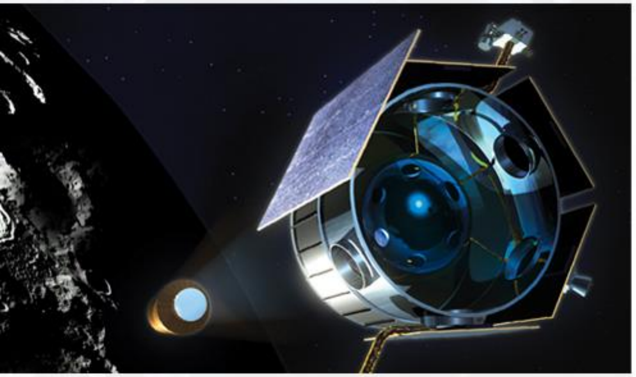
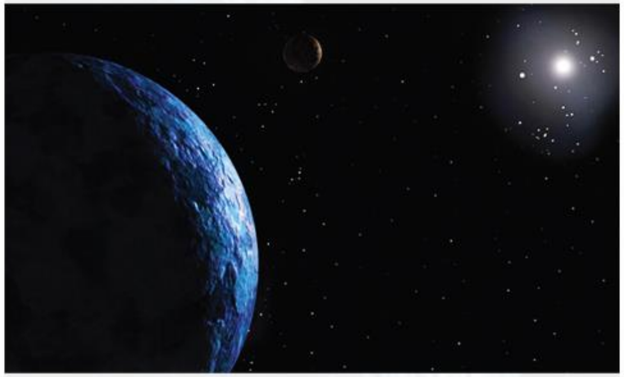




An Orbital Maneuvering Vehicle for Transport Beyond Earth Orbit - Updated

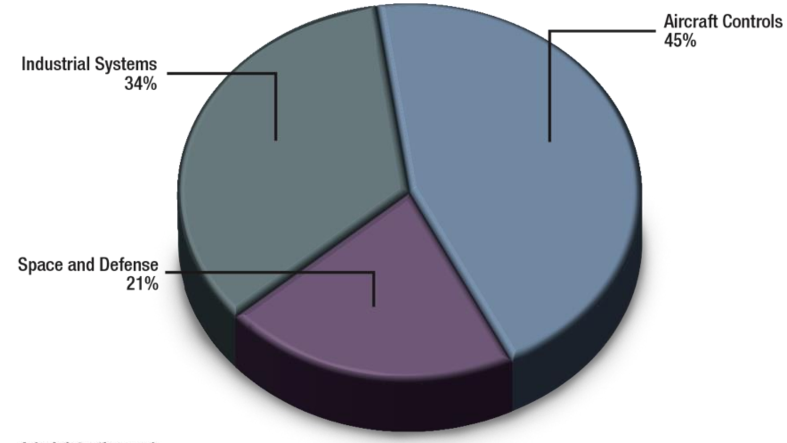
International Small Satellite Conference (ISSC)

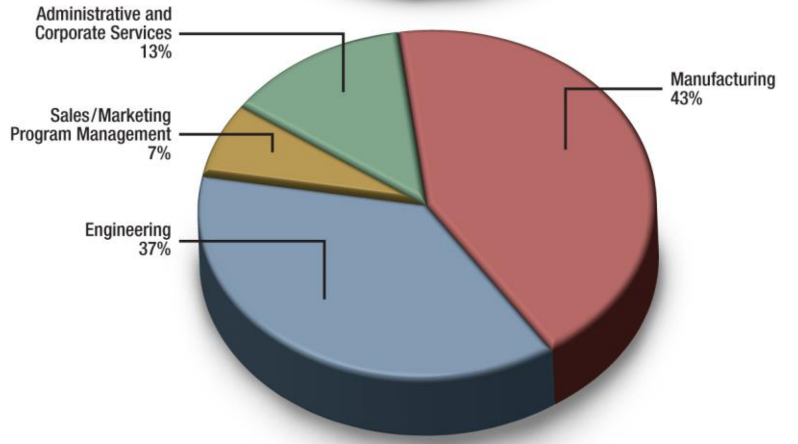
May 7, 2018

MOOG
SPACE AND DEFENSE GROUP

Company Background

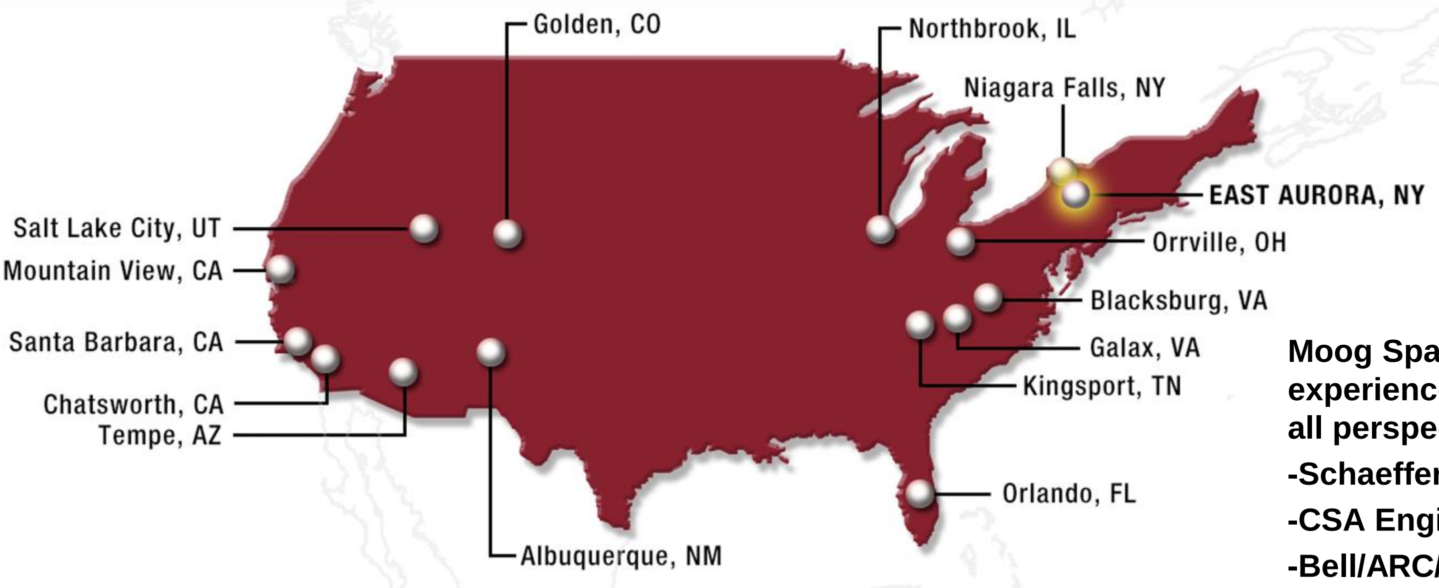
- **Founded in 1951 by Bill Moog**
- **Headquarters in East Aurora, NY**
  - Over 300 Acre Facility
- **Global Company**
  - 25 Countries
- **~11,000 Employees Worldwide**
- **$2.50 Billion in Revenue** (FY 2017)
- **Aerospace, Defense, Industrial**
- **Precision Control Systems Solutions and Component Provider**





MOOG SPACE AND DEFENSE GROUP

Moog Space and Defense Group Information



Moog Space leverages the unique experience from acquisitions to include all perspectives in the Space market

-Schaeffer Magnetics

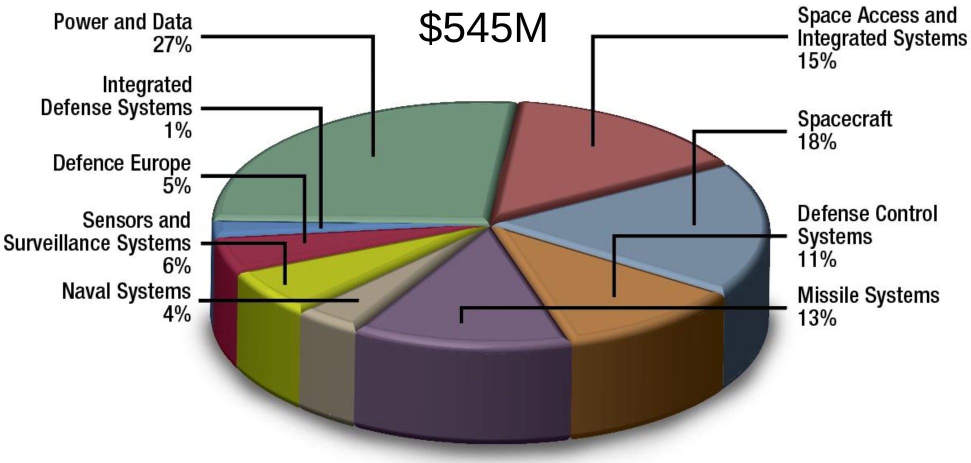
-CSA Engineering

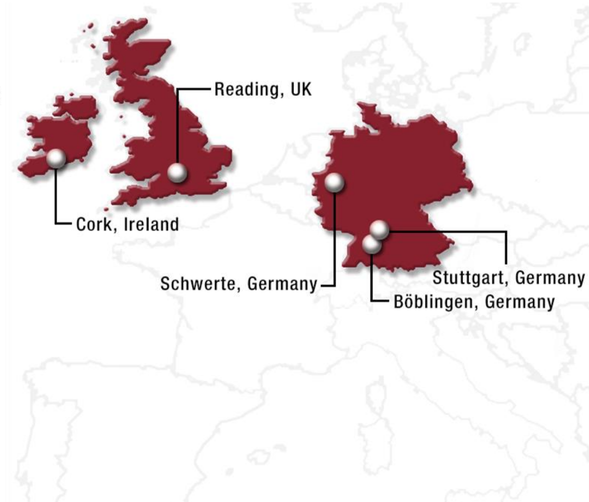
-Bell/ARC/AMPAC In-Space Propulsion

-Broad Reach Engineering

2017 Sales

$545M

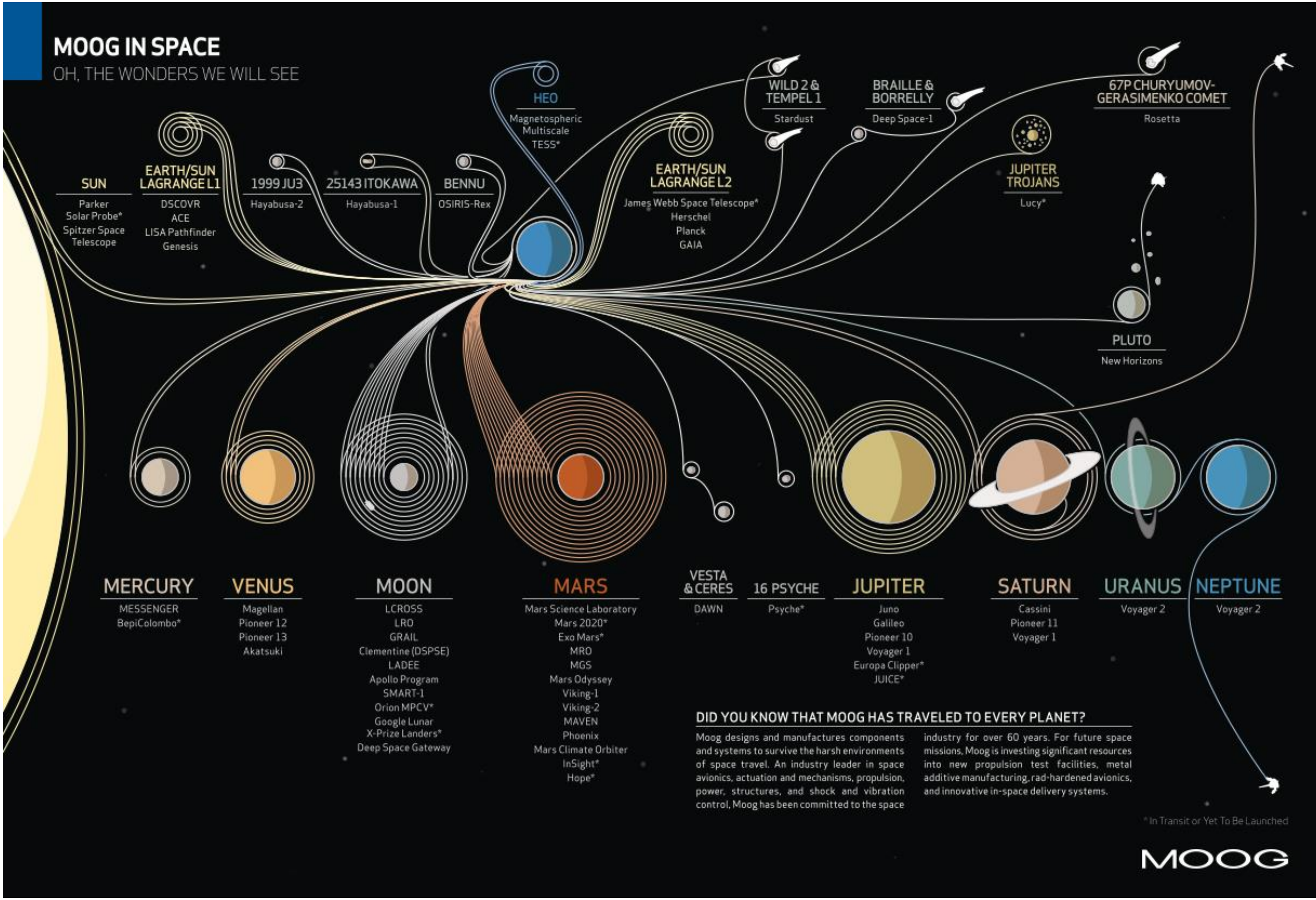




MOOG SPACE AND DEFENSE GROUP

Solutions for Every Stage of a Space Mission

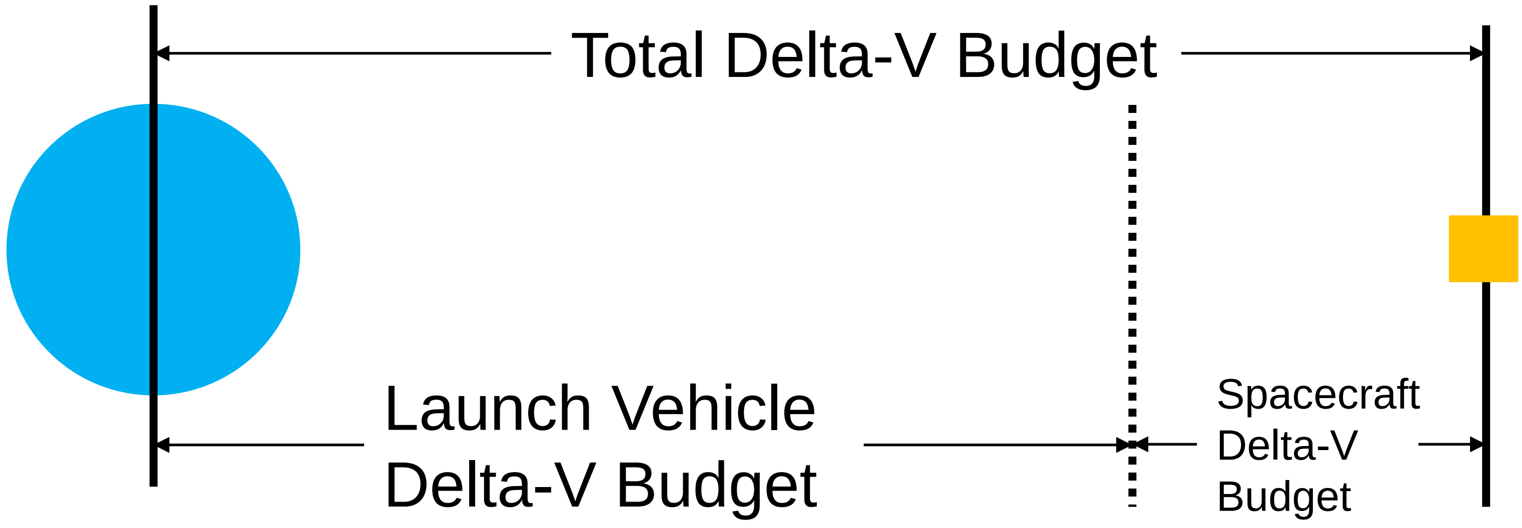
Moog Hardware Has Traveled to Every Planet

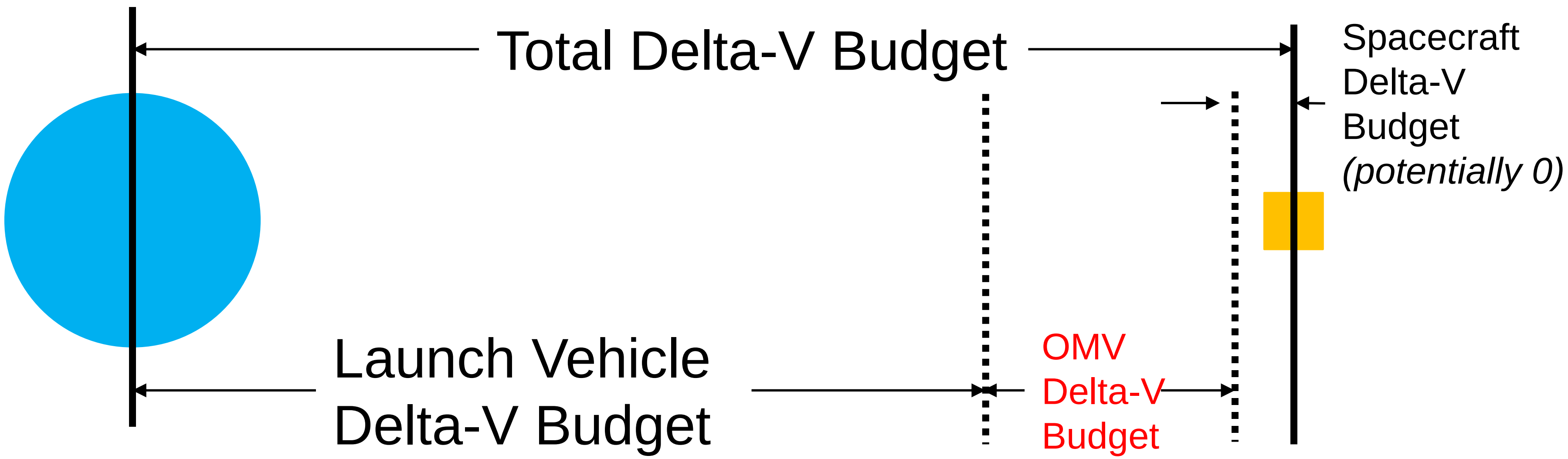


This document does not contain Technical Data or Technology as defined in the ITAR Part 120.10 or EAR Part 772

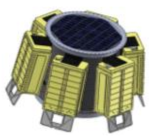
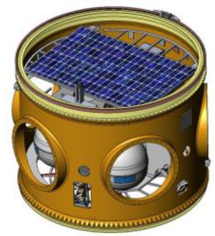
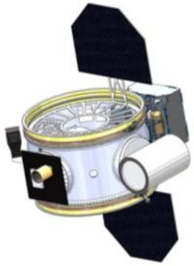
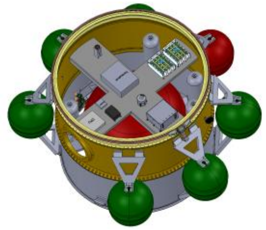
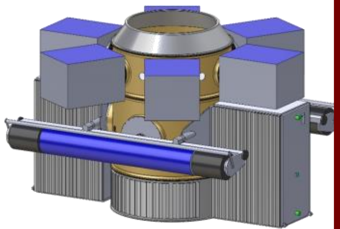
MOOG SPACE AND DEFENSE GROUP

Delta-V Budget Sharing (aka dV α Time α $$)





Moog OMV Family

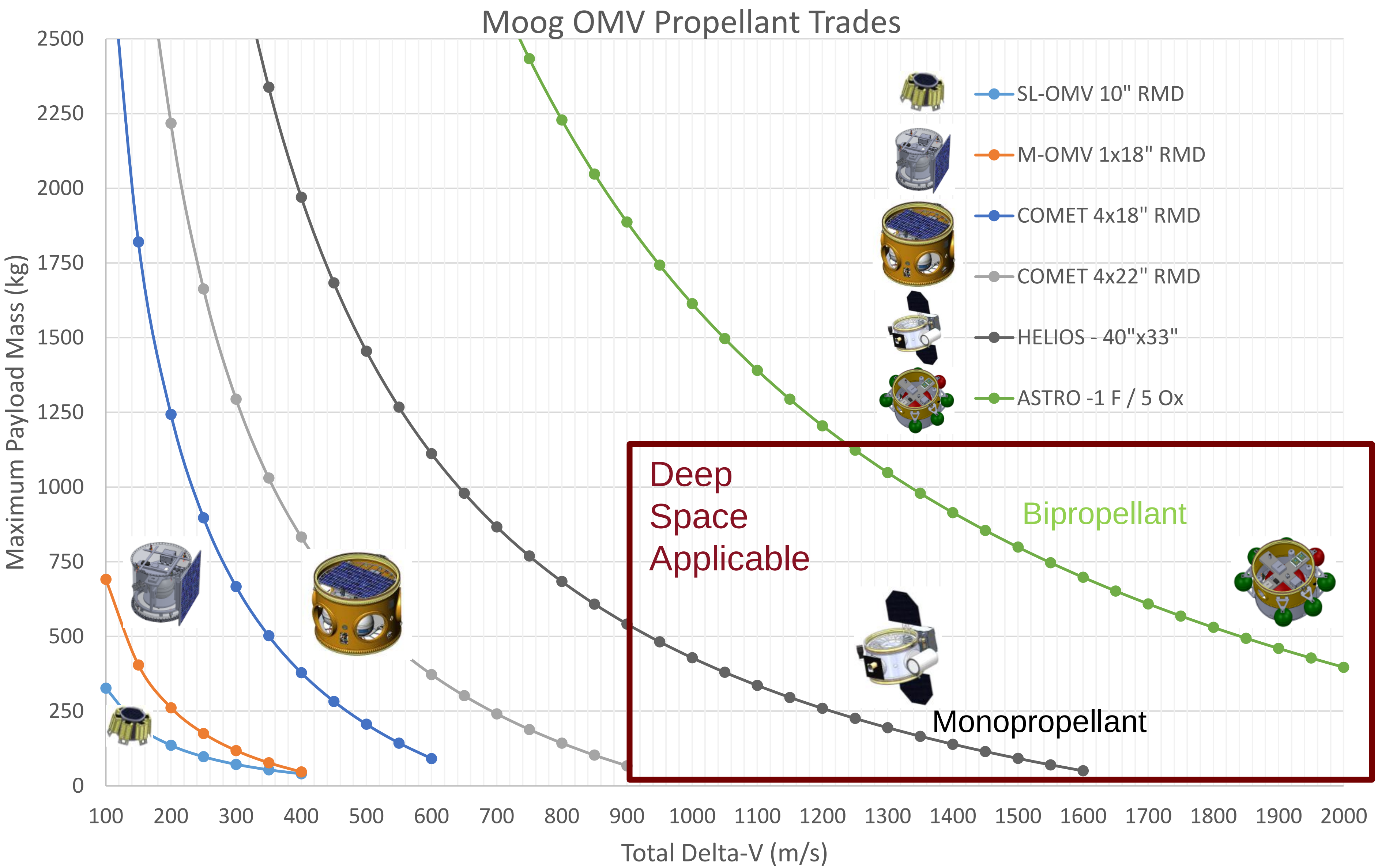
SL-OMV	M-OMV	COMET	HELIOS	ASTRO	JUPITER
					

Parameter	Monopropellant				Bipropellant	Electric
Propellant	LMP-103S	Hydrazine			Hydrazine/NTO dV + Hydrazine ACS	SEP: Xenon Cold Gas ACS
dV Thrust	4N	140 N		540 N	176 N	1.2 N
ACS Thrust	1 N each	1 N or 5 N each			5 N each	4 N each
Prop Volume	13.7 liters	38 liters	153 liters (245 liter option)	454 liters	700 liters (total)	>130 liters
100 m/s	327 kg	691 kg	2975 kg	N/A	N/A	Designed for 5000 kg to 6000 m/s
200 m/s	136 kg	261 kg	1243 kg	4552 kg		
400 m/s	40 kg	47 kg	378 kg	1970 kg	5319 kg	
1000 m/s	N/A	N/A	N/A	428 kg	1616 kg	
1600 m/s				50 kg	700 kg	
2000 m/s				N/A	400 kg	

Deep Space Applicable

MOOG SPACE AND DEFENSE GROUP

Moog OMV Family – Mass/Delta-V Performance



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OMV CONOPS - Science Orbits

- Many science missions are interested unique orbits where Rideshare is difficult (e.g. L1, L4/L5, Lunar, etc…)
- OMV can be used as part of a GTO rideshare to transfer to several orbits
- In addition to reaching the desired orbit, OMV can be used as part of the mission or even a Hosted Payload Platform (HPP)
  - Particularly interesting when mixing missions/customers to lower costs
- Moog has assessed the following orbits:
  - Elliptical Earth Orbit at unique inclinations
  - Earth Sun L1 (ESL1)
    - Reference Small Satellite Paper SSC15-II-5
  - Earth Sun L4/L5 (ESL4/L5)
  - Lunar (from GTO and SLS)
  - Mars Transfer Orbit
    - As a "drop stage" for a Mars spacecraft

Table 1: Delta-V Budget

Activity	Delta-V
Launch Vehicle drops OMV in GTO	n/a
OMV Perigee Burn	250 m/s
OMV Perigee Burn	250 m/s
Escape Burn to Transfer Orbit	250 m/s
Trajectory Correction Maneuver	10 m/s
L1 Halo Orbit Insertion	200 m/s
Station Keeping	220 m/s
Wheel Desaturation	10 m/s
Disposal Maneuver	10 m/s
Margin (5%)	56 m/s
TOTAL	1261 m/s

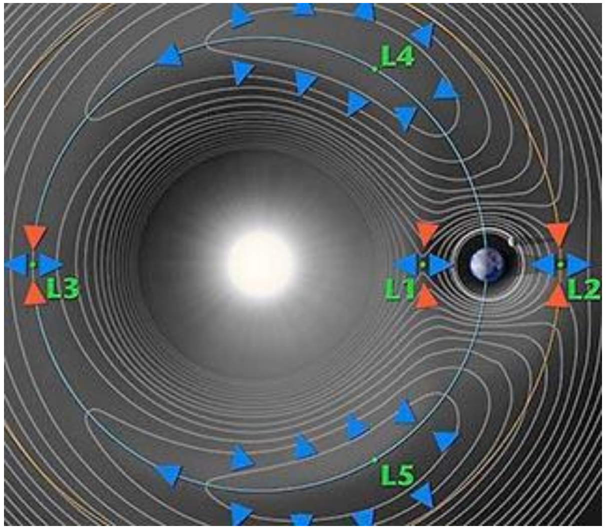
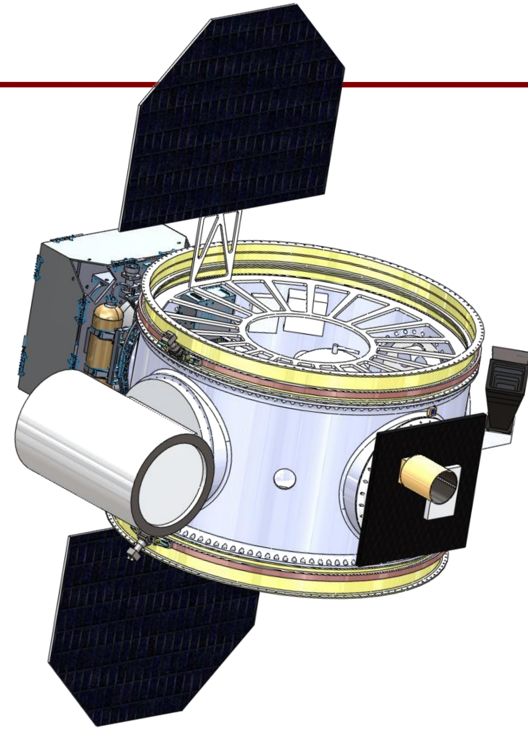


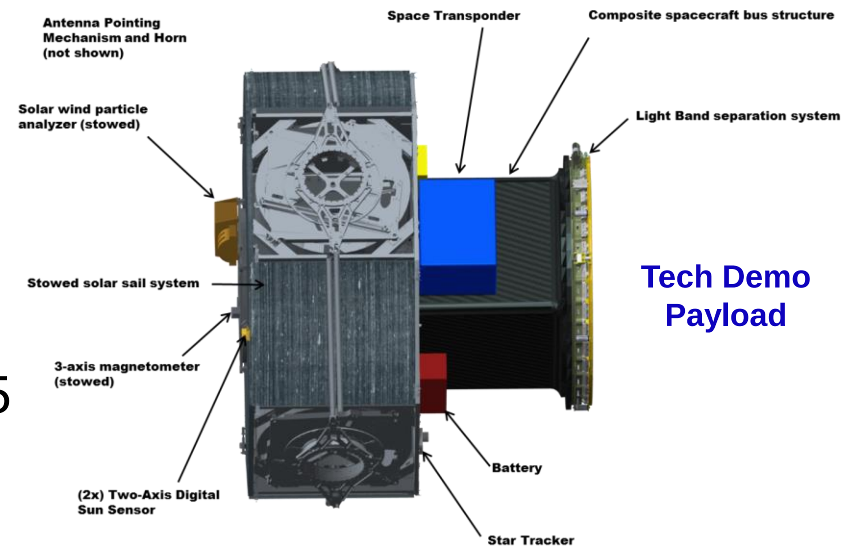
Photo Credit: NASA WMAP # 990529

MOOG SPACE AND DEFENSE GROUP

NASA Partnerships (1/4)

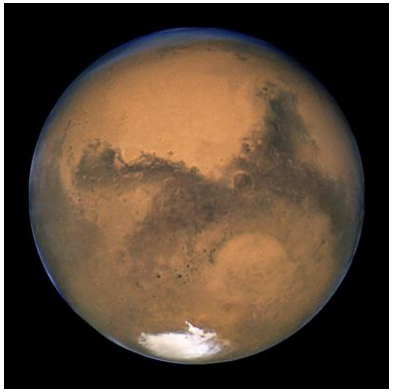
- Moog has teamed with NASA Ames and NASA Langley on a multi-purpose mission concept based on an OMV
  - Motivated by the need for a low-cost platform to fulfil operational and hosted payload missions at the Earth-Sun L1 using a rideshare compatible platform
- Mission Concept
  - Moog worked directly with both sites collaboratively to iterate on mission CONOPS
  - Moog and NASA came up with a flexible workshare leveraging the best of each organization
  - OMV architecture is flexible to handle this mission concept and easily convertible to other concepts
- Paper published and presented at 2015 Small Sat Conference
  - SSC15-II-5

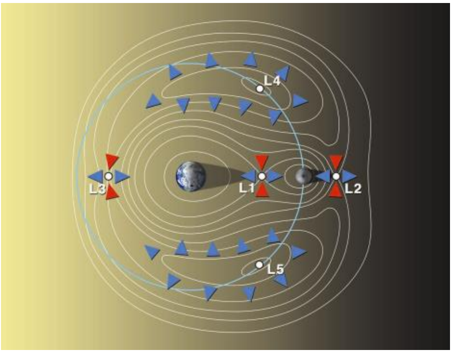


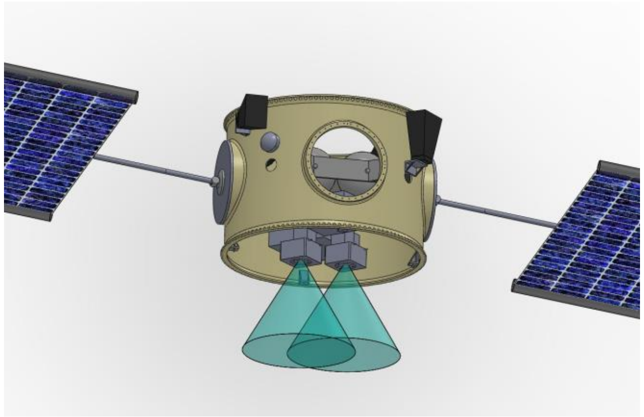


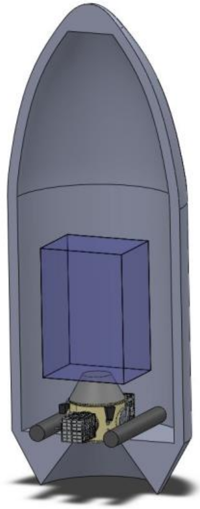
NASA Partnerships (2/4)

- Moog has worked with NASA Marshall as part of a Cooperative Agreement Notice (CAN)
- The CAN has been to investigate mission concepts enabled by an OMV
  - Initial concept for an “ESPA stack”
- Concepts with a High Power Solar Electric Propulsion (HP-SEP) OMV
  - Science Missions
    - Helio, Astrophysics, Lunar, Mars, and beyond Mars
  - Space Asset Management (SAM)
    - Hubble
    - ENVISAT
    - Rocket Bodies and other defunct satellites
- Paper published and presented at Reinventing Space 2016 in London
  - BS-RS-2016-28

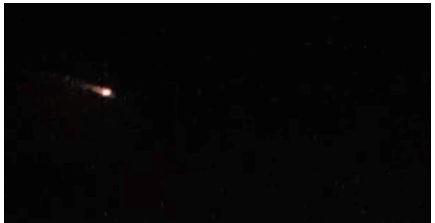








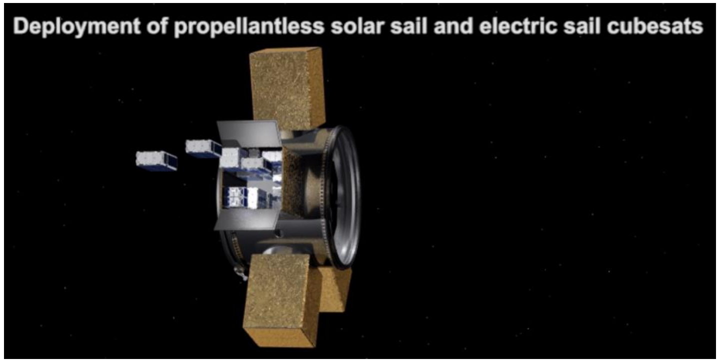

WT1190F – Nov 13, 2015

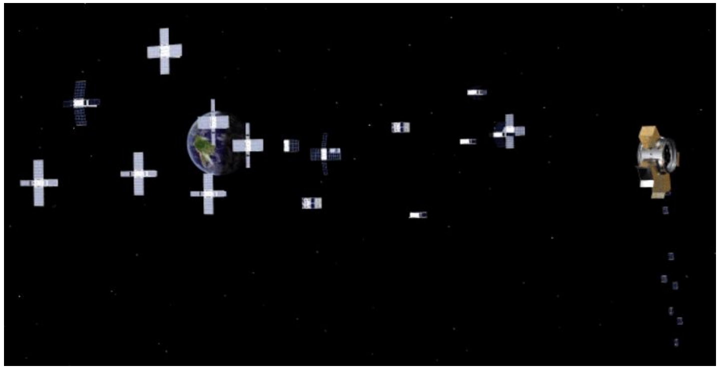

Soyuz – Dec 23, 2015

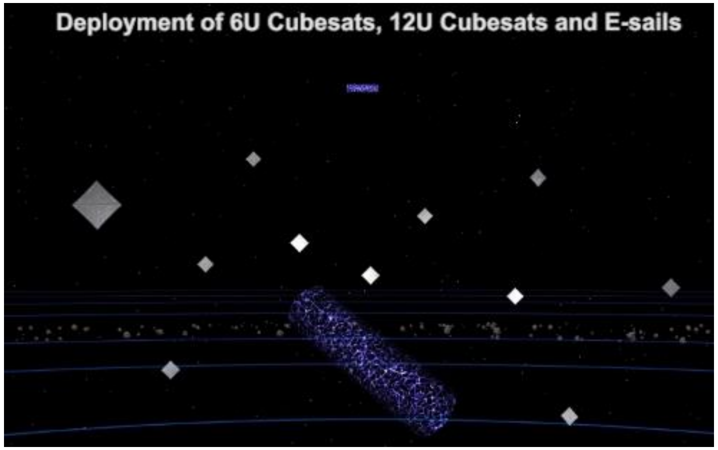
MOOG SPACE AND DEFENSE GROUP

NASA Partnerships (3/4)

- Moog has worked with NASA Marshall on a separate program to support a NASA Innovative Advanced Concepts (NIAC) for an Electric Sail (E-Sail)
- E-Sail can only work once it is outside of Earth's Magnetosphere so requires a transfer vehicle
- OMV can be used to carry several E-Sails including traditional Solar Sails
  - Launch on a GTO or SLS launch
- NASA MSFC presented paper and video at Small Sat 2017 and AIAA SciTech 2018



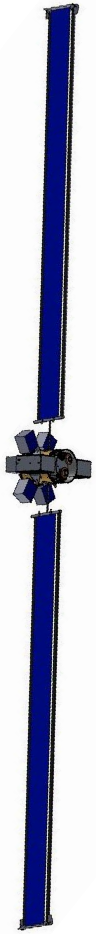


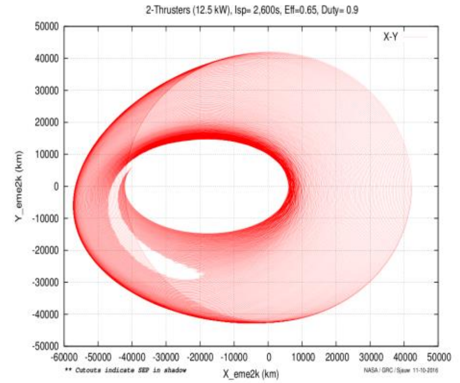


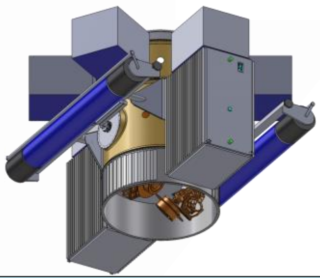
MOOG SPACE AND DEFENSE GROUP

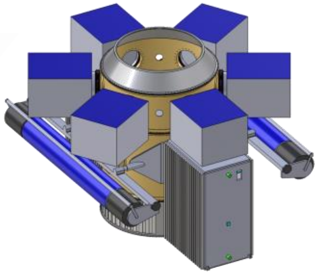
NASA Partnerships (4/4)

- Moog recently engaged with NASA Glenn under a Space Act Agreement (SAA) to further evaluate the HP-SEP OMV
  - Demonstrates large, light Flexible solar arrays (17 kW each)
  - Demonstrates high power Hall thrusters (12 kW) and throughput >900 kg xenon per engine
  - Demonstrates Orbit raising and maneuvers with large SEP system and radiation impact on arrays
  - Carries up to Six Smallsats to GEO
  - Can extend to Lunar Orbit
- Paper published and presented at International Electric Propulsion Conference (IEPC) 2017
  - IEPC-2017-396





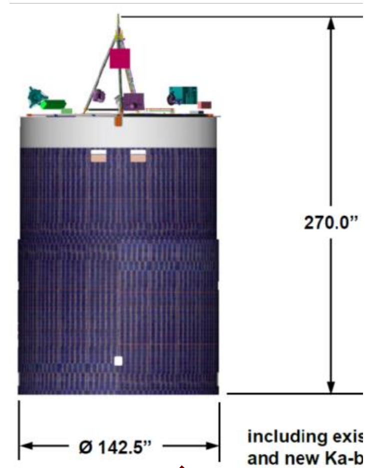




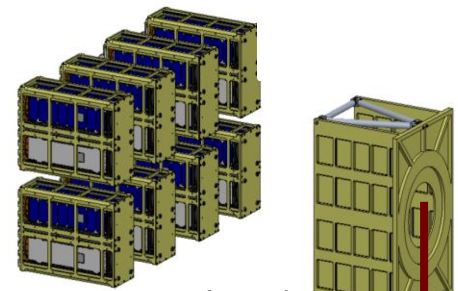
Spacecraft MEL Rack-up (Mass) - Case #1 ESPA OMV 2016 CD-2016-139				
Main Subsystems	Basic Mass (kg)	Growth (kg)	Predicted Mass (kg)	Aggregate Growth (%)
ESPA OMV	3094.2	184.8	3278.9	
Power and Propulsion Module	3040.5	178.7	3219.2	6%
Electrical Power Subsystem	301.0	97.8	398.8	32%
Thermal Control (Non-Propellant)	92.0	16.6	108.6	18%
Propulsion (EP Hardware)	337.1	33.7	370.7	10%
Propellant (EP)	1890.0		1890.0	0%
Structures and Mechanisms	420.4	30.7	451.1	7%
Estimated Spacecraft Dry Mass (no prop,consum)	1150.5	178.7	1329.2	16%
Estimated Spacecraft Wet Mass	3040.5	178.7	3219.2	
System LeveL Growth Calculations Power and Propulsion Module				Total Growth
Dry Mass Desired System Level Growth	937.5	281.3	1218.8	30%
Additional Growth (carried at system level)		102.6		11%
Total Wet Mass with Growth	3040.5	281.3	3321.8	
Demo Control Module	53.6	6.1	59.7	11%
Attitude Determination and Control	16.3	0.5	16.8	3%
Command & Data Handling	16.8	2.9	19.6	17%
Communications and Tracking	6.5	0.2	6.7	3%
Thermal Control (Non-Propellant)	14.1	2.5	16.6	18%
Estimated Spacecraft Dry Mass	53.6	6.1	59.7	11%
Estimated Spacecraft Wet Mass	53.6	6.1	59.7	
System LeveL Growth Calculations Demo Control Module				Total Growth
Dry Mass Desired System Level Growth	53.6	16.1	69.7	30%
Additional Growth (carried at system level)		10.0		19%
Total Wet Mass with Growth	53.6	16.1	69.7	

ESPA/OMV Form Factor for SLS

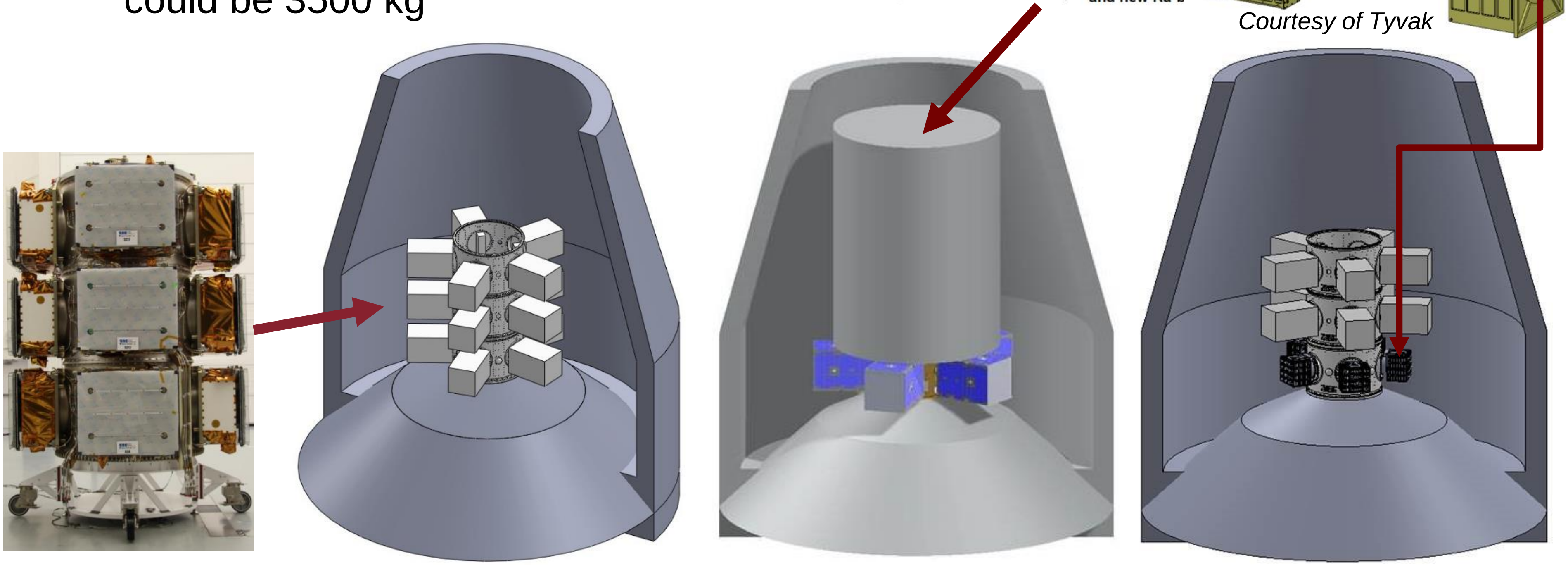
- SLS has very large volume but potentially < 6000 kg CPL Mass
- Each ESPA can carry over 2000 kg of Secondary Payload
- Propulsive ESPA is 550 kg minimum (up to 1500 kg for Bipropellant variant)
- Single Propulsive ESPA and Full Payload could be 3500 kg



18x6U CubeSats Can fit on a single 24” port



Courtesy of Tyvak



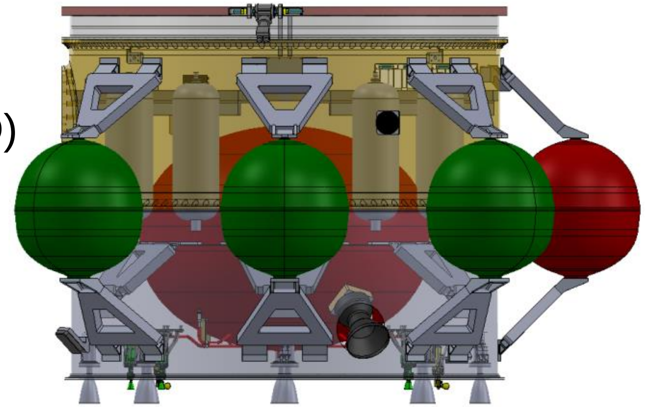
METEOR - Maneuverable ESPA Tug for Extended Orbital Range

- Enhanced version of COMET focused on being Hosted Payload Platform (3 year life) including operations in LEO, GEO, or beyond
- Key Specifications
  - Vehicle mass 398 kg, Propellant mass 153 kg
  - Monoprop hydrazine
    - 6 x 1N ACS thrusters , Isp = 231 s
    - Option: 4 x 22N DeltaV thrusters, Isp = 233 s
  - 6 DOF control including Reaction Wheels
  - Higher Data Rate up to Ka-Band
  - 4-, 5-, or 6-port ESPA ring, 42" tall, 62" diameter
    - One port potentially occupied with downlink antenna
  - Up to 1500 kg of Port-mounted Payload
  - Orbit: LEO, GEO, Lunar, Lagrange Points
- Baseline Mission Class: Hybrid C/D
- 24-28 months ATP to Launch

HELIOS and ASTRO

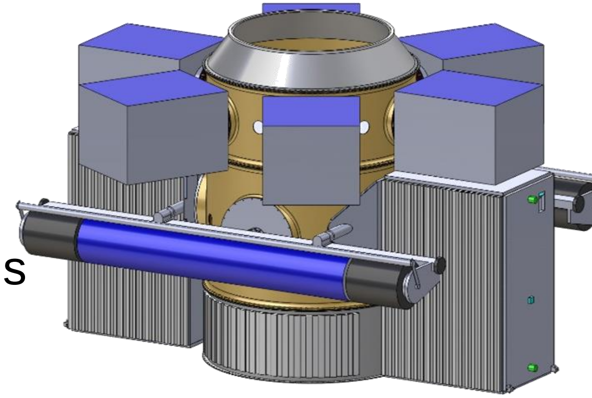
- HELIOS and ASTRO are High Delta-V Variants both enabled for GTO to GEO or Deep Space
- HELIOS and ASTRO only differ in propulsion system configuration
  - HELIOS = Monopropellant
  - ASTRO = Bipropellant
- Key Specifications
  - Vehicle mass 400-460 kg
  - Propellant mass 454 kg (HELIOS) or 829 kg (ASTRO)
  - Dual Mode Hydrazine/NTO or Monoprop Hydrazine
  - 6 DOF control including Reaction Wheels option
  - 3 port ESPA ring, 54" tall, 62" diameter
  - Up to 700 kg of Port-mounted Payload
  - Orbit: GTO, GEO, Deep Space
- Baseline Mission Class: Hybrid C/D
- 24-28 months ATP to Launch

ASTRO
(with Bipropellant System and External Tanks)

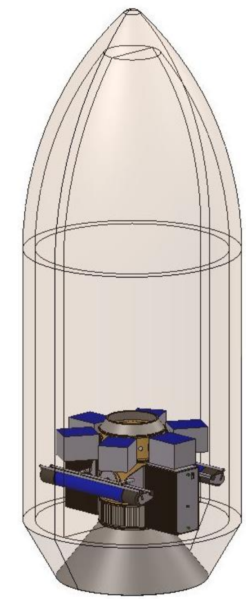


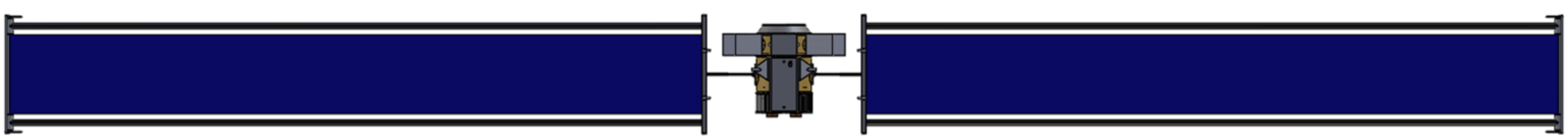
HP-SEP OMV Demonstration Platform

- Leverage OMV platform to demonstrate High Power Solar Electric Propulsion (HP-SEP)
  - 2x12.5 kW Hall Effect Thrusters
  - HP-SEP OMV modeled with 2x17 kW Arrays (below)
- ESPA-based platform allows for Secondary Payloads (up to 6x300 kg)
- Wet Mass ~5100 kg with 1800 kg Payloads
  - >10 km/s
- System scalable for small delta-V requirements
- Design was matured in partnership with NASA Glenn



Mass Summary				
Item	**Mass (kg)**	**Contingency (kg)**	**TOTAL (kg)**	**Notes**
Platform SubTotal	**1204**	**196**	**1400**	
Secondary Payloads	1800.00	0.00	1800.0	Maximum 6x300 kg
Dry Mass	**3004**	**196**	**3200**	
Xenon Propellant	1890	0	1890	Maximum
Expected Wet Mass	**4894**	**196**	**5090**	**Fully Load Configuration**





Contact Info

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