Mission Design Challenges for Multi-Manifest Missions

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CubeSat Workshop 2013

Athena™

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Multi-manifest Mission Design Challenges

- The increased complexity of deploying multiple small satellites and cubesats on mutli-manifest missions requires special attention to mission design
- The challenges to executing multi-manifest missions span the entire spectrum of a launch service:
  - Technical and performance launch vehicle constraints
  - Multi-Customer contracting
  - Regulatory approvals (FAA, FTC, JSpOC, ITAR, etc)
  - Integration management, logistics, and facilities support infrastructure
  - Detailed mission design and flight software development
- Mastery of these challenges is the key to offering low cost reliable launch services to multiple small satellite customers

Multi-manifest mission stress all aspects of the launch service

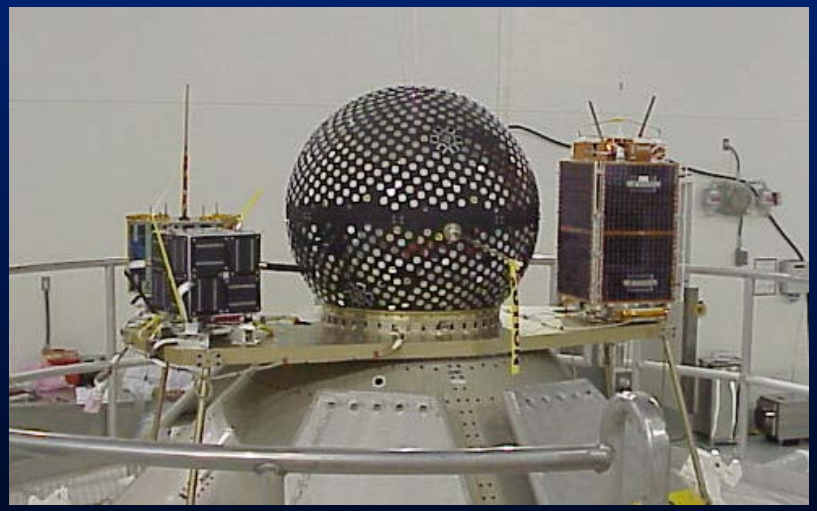
Technical Considerations for Multi-manifest Missions

- There are significant technical challenges to executing multi-manifest missions. These include:
  - Integrating a variety of mass and volumes in a dynamic environment
  - Strong, low mass, low cost, multi-payload adapter system
  - Adapting the launch profile to accommodate a wide range of inclinations and orbital altitudes
  - Verification that all payloads will not adversely impact the mission or other payloads
  - Ensuring adequate ground communications
  - Ensuring no re-contact between deployments
  - Vehicle battery power utilization and management
  - Propellant utilization and optimization of Delta-V
  - Ensuring injection accuracy and minimizing orbital debris concerns

Multi-variable optimization required for mission success

Athena's Proven Multiple Payload Capability

- Athena's multiple payload capability was successfully demonstrated on the NASA Kodiak Star Mission
  - Three Satellites to 800km
  - One Satellite to 500km
  - Injection errors < 2km & <5km



KLC Payload Processing Facility

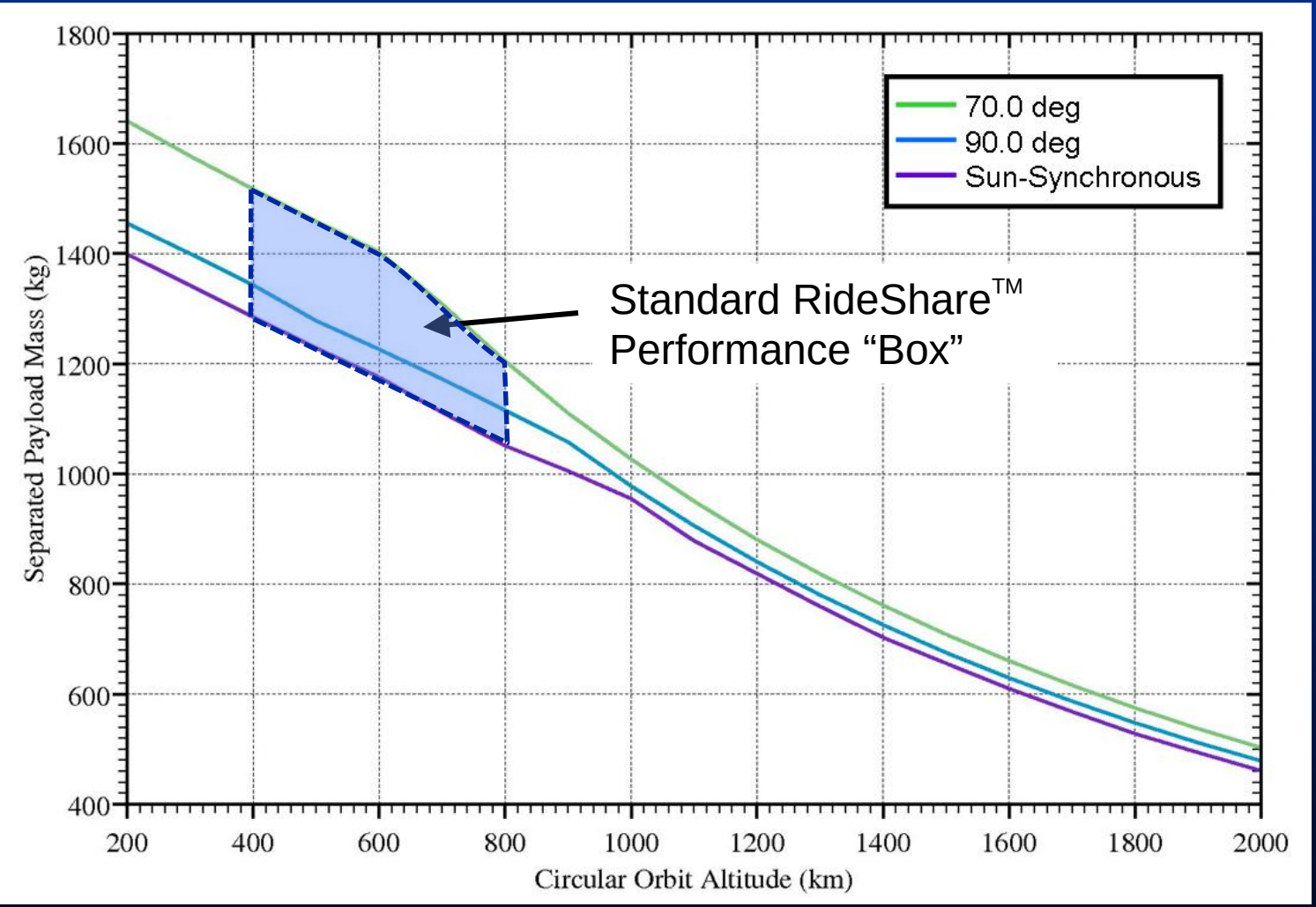
Introduction of Athena RideShare™

In 2011 LM/ATK introduced our Athena RideShare™ concept to the small satellite market

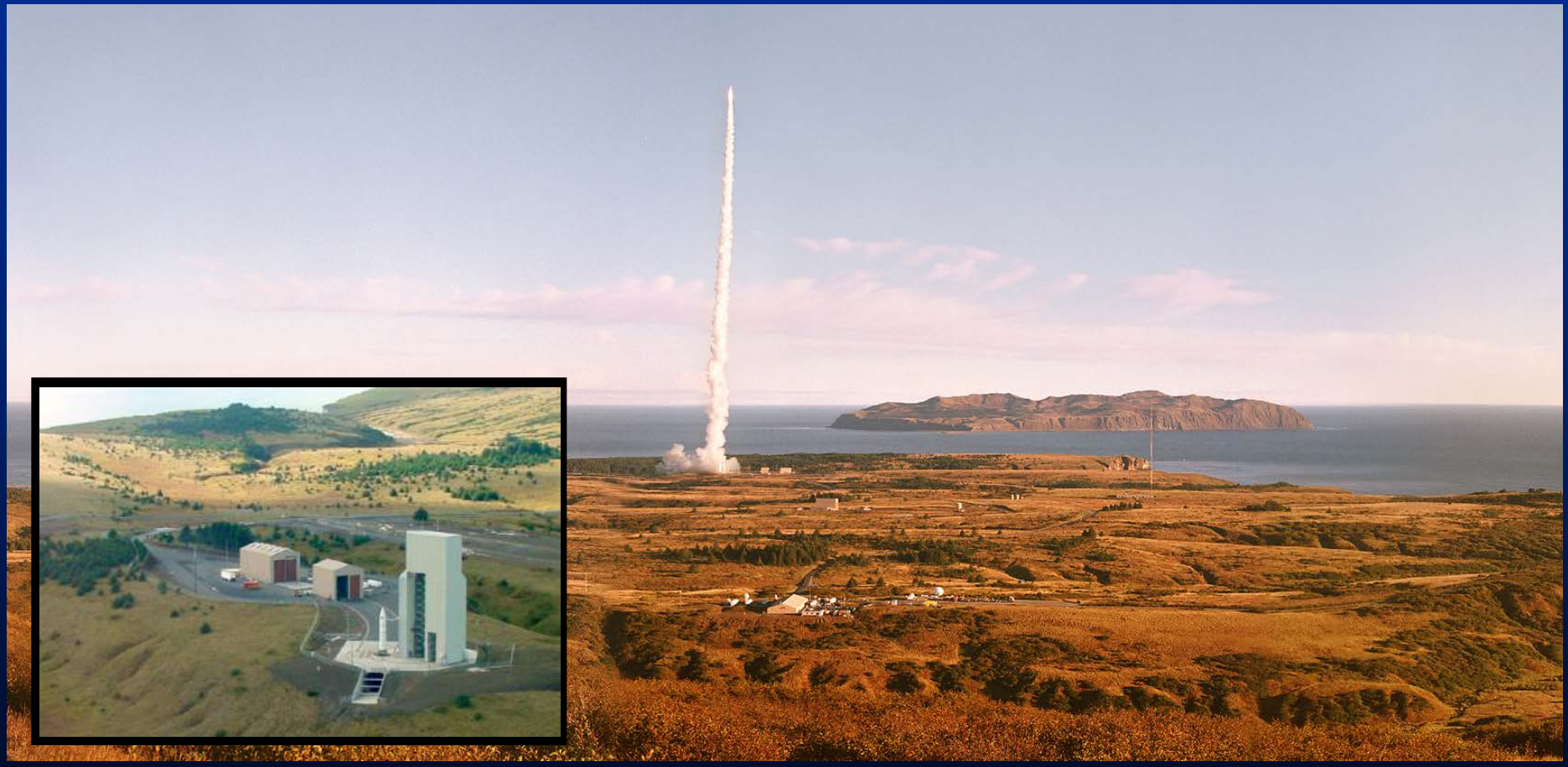
- Objective is to have annual Athena IIc launches from Kodiak
  - 70 degree to sun synch inclination, 400 to 800 km orbit(s)
- Multi-manifest mission so each of the ride share satellites can fly at an affordable price
- Accommodations for 4 - 9 ride share satellites
- Frequent flyers will get a discount on future Athena RideShare™ flights
- P-POD opportunities are available on every flight
- There are no “primary” or “secondary” payloads – everyone rides in the Athena bus, and we drive
- One “premium service” available: 1st injection event, set mission inclination and first orbit altitude

Athena IIc RideShare™ Launch Vehicle

Athena IIc High Inclination Performance



Kodiak Launch Center – RideShare™ Mission Site



Contractual Launch Service Relationships

P-POD Payload Integrators

tyvak NANO-SATELLITE SYSTEMS LLC

TriSept Corporation

SPACEFLIGHT

Integrators contract P-POD services for multiple customers

- NRO
- SMC
- NRL
- NASA
- Universities
- International
- Commercial
- etc

LM FFP contracts
Secondary Payload:
Space delivery service for up to 24 P-PODS

LM FFP contract
RideShare Payloads:
4-9 @110kg – 440kg

Multiple Ride Share Payload Customer Contracts

LM & ATK provide
Athena IIc Launch Service

Launch from KLC

CubeSat Customers contract directly with Tyvak, TriSept or Spaceflight for integrated P-POD space lift services

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Highly Capable Injection Stage is Key for Multi-Payloads

- Athena's standard Orbit Adjust Module (OAM) is the key to our multi-payload injection capabilities
  - Provides 2 orbit, 3 hour mission timelines, unlike other systems
  - Allows for multiple orbits on the same mission for maximum flexibility
  - Permits very precise orbit insertions for multiple satellites
  - "Store & Forward" communications ensures state vectors for all separation events are captured
  - End of life deorbit assist maneuver minimizes launch vehicle orbital debris

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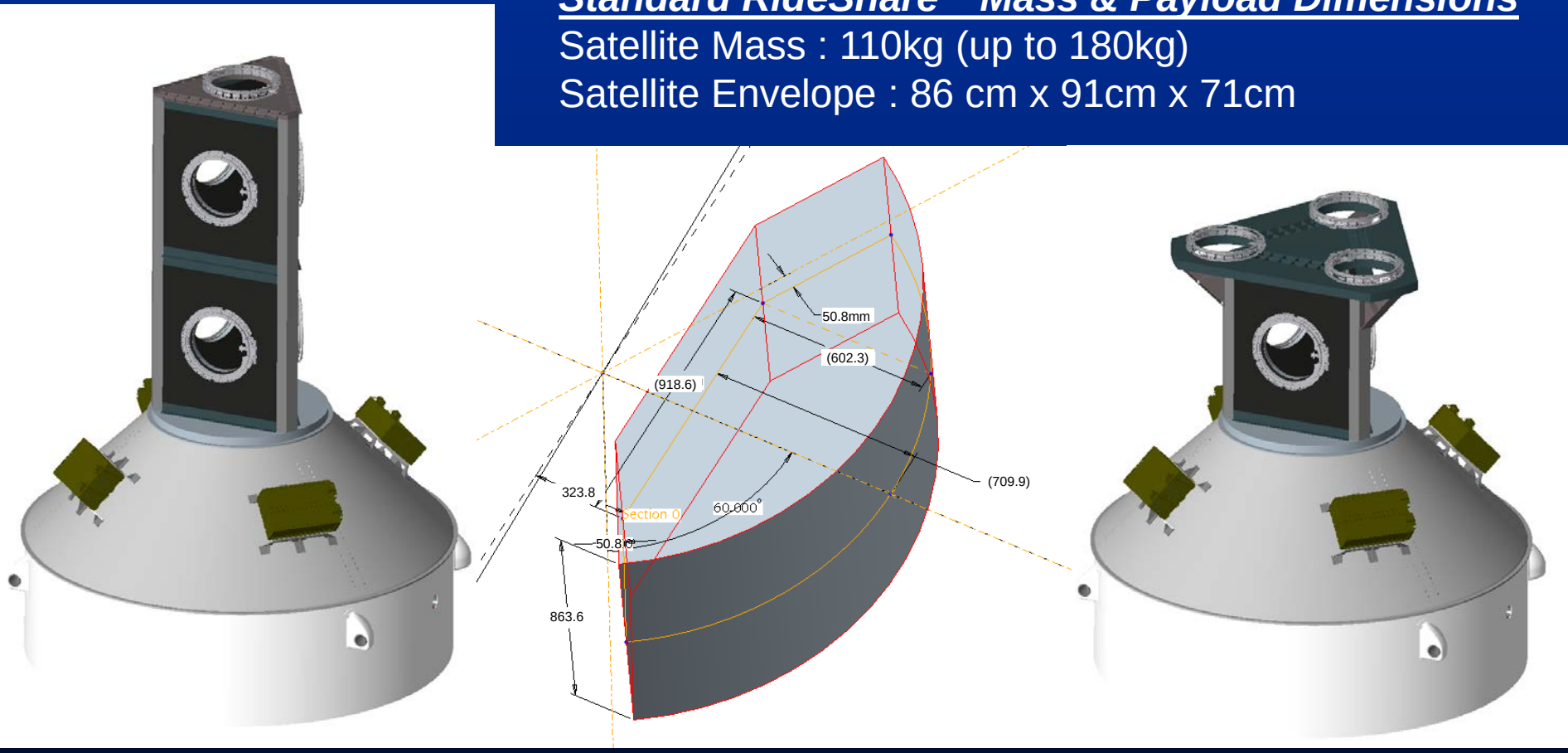
Initial Multi-Payload RideShare™ Accommodations

Standard RideShare™ Mass & Payload Dimensions

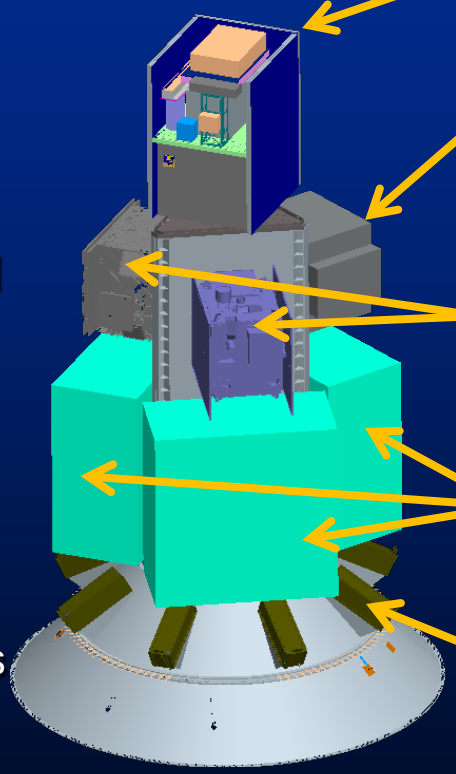
Satellite Mass : 110kg (up to 180kg)

Satellite Envelope : 86 cm x 91cm x 71cm

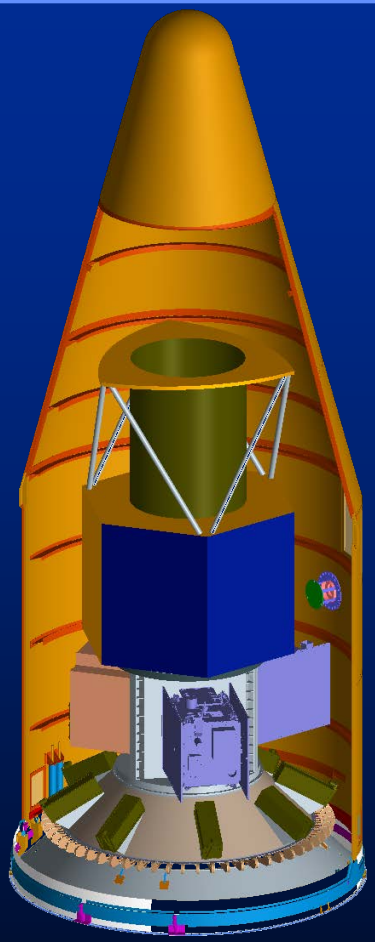


Multi-Payload Compatibility Assessment Phase

- In 2012 LM successfully completed an initial multi-payload compatibility assessment for the USAF (STPSat-3)
  - Detailed mission design and flight software development
  - Initial coupled loads assessment (CLA) performed with Moog CSA Engineering SoftRide incorporated into Multi-Payload Adapter (MPA) design
  - MPA development through PDR
  - STPSat-3 was Premium Service customer
    - Two additional commercial customers and 16 P-PODs to deploy on 1st orbit
    - Commercial customer to deploy 3 satellites on 2nd orbit



Multi-Payload Configuration Versatility Assessments



- Throughout 2011 and 2012 LM analyzed and completed mission design solutions for a wide variety of customer payload configurations
- Key objectives met:
  - Exploration of the limits of Athena system performance capabilities to accommodate wide mix of spacecraft mass/volumes and optimization of orbit maneuvering and insertion capabilities
  - Rapid integration and build of flight software mode phases through modular cataloging
  - Refinement in modeling OAM thrust profiles / usage curves for precise performance predictions
  - Detailing of modular MPA baseline design and harness routing solutions

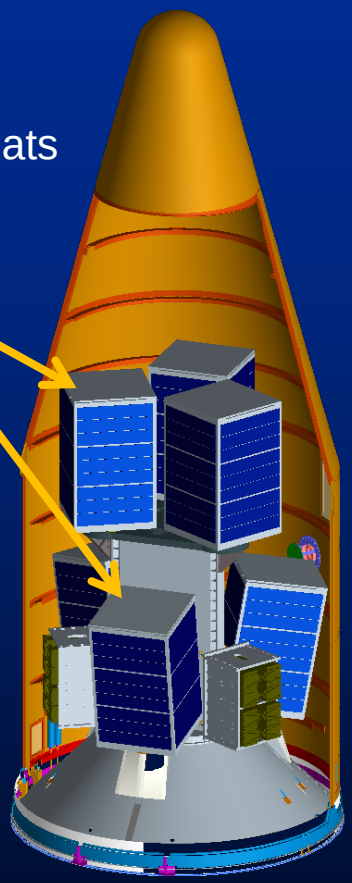
Athena RideShare™ mission design capability envelope fully defined

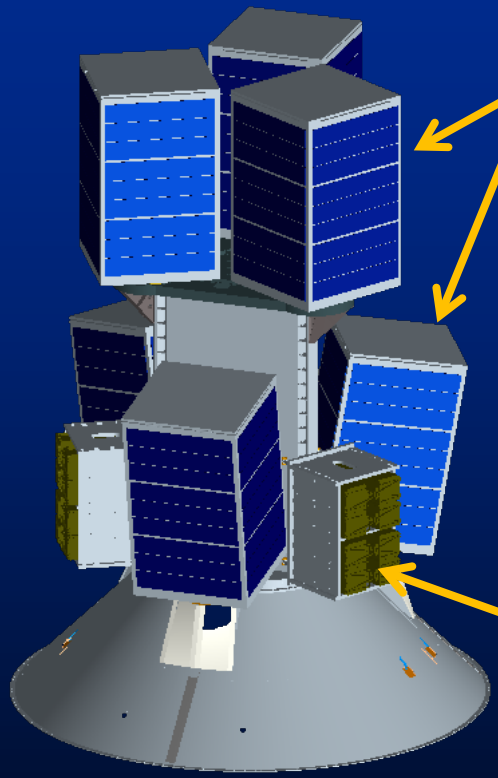
2015 & 2016 Commercial RideShare™ Configuration

Athena

6 ESPA-class payloads +
3 x 24U CubeSat carriers

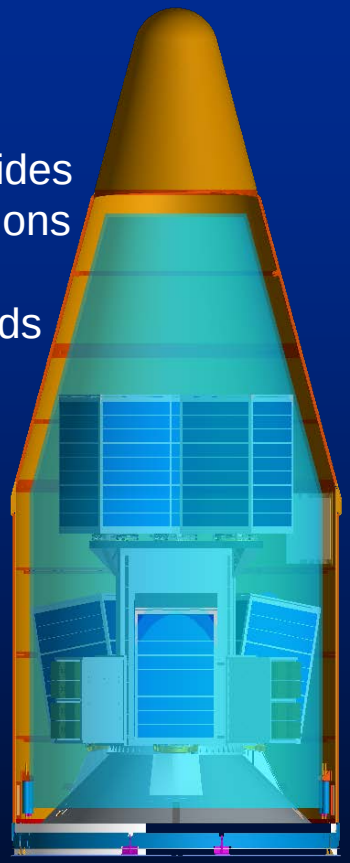
6 x CommSats
Primary
Payloads





92” PLF provides
accommodations
for 6 x ESPA
Class Payloads

3 x 24U
CubeSat
Carriers



RideShare™ performs up to 30 in orbit separation events

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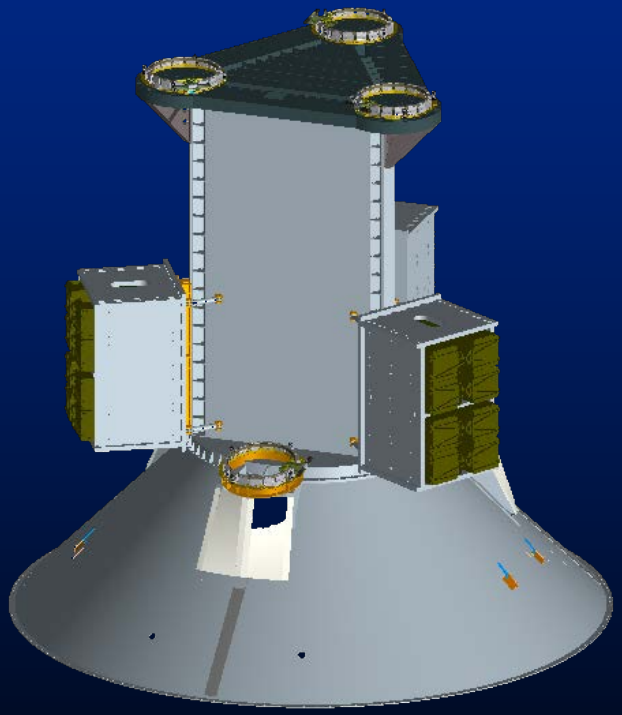
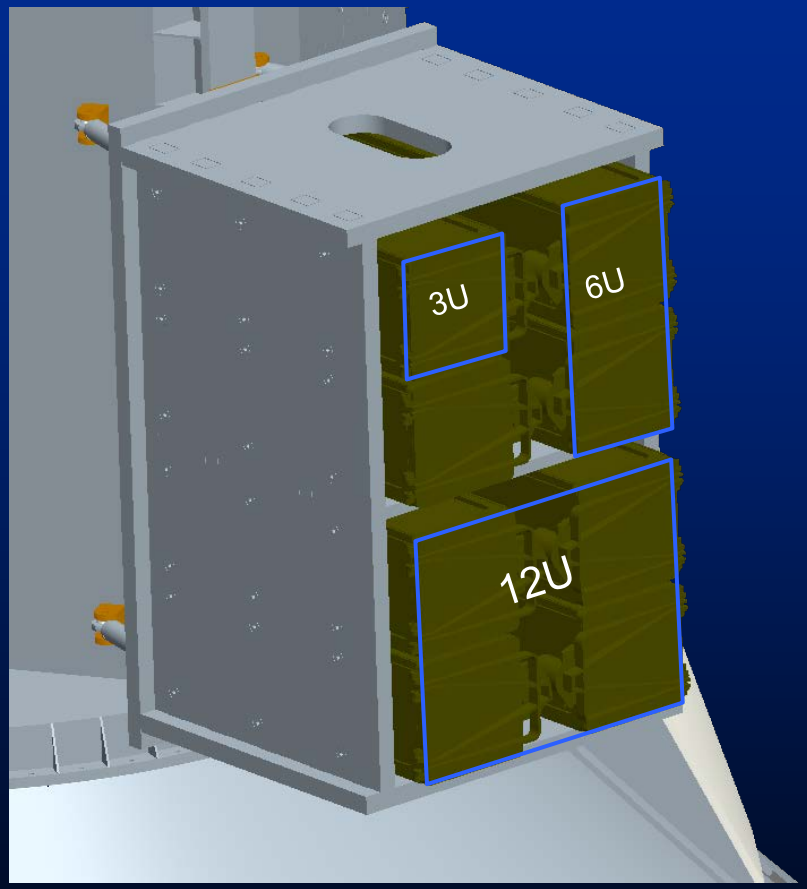
Capability to Fly 72U of CubeSats on each mission

Athena Composite P-POD Carrier (ACPC) – 3 per flight

Mix & Match:

- 24 x 3U P-PODs
- 12 x 6U containers
- 6 x 12U containers





2015 & 2016 RideShare™ Mission Design

- Launch Location:
  - Kodiak Launch Complex (KLC); Launch Pad 1 (LP-1)
- Orbital Requirements and Assumptions

Parameter	Primary Orbit	Secondary Orbit	Tertiary Orbit
Altitude	515 km Circular*	475 km Circular*	450 x 455 km
Inclination (deg)	97.40	97.35	97.35

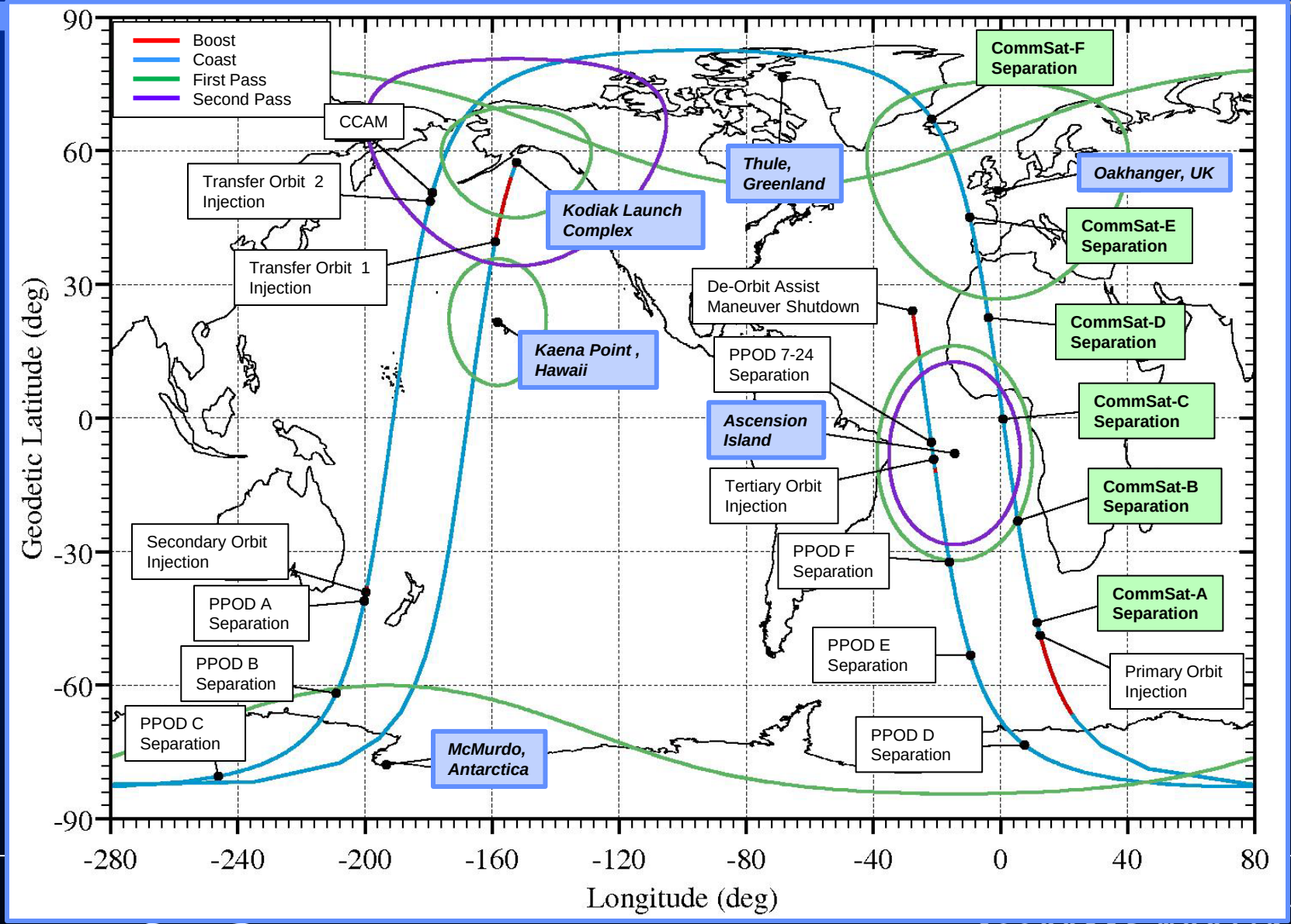
* First Spacecraft Deployment; Subsequent deployments can be in slightly elliptical orbits, if desired, to assist with Constellation Phasing/Spacing

- Launch Vehicle Performance Capability Accounts for:
  - Boost Phase Dispersions; Reserve DV/Propellant in OAM
  - Range/Flight Safety Requirements
  - Center of Gravity Offsets for Multiple Payloads
- No OAM Activity for 5 minutes following Each Primary Spacecraft Separation
- OAM Performs Contamination and Collision Avoidance Maneuver (CCAM) Following Final CommSat-Spacecraft Deployment (Small Inclination change)
- OAM Performs De-Orbit Assist Maneuver (DAM) After Completing All Payload Separation Events; Perigee Altitude < 148 km (< 80 nmi)
  - No Space Debris

Premium P-POD Deployment Description

- Six 3U P-PODS for this Deployment Sequence
- Second Orbit Conditions
  - Altitude: 475 km Circular (initial separation event altitude)
  - Inclination: 97.44 deg
- Mission Features/Options
  - Orbit Adjust Module (OAM) Maneuvers Spacecraft to the Desired Attitude and Attitude Rates Prior to Deployment
  - Separation State Vector Stored in Flight Software for Each Deployment and Transmitted to Next Available Ground Tracking Station (Example: Ascension Island Second Pass)
  - Post-Deployment Wait (No Thruster Activity on OAM) for 5 min Following S/C Separation
    - S/C Spacing and Eliminates Potential Thrust Exhaust Contamination
  - Optional ΔV Burn Performed After Post-Deployment Wait (Example: 3-5 ft/s)
    - Additional Spacing or Slight Plane Change
  - Repeat: OAM Maneuvers to the Desired Attitude and Attitude Rates for Second S/C Deployment….

RideShare™ 2015 & 2016 Mission Ground Track



We have defined multi-payload standard services

- Standard Services :
  - Full Mission Integration Experience
    - Unique ICD w/ Requirement Verification Matrix
    - Complete CDRL Analyses & Reports
  - Processing Facility – KLC PPF (Shared)
  - SoftRide load attenuation if required
  - 15”, 12” or 8” MLB Separation System
  - 2 PLF Access Doors
  - Environmentally Conditioned PLF (Encapsulation thru Launch)
  - Release Signal/Discrete
  - Highly Accurate Orbit Injection
  - Post Flight Report

Summary

The Future Requires Low Cost Access to Space

- Buying a rocket for every mission is too expensive
- There needs to be a cost effective approach to space access
  - The laws of physics don't change
  - Costs for Delta-V are not going to significantly decrease
- However, we have expanded the launch services business model for small satellite customers looking for reliable low cost access to space
- Athena Launch Services plans to offer -
  - Annual RideShare™ missions
  - Payload opportunities that meet customer price points

Athena Offers Full Service at Fixed Prices