FISO telecon 8-6-2015
http://spirit.as.utexas.edu/~fiso/archivelist.htm

America's Ride to Space

Orbital Disposal of Launch Vehicle Upper Stages

John G. Reed
United Launch Alliance
GN&C Sr. Technical Fellow

America's Ride to Space

Agenda

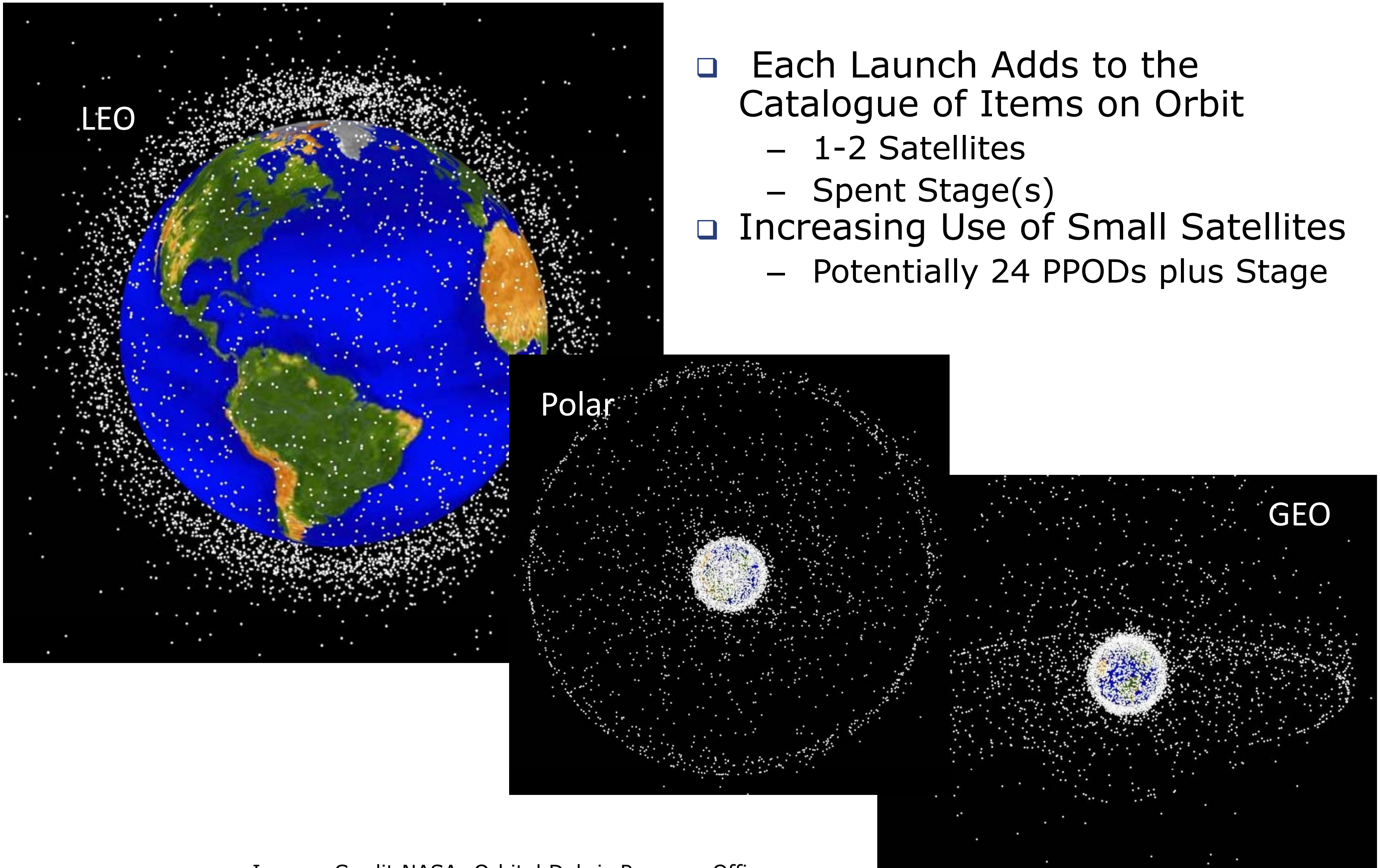
- Background
- Deorbit
- Disposal Issues
- Compliant Disposal Process
- Future Evolution

Timely Topic

Background

- Historically Efforts Focused on Debris Mitigation
  - Early Studies linked Space Debris to Upper Stage Fragmentation
  - Focused Energy on Upper Stage Safing and/or Removal
  - Many Satellite Vehicles Needed All Launch System Performance
- International Coordination of Practices
  - Stems from Inter-Agency Space Debris Coordination Committee (‘93)
- USG Orbital Debris Mitigation Standard Practices (circa ’97)
  - Long Required Specific Safing & Disposal Behaviors
  - Applies to Both Satellite End-Of-Life and Launch Vehicles
  - Specifies Safing Requirements and Acceptable Disposal Orbits
- Recent Studies Identified Space Congestion as Major Concern
  - Every Launch Creates Multiple Orbital Items

Space Congestion



- Each Launch Adds to the Catalogue of Items on Orbit
  - 1-2 Satellites
  - Spent Stage(s)
- Increasing Use of Small Satellites
  - Potentially 24 PPODs plus Stage

Images Credit NASA: Orbital Debris Program Office
http://orbitaldebris.jsc.nasa.gov/photogallery/beehives.html#leo

America's Ride to Space

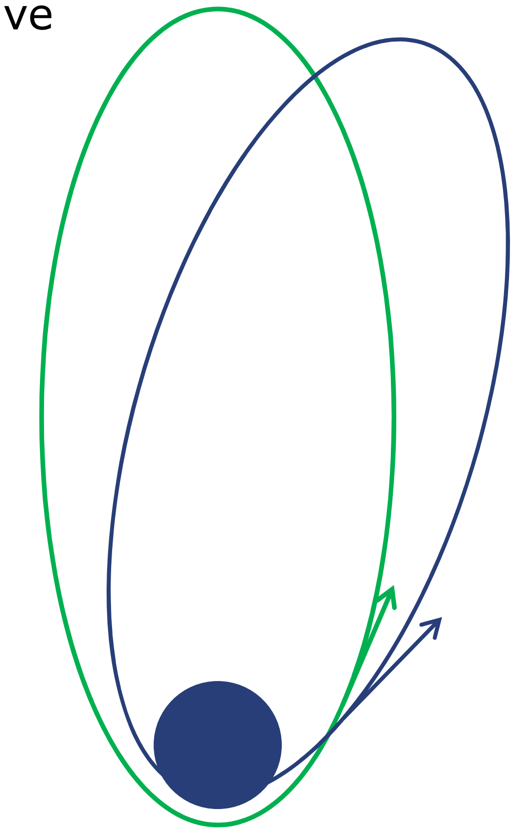
Energy Aspects

- Historically Spacecraft Need Every Ounce of LV Performance
  - Never Want to Pay for More Rocket than Needed
  - Lifetime Traded to Finish off the Orbit with SV Propellant
  - Kick Stages are relatively low efficiency
- De-orbit from LEO Can Require >250 m/s Delta-V
  - Certainly Feasible, with very small impact on SV
  - Less than 90 minute mission extension to position Impact Point
  - Challenges
    - Retaining sufficient propellant and Accurate short burn GN&C
- Perigee Altitude Impacts
  - De-orbit/Breakup can occur with Positive Perigee Altitude
  - Shallow Alpha at Breakup results in wider debris
- For Specific Impacts, Apply the Rocket Equation
  - Function of Engine ISP and masses of the payload and upper stage

    $dv = Isp * g0 * \ln(mf/me)$
  - For more information, refer to "Orbital Disposal of Launch Vehicle Upper Stages" Presented at AIAA Space 2015

GTO De-Orbit

- De-orbit from Low Perigee GTO
  - Function of where along orbit Disposal is Performed
  - Apogee adds 5 hour coast but only 90 m/s of Delta-V
  - Immediate Disposal, near Perigee is expensive
  - Challenges
    - Burn Placement (Coast Length)
    - IIP Variability



MEO and Electric Propulsion Orbits

- Some Missions Benefit from High Perigee Injection
  - One Example are Electric Propulsion System SV's
  - Reduces the SV Delta-V to GSO over Standard GTO
- High Perigee GTO Creates Additional De-Orbit Challenges
  - Larger Perigee Reduction Required for Re-entry
  - Mission Duration is typically Longer than Standard GTO

Geo-Stationary Orbit

- Geo-Stationary Orbit, Circular at a Fixed Point over the Earth
  - Lowering Perigee Down to Earth is Comparable to Raising it to GEO
  - Typically Inserting Near Equatorial
    - Objective is SV has Minimal Need to Adjust Orbit
  - Position Movement at GEO is typically degrees/day
    - Would have to move the IIP by applying multiple burns
  - Likely Less Energy Required to go Heliocentric
    - Simple Push Apogee beyond Lunar and Escape
  - Either Case Assumes significantly more Propellant for Disposal

Drives Consideration for Disposal Orbits

Disposal Orbit vs. De-orbit

- Disposal Characterizes the Minimum Requirements
  - Driven by Long Term Perspective
  - Ensure that Orbits Decay within 25 Years
  - Ensure than Non-Re-Entry Orbits Don’t Conflict for 100 Years
  - Requirements Recognized in Space Policy
- Drives USG Agency’s Compliance Documents
  - Each Agency Defines Specific Requirements

America's Ride to Space

Disposal Orbits

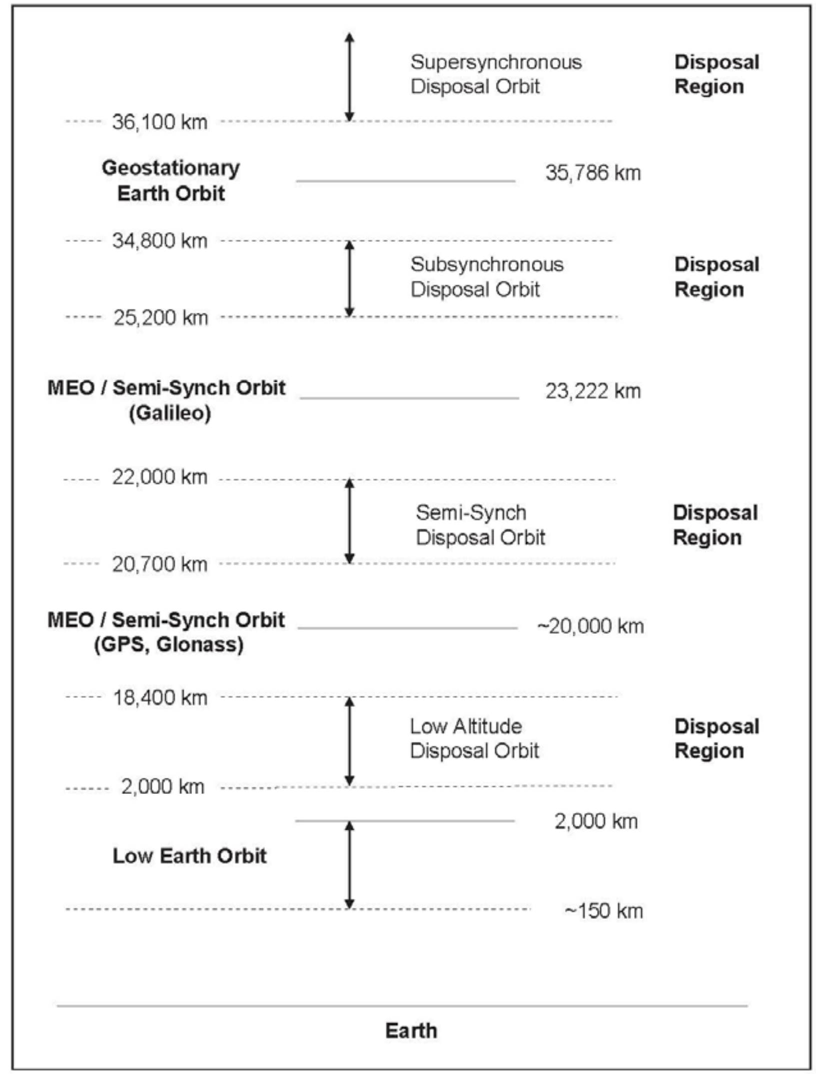
- NASA STD-8719.14, “Process for Limiting Orbital Debris,” 28 Aug. 2007
  - Removal of objects at End of Mission is preferred, *but specific* disposal orbits may be used
    - (Where removal from orbit or limiting lifetime to less than 25 years cannot be accommodated, specific disposal orbits are recommended)
      - Missions near GEO: spent stage to be maneuvered to an orbit above GEO
        - (minimum altitude of GEO + 200 km for a minimum of 100 years after disposal)
      - Near circular orbits between 19,100 & 20,200 km: shall NOT be used
        - (stay away from GPS)
      - Other orbits: spent upper stage may be left in an orbit with perigee above 2,000 km above Earth's surface and 500 km below GEO
        - (stay above ISS and below operational GEO belt)

America's Ride to Space

Disposal Requirements

- Notional USAF Approach:
  - Removal of objects from orbit at end of life is preferred
    - Controlled re-entry or escape trajectory
  - Re-entry in less than 25 years with casualty risk < 1 in 10,000 is the next best option
    - ULA upper stages <u>cannot</u> meet the random re-entry casualty risk by an order of magnitude
  - When not possible, specific disposal orbits may be used with specific altitude ranges and eccentricity requirements.

Operating, Storage and Disposal Regions/Orbits.



Disposal Orbit Challenges

- GPS Belt Crossing
  - USAF Excludes Orbits that Cross GPS Altitude
  - Results in Mixed Compliance for High Perigee GTO missions
  - Driving to Consensus, Leveraging Big Sky Principal
  - Disposal Requires a Single Apogee Lowering Burn
- GEO/MEO Circular Storage
  - Ideal Design Requires 2 Disposal “Burns” ½ Period Apart
  - Insert Satellite and Use Apogee and Perigee Raise Maneuvers
  - Challenge with Short Burn and Long Duration
  - Lower Thrust Would Provide Other Options

ULA Mission Design

- Disposal Mission Design Implementation Considerations
  - Mission Interface Control Document (ICD) requirements
  - Delivery orbit
    - Low Earth Orbit (LEO)
    - Medium Earth Orbit (MEO)
    - Geo-synchronous Earth Orbit (GEO)
    - High Eccentricity Orbit (HEO)
  - Orbital lifetime assessment
  - Upper Stage main engine propellant margin
  - Other consumables margins

Typical Disposal Implementation

- LEO Orbits
  - Minimize orbit lifetime, Guided Reentry, or Earth Escape
- MEO Orbits
  - Utilize designated Earth orbital disposal orbit
- GEO Orbits
  - Utilize designated Earth orbital disposal orbit
- HEO/GTO Orbits
  - Minimize orbit lifetime, Guided Reentry, or designated Earth orbital disposal orbit

Upper Stage Disposal Usage

- Disposal scenarios available to both Atlas and Delta upper stages
- Controlled Re-entry
  - Eight Recent/Near Term Missions
- Hyperbolic Escape
  - Two Recent, plus all interplanetary missions
- Disposal Orbits (orbits defined as safe storage orbits)
  - Five Recent/Near Term Missions
- Meet 25 year orbit lifetime
  - Three Recent/Near Term Missions

Path Forward

- Missions with GSO or GTO are most difficult
  - GSO missions are performance critical
  - Difficult to raise apogee and perigee
  - GTO missions always want every last drop of performance
    - Directly translates into operational lifetime
- Increasing Compliant Disposal Coverage
  - With USAF Support, Increase Percentage of Compliant Missions
  - Increased Cost for Some Missions
- Most missions will be compliant in the Near Term
- Investigating Enabling Technology for Full Compliance
  - H_2O_2 Thrusters
  - Fuel Cell Technologies
  - Integrated Vehicle Fluids

H2O2 Thruster

- ULA Initiated Investigation
  - More Details in Various Published Papers
  - Leveraging Upper Stage Residual H2 and O2
  - Convert Liquid or Gas Into Thrust
- Enable Longer Duration, Lower Thrust Solutions
  - Mitigate short burn aspects
  - Mitigate boil-off concerns
- In 2015, USAF issued SBIR
  - Focused on Ignition System
  - Enables broader application of basic technology
  - Covers much of the Thruster Qualification Risk

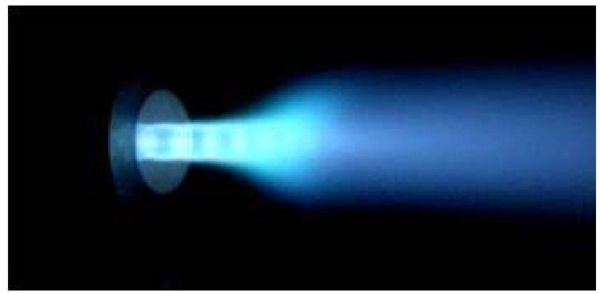
ULA
America's Ride to Space

H2/O2 Thruster

Innovative Engineering Solutions
IES

H2/O2 Thruster firing in IES's purpose built Steam Ejector vacuum facility

Hot Hydrogen Oxygen flame impinging on deflector shield



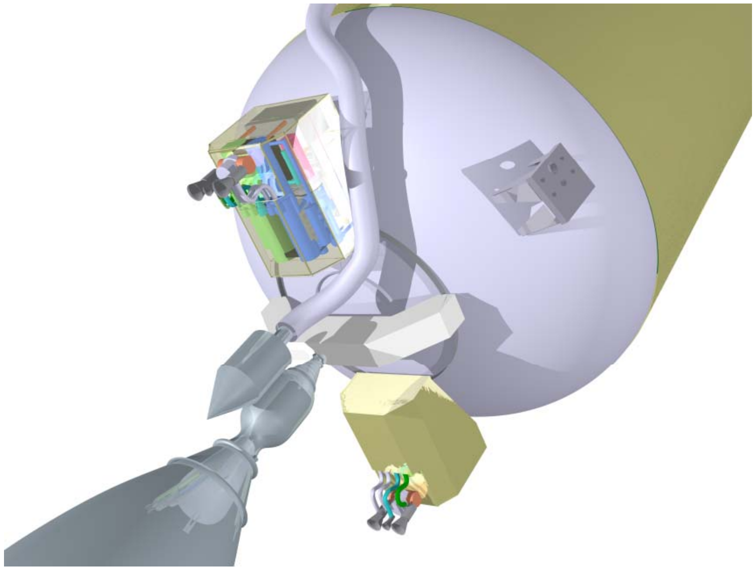
NASA MSFC's Space Exploration Test Facility
Trace methane added so exhaust is visible

ULA and IES have completed development of the H2/O2 thruster which will be qualified for flight in 2015

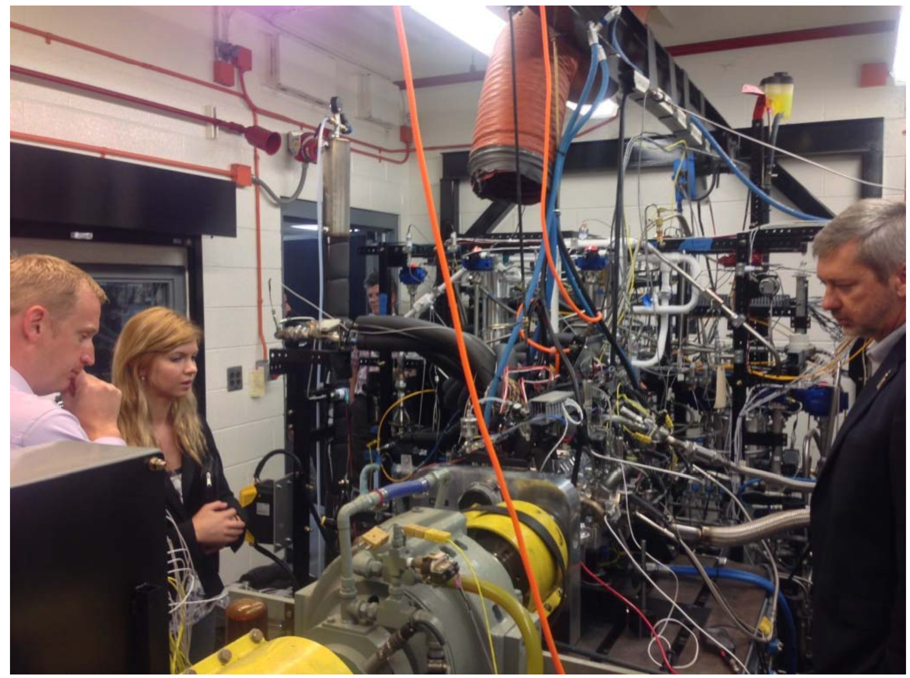
Fuel Cell Technology

- ULA Initiated Investigation
  - More Details in Various Published Papers
  - Leveraging Upper Stage Residual H_2 and O_2
  - Convert Liquid or Gas Into Power
  - Matured System Concept Designs
- Enable Longer Duration Operations
  - Allows More Optimal Burn Placement
  - Continuous Low Flow Mitigates Boil-off Concerns
- In 2015, USAF issued SBIR
  - Focused on Continued Technology Demonstration
  - Enables Broader Understanding of Basic Technology
  - Hopefully Continues to Reduce Implementation Risks

Integrated Vehicle Fluids



IVF System mounted to
Centaur Aft bulkhead



IVF System undergoing cryo testing
In Roush's Dynamometer Facility

ULA and Roush have racked up hundreds of hours of testing
of the Full scale IVF prototype

Integrated Vehicle Fluids

- ULA Initiated Investigation
  - More Details in Various Published Papers
  - Managing Upper Stage H2 and O2
  - Convert Liquid and Gas Into Power and Thrust
  - Testing of Various Elements
- Enables Integrated Solution to Upper Stage Operations
  - Provides Benefit/Flexibility to Upper Stage Operations
  - Provides Baseline Pressure Control for Upper Stage Tanks
- In 2015, Continued IRAD Efforts
  - Focused on Continued Technology Demonstration and Risk Reduction

Summary

- Upper Stage Disposal is a Challenging Technical Problem
  - For Many Missions there is an Impact to the SV Operations
- US Government Agencies Have a Significant Role
  - Shaping Management of Space Congestion
- ULA has been Year-on-Year Improving our Disposal Compliance
  - Working Closely with our US Government Customers
  - Defining the Best/Cost Effective Approaches to Compliance
- ULA is using Innovation to Meet a National Need
  - Extending Existing Capabilities
  - Pursuing New or Innovative Applications of Technologies