Enhancing United States Space Force Interoperability via Mission Life Extension

NDIA 2023 Systems & Mission Engineering Conference

18 October 2023

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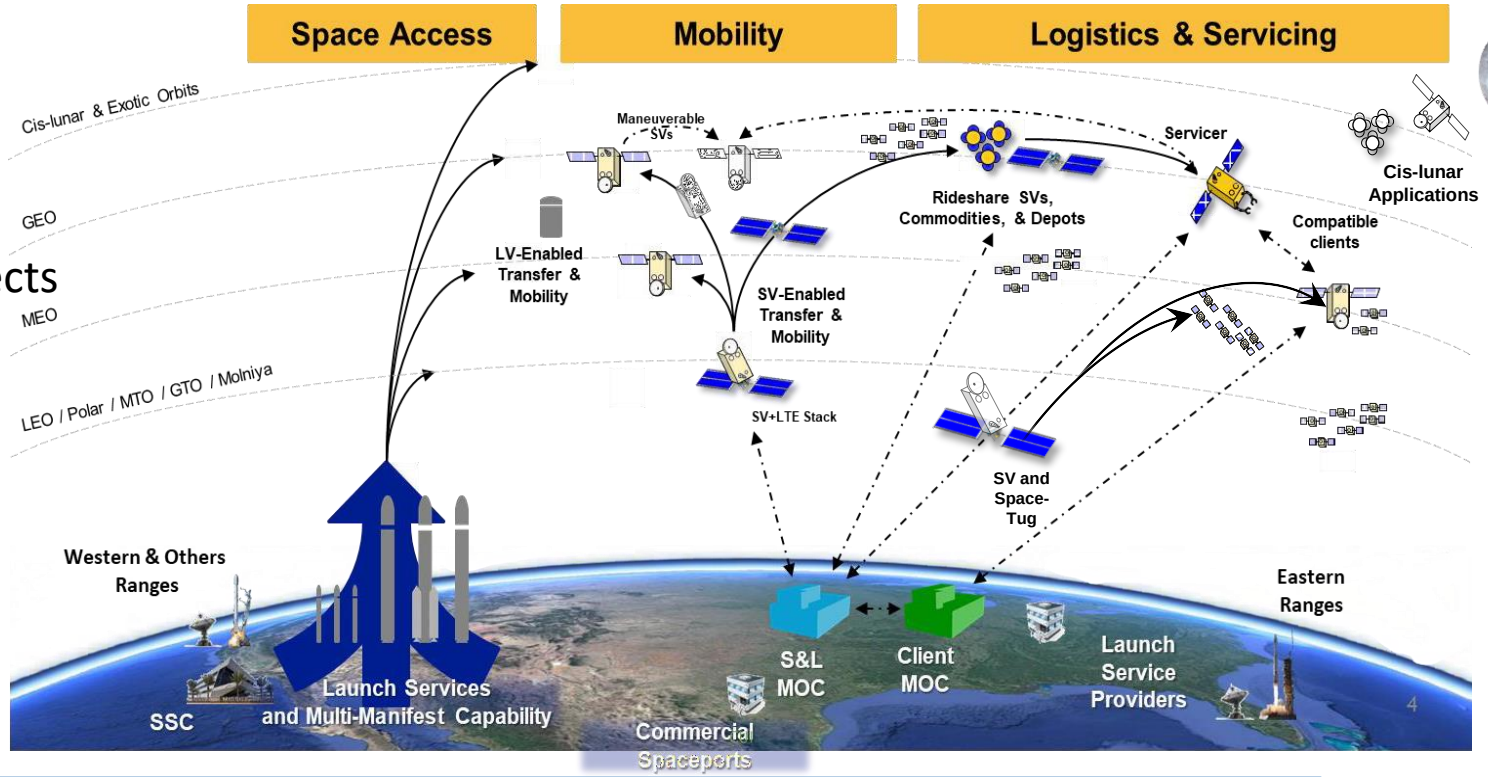
Interoperability is Key to USSF Fleet Affordability, Resilience, & Effectiveness

Space Capstone Doctrine 4.0 on Sustainment: “Interoperability is the ability to act together coherently, effectively, and efficiently to achieve tactical, operational, and strategic objectives.” (1)

- Military fleets integrate numerous Space Vehicle types
  - Multiple Commands & Forces
  - International Allies & Coalitions
  - Commercial Providers
  - Ground, Sea, Air, Underwater, & Space
- Operational Compatibility is required in all aspects
  - Hardware
  - Software
  - Operational Protocols
- Across a Range of Subsystems & Consumables
  - Fluid & Gaseous Propellants
  - Electrical Power
  - Repair & Updates



Plan Scenario Distributes Functionality & Assets for Space Access, Mobility, & Logistics across LEO, MEO, GEO, & HEO

In-space Servicing first demonstrated in 1993

Compatible Design & Preparation of Clients has been Prerequisite to Servicing

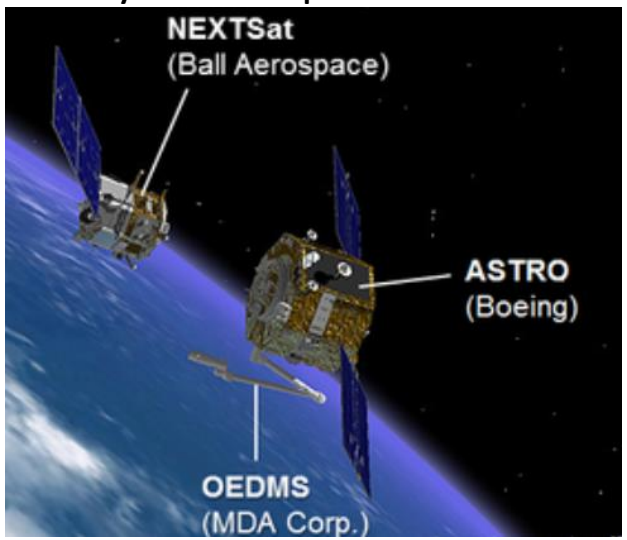
Astronaut servicing HST in Payload Bay

NASA Hubble Space Telescope (HST)

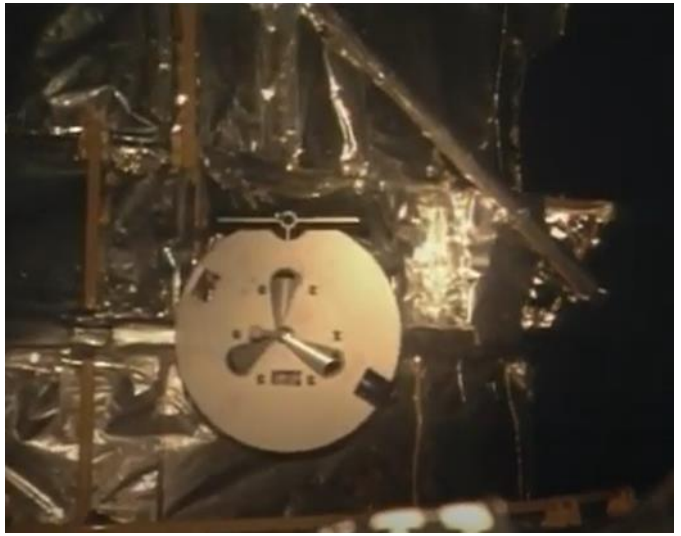
- First of Five HST servicing missions accomplished in 1993 by Shuttle Orbiter
- Enabled by serviceability features originally designed-in by NASA
- Piloted Docking into Payload Bay & locked to HST Grapple Fixture
- Astronaut attached to Robotic Arm for servicing operations
- 5 original instruments designed as Orbit Replaceable Units (ORUs) have all been replaced via modular changeout
- Solar arrays, guidance sensors, gyroscopes & other subsystems replaced

DARPA Orbital Express

- 2007 in-space demo of Rendezvous & Prox Ops
- 6-DoF Manipulator Arm
- Docking, Refueling, Module Changeout
- Multiple transfers of gases & fluids
- 3 months of mission operations on orbit



Orbital Express ASTRO Servicer, NEXTSat Client & Manipulator System



HST Grapple Fixture used for Docking

Emerging Solutions for Servicing are not yet Standardized & Industry is expected to converge on Multiple Standards

Docking

Moog ESPA Ring (1)
Evolved Secondary Payload Adaptor- TRL8

Astroscale Docking Plate (2)
TRL7 on Elsa-d in 2021

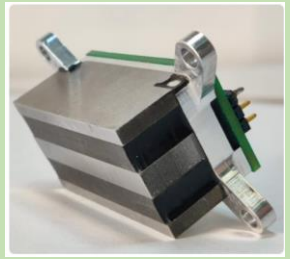
Lockheed Martin ASPIN (3)
Augmentation System Port Interface
Released as Open System 2022

Tethers Unlimited (4)
Androgynous AXON Connector
2025 Planned Launch

Grappling

Redwire Archinaut 1
Robotic Arm (5)
NASA OSAM-2 Demo
2024 launch scheduled

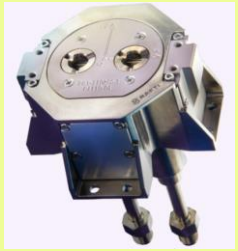
Harvest Moon (6)
Dexterous Adaptive Robotic Gripper



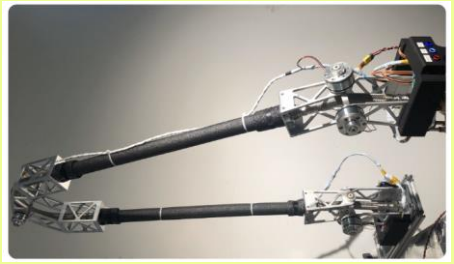
Altius Space Machines (7)
Electro-Permanent Magnetic Attach

Tethers Unlimited (8)
Kraken Robotic Arm

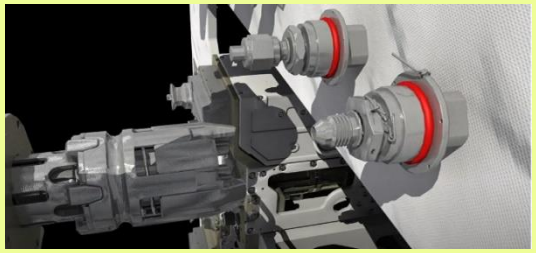
Refueling Interface



OrbitFab TRL7 Open System Rapid Attachable Fluid Transfer Interface (RAFTI) (9)



Altius Space Machines (10)
Fluid Transfer Coupling- 2024 Launch



Maxar- NASA 2011 Robotic Refueling Mission 1 uncovered legacy satellite fill valve & transferred Ethanol (11)

Challenge: Legacy DoD Orbital Assets were not Designed to support Servicing or Refueling

- Currently, DoD is operating Hundreds of Satellites in Earth Orbit

- Nearly all of these Legacy Satellites were not designed to accommodate Servicing or Refueling
  - Satellite Bus Architectures are not Modular and replacement of Instruments & Subsystems is a complex task
  - External Propellant Fill Valves are not provided
  - Dedicated Docking or Grappling Fixtures are not provided

- At End of Life, the current Concept of Operations designates Legacy Satellites as Candidates for Disposal

- Some DoD Satellites remain useful & would benefit from extending Operational Life
  - Propellant used for station keeping & Maneuvering is typically the limiting factor
  - By End of Life, some Instrument Subsystems are Obsolete and require updating
  - For smaller & less costly assets, replacement can be more cost effective than updating
  - Larger, more exquisite assets in higher orbits may be worth refreshing
  - At the Fleet level, continuous replacement of Constellations can be unaffordable & complex

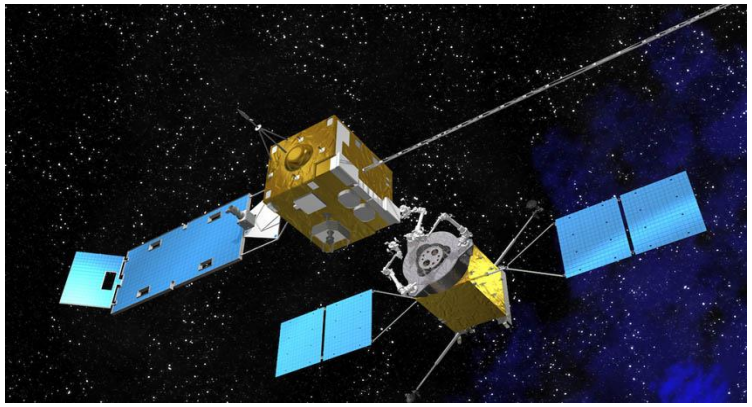
Mission Life Extension can benefit unprepared Legacy Space Vehicles

- Commercial Space Providers are implementing capabilities for extending usefulness of Legacy Satellites
- This operational capability is known as “Mission Life Extension” (MLE)
- Secure & Reliable Docking that takes advantage of common legacy satellite features is Prerequisite to MLE
  - Most Satellites were pre-equipped with Payload Adaptors for integration into their original Launch Vehicle
  - Station keeping Thrusters on most Satellites provide a Nozzle that can serve as a physical connection point
  - A range of other novel techniques are emerging for establishing & maintaining physical control of client vehicles
    - Robotic Arms for Satellites with Grapple points
    - Magnetic attachment
    - Electrostatic “Gecko” adhesion
- After docking, MLE Servicer is incorporated as an ongoing part of the Client Space Vehicle (SV)
  - Servicer provides propulsive services to Client SV
  - Servicer maintains Station keeping duties
  - With Delta-V now replenishable, Client SV can accomplish sustained maneuver for extended periods.
- MLE provides an early initial step towards full Fleet Sustainability

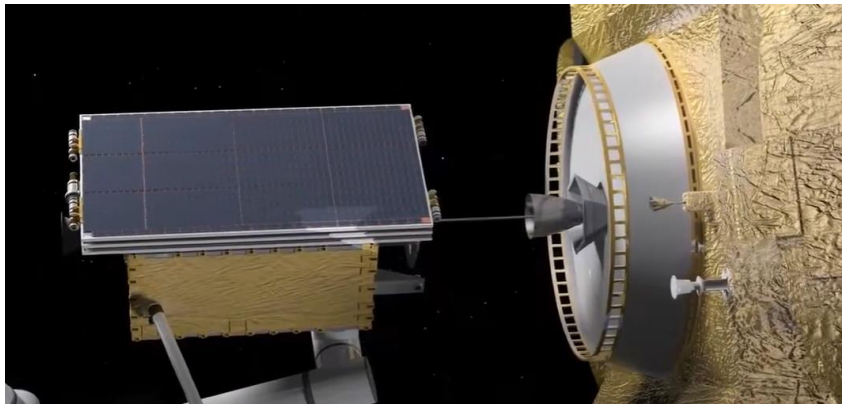
Commercial Providers are Implementing MLE now & offering services to DoD Legacy Vehicles

Space Logistics LLC Mission Extension Vehicle

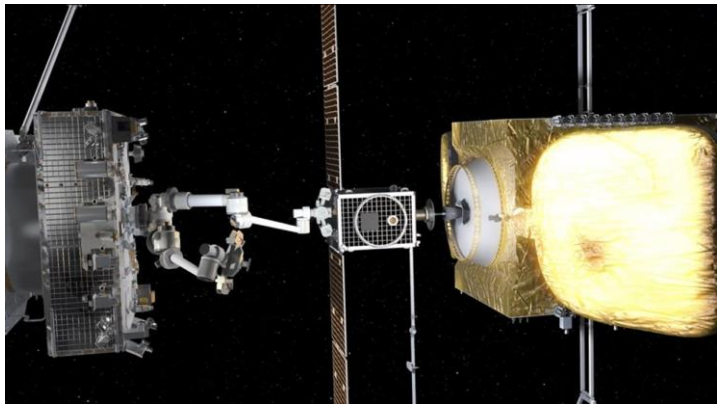
- Northrop Grumman (NG) developed & flew the first MLE-capable system, their Mission Extension Vehicle (MEV)
- NG created wholly-owned subsidiary, Space Logistics LLC, to build & operate MLE systems.
- First product, MEV, completed historic first in-orbit docking with IntelSat client in Feb 2020.
  - MEV remains attached to provide propulsive assist.
  - MEV-2 mission also completed for second IntelSat life extension in April 2021
- In 2024, next-generation Mission Extension Pod (MEP) is scheduled to be launched & attached to Optus satellite to provide augmented on-board delta-v that will extend operational lifetime.
- New Mission Robotic Vehicle replaces docking fixture with robotic arms that will attach MEP to client



MEV docking with IntelSat on MEV-1 mission, Feb 2020 (1)



MEP being installed by MRV (2)

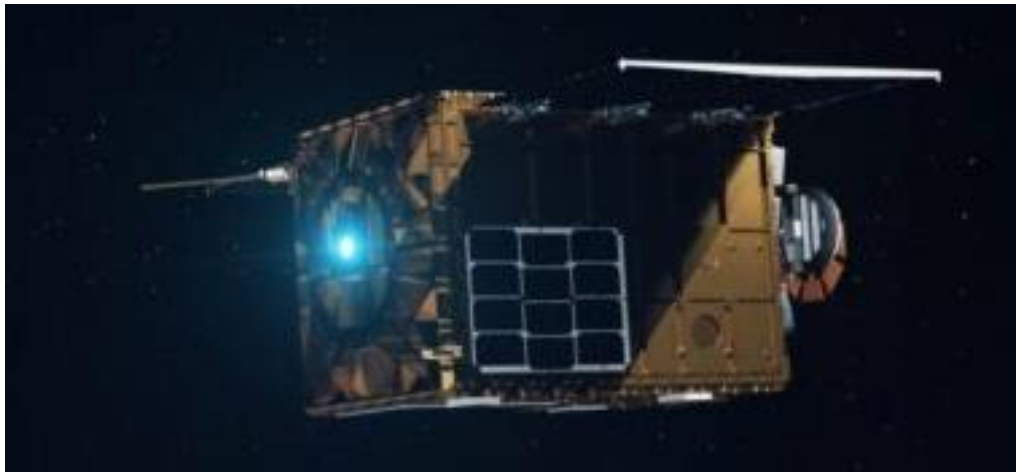


MRV plans to install MEP jetpack on Australian Optus satellite in 2024 (3)

Starfish Space

- Starfish is developing an MLE jetpack designated Otter that will attach to client SV to provide additional Delta-V capacity for station keeping, maneuver.
- Versatile pseudo-docking mechanism called Nautilus by electrostatically attaching a 10” x 10” plate to a flat surface on the client SV.
- To validate Otter performance, Starfish launched a demonstration mission in June 2023 of a subscale vehicle designated Otter Pup.
- Post-launch anomaly caused Otter Pup to tumble in orbit for two months at a significant rate of about one revolution per second.
- In August, Starfish demonstrated power and effectiveness of Nautilus by employing it to de-spin and stabilize the tumbling Otter Pup.
- Starfish is proceeding with build of full-scale Otter and plans for 2024 launch & commercial operations.

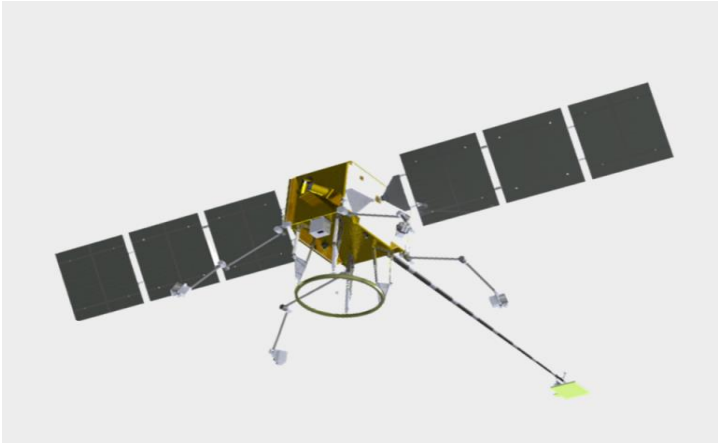
Otter Pup engaging Robotic Arms on approach to client (1)



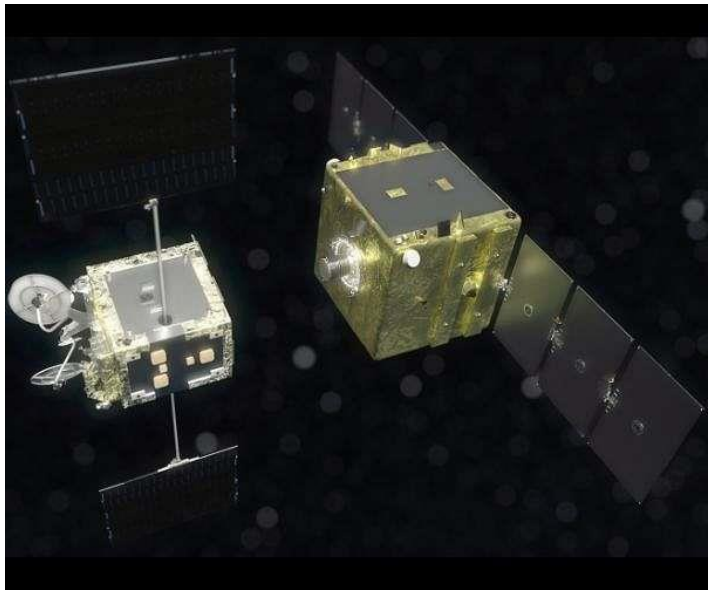
Otter Pup in transit with Robotic Arms stowed (2)

Astroscale LEXI

- Astroscale is developing a family of SVs to provide orbit transfer, debris removal, servicing, refueling, end-of-life disposal, & MLE capabilities.
- In 2021, completed privately-funded End of Life Services by Astroscale demonstration (Elsa-d) to demonstrate satellite disposal capability.
- Astroscale plans orbital propellant depots & refueling servicers.
- Life Extension in Orbit (LEXI) vehicle planned for 2024 launch to GEO.
- LEXI utilizes multiple robotic arms to grasp & secure client SVs.
- LEXI MLE capabilities include attitude control, station keeping, momentum management, inclination correction, GEO relocation & retirement to graveyard orbit.
- Sep2023- AATS awarded contract to Astroscale for 2026 delivery of prototype DoD Servicing Vehicle for refueling of compatible satellites

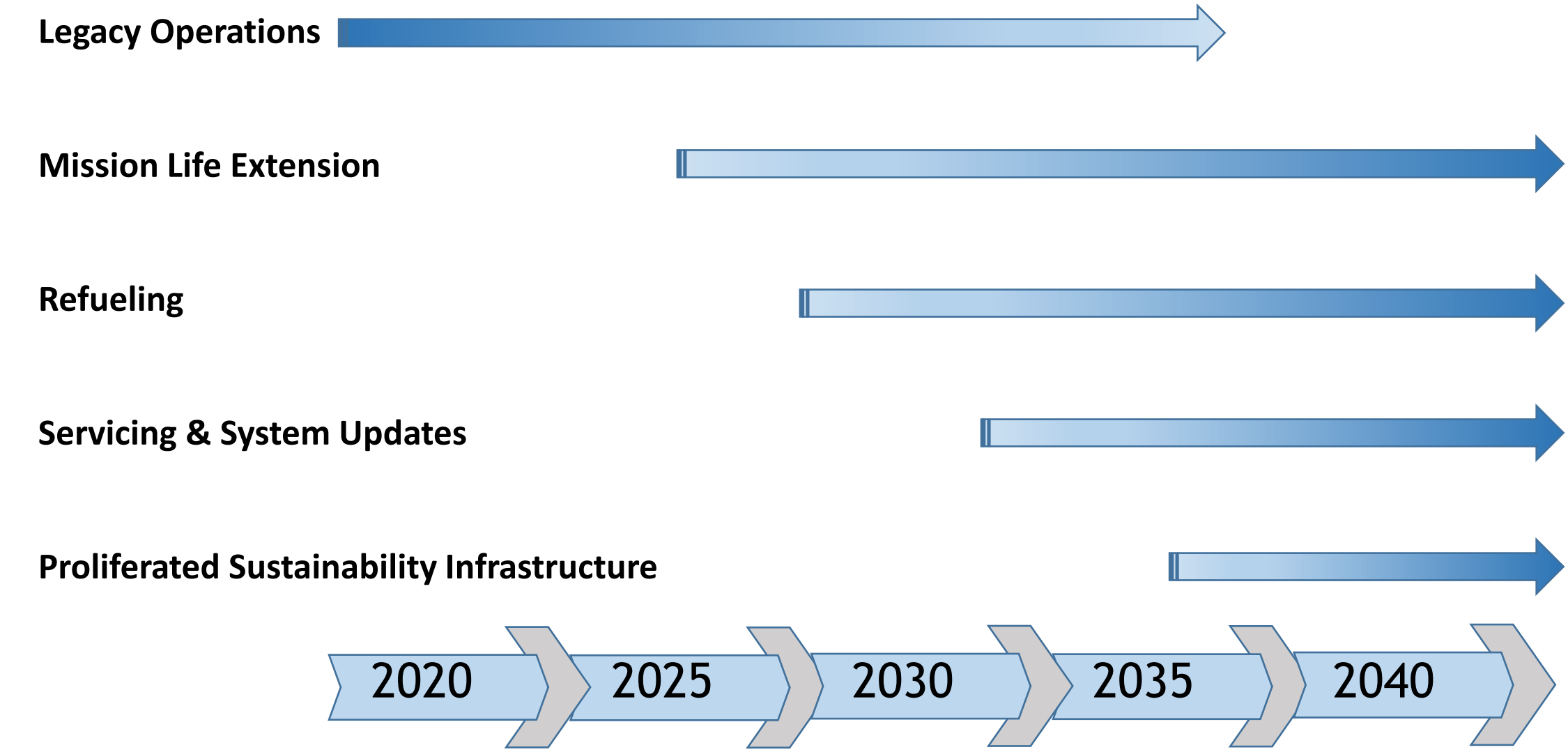


LEXI Vehicle with refueling probe extended (2)



Astroscale prototype DoD Servicing Vehicle (1)

Notional Transition to Sustainable USSF Fleet Operations



Summary

- Several Commercial Providers are maturing and implementing capabilities to accomplish Mission Life Extension on unprepared space vehicles.
- Capability is available now and many commercial alternatives are expected to become available in the near term.
- Although no DoD program presently requires in-space refueling or servicing, many of our Legacy Satellites could potentially take advantage of additional Delta-V.
- Selected future DoD satellite system architectures are likely to design-in the capability to accept servicing and refueling, where added lifetime and effectiveness could be beneficial.
- Transition to a servicing-based architecture will require lead time and a focused strategy for optimizing interoperability across the fleet.
- In the meantime, Mission Life Extension can provide military utility in the form of cost savings, and enhanced resiliency, responsiveness, and effectiveness.
- Industry is converging on standard approaches, ConOps, and interfaces; however, single standards are unlikely due to variations in client types, propellant types, and scale.

Assured Access to Space