System F6

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Tactical Technology Office

Program Overview Briefing

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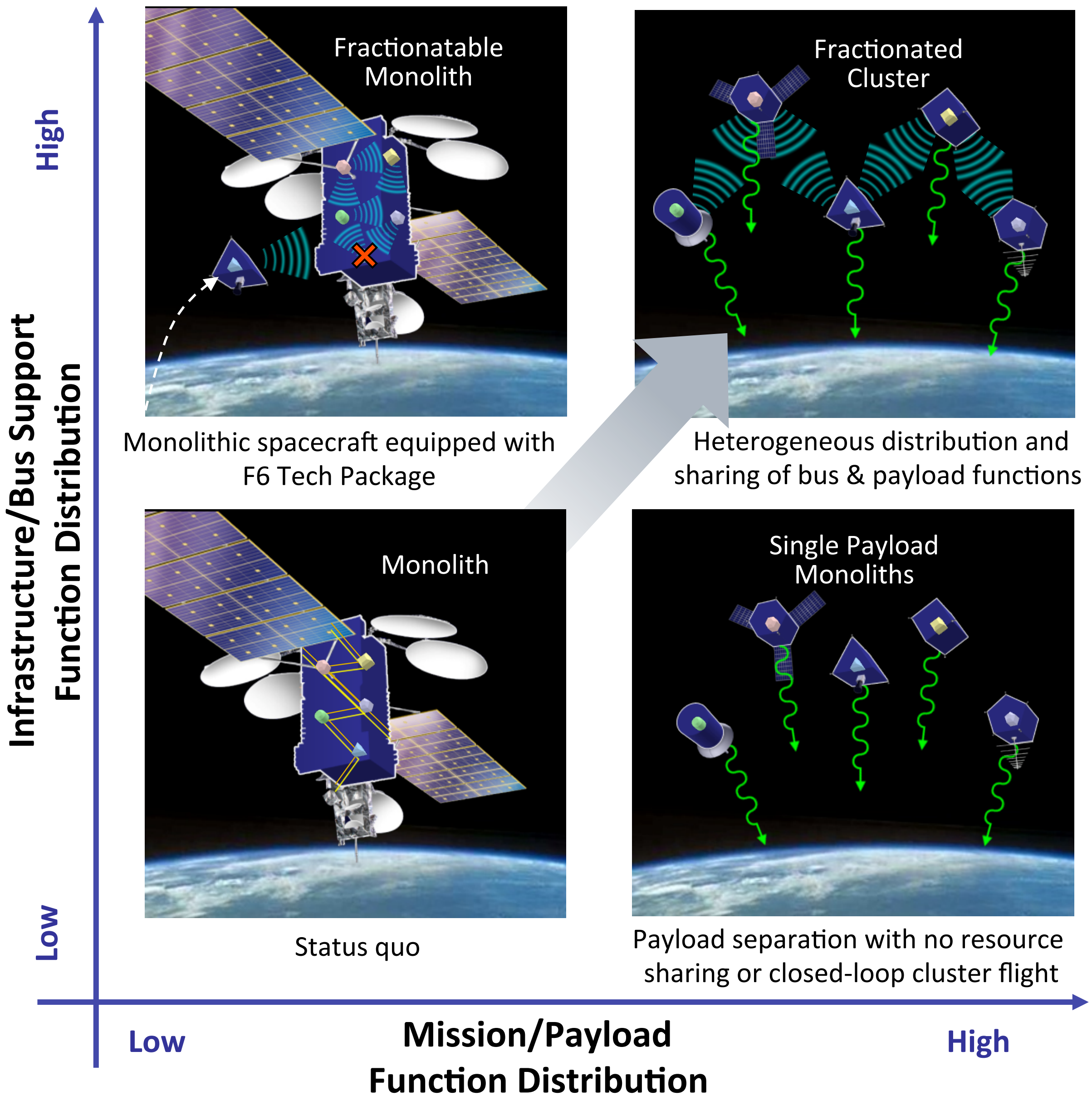
Fractionated Space Architectures



Enablers of Fractionated Space Architectures

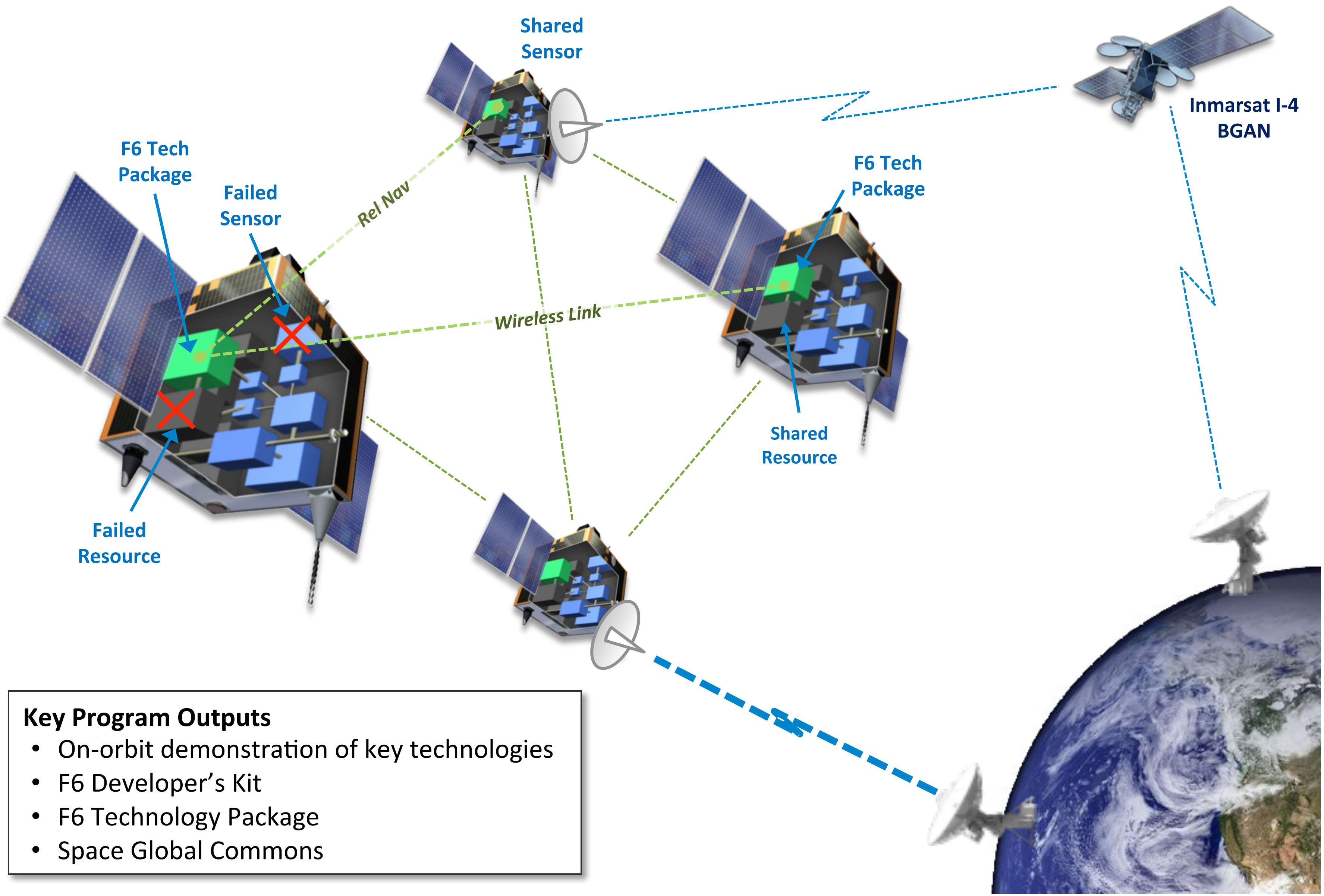
- Cluster maintenance
- Rapid cluster maneuvering
- Relative navigation
- Wireless networking
- Real-time resource sharing
- Multi-level security

- 24/7 LEO-ground connectivity

- Open F6 Developer's Kit
- Modular F6 Tech Package

- Adaptability Metrics
- Design-for-Adaptability Tools

System F6 Demonstration Concept

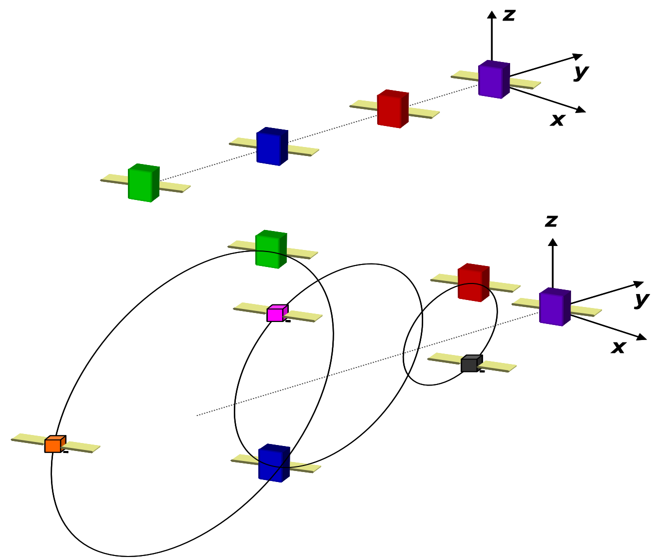


Key Program Outputs

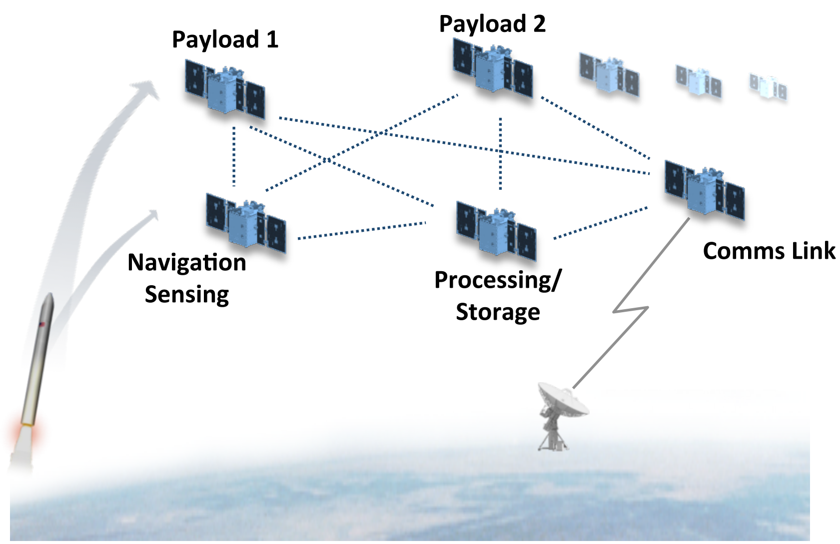
- On-orbit demonstration of key technologies
- F6 Developer's Kit
- F6 Technology Package
- Space Global Commons

Key Capabilities for On-Orbit Demonstration

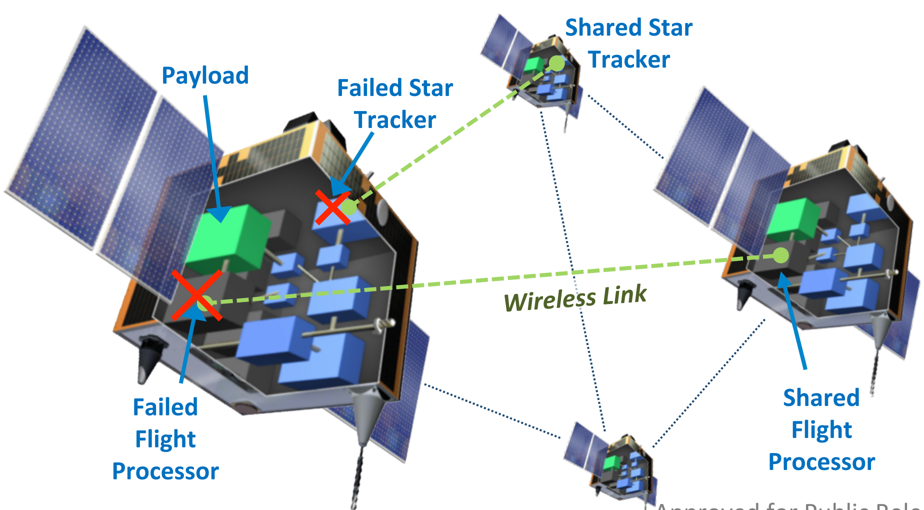
Demo 1: Long-Duration Cluster/Network Maintenance



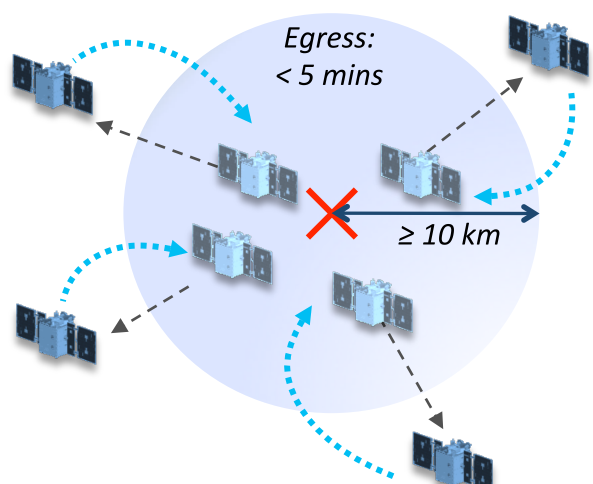
Demo 2: Resource Sharing at Multiple Security Levels



Demo 3: Cluster-Level Fault Tolerance



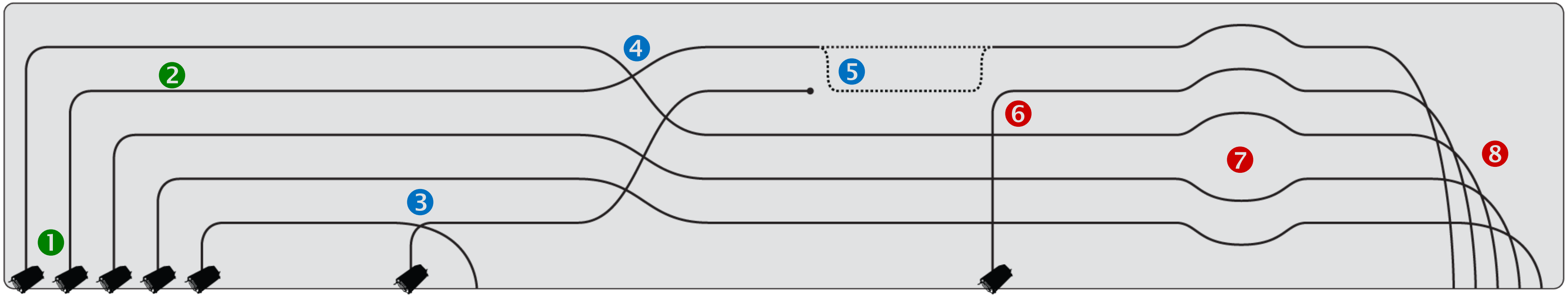
Demo 4: Defensive Scatter and Re-Gather



Military Utility of Fractionated Architectures

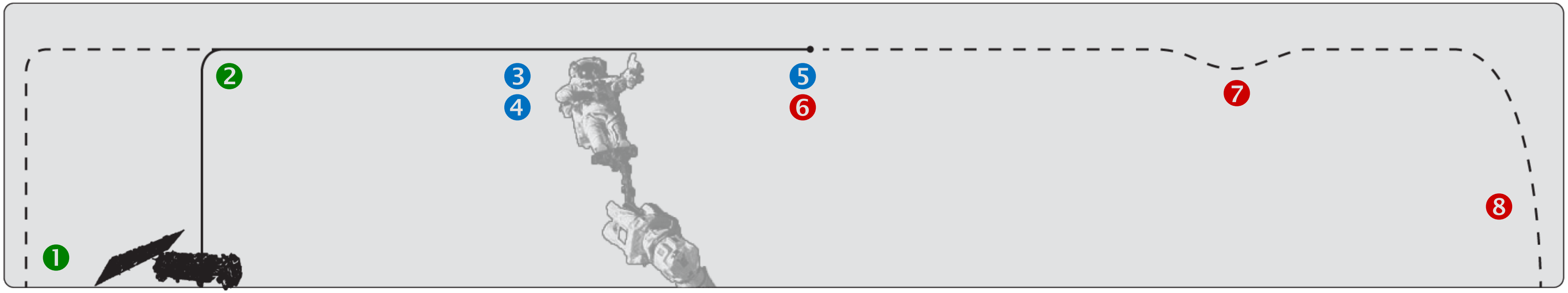
Fractionated System

F6 combines the strategies of distribution, modularization, and servicing into a single architecture, creating *virtual spacecraft* made up of free-flying, wirelessly networked elements. In addition to diversifying cost, schedule, and performance **risk**, this approach provides a more **responsive**, **adaptable** and **survivable** system than traditional, monolithic satellites.



1. Incremental deployment
2. Utility accrues before all pieces on orbit
3. Component upgrade/replacement possible
4. Reconfigure for different missions
5. Cluster-level redundancy
6. Replace failed components
7. Scatter to avoid attack or debris
8. Graceful degradation

Monolithic System



1. Single component can delay launch
2. No utility until entire system is launched
3. Upgrades rarely feasible
4. Capabilities strictly set
5. No system-level redundancy
6. Failure of any part may prove catastrophic
7. Larger target is more vulnerable
8. Capability ends abruptly

Program Philosophy

- Focus on architecture development, standards, and protocols
- Make information assurance a centerpiece of the architecture
- Write the software first, including new design tools, and plan for Verification & Validation
- Target best-of-class performers, including non-traditional and international
- Everything is open-source and maximally ITAR-free
- Build a community around the technology; use it to build the standard

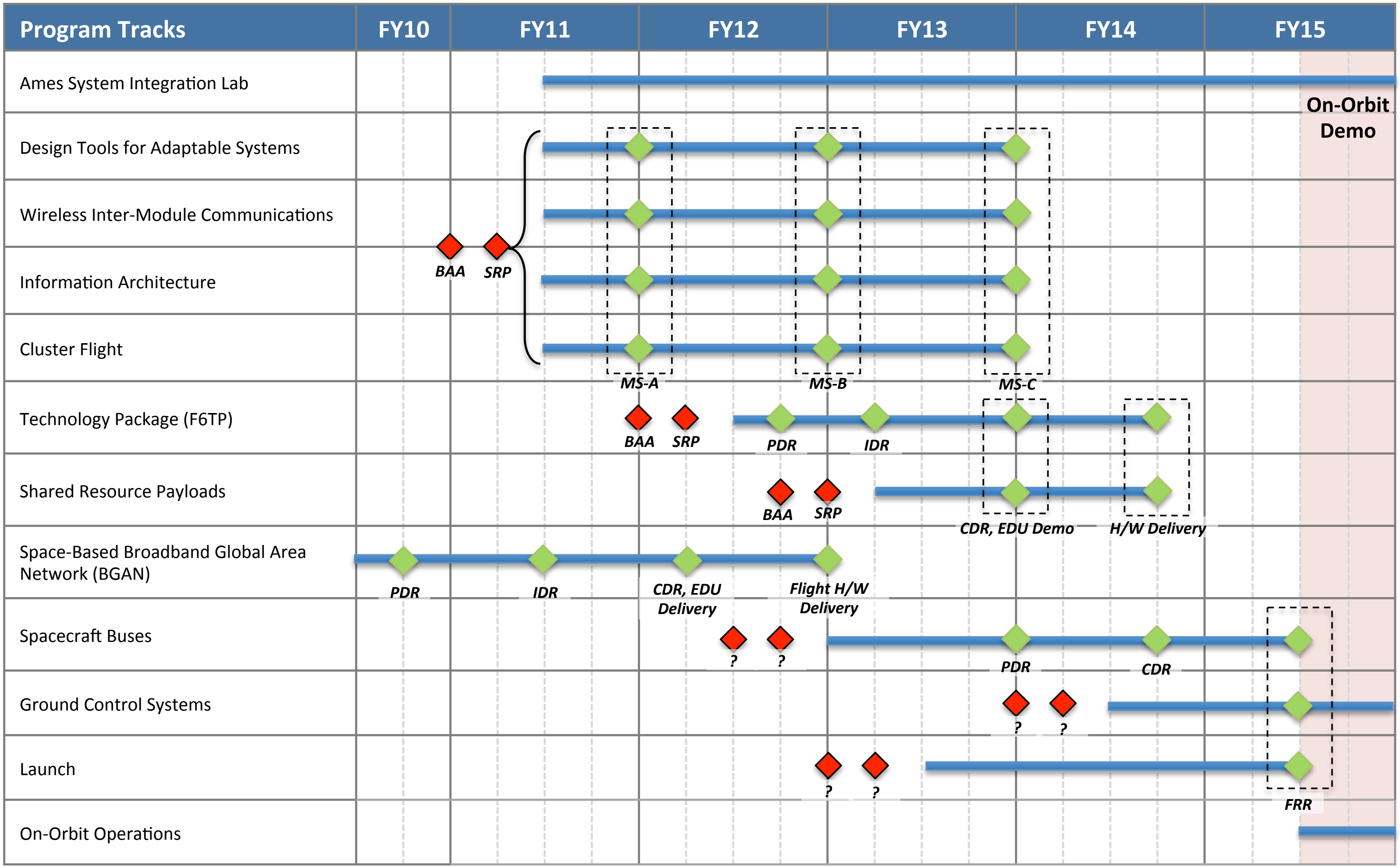
Program Structure – Top-level Goals

- Demonstrate the feasibility and benefits of replacing large monolithic spacecraft with a cluster of wirelessly-interconnected modules capable of sharing/utilizing resources.
- Develop open interface standards (FDK) that enable a space "global commons" for the sustainment and development of future fractionated systems
- Develop technology packages (F6TP) that can be installed on a wide range of spacecraft buses to enable them to fully participate in a fractionated cluster.
- Develop a space-based transceiver to utilize existing Broadband Global Area Network (BGAN) service of the Inmarsat network.
- Functional demos
  - Semi-autonomous long-duration maintenance of a cluster and network and ability to add or remove modules.
  - Securely share resources across the cluster network with real time guarantees across multiple security domains.
  - Autonomously reconfigure the cluster for safety and mission critical functionality despite network degradation or component failures.

Program Structure – Artifacts

- F6 Developer's Kit – everything needed for an independent third party to develop a module that can fully participate in a fractionated cluster
  - Interface standards, protocols, software, behaviors/rules
  - Reference implementation
  - Freely distributed under an open source license
- F6 Tech Package(s) – modular physical instantiation of the FDK that enables a spacecraft bus to become a fractionated cluster module
  - Cross-link, protocol stack, middleware, cluster flight software
  - Multiple sources, capable of supporting multiple bus types
  - Goal is for a fully productized commercial off-the-shelf item
- Shared Resource Payloads (e.g., Inmarsat SB-SAT)
- Spacecraft Buses
- Launch Vehicle(s)

Program Schedule



System F6 Technical Areas

- Four key enabling technologies:
  - Design Tools for Adaptable Systems
  - Wireless Inter-Module Communications
  - Information Architecture
  - Cluster Flight

<table>
<tr><th>OSI Model</th><th colspan="5"></th></tr>
<tr><td>Layer 7
(Application)</td><td></td><td>Cluster Flight
(BAA Technical Area 4)</td><td>Payload Application
in Security Domain A</td><td>Payload Application
in Security Domain B</td><td>...</td></tr>
<tr><td>Layer 6
(Presentation)</td><td colspan="5" rowspan="4">Information Architecture
(BAA Technical Area 3)</td></tr>
<tr><td>Layer 5
(Session)</td></tr>
<tr><td>Layer 4
(Transport)</td></tr>
<tr><td>Layer 3
(Network)</td></tr>
<tr><td>Layer 2
(Data Link)</td><td colspan="5" rowspan="2">Wireless Inter-Module Communications
(BAA Technical Area 2)</td></tr>
<tr><td>Layer 1
(Physical)</td></tr>
</table>

Design Tools for Adaptable Systems

- Scope
  - When does the business case for fractionated architectures close?
  - When it does close, how should a system be optimally fractionated?
  - Quantitative measure of adaptability
  - Quantitative trade-offs between adaptability and traditional system attributes (size, weight, power, cost, performance, etc.)
- Deliverables
  - Milestone A: Algorithm development complete, prototype implementation
  - Milestone B: Fully-functional, polished, well-documented, user-friendly tool
  - Milestone C: Tool validated against real data sets

Wireless Inter-Module Communications

- Scope
  - Layers 1 and 2* inter-spacecraft wireless communications for up to 20 modules
  - Looking for interesting point solutions—no specific performance requirements
  - Ranges and data rates of interest: 100 m to 100 km, 100 kbps to 10 Gbps
  - Interested in throughput, availability, scalability, size, weight, power, pointing requirements, interference resistance, detection range
- Deliverables
  - Milestone A: Preliminary design, parametric model, draft FDK
  - Milestone B: Detailed design, full terrestrial prototype test, final FDK
  - Milestone C: Four complete flight-ready units

** Layer numbers refer to the OSI Reference Model*

Information Architecture

- Scope
  - Layers 3 through 7 information architecture for space and terrestrial network
  - Expose spacecraft and terrestrial devices as network-addressable nodes
  - Provide real-time distributed resource sharing across multiple security domains
  - Real-time fault tolerance, i.e., network and resource reconfiguration to maintain safety-critical functions and gracefully degrade mission capability
  - Additional considerations:
    - Throughput of available space-capable hardware
    - Principal security controls corresponding to DCID 6/3 PL5
    - Link encryption requirements—details TBD
    - V&V approach for distributed dynamic systems
- Deliverables
  - Milestone A: Preliminary design, draft FDK
  - Milestone B: Detailed design, complete implementation, final FDK
  - Milestone C: V&V for flight

Cluster Flight

- Scope
  - Long-duration semi-autonomous cluster ops for up to 20 modules
  - Autonomous rapid maneuvering capability—defensive scatter (20 km, 5 mins)
  - Holistic approach to collision avoidance—safe to most probable failure modes
  - Looking for interesting point solutions—no specific performance requirements
  - Cluster size range of interest: 100 m to 100 km
- Deliverables
  - Milestone A: Preliminary design, parametric model, draft FDK
  - Milestone B: Detailed design, complete implementation, final FDK
  - Milestone C: V&V for flight

DARPA Team

- TA1: Design Tools for Adaptable Systems
  - Catholic University of America (CUA)
  - Palo Alto Research Center (PARC)
  - Caltech Jet Propulsion Laboratory (JPL)
  - Stevens Institute of Technology
  - Univ of So Cal Info Sciences Inst (USC/ISI)
- TA2: Wireless Inter-Module Communications
  - Aeronix
  - Argon ST
  - Southwest Research Institute (SwRI)
  - Space Micro
- TA3: Information Architecture
  - Carnegie Mellon University (CMU)
  - Vanderbilt University
  - QinetiQ North America
  - mZeal Communications
  - Raytheon BBN
  - Referentia Systems
  - University of Pittsburgh
  - Univ of So Cal Info Sciences Inst (USC/ISI)
- TA4: Cluster Flight
  - Microcosm
  - Aurora Flight Sciences
  - Northrop Grumman
  - Emergent Space
- Other Performers
  - Inmarsat Navigation Ventures Ltd (INVL)
  - Naval Postgraduate School (NPS)
  - Johns Hopkins Appl Physics Lab (JHU/APL)
- Government Team
  - NASA Ames Research Center
  - Naval Research Laboratory
  - Booz Allen Hamilton
  - Kinsey Technical Services (KTSi)
  - Oxford Systems Inc
  - RKF Engineering
  - Value-Driven Design Institute
  - National Security Agency (NSA)

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