ULA Rideshare with CubeSat Missions for Lunar & Inter-Planetary Exploration

2nd Interplanetary Cubesat Workshop
Cornell University

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Rideshare – A Low-Cost Solution For Space Access

- **What is Rideshare?**
  - The approach of sharing the available performance and volume margin with one or more spacecraft that would otherwise go unused by the launch vehicle
- **Advantages to Rideshare**
  - Provides the payload customer the opportunity to get their spacecraft to orbit in an inexpensive and reliable manner
    - Cost-savings are realized by sharing a ride with the primary
      - Allows more funding to be applied to the rideshare mission
    - Rideshare payload receives the benefits of full-up launch service
    - Payload is launched on a highly reliable launch vehicle
- **Such an approach was demonstrated in 2009, when the Lunar Crater Observation and Sensing Satellite (LCROSS) was successfully flown as a secondary payload on an Atlas V that launched the Lunar Reconnaissance Orbiter (LRO) mission to the Moon**

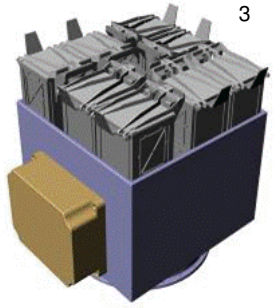
ULA Rideshare Missions Since 2000 (Current Launch Vehicles)

MISSION	VEHICLE	LAUNCH DATE	RIDESHARE TYPE	RIDESHARE HARDWARE USED
Globalstar 7	Delta II 7420	2/8/2000	Multi	Post Dispenser
EO-1/SAC-C/Munin	Delta II 7320	11/21/2000	Dual + Secondary	DPAF
Jason-1/TIMED	Delta II 7920	12/7/2001	Dual	DPAF
Iridium-12	Delta II 7920	2/11/2002	Multi	Platform Dispenser
ICESat/CHIPSAT	Delta II 7320	1/12/2003	Dual	Reduced-Height DPAF
GPS IIR-8/XSS-10	Delta II 7925	1/29/2003	Secondary	Delta II Guidance Section
Delta IV Heavy Demo/Nanosat-2	Delta IV Heavy	12/20/2004	Piggyback	Mission-unique bracket
CALIPSO/CloudSat	Delta II 7420	4/28/2006	Dual	DPAF
STP-1 (Orbital Express/ESPA)	Atlas V 401	3/8/2007	Secondary	ESPA
LRO/LCROSS	Atlas V 401	6/18/2009	Secondary	ESPA
NPP/ELaNa III	Delta II 7920	10/28/2011	Secondary	Delta II P-POD
NROL-36/OUTSat	Atlas V 401	9/13/2012	Secondary	ABC
NROL-39/GEMSat	*Atlas V 501*	*2013*	*Secondary*	*ABC*
AFSPC-4/ANGELS	*Delta IV M+(4,2)*	*2014*	*Secondary*	*ESPA*

ULA is the most experienced US rideshare launch service provider

Rideshare Spectrum of Capabilities

A range of capabilities address differing size, mass, and other Requirements, while providing individual operational advantages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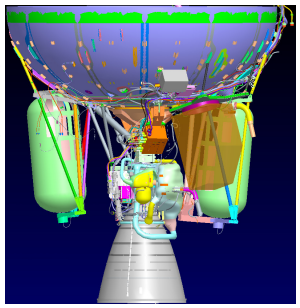

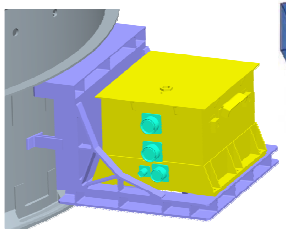

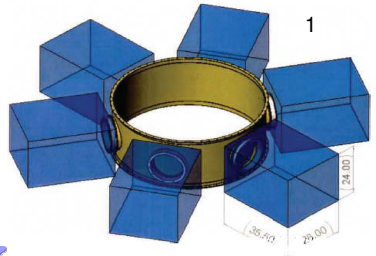
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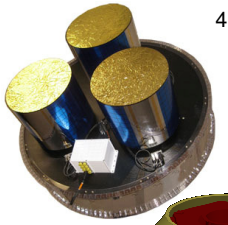
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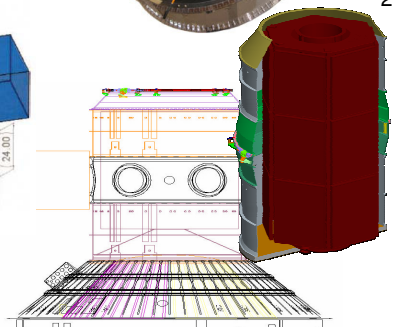
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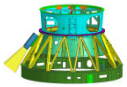
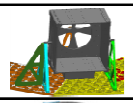
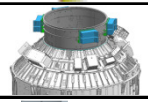
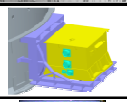
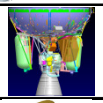
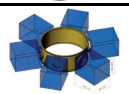
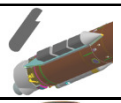
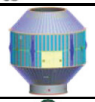
P-Pod°	ABC	CAP	ESPA*	IPC / A-Deck	DSS
Poly PicoSat Orbital Deployer	Aft Bulkhead Carrier	C-Adapter Platform	EELV Secondary P/L Adapter	Integrated Payload Carrier	Dual Satellite System
10 kg	**80 kg**	**100 kg**	**200 kg/ea.**	**500+kg**	**5000 kg**
R&D Development	Releasable in LEO	2-4 Slots per Launch	ESPA Way Fwd Progress	Mix and Match H/W Internal and External P/L	All Flight Proven H/W
Dynamically Insignificant	Isolated from Primary S/C	Less obtrusive than ESPA	STP-1 Flew 2007	SP to 60 in. diameter	Sp to 100 in diam.
First flight ILC 2011	First flight ILC 2010	First flight Fist Flight 2010	SERB List from the DoD Space Test Program	Last Flight LRO/LCROSS	CDR 4Q 2009 ILC 2011

Delivering a Wide Range of Small Spacecraft with the Appropriate Conops and Technical Accommodations

1 ESPA Graphic courtesy of CSA Engineering, Inc
2 COTSAT courtesy of NASA/AMES
3 NPSCuL courtesy of NPS
4 A-Deck courtesy of Adaptive Launch Solutions

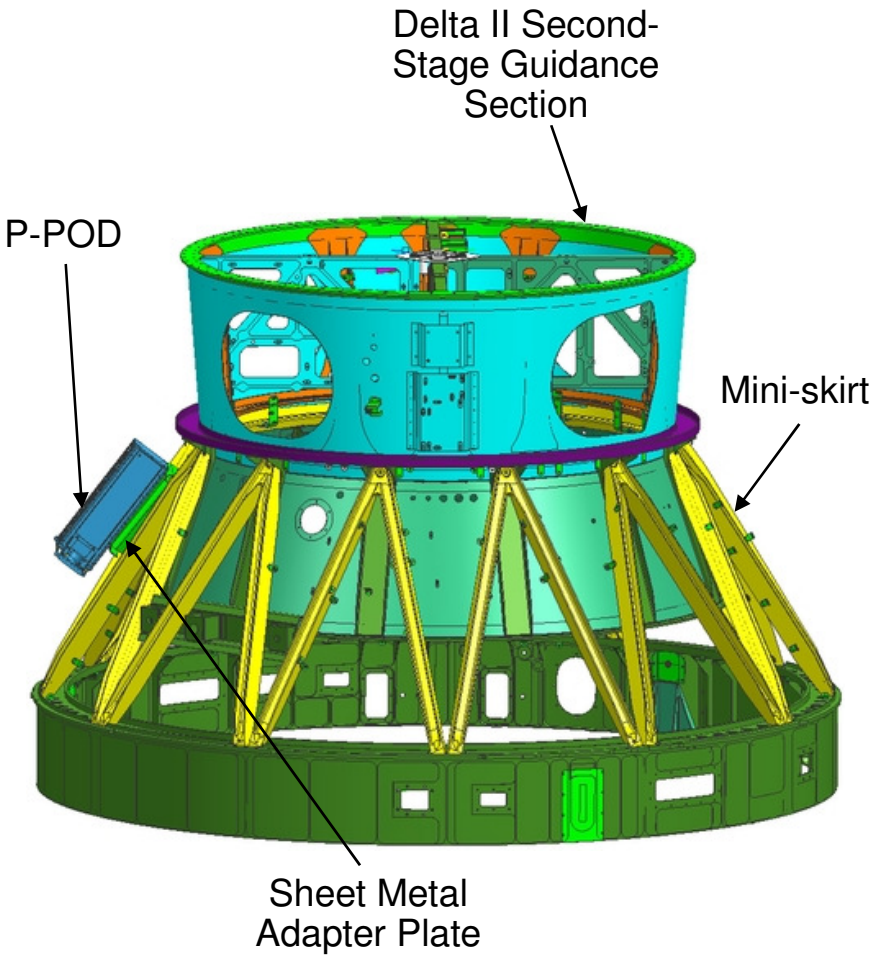
ULA Rideshare Capability Overview

CAPABILITY	MAXIMUM MASS PER PAYLOAD	VOLUME	INTERFACE	MAXIMUM # / LAUNCH	COMPATIBILITY DII	COMPATIBILITY DIV	COMPATIBILITY AV	STATUS
Delta II Second-Stage Mini-Skirt 	1.0 kg (2.2 lb)	10 cm^3 (4 in^3)	P-POD	6 Cubesats	X			ILC 2011
Delta IV Equipment Shelf 	1.0 kg (2.2 lb)	10 cm^3 (4 in^3)	P-POD (NPSCuL)	24 Cubesats		x		Concept Development
ULA EELV P-POD 	1.0 kg (2.2 lb)	10 cm^3 (4 in^3)	P-POD	24 Cubesats		x	x	Concept Development
CAP (C-Adapter Platform) 	45 kg (100 lb)	23 cm x 31 cm x 33 cm (9 in x 12 in x 13 in)	15" clampband	4		x	x	ILC 2012
ABC (Aft Bulkhead Carrier) 	77 kg (170 lb)	51 cm x 51 x 76 cm (20 in x 20 in x 30 in)	15" clampband or P-POD	1			x	ILC 2012
A-DECK (Auxiliary Payload Deck) ***(Adaptive Launch Solutions)*** 	905 kg (2,000 lb)	152-cm dia. (60-in dia.)	15", 23", 37" clampband	1		x	x	ILC 2012
ESPA (EELV Secondary Payload Adapter) ***(Moog CSA Engineering)*** 	180 kg (400 lb)	61 cm x 71 cm x 96 cm (24 in x 28 in x 38 in)	15" bolted	6		x	x	Operational
IPC (Integrated Payload Carrier) 	910 kg (2,000 lb)	137-cm dia. (54-in dia.)	8", 15", 37" clampband	1		x	x	Operational
XPC (External Payload Carrier) ***(Special Aerospace Services)*** 	1,590 kg (3,500 lb)	20.1 m^3 (710 ft^3)	60" diameter	1			x	PDR 12/2010
DSS-4M (Dual Spacecraft System - 4M) 	2,270 kg (5,000 lb)	254-cm dia. x 127 cm (100-in dia. x 50 in)	37" clampband	1		x	x	ILC 2012
DSS-5M (Dual Spacecraft System - 5M) 	5,000 kg (11,000 lb)	4-m dia. x 6.1 m (13.1-ft dia. x 20 ft)	62" bolted	1		x	x	Concept Development

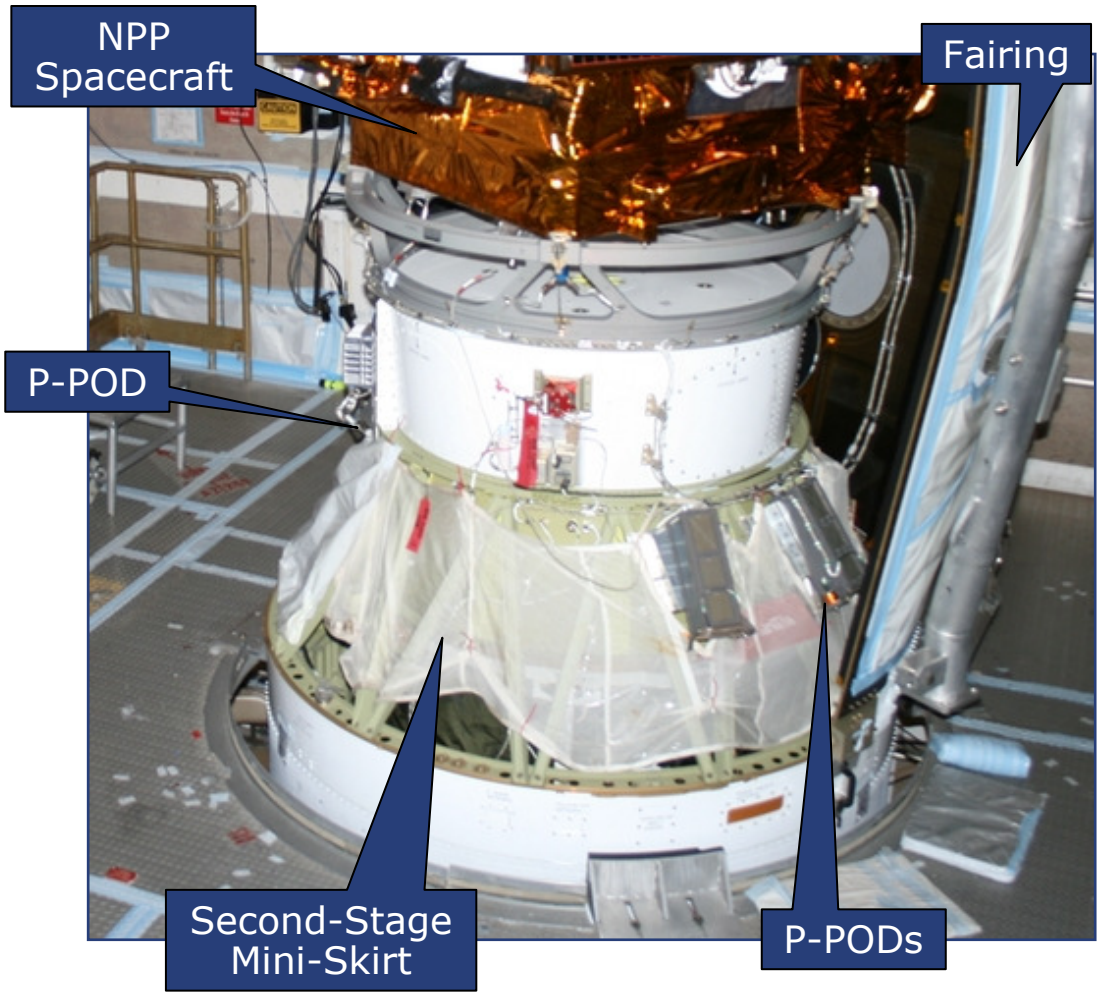
Delta II P-POD

Delta II P-POD	
Description	A Cubesat P-POD dispenser attached to the Delta II second-stage mini-skirt
Vehicle	Delta II
Capacity	3 P-PODs (9 Cubesats)
Interface	P-POD Dispenser
Mass	1.0 kg (2.2 lb) per 1U Cubesat
Volume	10 cm^3 (4 in^3) per 1U Cubesat
Status	Operational; first launch 10-2011 on NASA NPP

Additional P-POD opportunities are expected to available on the four upcoming NASA Delta II launches between now and 2016



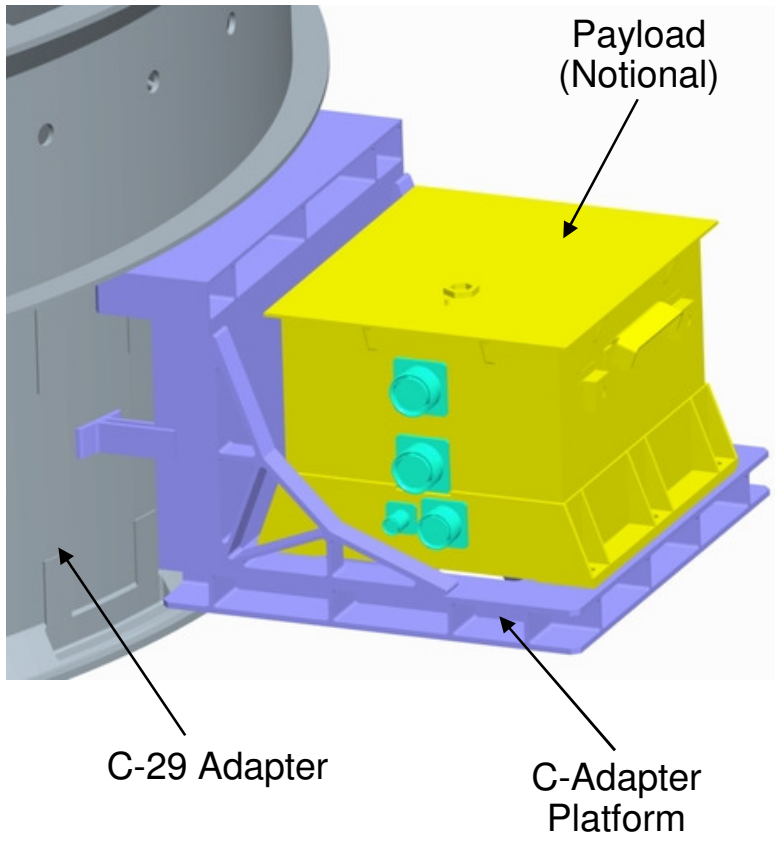
ELaNa III P-PODs Installed On NPP – Delta II Second-Stage Mini-Skirt



C-Adapter Platform (CAP)

C-Adapter Platform (CAP)	
Description	A cantilevered platform attached to the side of a C-adapter to accommodate secondary payloads
Vehicle	Atlas V, Delta IV
Capacity	4 CAPs per C-adapter
Interface	8-in Clampband
Mass	45 kg (100 lb)
Volume	23 cm x 31 cm x 33 cm (9 in x 12 in x 13 in)
Status	First launch TBD

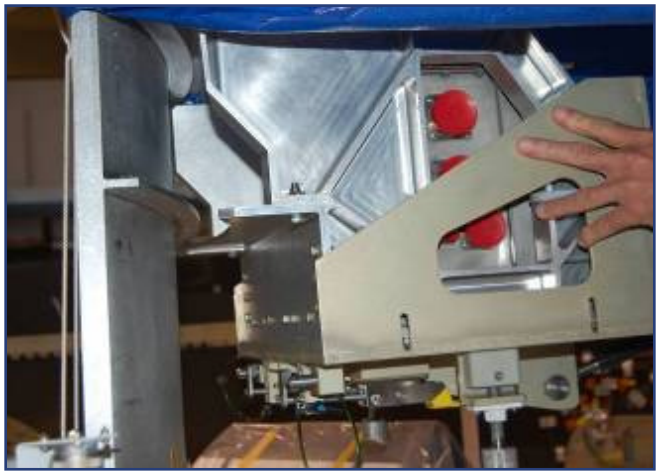
The CAP was originally designed to accommodate batteries that are part of the Atlas V extended-mission kit hardware



Hosted experiments?

CAP/GSO Battery Test Installation Photos

Entering 5.4-m PLF BM door



Positioning ABP using GSE

ABP fastener installation

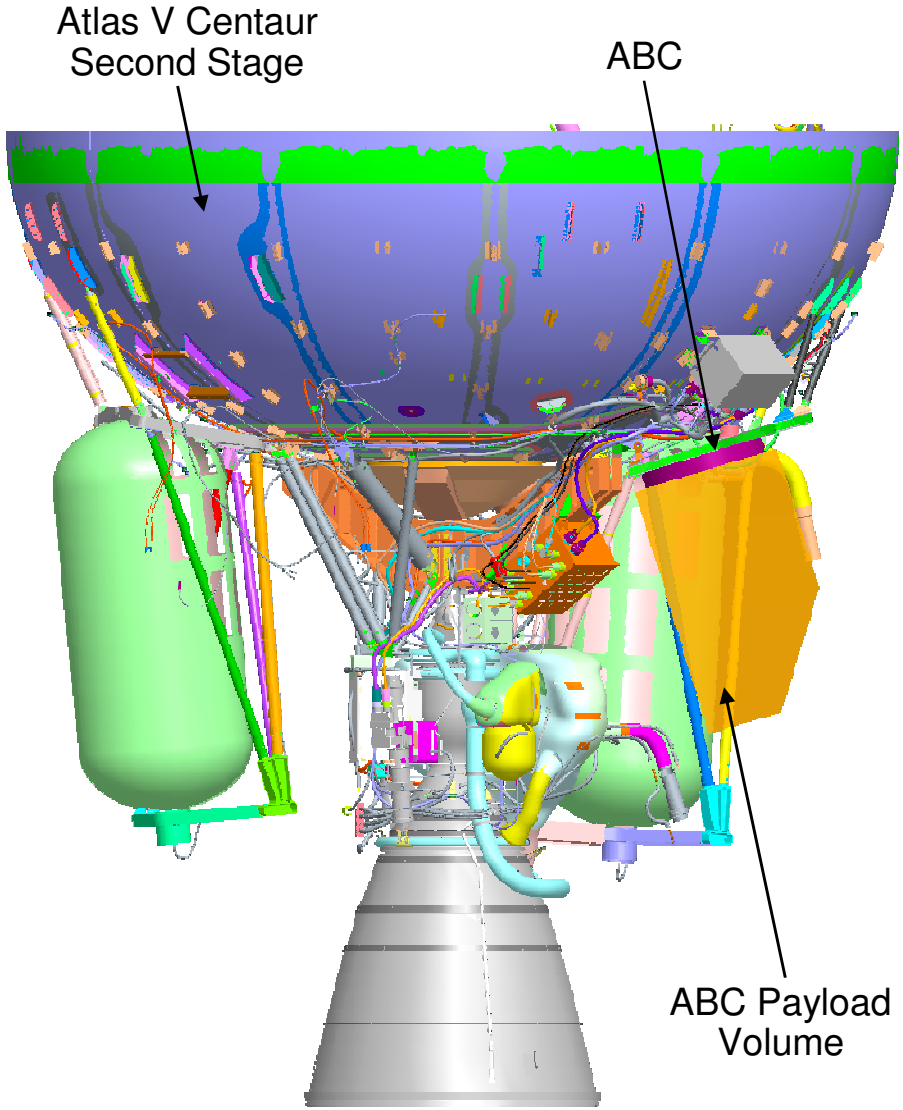
Maneuvering GSE scoop

Battery-only installation/removal

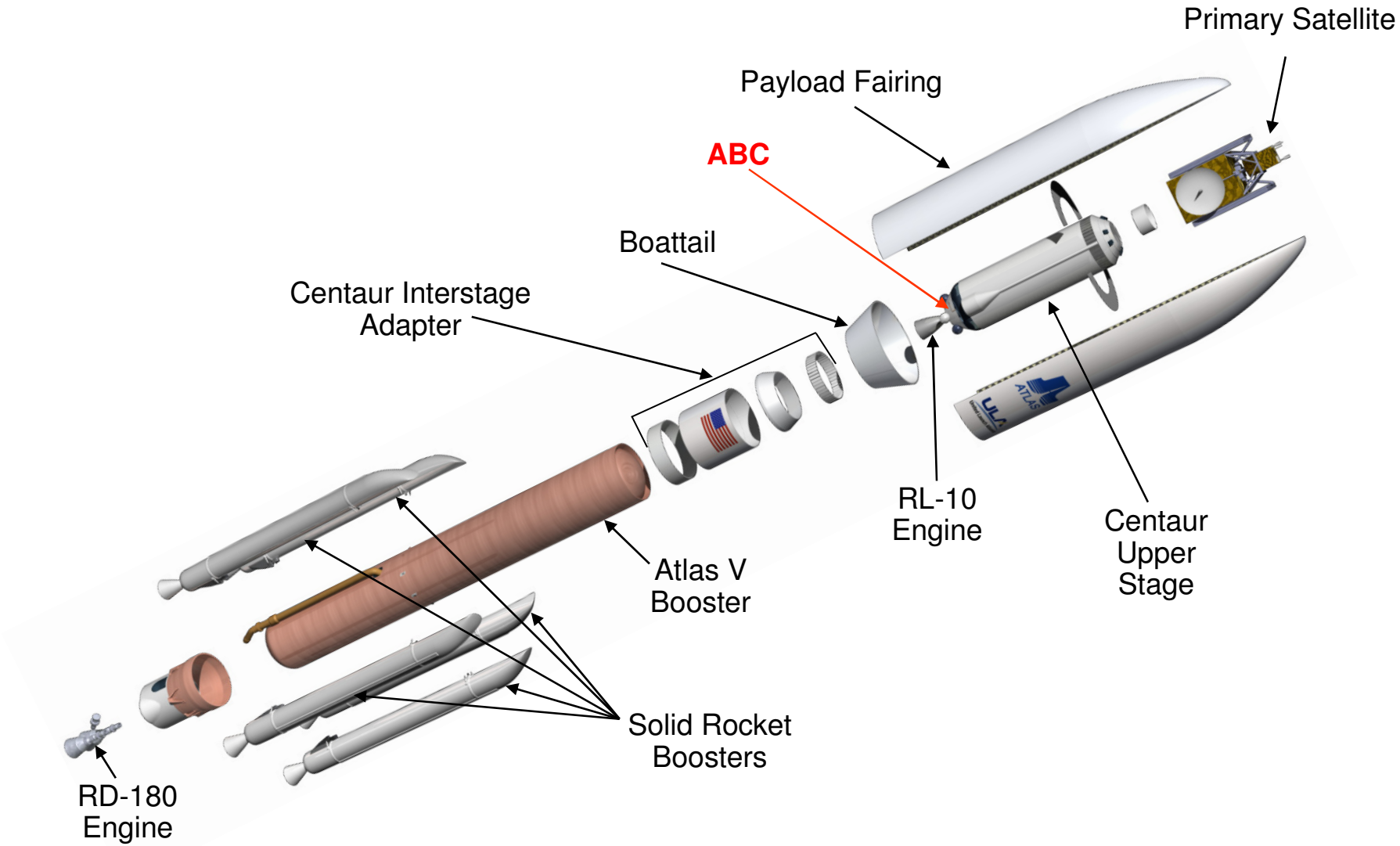
Rear battery fastener installation

Aft Bulkhead Carrier (ABC)

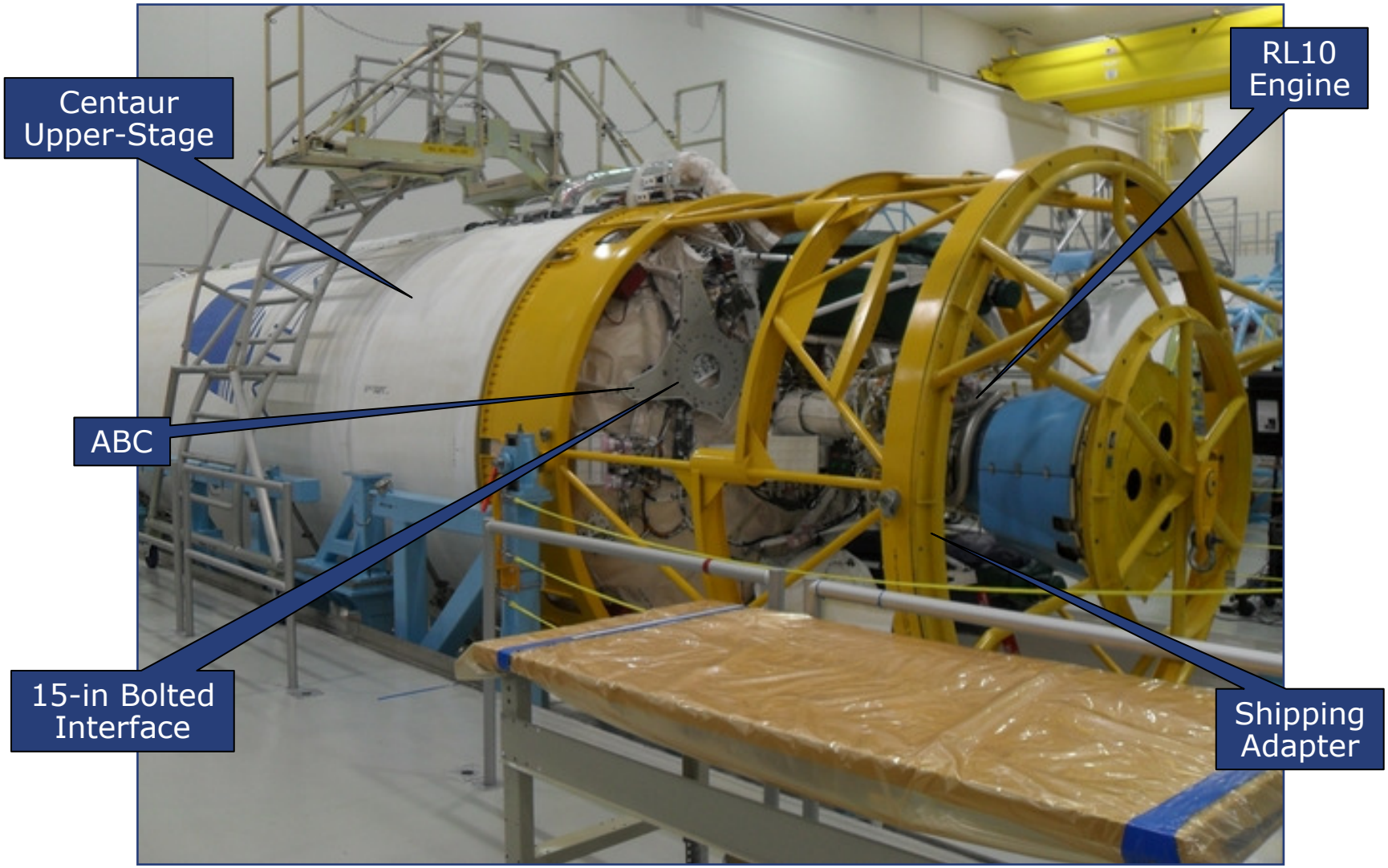
- Description
  - I/F located at the aft-end of the Atlas V Centaur second-stage
- Capabilities
  - Mass: **96 kg**
  - Volume: 51 cm x 51 cm x 76 cm (20 in x 20 in x 30 in)
  - Interface: 15-in clampband or P-POD dispenser
  - Capacity: 1 slot
  - Vehicle: Atlas V
- Status
  - First fight L-36 9/2012
  - ABC Users Guide available
- Why?
  - Sep from primary – release any time, no contamination, no re-contact, no security



ABC Location - Atlas V 5XX

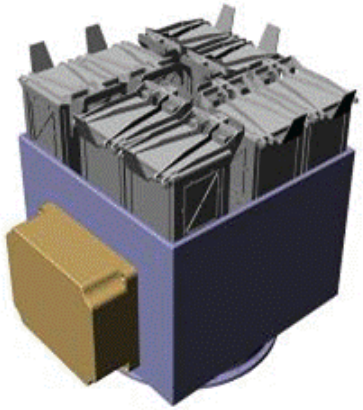


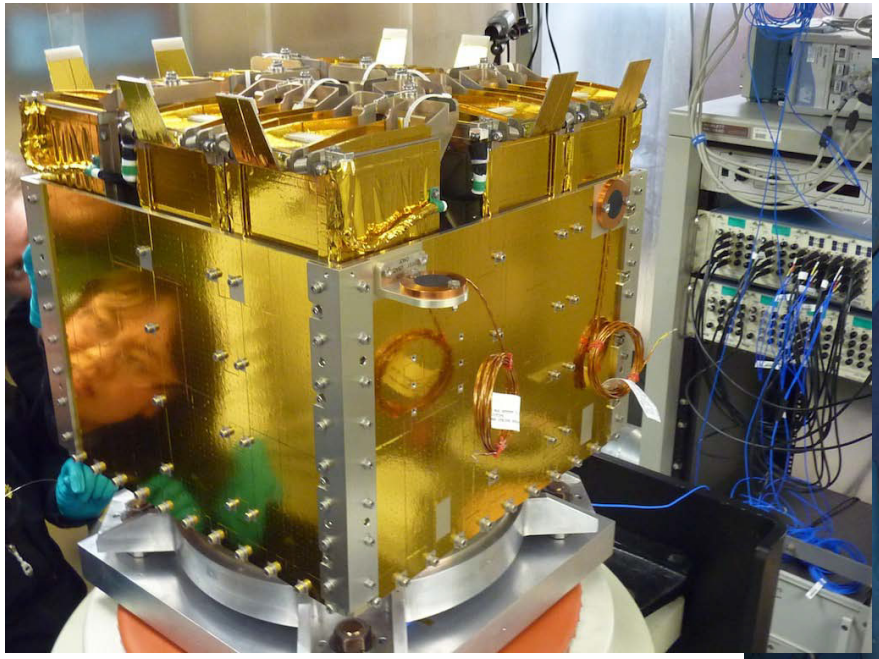
ABC Installed on Centaur

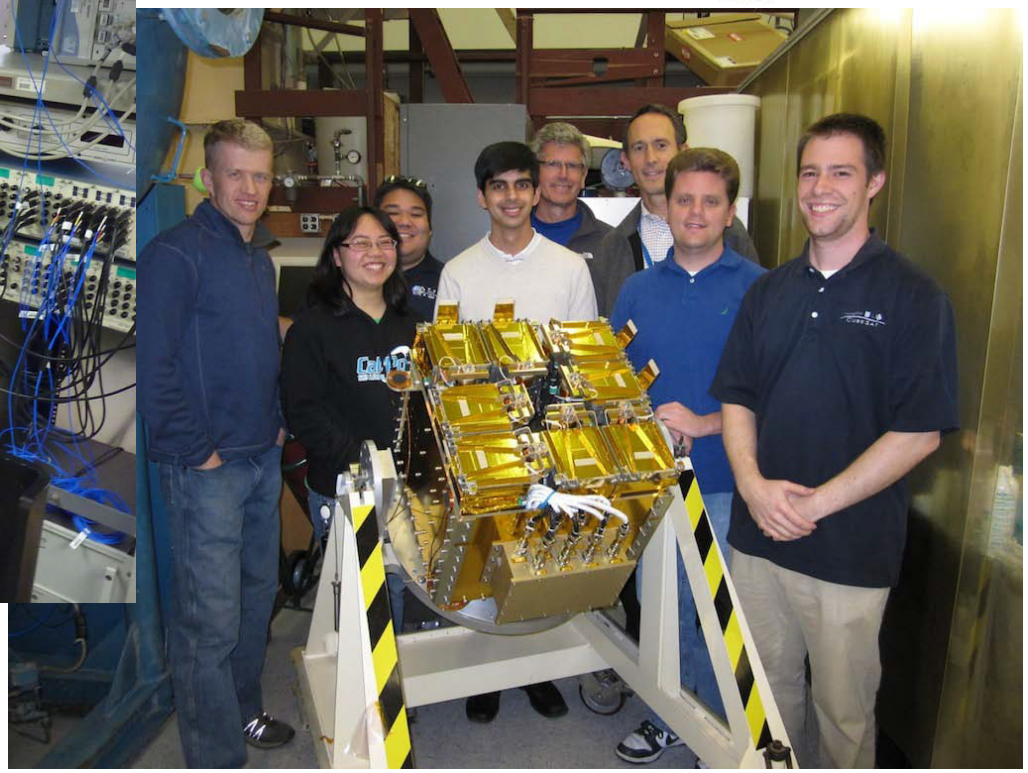


OUTSat Mission on L-36

- Integration onto Atlas completed
- Launch date Aug 2, 2012 (first-flight)
- Next flight, pending L-39

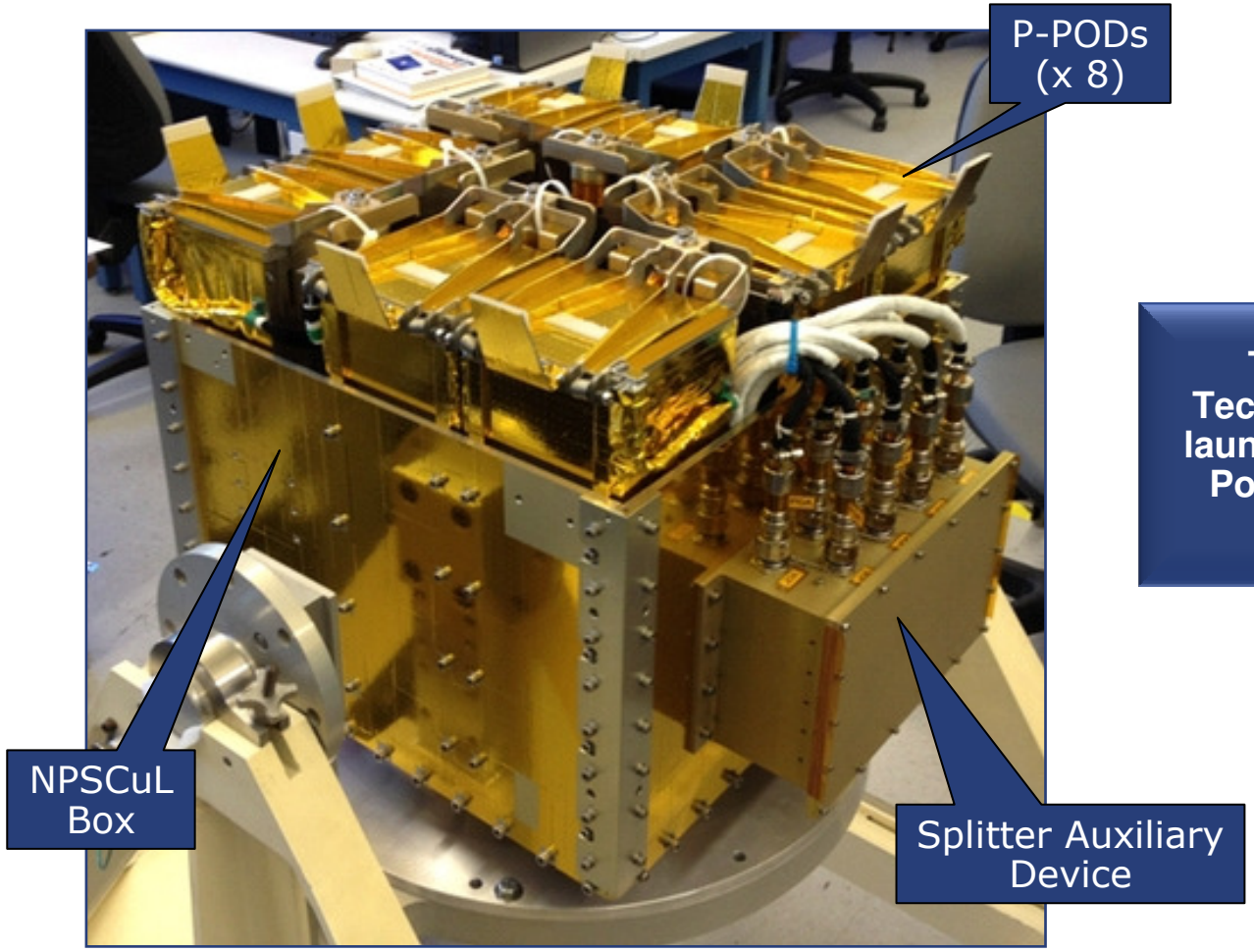






Photos courtesy Maj. Wilcox NRO/OSL

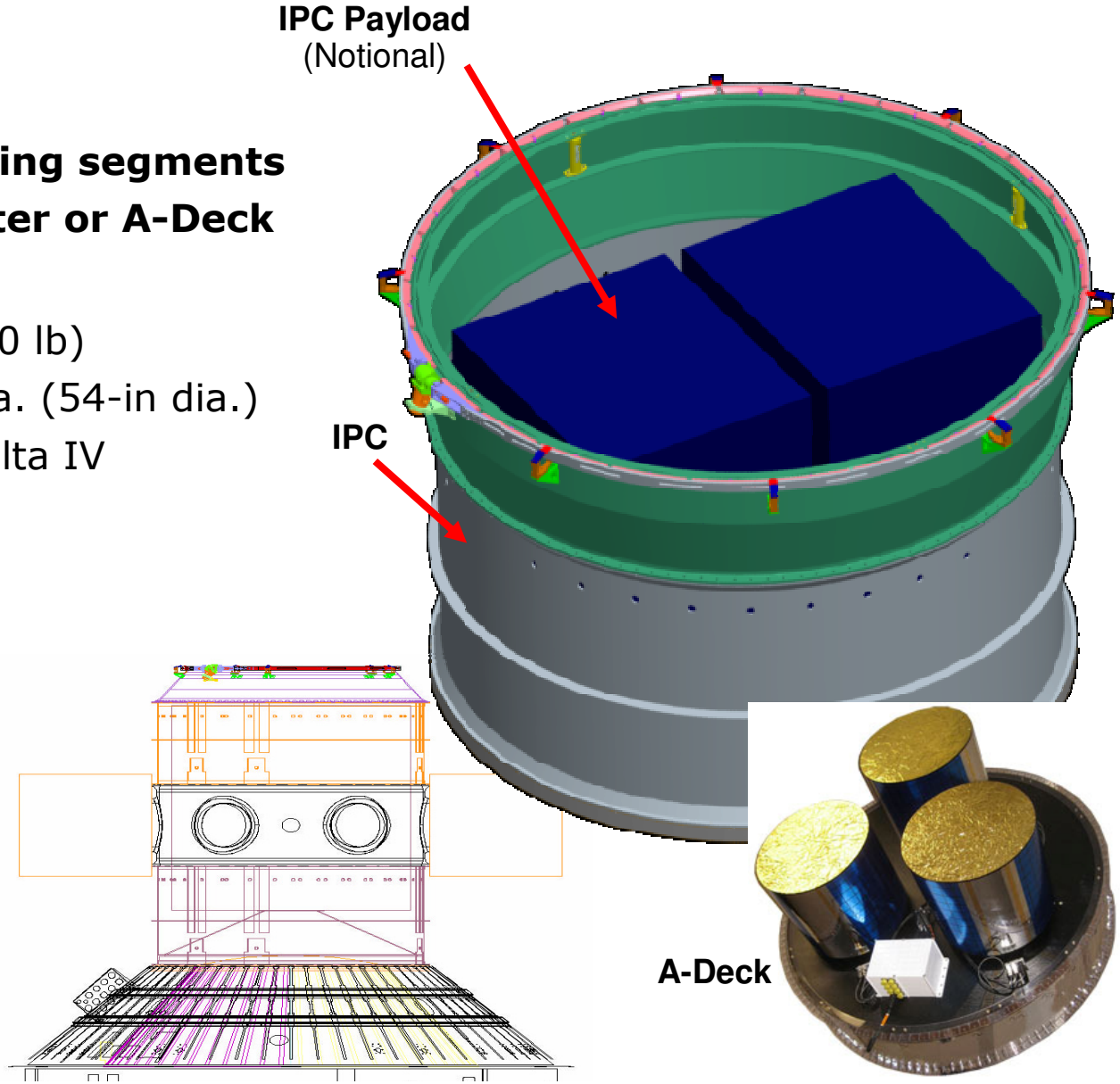
ABC/NROL-36 - OUTSat & Naval Postgraduate School Cubesat Launcher (NPSCuL)



The Operationally Unique Technologies Satellite (OUTSat) launched 8 P-PODs via the Naval Postgraduate School Cubesat Launcher (NPSCuL)

Integrated Payload Carrier (IPC)

- Description
  - A flexible **stack of ring segments**
  - Config: **conic adapter or A-Deck**
- Capabilities
  - Mass: 910 kg (2,000 lb)
  - Volume: 137-cm dia. (54-in dia.)
  - Vehicle: Atlas V, Delta IV
- Status
  - IPC is operational
- Why?
  - Large volume
  - on centerline
  - treated as single SC
  - height up to 7 ft

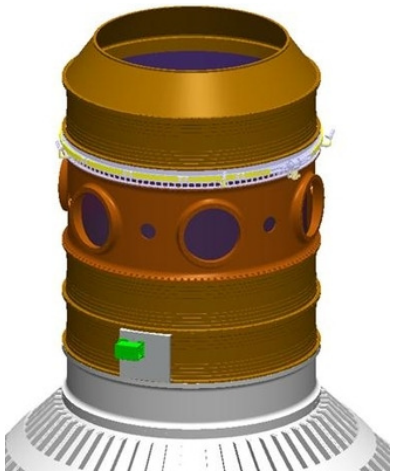


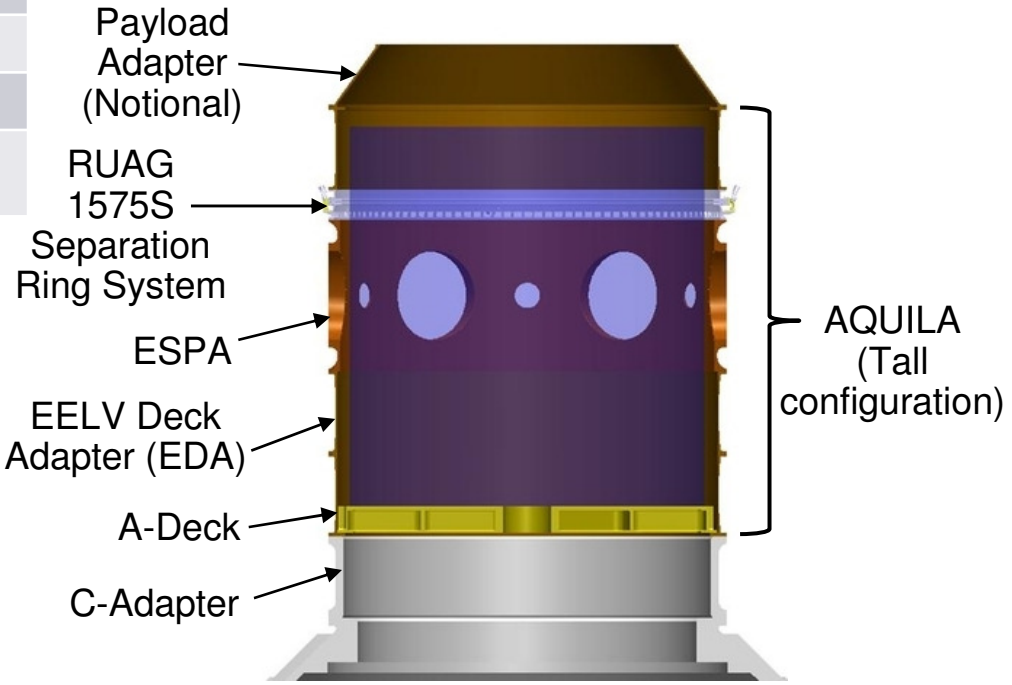
AQUILA

AQUILA	
Description	A flat deck and cylindrical spacers, located between the forward-end of the second stage and the primary payload
Vehicle	Atlas V, Delta IV
Capacity	Multiple payloads per AQUILA
Interface	Variable
Mass	1,000 kg (2,200 lb)
Volume	142-cm dia. (56-in dia.) x 152 cm (60 in)
Status	In development; CDR 04-2012
Developer	Adaptive Launch Solutions (ALS) *(Jack Rubidoux, jrubidoux@adaptivelaunch.com)*

Graphics courtesy of ALS

AQUILA modular adapters are rated to support a primary payload mass up to 6,350 kg (14,000 lb)

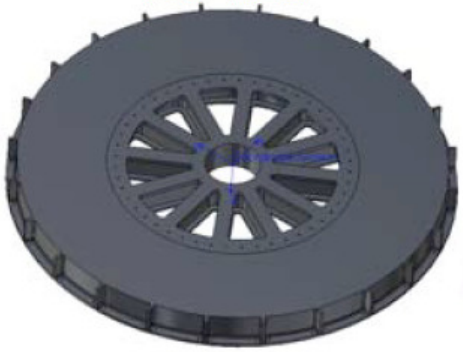




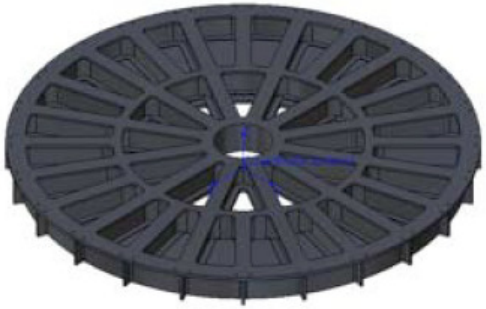
A-Deck Structure

One Mini-Spacecraft Configuration

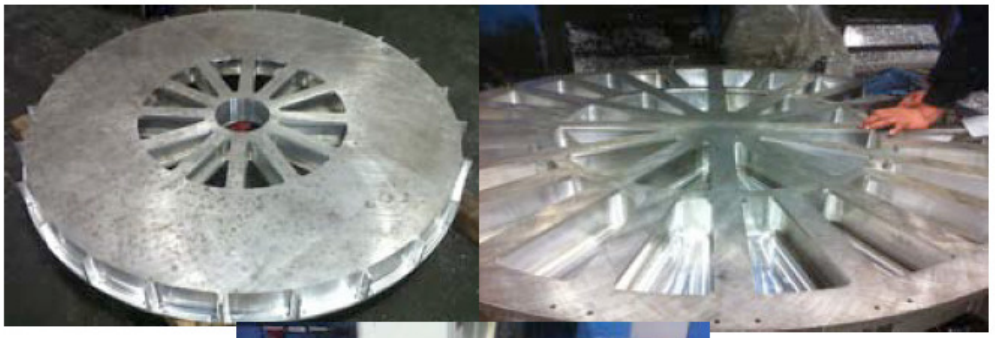
TOP VIEW

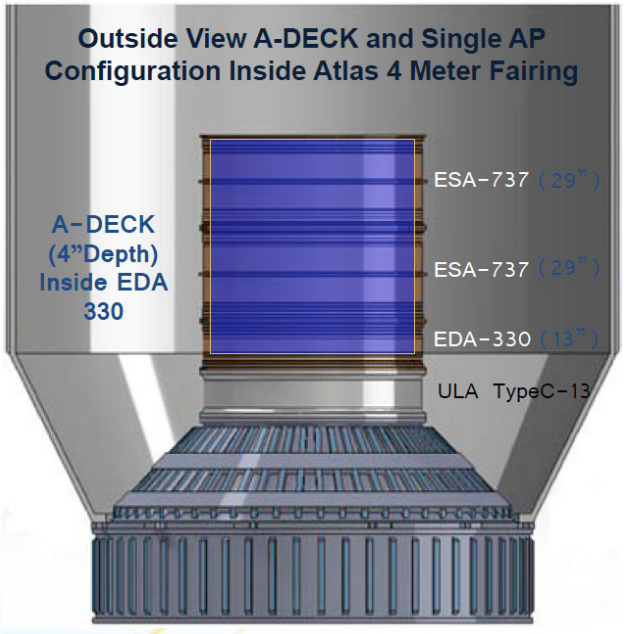


BOTTOM VIEW



- **Structural Component Approach**
  - Monolithic Aluminum Design
  - Spider Pattern Centered Drilled
  - CNC Machined
  - Designed for 1000 kg Load Bearing Capability
  - MiL Spec Drilling for Fasteners





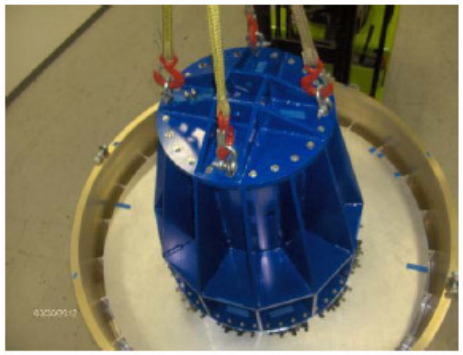
* Slide courtesy of Lt Col Guy Mathewson. NRO and Adaptive Launch Solutions

A-Deck Structural Testing

A-DECK arrives at NTS Test Facility

A-DECK carried to EDA 330

A-DECK lowered in EDA 330



Mass Simulator on A-DECK

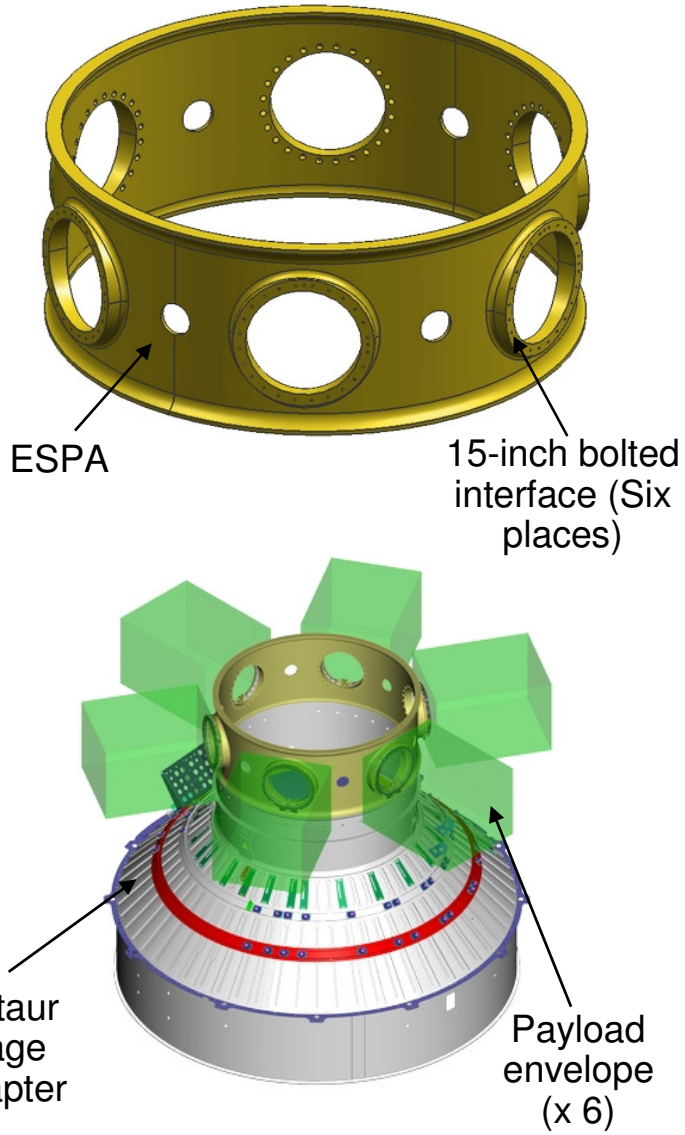
A-DECK Suspended in Acoustic Test Chamber

* Slide courtesy of Lt Col Guy Mathewson. NRO and Adaptive Launch Solutions

EELV Secondary Payload Adapter (ESPA)

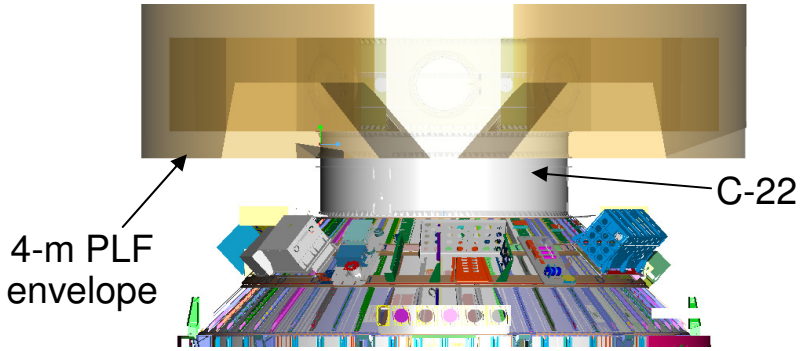
EELV Secondary Payload Adapter (ESPA)	
Description	An adapter located between the second-stage and the primary payload, which can accommodate up to six secondary payloads
Vehicle	Atlas V, Delta IV
Capacity	6 payloads per ESPA
Interface	15-in Bolted Interface
Mass	181 kg (400 lb)
Volume	61 cm x 71 cm x 96 cm (24 in x 28 in x 38 in)
Status	Operational; first launch 03-2007 on STP-1
Developer	Moog CSA Engineering *(Joe Maly, jmaly@csaengineering.com)*

ESPA hardware will be used to launch a rideshare mission in 2014, and additional missions are being evaluated

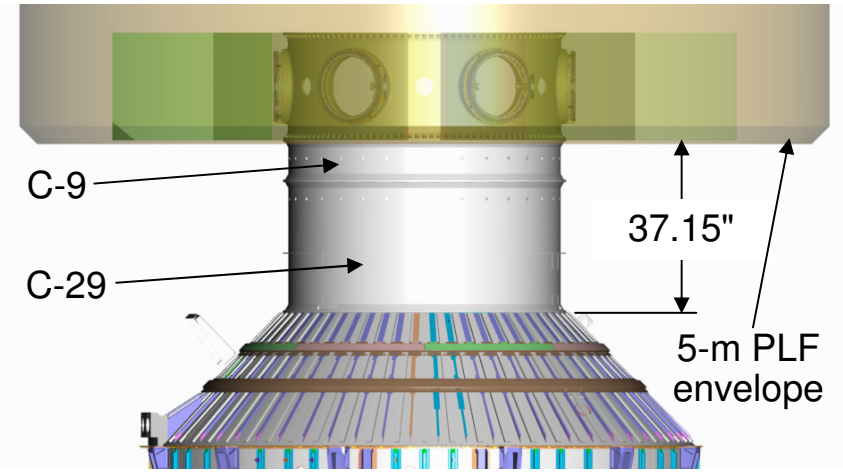


ESPA Flight Hardware Configuration - Atlas V

- Description
  - 4-m stack
    - SIS-compliant C-22 adapter on Centaur Forward Adapter (CFA)
  - 5-m/5-m GSO stack
    - SIS-compliant C-29 adapter on CFA
    - SIS-compliant C-9 above C-29
- Summary
  - Two configurations for Atlas
  - Common C-9 adapter between Atlas and Delta
  - New engineering for C-22
  - New engineering for C-9

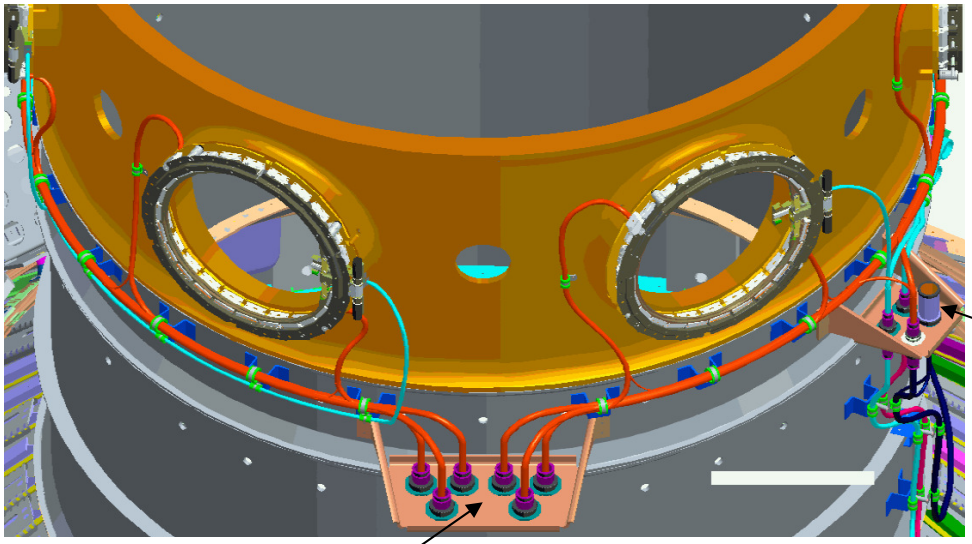


4-m Atlas V



5-m Atlas V

Avionics Flight System Design Overview
Common Routing Scheme for ESPA Chassis



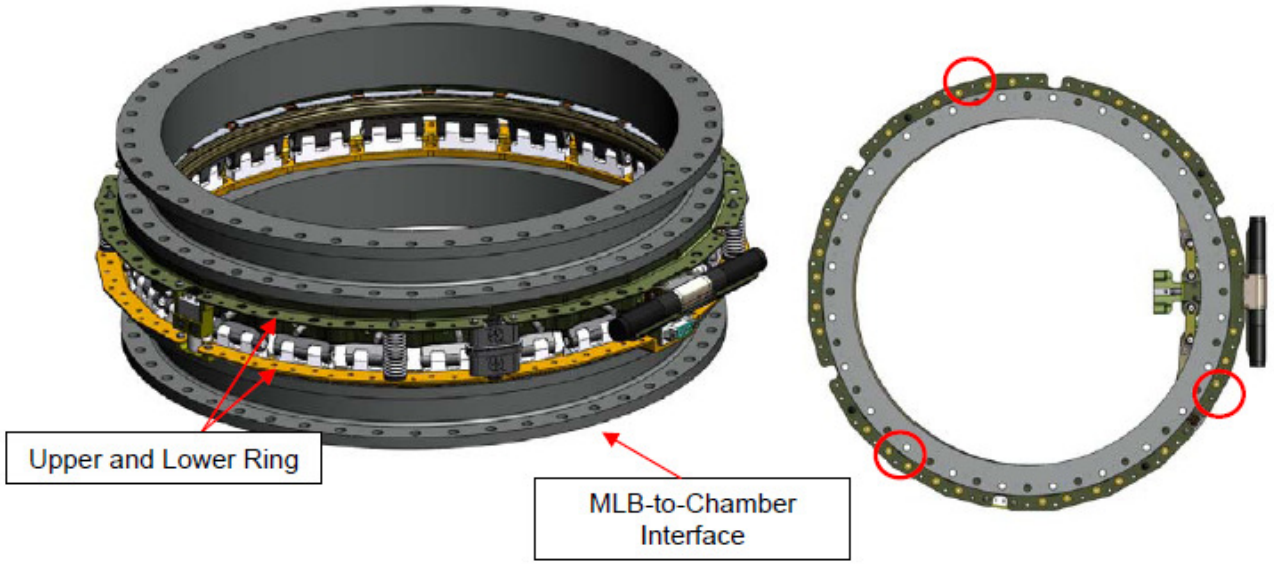
- Same panels used on Atlas and Delta
- Harnesses forward of panels are common for any mission

- MLB Separation Panel
  - Houses 4 connectors with common forward harness routing:
    - 2 Connectors for routing to MLB Motors (Shell size 17)
    - 1 Connector for routing Sep Signal (part of APL Servicing Harness) (Shell size 15)
    - 1 Atlas Bussing Connector (Shell size 15, used for Atlas only)
  - Aft harness routing is dependent upon vehicle:
    - Atlas: Aft harnessing routes to Atlas SEIP/URCU Panel and Atlas Main SEIP Panel
    - Delta: Aft harnessing routes to both LEAC Panels

- APL Servicing Panel
  - Houses 6 connectors (Shell size 25) each with a different clocking to prevent miss-mate
  - Forward harnessing routes to all 6 ESPA portals in order to charge APLs before flight
  - Aft harness routing is dependent upon vehicle:
    - Atlas 4-m: Aft harness routes through boat-tail door (disconnected before flight)
    - Atlas 5-m: Aft harness routes through base module door (disconnected before flight)
    - Delta: Aft harness routes to Delta Fairing Connector Panel located on PAF (in-flight harness)

Separation Systems

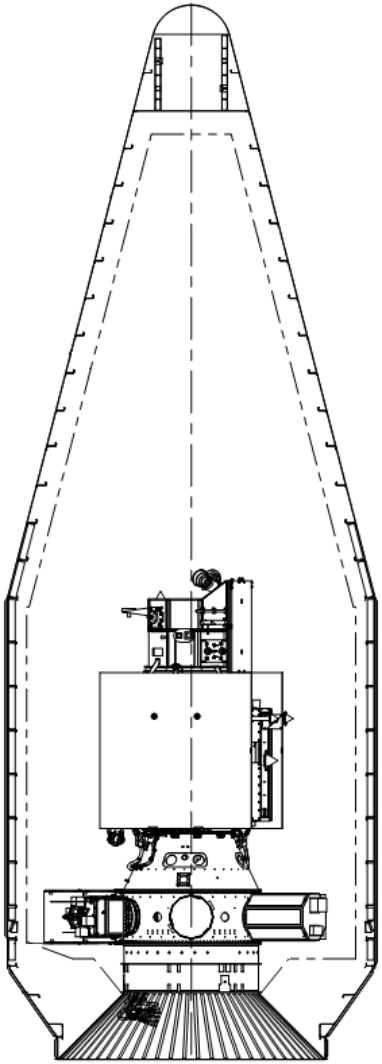
- MLB (MkII Motorized Lightband)
  - Risk Reduction Testing on-going
    - Thermal test completed - nominal
    - Vibration test completed – some degradation in current signature
  - Vibration data evaluated proceeding on to shock testing
  - Shock Test pending



2.4: Expected Thermocouple Locations

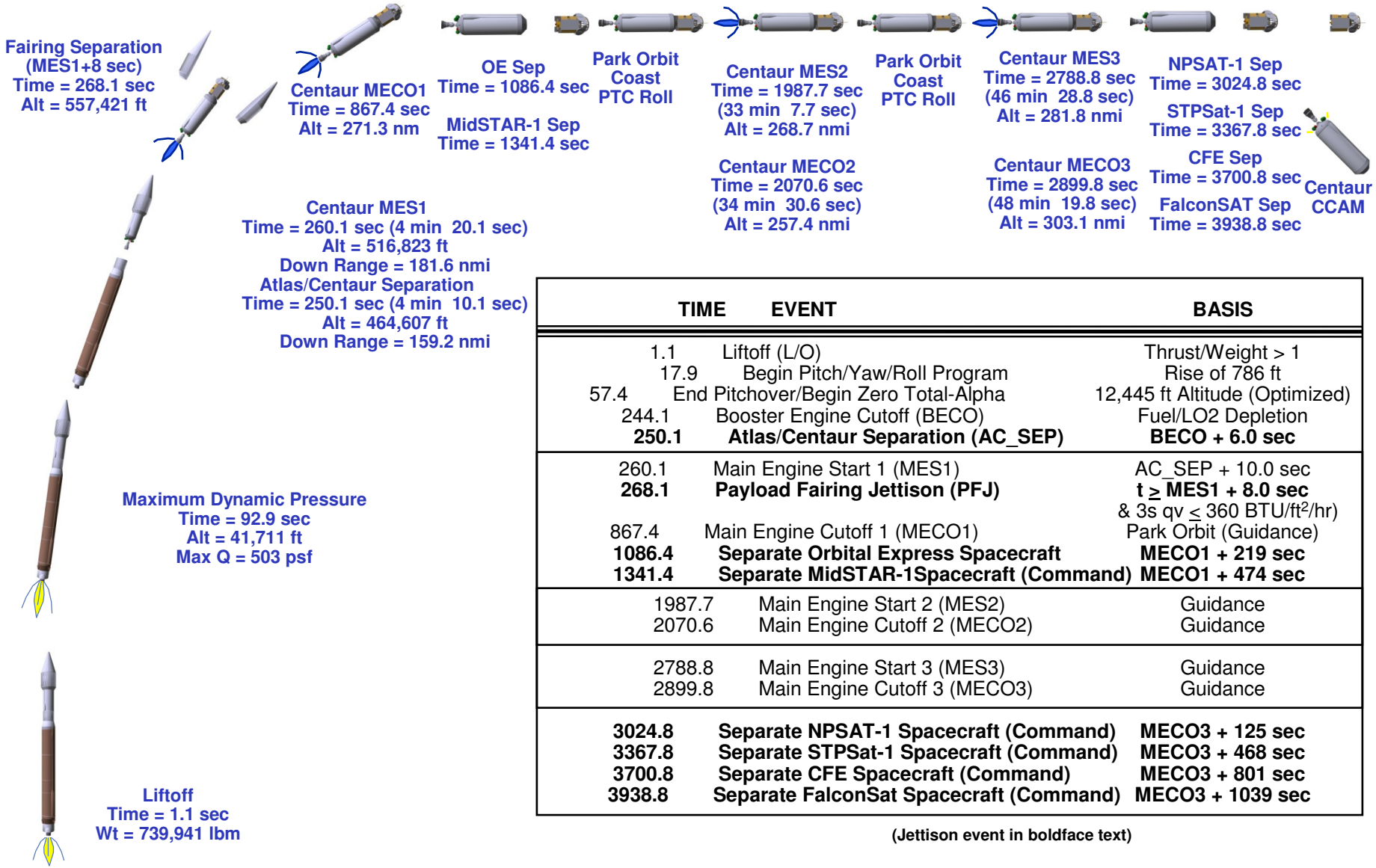
STP-1 Mission Overview

- STP-1 program consists of multiple satellites integrated into one payload stack.
- Baseline design: 2 spacecraft separation orbits
  - Orbit 1: 492 km circular; 46.0° inclination
    - Orbital Express (sun-relative separation)
    - MidSTAR-1
  - Orbit 2: 560 km circular; 35.4° inclination
    - NPSAT1 (sun-relative separation) [Mass Simulator]
    - NPSAT1 mass simulator will not be deployed
    - STPSat-1
    - CFE
    - FalconSAT-3



STP-1

STP-1 Mission Profile



TIME	EVENT	BASIS
1.1	Liftoff (L/O)	Thrust/Weight > 1
17.9	Begin Pitch/Yaw/Roll Program	Rise of 786 ft
57.4	End Pitchover/Begin Zero Total-Alpha	12,445 ft Altitude (Optimized)
244.1	Booster Engine Cutoff (BECO)	Fuel/LO2 Depletion
250.1	**Atlas/Centaur Separation (AC_SEP)**	**BECO + 6.0 sec**
260.1	Main Engine Start 1 (MES1)	AC_SEP + 10.0 sec
268.1	**Payload Fairing Jettison (PFJ)**	**t ≥ MES1 + 8.0 sec** & 3s qv ≤ 360 BTU/ft²/hr)
867.4	Main Engine Cutoff 1 (MECO1)	Park Orbit (Guidance)
1086.4	**Separate Orbital Express Spacecraft**	**MECO1 + 219 sec**
1341.4	**Separate MidSTAR-1Spacecraft (Command)**	**MECO1 + 474 sec**
1987.7	Main Engine Start 2 (MES2)	Guidance
2070.6	Main Engine Cutoff 2 (MECO2)	Guidance
2788.8	Main Engine Start 3 (MES3)	Guidance
2899.8	Main Engine Cutoff 3 (MECO3)	Guidance
3024.8	**Separate NPSAT-1 Spacecraft (Command)**	**MECO3 + 125 sec**
3367.8	**Separate STPSat-1 Spacecraft (Command)**	**MECO3 + 468 sec**
3700.8	**Separate CFE Spacecraft (Command)**	**MECO3 + 801 sec**
3938.8	**Separate FalconSat Spacecraft (Command)**	**MECO3 + 1039 sec**

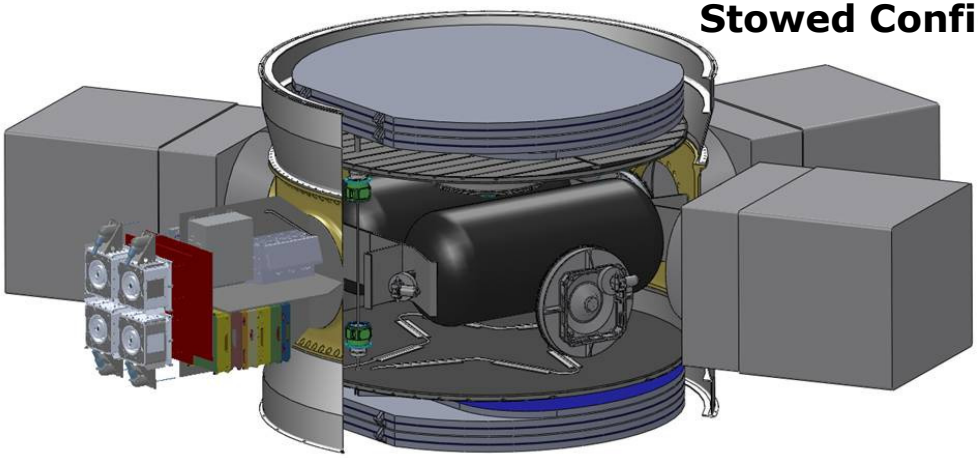
(Jettison event in boldface text)

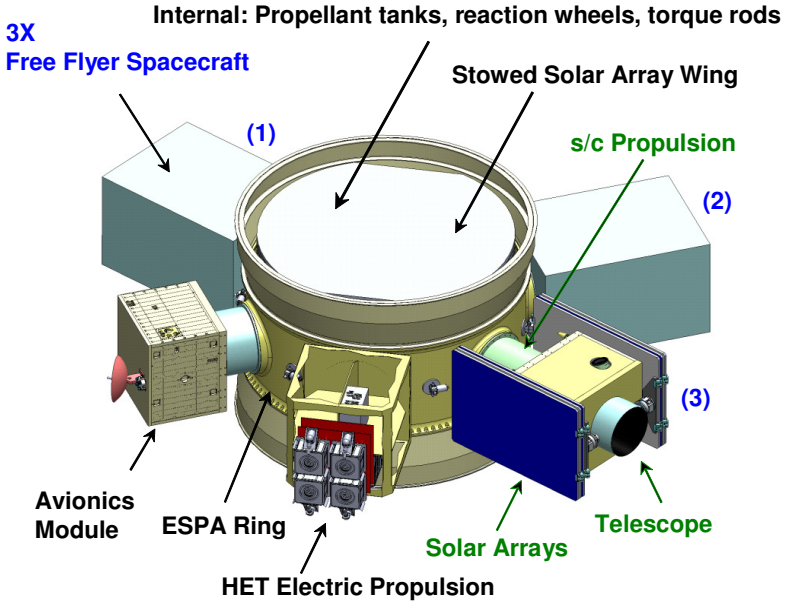
MULE Delivery System

United Launch Alliance

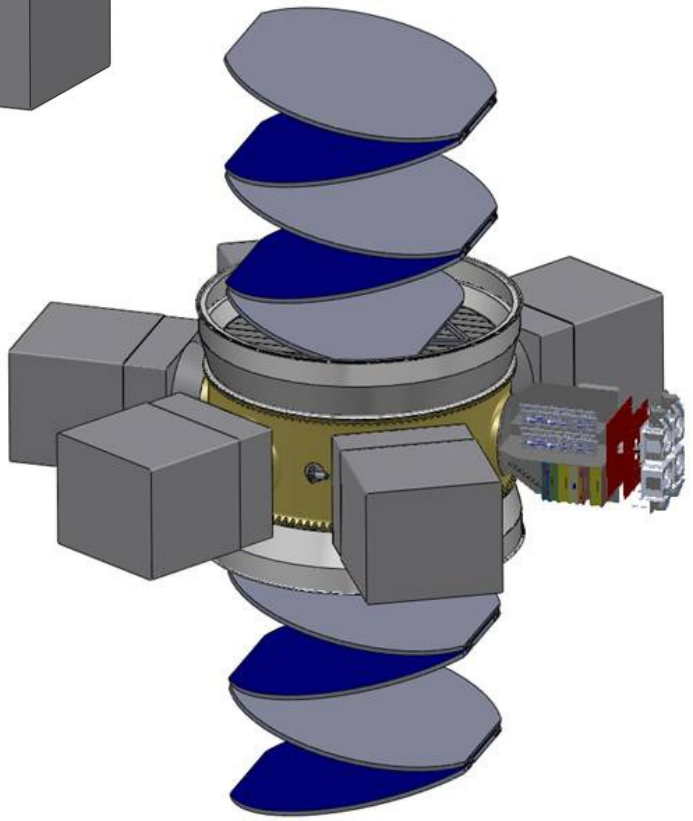
BUSEK Advanced Space Propulsion

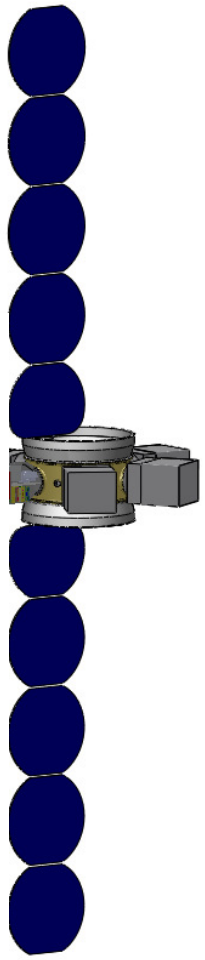
Stowed Configuration





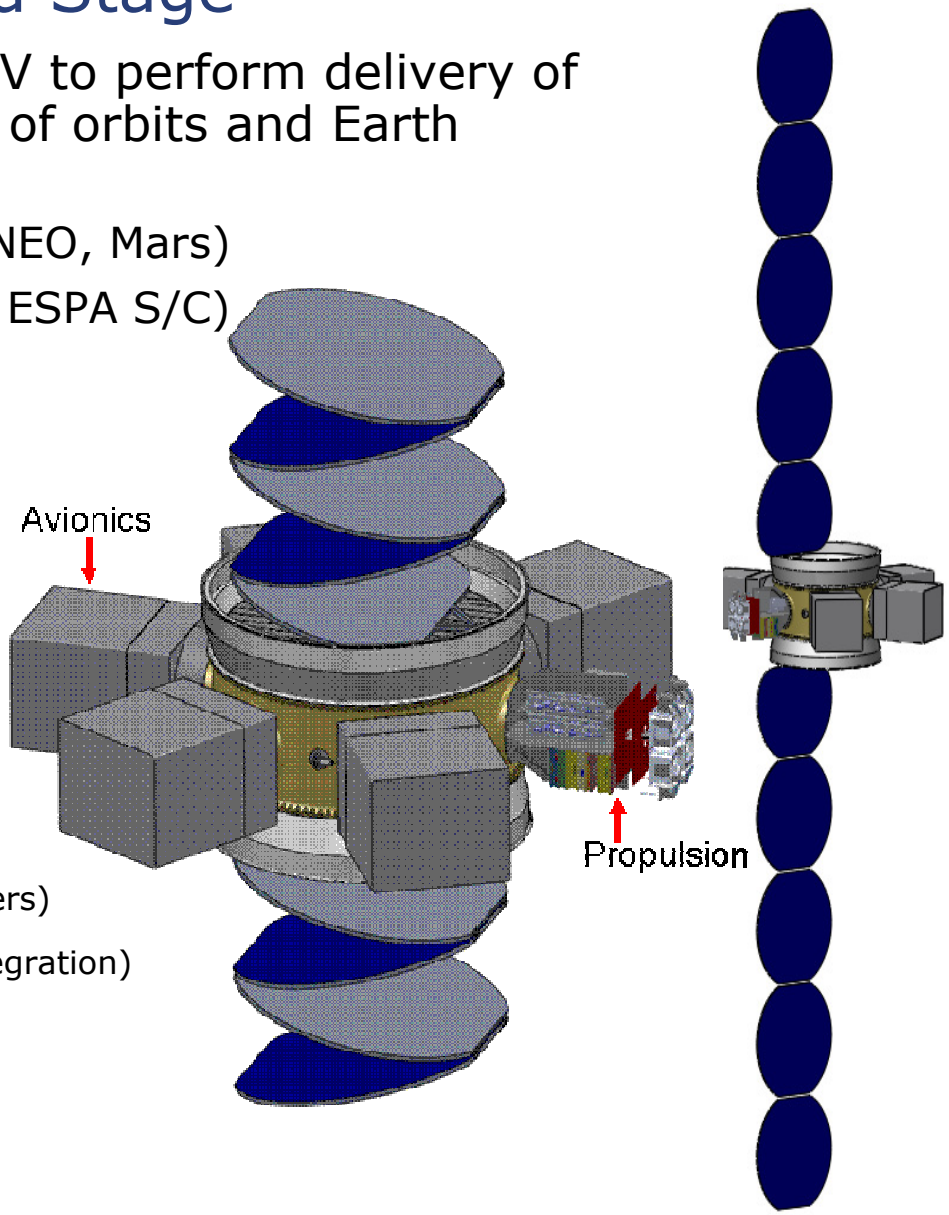
Deployed Configuratic





MULE (Multi-payload Utility Lite Electric) Third Stage

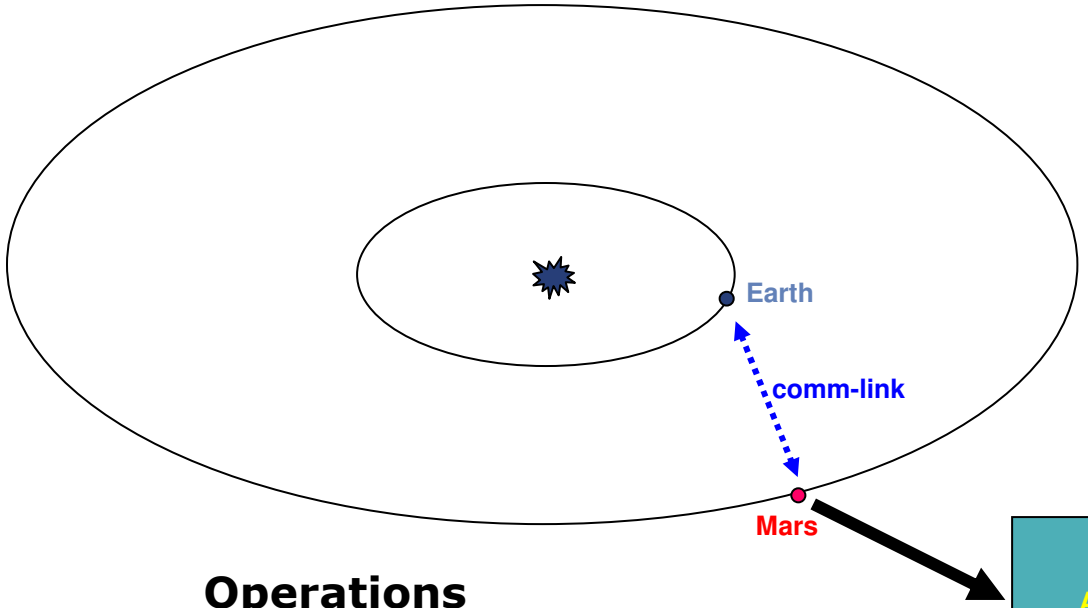
- **MULE stage** provides high deltaV to perform delivery of ESPA class payloads to a variety of orbits and Earth Escape missions
  - Delivery to Earth Escape (Lunar, NEO, Mars)
  - Delivery of a constellation (3 or 4 ESPA S/C)
  - Delivery to GSO
  - High delta-V
  - Solar Electric propulsion
  - Based on the ESPA Ring
  - On-orbit operations multi-yr



- Co-sponsors:
  - Oakman Aerospace (Avionics)
  - Busek Space Propulsion (Hall Thrusters)
  - Adaptive Launch Solutions (S/C Integration)

- Status – proposal development

Mars "TDRSS-lite" Delivery

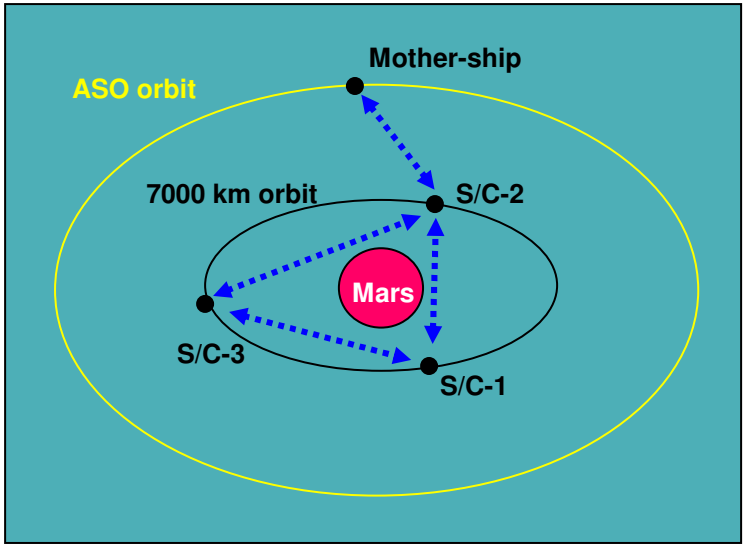


Con-Ops

- Rideshare Earth escape
- MULE Mars Rendezvous
- Deploy ea free-flyer s/c
- Move MULE to high orbit
- Deploy High-gain antenna

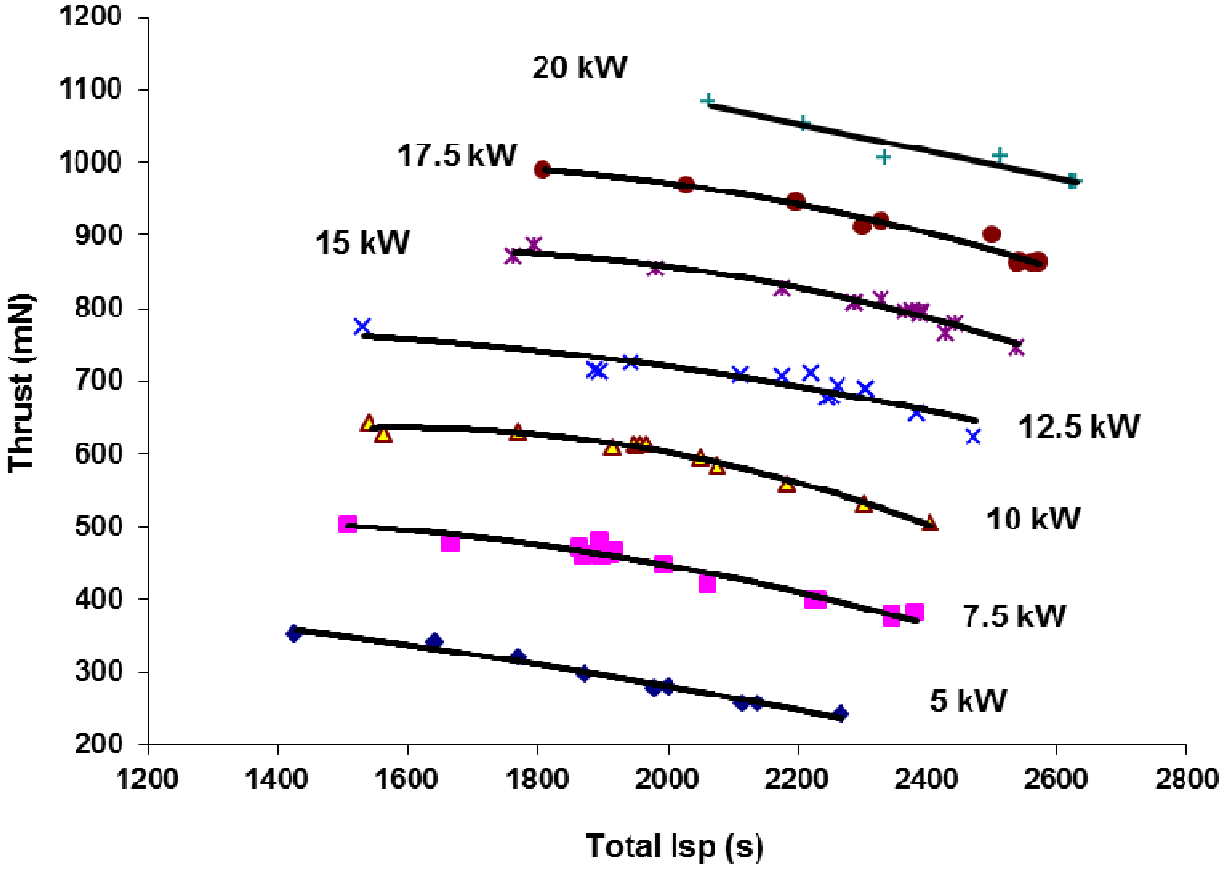
Operations

- Mother-ship in areostationary (ASO) orbit (11,000 mi above surface)
- MULE Stage switches power to high-gain
- Permits comm links:
  - Surface to Surface
  - Surface to Earth
  - Continuous surface observation
  - Internet-like service



Thrust vs. Isp (BHT-20K, Xe)

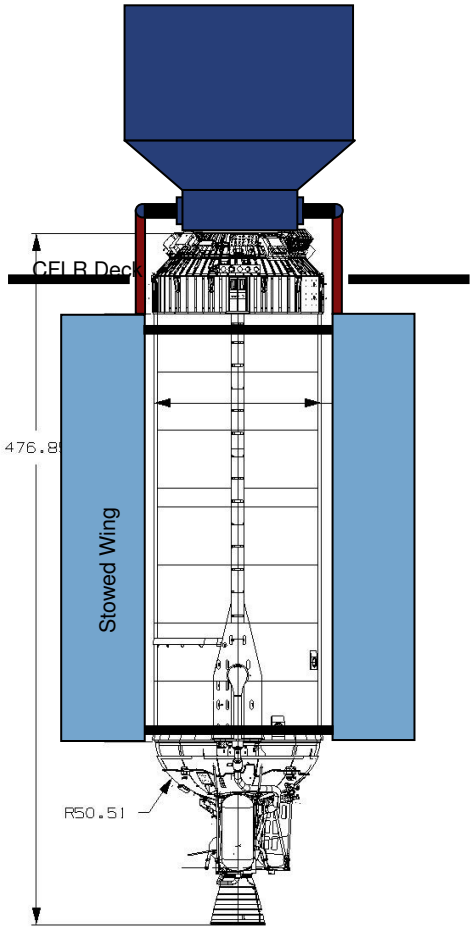
- T>1 N measured at 20-kW.
- Peak T/P~ 70 mN/kW at 200 V and 5 kW.
- Isp from 1430 s (200 V, 5-kW) to 2630 s (500 V, 20-kW).

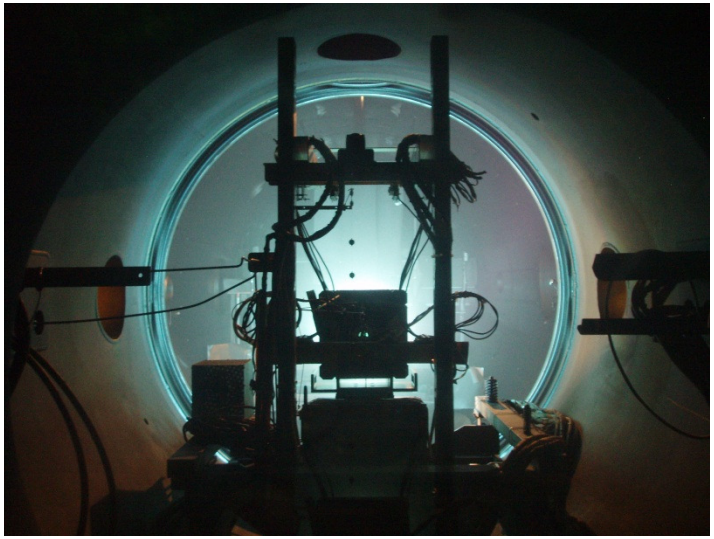


$$\left(\frac{\sigma_{I_{sp}}}{I_{sp}}\right)^2 = \left(\frac{\sigma_T}{T}\right)^2 + \left(\frac{\sigma_{\dot{m}}}{\dot{m}}\right)^2$$

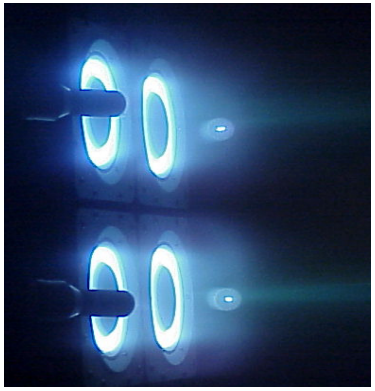
20 KW High Power System

- Busek has 20 kW thrusters
- ULA 20 KW array stowed config.

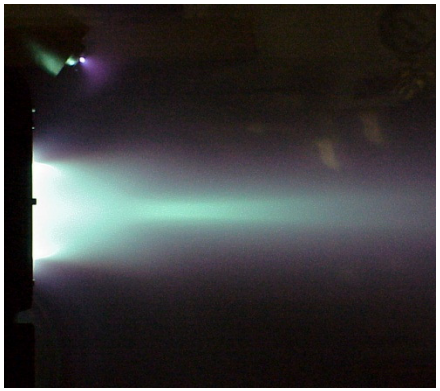




Busek 20-kW Thruster at GRC VF5



Cluster of Busek Xe HETs



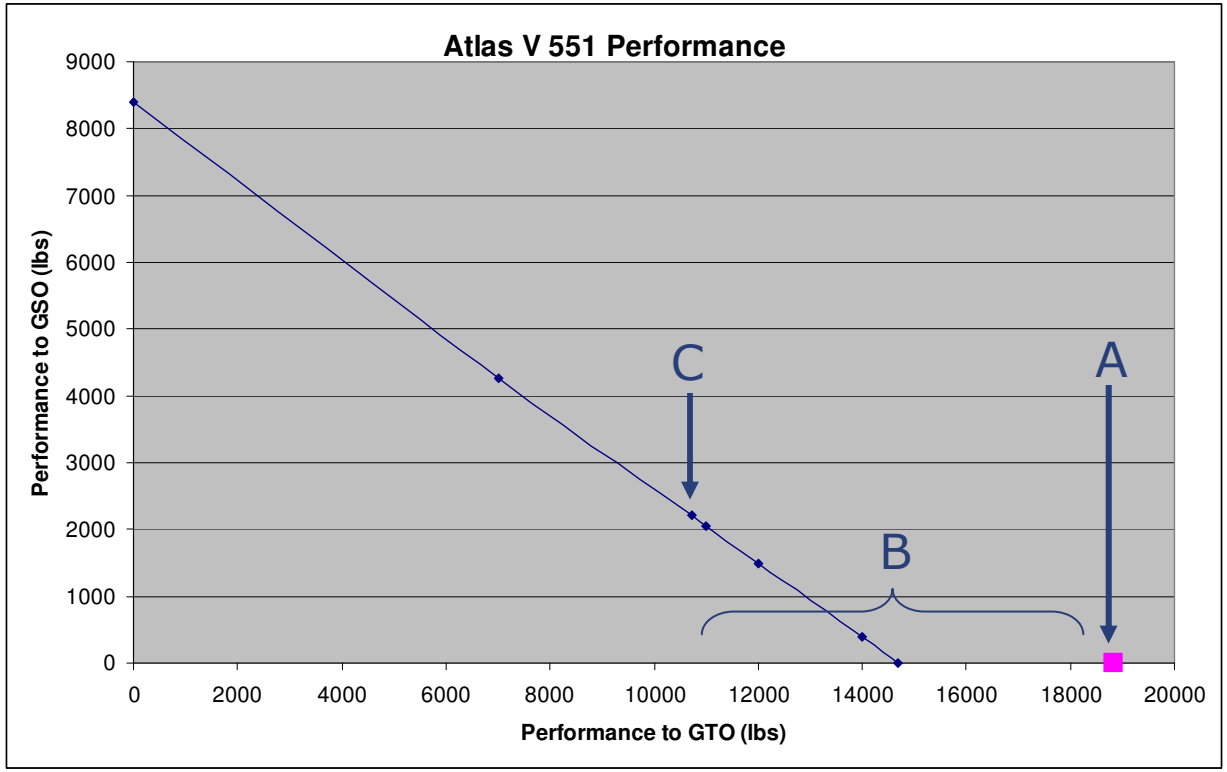
1-kW Iodine Plume

Delivery of a Rideshare P/L to GSO

A. Atlas V 551 can deliver 19,620 lbs (8,900 kg) to a GTO orbit.
   A 5M fairing is required for a GSO type mission

B. To deliver a rideshare P/L to GSO: requires an extended-mission-kit, a 5M fairing, a long coast, an additional burn to achieve GSO orbit.

C. To enable a 2,200 lbs (1000 kg) Rideshare mission, the Primary would be restricted to 10,700 lbs



MULE Rough Specs Summary

- MULE stage built on ESPA ring and standard ULA separation system
- Total mass of the MULE stage with 14,055lb SV is ~19,500lb
- ~4kW solar array on board (SS/L is flying them now)
- 4 of Busek 2kW thrusters on 2 gimbals
- GTO to GEO transit time <140 days
- Mars transit 3 years
- ULA has been working w/ Busek Propulsion on the Hall Effect thruster
  - Xenon I_{sp} = 1544 for Xe at 250 V, 200 W
- New solution launches with lite-wt composite tank to eliminating the need for heavy pressurized tanks
- Minimum delivery time first unit ~3 years
- EP Upper stage cost with all NRE ~$50-60M
- Re-flight unit ~$30-40M
- No significant technical challenge

What does it mean for Interplanetary Missions?

- Some of our missions (particularly polar ones) do Earth-escape disposal of the upper stage
- Some of the missions have fairly large margins
- It is possible to raise the apogee to beyond L1 for a separation
- The primary will dictate the time of launch and the moon can be anywhere in its orbit.
- However, if a Lunar exploration s/c could loiter long enough it could sync with and be captured by Lunar gravity
- Options:
  - ABC can support 80 kg s/c
  - ESPA can support (6) 200 kg s/c
  - A-Deck can support up to 2000 kg s/c

Potential Rideshare Opportunities

- Some of these missions are pending contract ward – must check current status.
- All potential mission opportunities will need to be:
  - Assessed for technical compatibility
  - Coordinated and approved by the primary payload customer

Mission	Customer	Vehicle	Site	Orbit	Margin, Excluding Disposal (kg)	FY15	FY16	FY17	Notes
GPS-IIF	USAF	401	ER	MEO - Direct	~600	IIF-4, IIF-6	IIF-7, IIF-8		Transfer orbits missions
GPS-III	USAF	411	ER	MTO	[~1100]		IIIA-2	IIIA-5	
SBIRS	USAF	401	ER	GTO	~100		GEO-3	GEO-4	
AFSPC	USAF	401	ER	GTO	TBD	AFSPC-8			
NRO	NRO	411	ER	GTO	TBD			L-61	
AEHF	USAF	531	ER	GTO	Performance Limited			AEHF-4	
MUOS	USAF	551	ER	GTO	Performance Limited	MUOS-4	MUOS-5		
GOES	NASA	541	ER	GTO	Performance Limited		GOES-R	GOES-S	
TDRS	NASA	401	ER	GTO	Performance Limited		TDRS-M	TDRS-N	
MMS	NASA	421	ER	GTO	Performance Limited	MMS			
Discovery	NASA	401	ER	Hyperbolic	TBD	D-12			Earth escape trajectories
ExoMars	NASA	421	ER	Hyperbolic	Performance Limited		EM		
Osiris Rex	NASA	401	ER	Hyperbolic	Performance Limited			OR	
Europa	NASA	551	ER	Hyperbolic	Performance Limited			EO	
Solar Orbiter	NASA	551	ER	Hyperbolic	Performance Limited			SO	
NRO	NRO	401	WR	TBD	TBD			L-79	LEO Missions Disposal TBD
NRO	NRO	541	WR	TBD	Performance Limited	L-67		L-42	
NRO	NRO	401	WR	TBD	TBD	L-55			
STP	USAF	401	WR	~700km 98 deg	**>5,000**			STP-3	
CLARREO	NASA	[Delta II]	WR	~600 km Polar	TBD			CLARREO	
ICESat	NOAA	[Delta II]	WR	Polar	TBD		ICESat-2		
DMSP	USAF	401	WR	~800km 99 deg	**>4,000**	DMSP-19/DSX	DMSP-20		
JPSS	NOAA	[Delta II]	WR	~800km 98deg	~900		JPSS-1		
GeoEye	GeoEye	401	WR	~700km 98 deg	**>4,000**			GEOEYE-2	
WorldView	Digital Globe	401	WR	~700km 98 deg	**>4,000**		WV-4		
Comm I-9	CLS	401	WR	TBD	**>4,000**		Comm I-9		

Summary

- Rideshare is a flight-proven solution to achieving various mission objectives
- Multiple ULA rideshare capabilities offer solutions to all mission types
  - Mass range 1 kg to 5,000 kg
  - Dimension range 10 cm to 6 m
- Designing and launching co-manifested missions is a better approach for maximizing mission capability to orbit

United Launch Alliance stands ready to evaluate and provide low-cost rideshare launch opportunities to SMC and the US Air Force

Nest Steps

- ULA can assist in brokering rideshares with primary customers
- ULA can assist for specific applications that may work
- ULA can work with primary customers for rideshare opportunities
- You are responsible for:
  - design rqts (ABC / ESPA Rideshare users guides),
  - required gates (pre-mission design, PDR, CDR, Range Safety)
  - perform the qualification and pre-integration