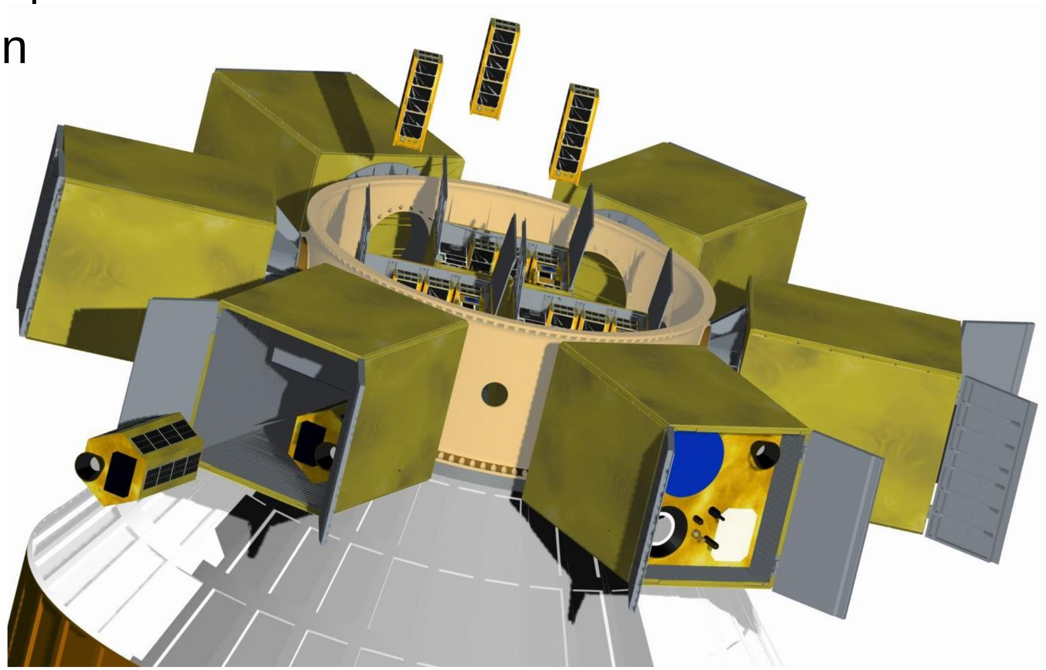
Moog engineers assembling dispenser stack (Photo Credit: ORBCOMM)

FANTM-RiDE™

Configurable enclosure for multi-manifest missions

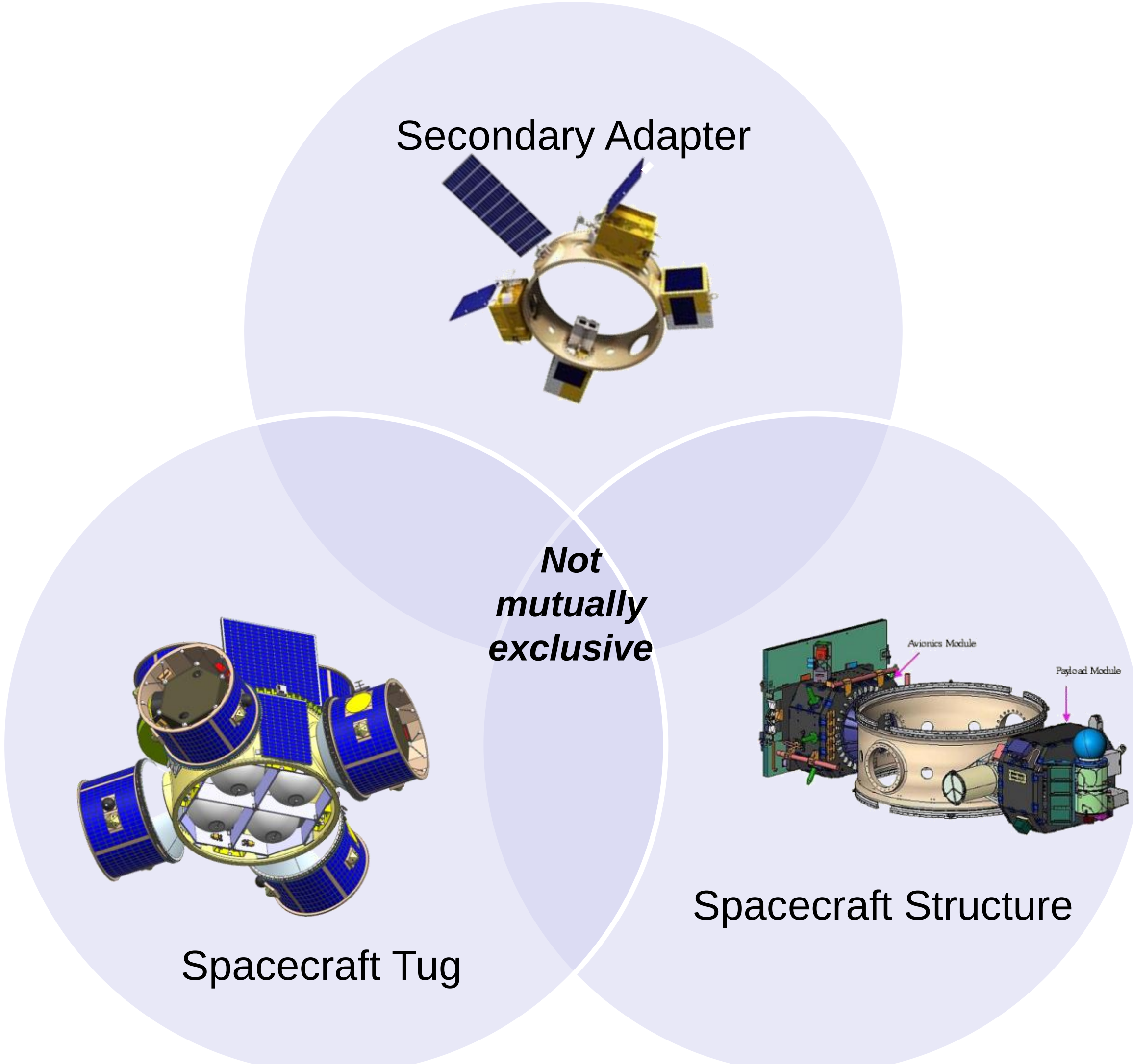
- Collaboration between Xtenti and Moog CSA
- Mix and match CubeSats with microsats and other nanosats in ESPAsat-sized box (610 mm x 610 mm x 812 mm)
  - FANTM-RAIL: CubeSat deployer in development
    - 3U and 6U spacecraft two deep along interior walls, leaving space for central microsat
  - Compatible with multiple launch options
- Mass tuned for flexible integration schedule
  - No need for last-minute coupled loads analysis
- Integration services provided by Xtenti





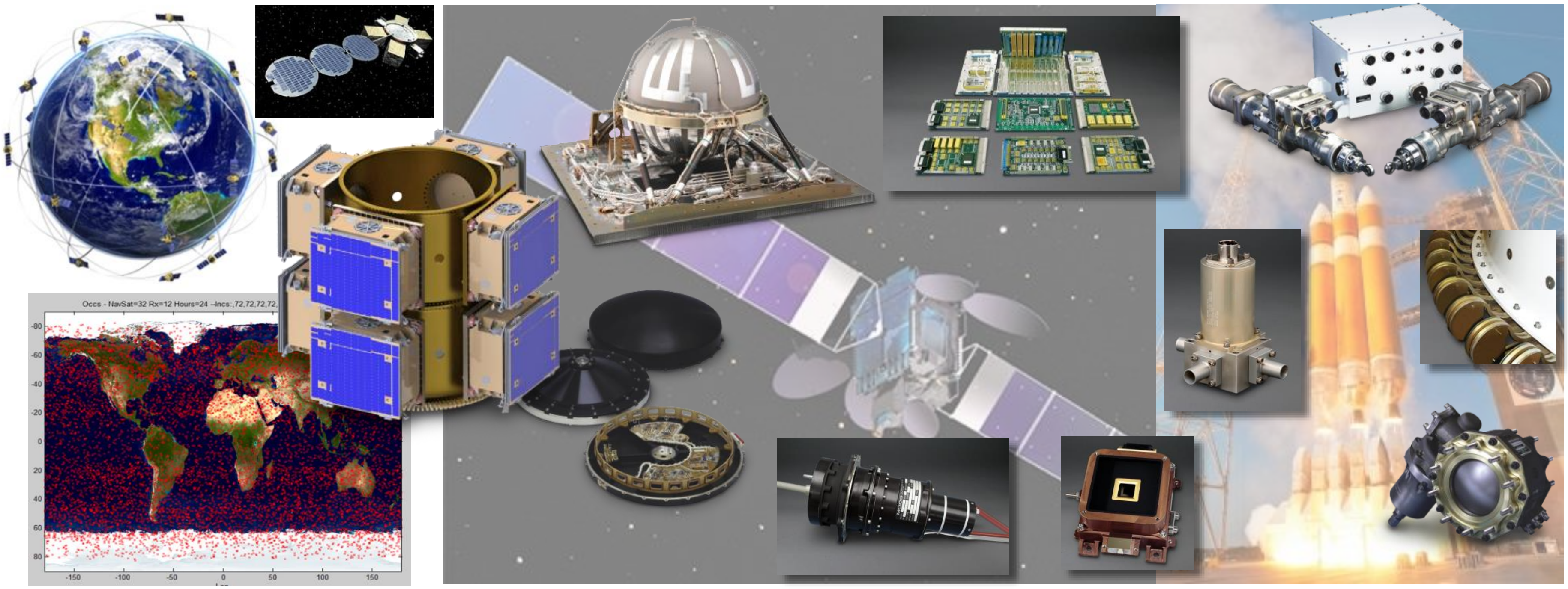
www.fantm-ride.com

Moog OMV Family



The OMV family of applications requires the use of scalable subsystem capability

OMV: Taking Advantage of Moog's Vertical Integration

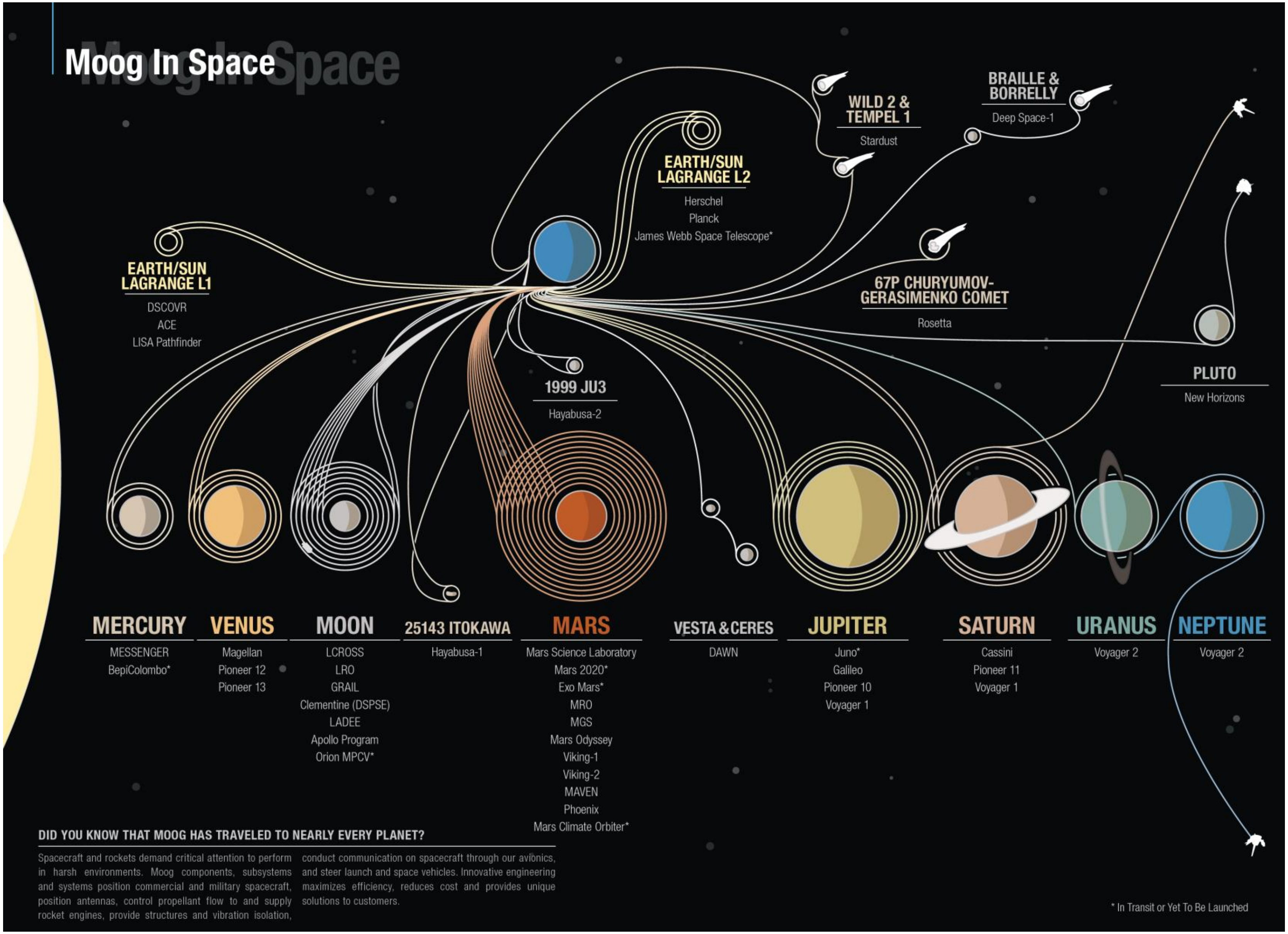


- Core structure – Moog ESPA
- Moog Integrated Avionics Unit (IAU)
  - Flight computer
  - On-Board Data Handling (OBDH)
  - Power conditioning and switching
  - Precision Orbit Determination

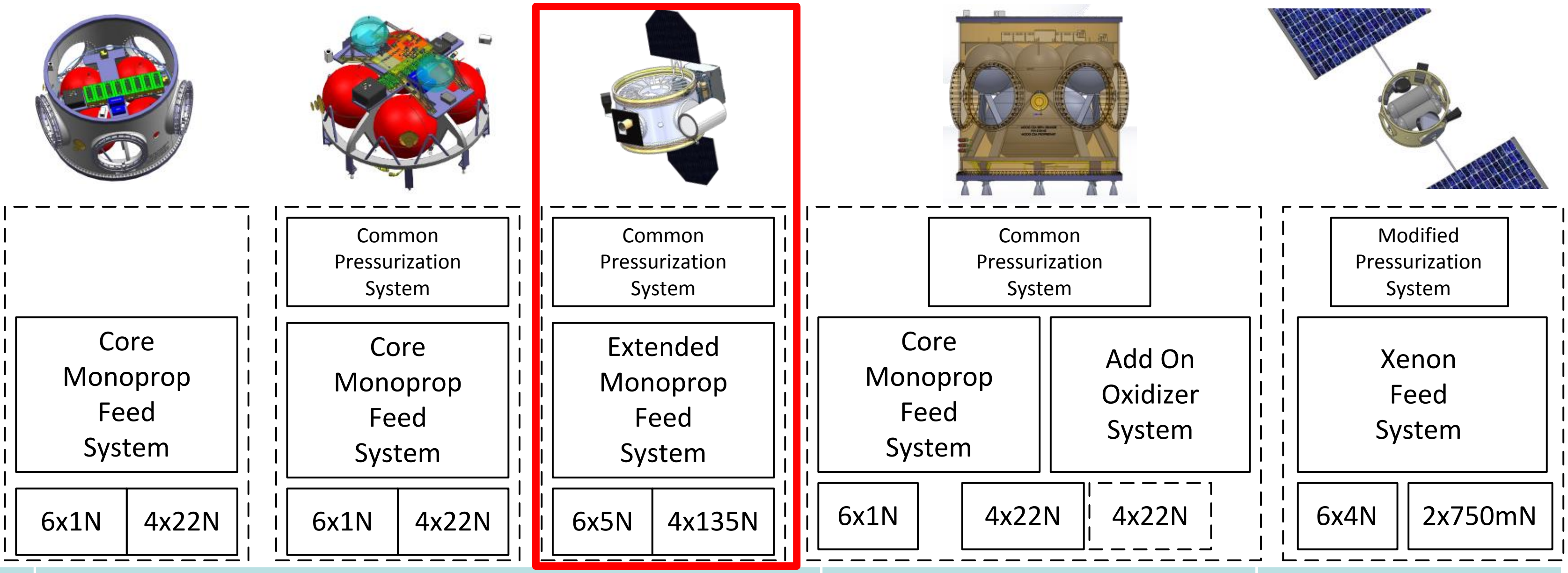
Chemical propulsion systems
Flight software
ACS actuators and sensors
Solar array / antenna pointing
EGSE & mission simulation software

Each OMV is specifically tailored for the mission requirements.

Moog In Space



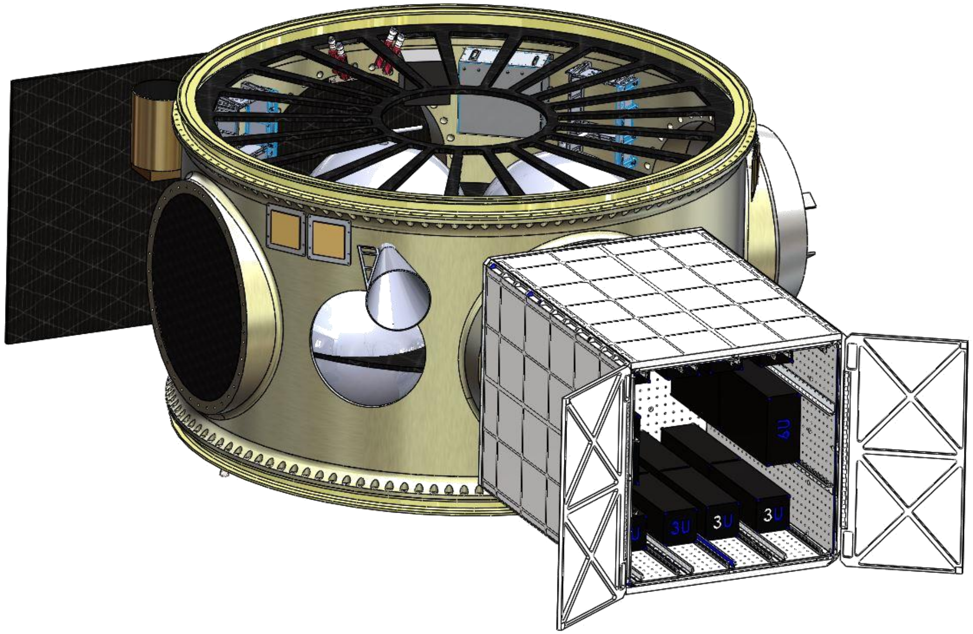
OMV Variants – Propulsion System Capabilities



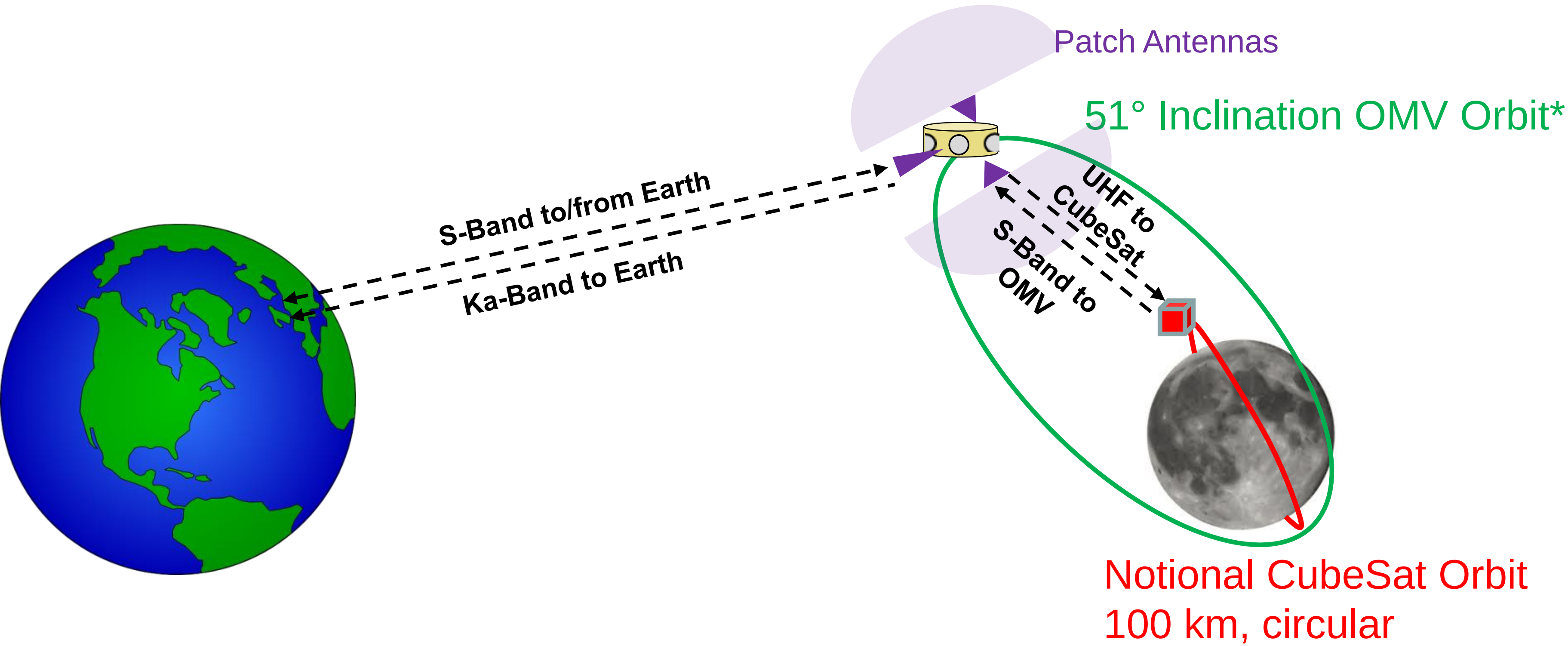
Parameter	Monopropellant			Bipropellant	Electric
Propellant	Hydrazine or LMP-103S			Hydrazine/NTO dV + Hydrazine ACS	SEP: Xenon Cold Gas ACS
dV Thrust	88 N	88 N	540 N	88 N or 176 N	1.5 N
ACS Thrust	1 N each	1 N each	5 N each	1 N each	4 N each
Prop Volume	234 liters	312 liters	611 liters	700 liters	130 liters
OMV Payload Performance at Various Delta-Vs (Monopropellant: Hydrazine to LMP-103S Range)					
400 m/s	800-1200 kg	1200-1800 kg	2700-3800 kg	5275 kg	N/A
1600 m/s	N/A	N/A	110-340 kg	580 kg	N/A
5000 m/s	N/A	N/A	N/A	N/A	600 kg

Lunar OMV for CubeSat Transportation and Communications

- Moog collaborated with Tyvak to understand the communications challenges for a small satellites at the moon
- Single payload carrying dispenser
  - FANTM-RiDE deployment device
  - 10 x 3U CubeSats
- Communications system tailored to simplify small satellites communications requirements
- Lightweight ESPA to minimize structural mass
- Propellant: Pressurized HPGP

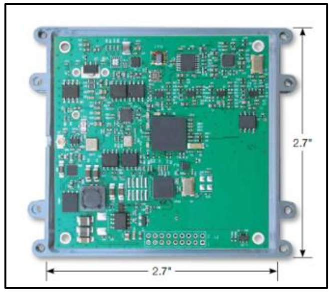


Lunar Communications Hub Example



Small Deep Space Transponder + SSPA (LRO Heritage) on OMV

L3 Cadet Nanosat Radio on OMV



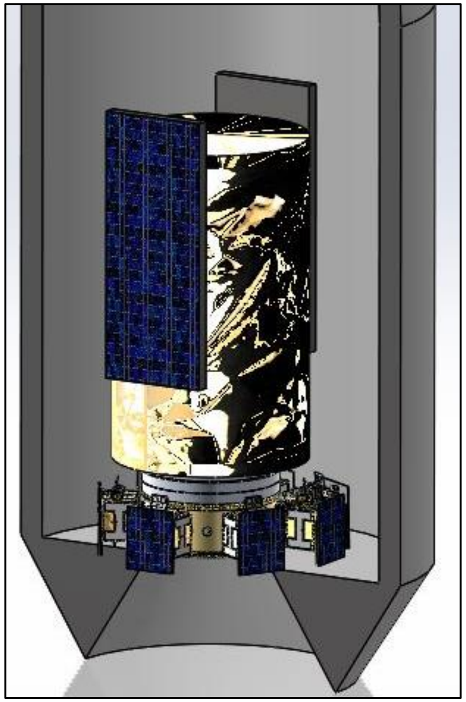
Benefits to Small Satellites

- Utilize existing radios
- Maintain low power options
- Less stringent pointing requirements
- Higher data throughput
- Lower cost (DSN not required)

**Reference: http://science.nasa.gov/science-news/science-at-nasa/2006/30nov_highorbit/*

Launch & Lunar Transfer

- Shared Launch Configuration
  - Dropped in GTO
  - Translunar Orbit Injection = Three Maneuvers + Lunar Capture
- Options utilizing weak stability boundary orbits are also under consideration depending on mission time constraints & excess launch vehicle capacity



Example secondary launch configuration

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**

Reference: Biesbroek, R. and Janin, G. "Ways to the Moon." ESA Bulletin 103, August 2000.

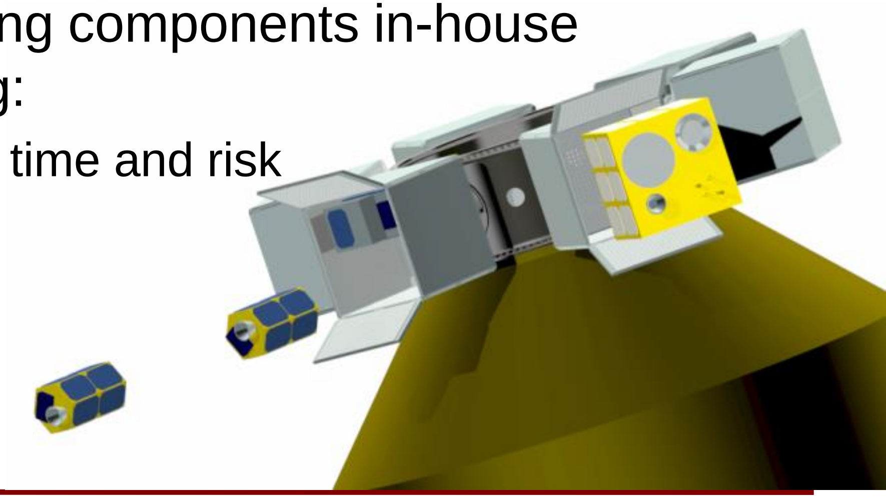
Mass Budget and Delta-V: 100 kg Payload

Mass Summary		
Subsystem	**Contingency + Mass**	
Avionics	7.3	kg
Communications	8.8	kg
Power	32.0	kg
ADCS	25.6	kg
Structure	207.8	kg
Propulsion & Pressurization System	66.9	kg
Thermal	6.2	kg
Harness	17.3	kg
Payload	100.0	kg
SubTotal	471.9	kg
HPGP Propellant	446.4	kg
Total	918.3	kg

Total Delta-V Capability: 1580 m/s with 10 kg margin

Conclusions

- An architecture that leverages Small Payloads + OMV opens up numerous possibilities for exploration beyond Earth's orbit and scientific discovery
  – Example simplified transportation for carrier and small payloads to reach orbit via a commercially procured GTO drop-off
  – Cost savings enabled by a shared launch and the ability to ferry multiple small payloads with diverse missions
  – Continued communications support to small payload missions after reaching their destination orbit (e.g. Lunar)
  – Offers secondary payloads an alternative lunar option to the EM-1 launch
- 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



Contact Info

Please contact us with any ideas and/or potential applications for this technology you would like to discuss

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