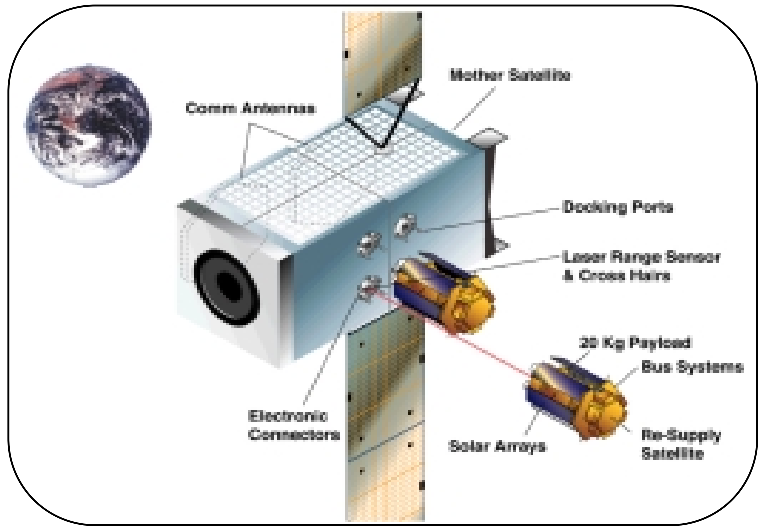
ORBITAL EXPRESS

A Comprehensive Architecture for the 21st Century



Sam B. Wilson, III

Tactical Technology Office

Defense Advanced Research Projects Agency

swilson@darpa.mil
(703) 696-2310

DoD Space Architecture Limits

Operational

- System availability concerns force risk intolerance
- Predictable orbits allow scheduling by adversaries
- Orbital infrastructure does not account for vulnerability
- Limited ability to tactically optimize orbital configuration
- Finite fuel restricts utility

Costs

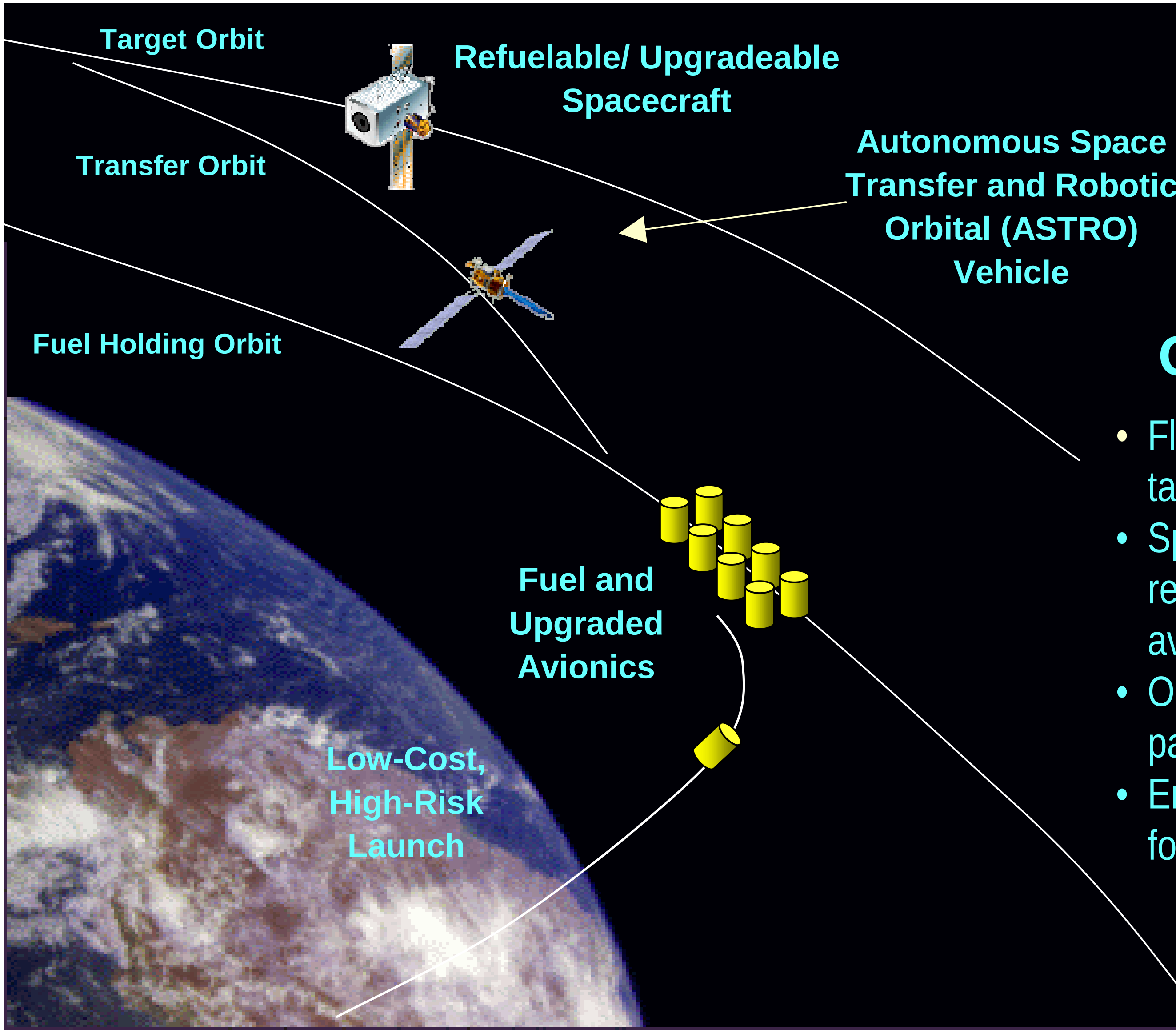
- Complex, highly redundant, cross-strapped designs
- Manned servicing is cost prohibitive —$2M+ /orbital-hr
- High fuel fraction costs for “maneuverable” satellites

Technology

- On-orbit technology at least 10-15 years old
- Unmanned satellite servicing requires development

2010 Space Architecture

- The Long View-



Orbital Express

- Fly satellites — strategic and tactical mobility
- Space commodities — satellite replenishment and satellite avionics (ORUs)
- On-demand, low-cost, small-payload launch
- Enable small, agile microsatellites for space control missions

Orbital Express
Military & Intelligence Advantage

- **Enable new and enhanced capabilities**
  - **Adjustable satellite coverage / optimization**
    - Optimize “thin” constellations to provide regional focus (greater coverage)
    - Operate at different altitudes as needed
    - Formation “flying”
  - **Random ΔV: Counter adversary activity scheduling (D+D)**
  - **Enable space control options**
    - Protection: evasive and unpredictable maneuvers
    - Situational awareness: highly agile surveillance system
  - **Leverage long-lived hardware — reduce cost, increase capability**
    - Extend lifetimes
- **Enable a revolution in space affairs**
  - **Extensible design + space commodities**

Commercial competitive advantage for US industry

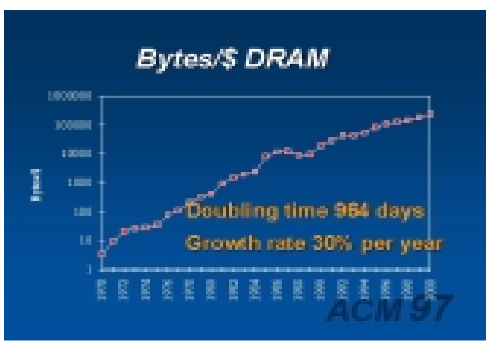
History of On-Orbit Servicing

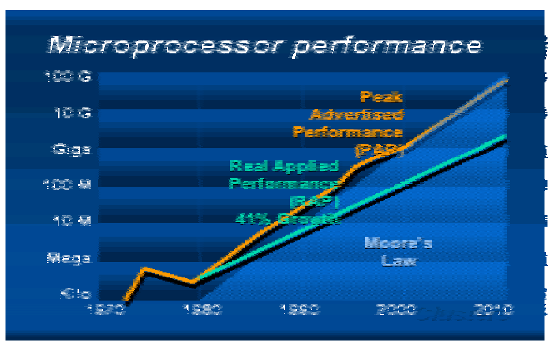
- ☆ **1999 (MIT/LL, JPL, NRL, Draper): Substantial cost saving + significant operational utility**
- ☆ **1999 (Leisman & Wallen): Up to $2B savings for upgrading GPS constellation vs. replacement**
- ☆ **1998 (NRL): 28% cost savings + greatly increased sensor availability attributable to spacecraft modular architecture design**
- ☆ **1987-1989 (SDIO / BMDO): 9% - 50% savings with on-orbit support**
- ☆ **1979 (Classified): "Significant" cost savings to a specific constellation attributable to on-orbit refueling**
- ☆ **1974 (TRW): 22% savings due to in-space servicing of DSP satellites**

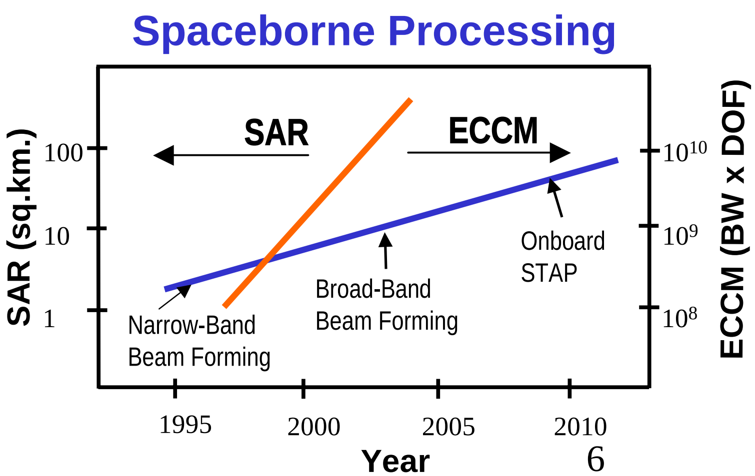
Numerous studies have shown refueling / upgrading produces significant life-cycle cost savings

P3I Satellite Architectures Extend "Moore's Law" To Space

- **Accommodate differing rates of technology advance**
  - **Orbital Replacement Units (ORU) to improve system performance over time**
  - **"Plug-and-Play" architectures can be made highly adaptable**
  - **Exploit long-lived components (bus, sensors, solar panels)**
- **Enable new capabilities**
  - **"Tightly coupled" systems—cross cueing/ tasking of new systems**
  - **Adapt to counter-measure threats**
- **Less initial risk reduction required on upgradable avionics**
- **Reduction in satellite systems' cost**





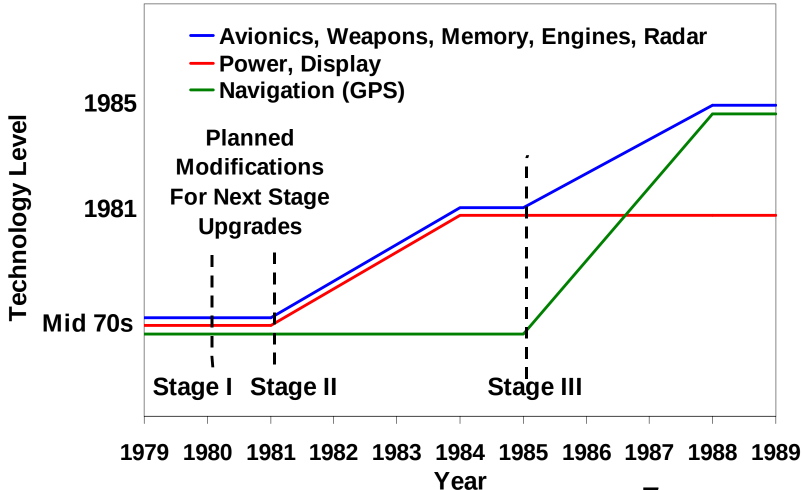


Planned System Upgrade
Standard Procedure for Aircraft

☆F-16 Multinational Staged Improvement Program (MSIP)

- **Plan progressive upgrades**
  - Airframe life is long - technology evolving slowly
  - Avionics technology progressing quickly - short obsolescence cycle
- **Retrofit upgrades to earlier F-16s**
  - Early airframes configured to accept future upgrades
- **Upgrade**
  - Processing speed, bandwidth and memory
  - Defense capability, displays, weapons and warning systems
  - Communications and navigation (GPS)

F-16 MSIP Planned Upgrades

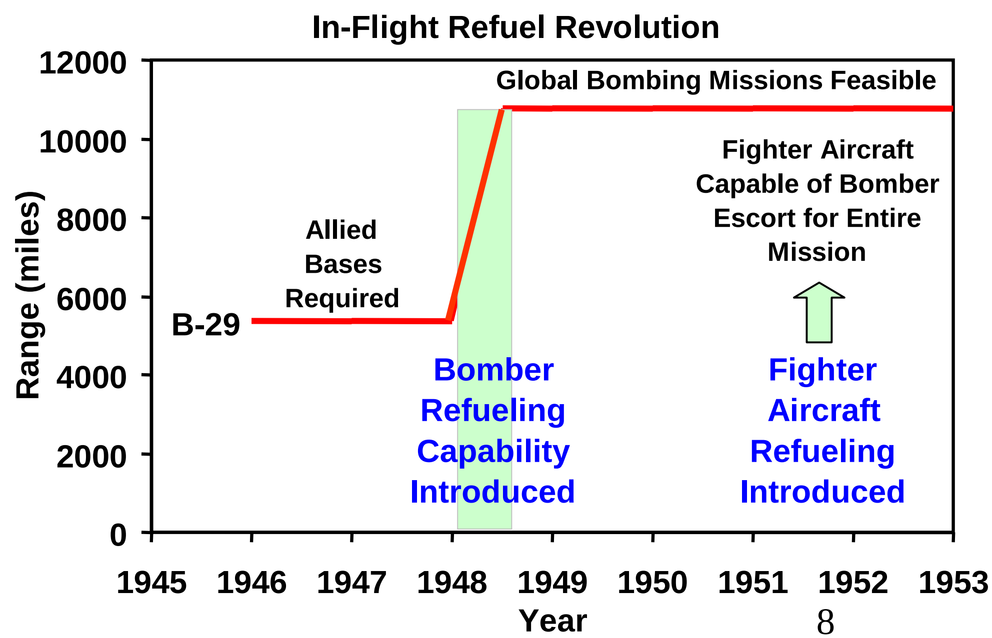


☆Advantages

- **Increase service life and capability**
- **Reduce cost and time to retrofit**

In-Flight Refueling - A Revolution in Military Aircraft Capabilities

- **Revolutionize aircraft missions**
  - **Extend range and duration**
    - Global missions feasible
    - Fighter escorts sustainable
- **Reduce cost and time compared to base refueling**



New Capability In Space: “Orbital Replenishment”

Navy’s underway replenishment (UNREP) capability provides:

- Force multiplier
- Flexibility
- Enhanced on-station time
- All commodities for extended operations: food, fuel, ammo, repair parts
- About 1 shuttle craft (fast replenishment ship) per 10 combatants (CVBG)

Man-in-loop required for:

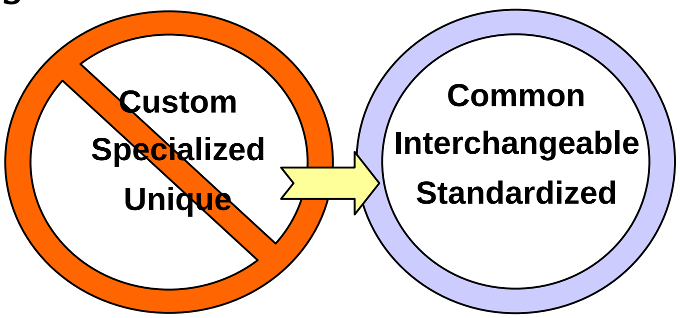
- Station keeping
- Dexterous manipulation
- Anomaly detection / crisis resolution

ORBREP versus UNREP:

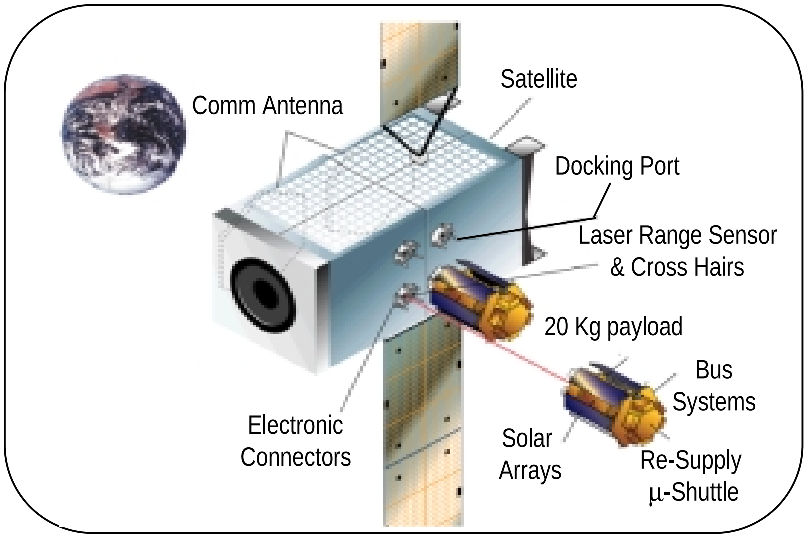
- Same force multiplier and flexibility benefits
- Man-in-loop required only for anomaly detection / crisis resolution
- Nominally one servicing spacecraft per orbital plane

New Refuelable & Upgradable Satellite Design/Architecture

- **Design, Build, Add an Extensible Satellite**
- **Preplanned Product Improvement (P³I) Satellite Design**
  - **Standards Based "Dockable" Interfaces**
    - Thermal
    - Signal
    - Power
    - Inertial



  - **"Plug and stay" ORUs for Avionics P3I**
    - Electronics
    - Power systems
    - Stabilization
    - RF elements

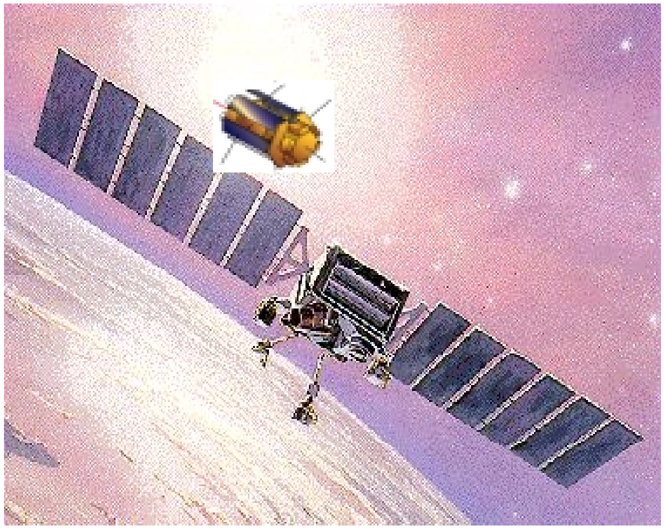


  - **Extensible Avionics**
  - **Refuel Spacecraft Features**
  - **Expendables Replenishment**
    - Fuel, batteries, cryogens

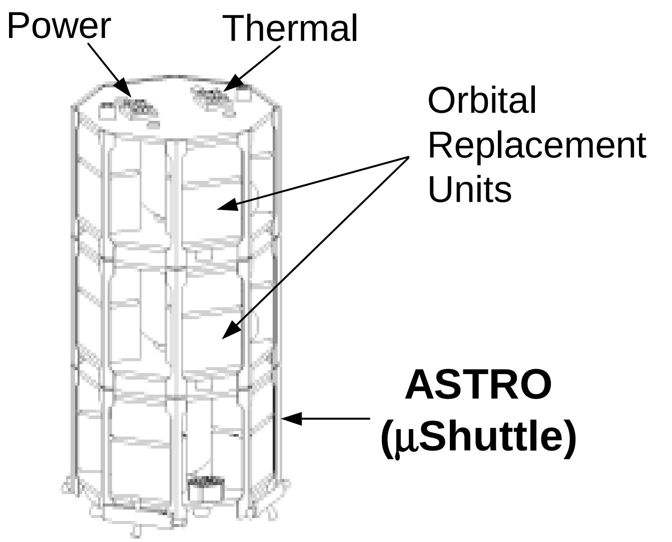
ASTRO Servicer

Autonomous Space Transporter and Robotic Orbiter

- ☆ **Design, Build, and Demo a Servicer for In situ Refueling and Modular Upgrade**



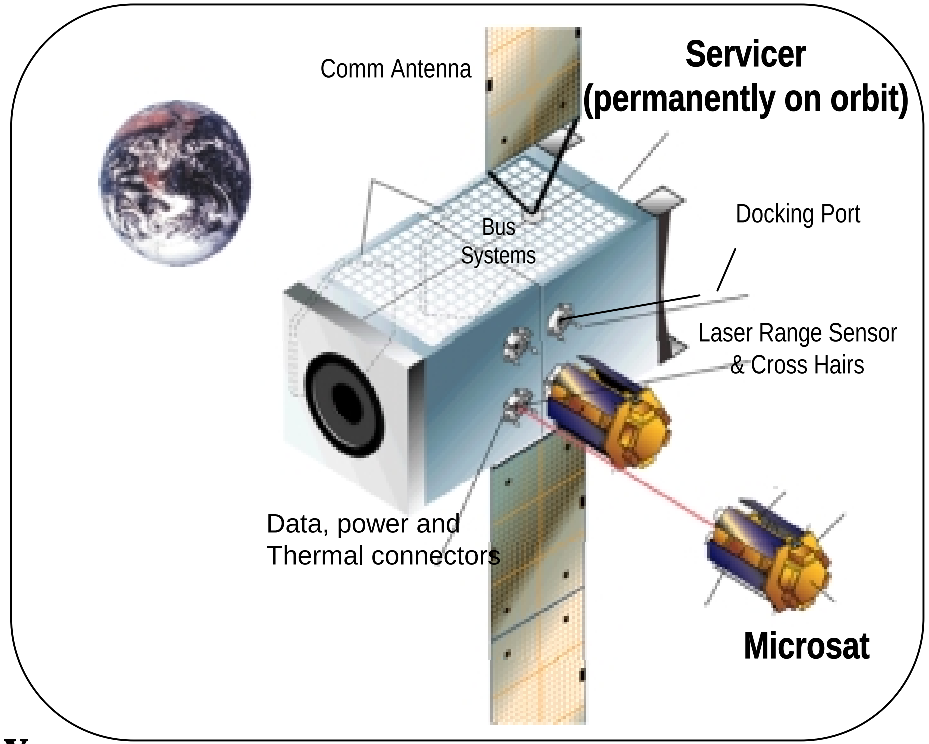
- ☆ **Servicer Functions:**
  - ⇨ **Avionics/fuel canister capture, transport**
  - ⇨ **Autonomous satellite rendezvous & docking**
  - ⇨ **Fuel/Orbital Replacement Unit delivery**
  - ⇨ **Inspection**
  - ⇨ **Host platform for MicroSatellites**



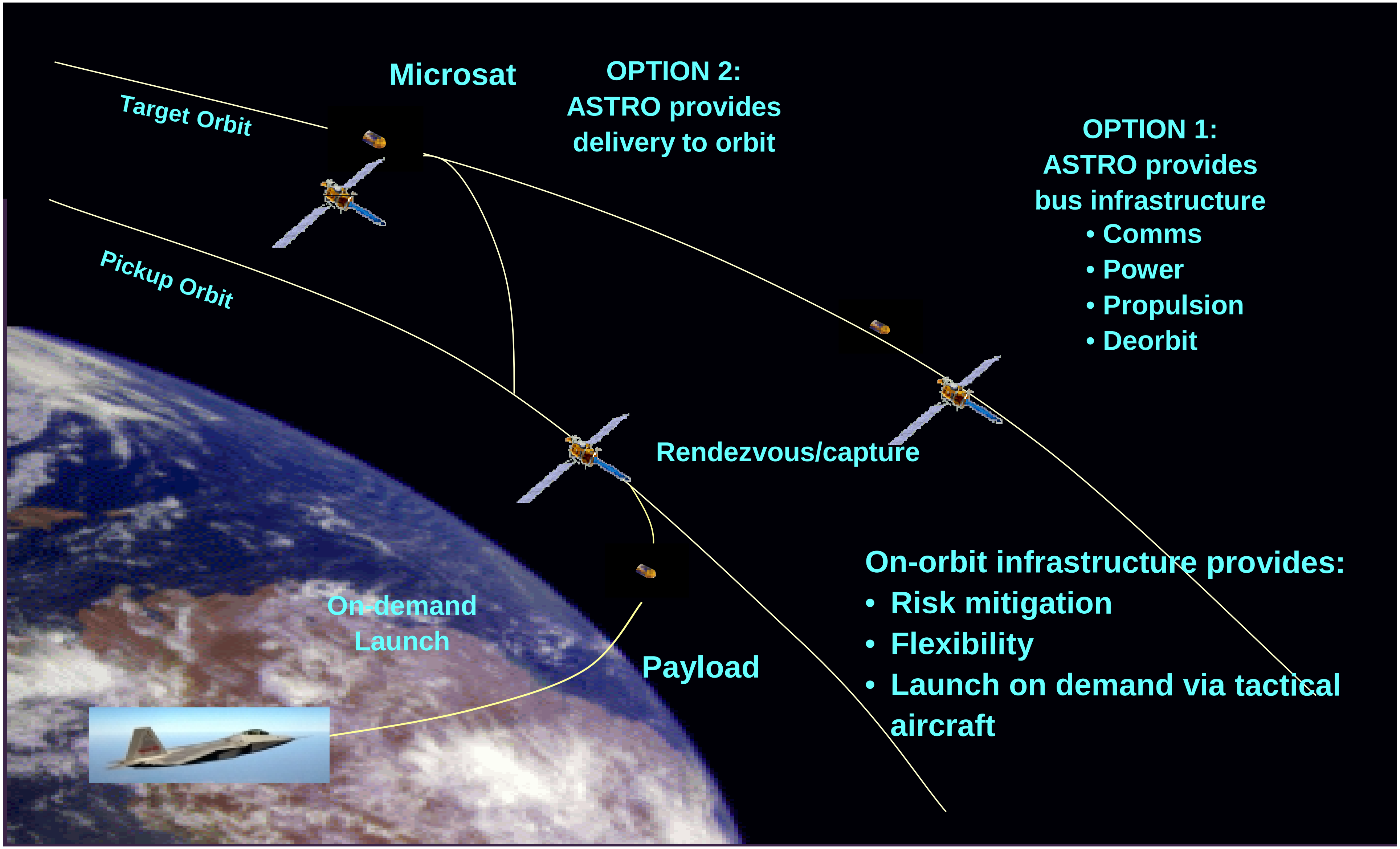
- ☆ **Technical Challenges & Opportunities:**
  - ⇨ **Autonomous rendezvous/precision docking**
  - ⇨ **Soft capture mechanism**
  - ⇨ **Electrical/photonic/thermal interfaces**
  - ⇨ **Propulsion & attitude systems**

Enabling a Robust MicroSatellite Capability/Architecture

- **A space logistics vehicle (e.g. the Orbital Express ASTRO vehicle) can provide bus functions to MicroSatellites**
  - **Maneuverability / orbit raising**
  - **Power**
  - **Communications**
  - **Attitude control**
- **Risk is mitigated by using proven on-orbit bus systems**
- **More MicroSatellite mass can therefore be devoted to payload**
- **Use of low-cost, on-demand launch opportunities (F-15 /F-22, secondary payload) for delivering MicroSats to orbit now becomes feasible**



Orbital Express Enables
Robust MicroSatellite Architecture



Why MicroSatellites?

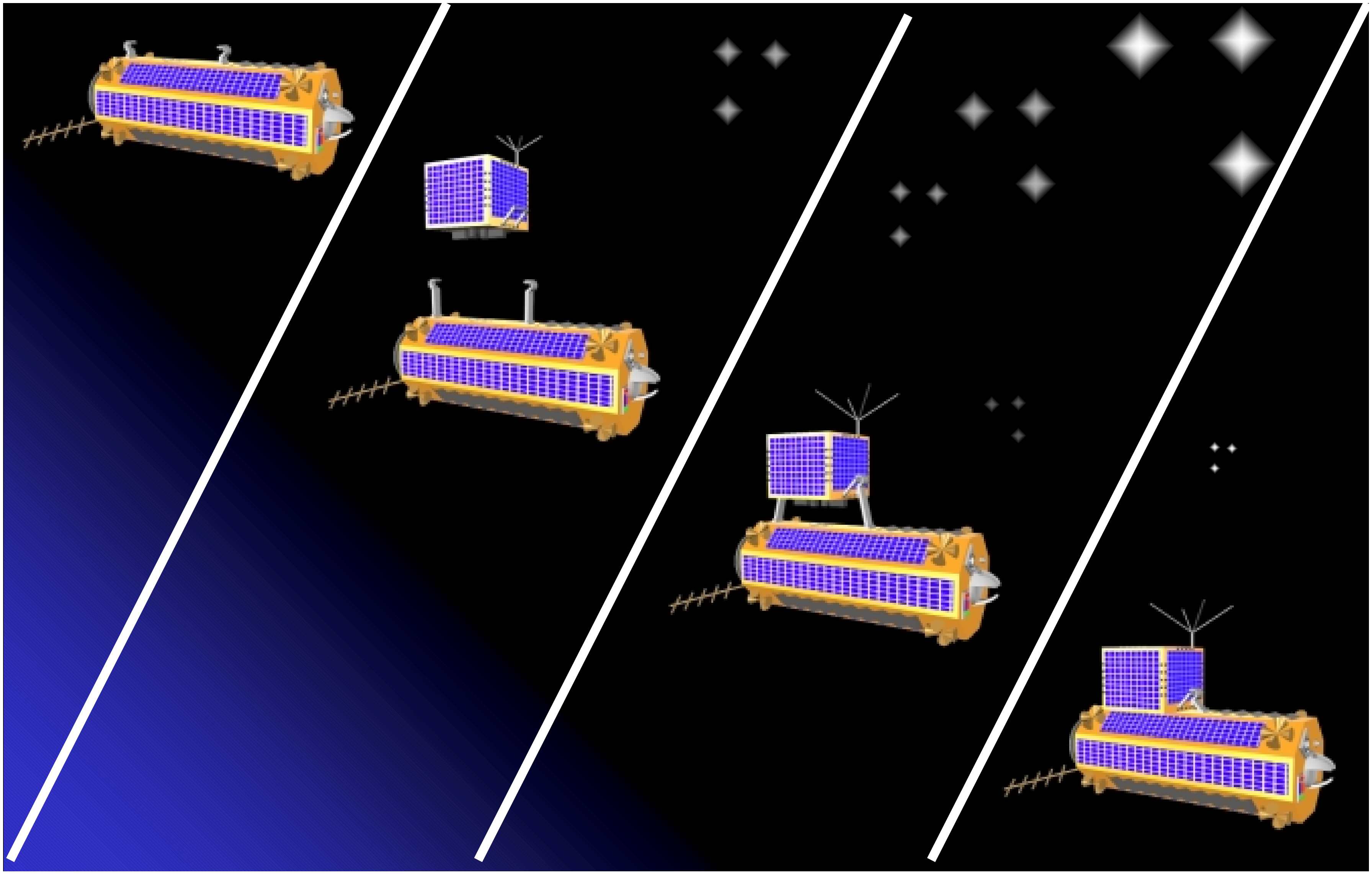
- Lower weight ↔ lower launch costs
- Leverage excess capacity on large vehicles through secondary payload capability
- Expand number of organizations manufacturing spacecraft
- Cluster operations ↔ graceful degradation, distributed functionality
- Low observability

What Limits Useful Missions for MicroSatellites?

- **Mass drivers in satellite design**
  - **Structure: Must withstand launch acceleration and vibration loads**
  - **Solar panels: Must be deployable if mission requires high electrical power (e.g., comms)**
  - **Batteries: Required for operability / sustainment during eclipse (almost 50% of time for LEO spacecraft)**
  - **Optics: Massive primary elements required to obtain adequate resolution**
  - **Radar: Array, transmitter, power storage & handling are large for adequate resolution**
  - **Propulsion: Thrusters and fuel (maneuverability, orbit maintenance, deorbit)**

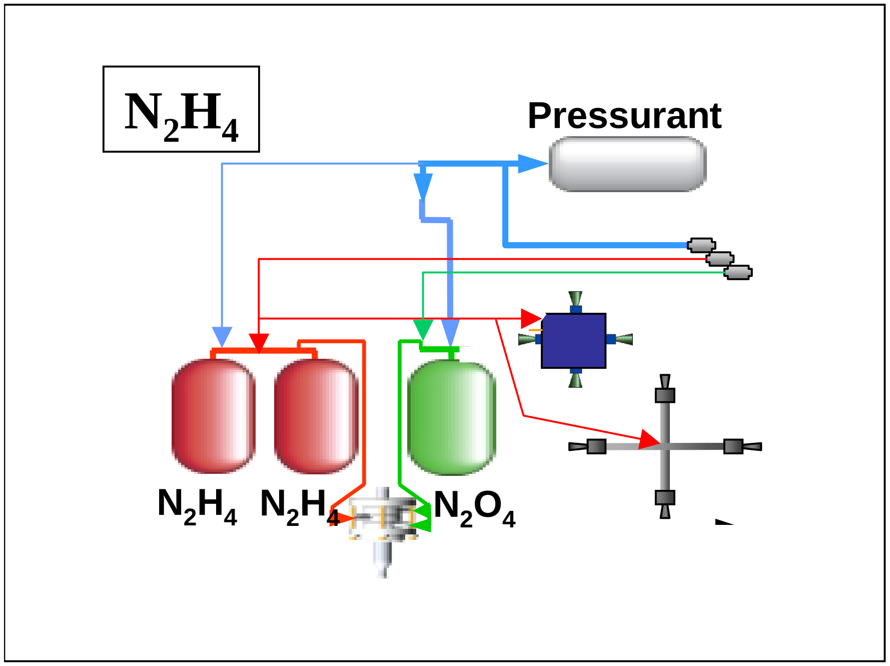
The weight required for bus functions can limit payload weight and capability.

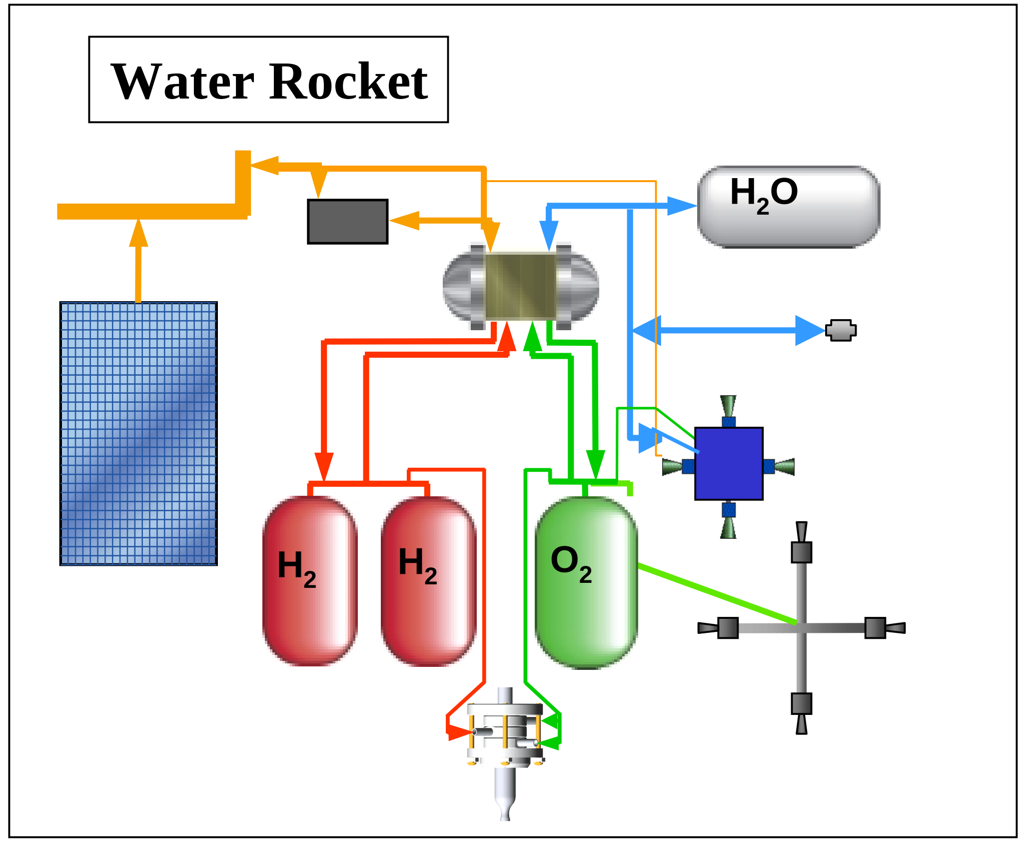
ASTRO MicroSat Docking



What is the Right Fuel Infrastructure?

TTO
Tactical Technology Office



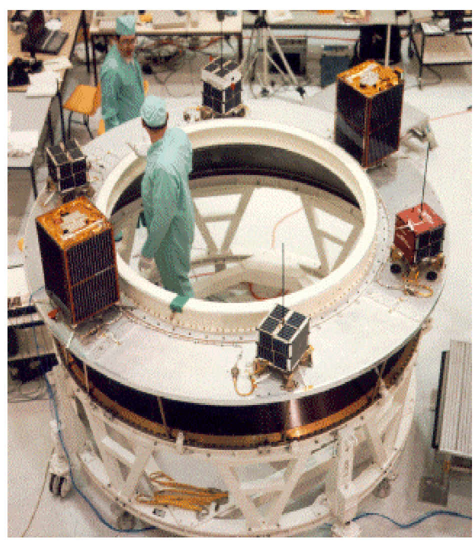


☆ Fuel attributes

- High Isp
- Long-term on-orbit storage
- Relatively non-hazardous at launch
- Multi-mode
- Multiple resupply options

Delivering Material To Space

Launch Option	*Average Cost*
Dedicated	**$ 5,000 - 10,000 / lbW**
Piggy Back/Adapter Rings	**$ 1,000 - 2,000 / lb**
High Tempo - High Risk/Low Cost	**$?**
Gun Launch from Earth	**$?**
Aircraft Launch	**$?**



Summary

- **A comprehensive on-orbit servicing architecture enables:**
  - **Ready availability of fuel, providing the tactical agility required for a wide range of current and emerging missions**
  - **Modular replacement function leading to multi-mission capability and life extension**
  - **Bus functions and orbit transfer service for MicroSatellite operations**
  - **Reduced mission risk through proven on-orbit infrastructure**
- **All of these provide opportunities for new and enhanced military applications**
- **Life cycle cost reductions will come when infrastructure is in place**