5. Satellite Operations

Area Description

Satellite operations (SatOps) are conducted to:

- Verify and maintain satellite health
- Reconfigure and command the spacecraft
- Detect, identify and resolve anomalies
- Perform launch and early orbit operations.

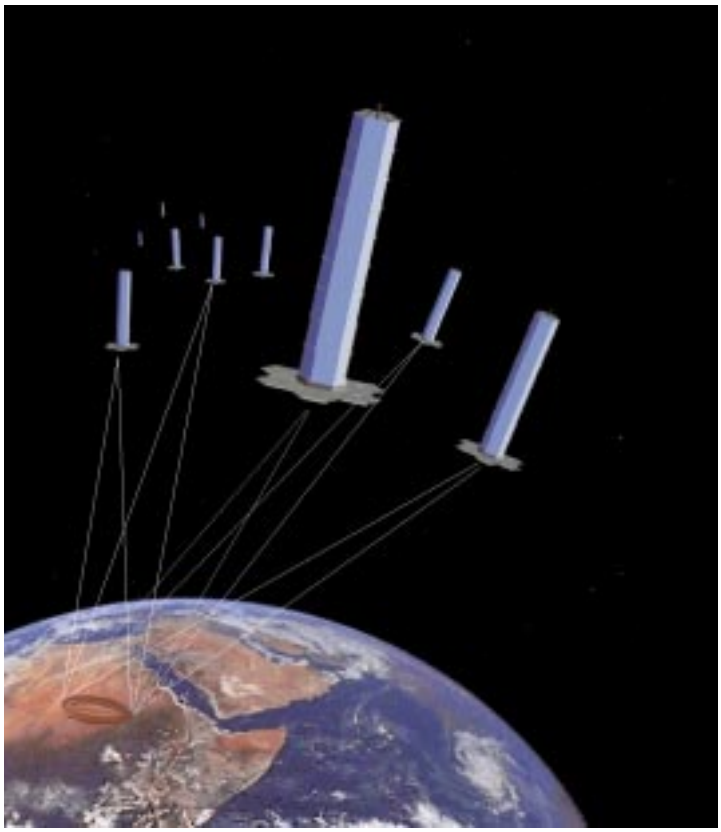
Additionally, any systems required to maintain the spacecraft operations that are not payload-specific are considered in this area.

Traditionally, the three basic functions of SatOps are telemetry monitoring, tracking, and commanding (TT&C). Satellite operational activities and their prior planning are typically labor-intensive.

Emerging space-based architectures will stretch the capacity of current SatOps. This can happen in one of several ways. Increased sensor data collection capability will require high-capacity communications. Individual satellites may be expanded into constellations (i.e., networks of satellites) to provide global coverage, thereby increasing the complexity of operations. Clusters of cooperating and maneuverable satellites may replace single satellites and may enable new missions and performance capabilities, but will also complicate command and control (C2). These new missions may need high-speed data links (ground-to-space and space-to-space), on-board intelligence, and a new ground support infrastructure.

On-orbit refueling and servicing of operational satellites would extend spacecraft life and effectiveness. On-orbit refueling and improvements in propulsion efficiency would enable surveillance constellations to maneuver more, whether for survival, to inspect space objects, or simply to change orbits more readily. On-orbit servicing would involve replacement of components (such as batteries) and insertion of "plug-and-play" modules (such as processors and data storage units). These new concepts would also need a new support infrastructure, such as orbit transfer vehicles and upgradable or reusable spacecraft.

Effective SatOps is the other contributor to Assured Access: once on orbit, space-based capabilities must remain reliably available. Moreover, the more spacecraft that are placed in more orbits, the more complex and important their effective operation becomes. From human ground-based control of individual satellites, future constellations will need to interoperate and perform more of their own housekeeping functions autonomously, with the human role "reduced" to monitoring and emergency responsiveness. Multi-satellite and multi-constellation operations and control would need to become routine so that primary focus may be on their mission-specific products and services for the warfighter and other customers. Both NASA and DARPA, as well as the Services, are pursuing spacecraft autonomy as an enabler for many on-orbit functions. When this capability emerges, questions of when and how humans will need to be in the monitoring and decision loop will also need to be addressed — not only for spacecraft life, health and orbit-keeping, but also for functions ranging from servicing to weapons management.



Distributed Spacecraft

Mission Area Objectives

Enduring		*Secure*	*Robust*	
Integrated operation/mission planning	On-demand command and control	Precision tracking and geolocation of critical space assets	Global space traffic control	Routine on-orbit satellite servicing
Autonomous, fault-tolerant, gracefully degradable SatOps				

Supporting Capabilities

Use of Global Positioning System (GPS) for launch range safety and spacecraft position determination

Space-based relay for telemetry and command dissemination

Improved terrestrial and space weather forecasting for launch and satellite operations

Standard protocols for space-to-space communication links

Advanced command and control networks and architectures

On-board fault detection, isolation, and recovery

Increased fault-tolerance and graceful degradation

Advanced, robust and high-volume on-board processing

Advanced constellation/formation flying concepts and techniques

On-board precision navigation; rendezvous/station-keeping concepts and techniques

On-orbit servicing functions: re-supply of consumables, repair/replacement of components, and reconfiguration of spacecraft

Distributed/collaborative satellite clusters

Interoperable, modular and standard spacecraft components and interfaces

Current Technology Initiatives *(Highlights of Current FYDP)*

Several projects are investigating the use of distributed systems of microsatellites, flying in formation and working together, to perform space missions. Among the challenges of this approach is how to command and control clusters of satellites most efficiently. New techniques are needed to allow an operator to treat a cluster as a single "virtual" satellite, and thus avoid increasing ground operations cost.

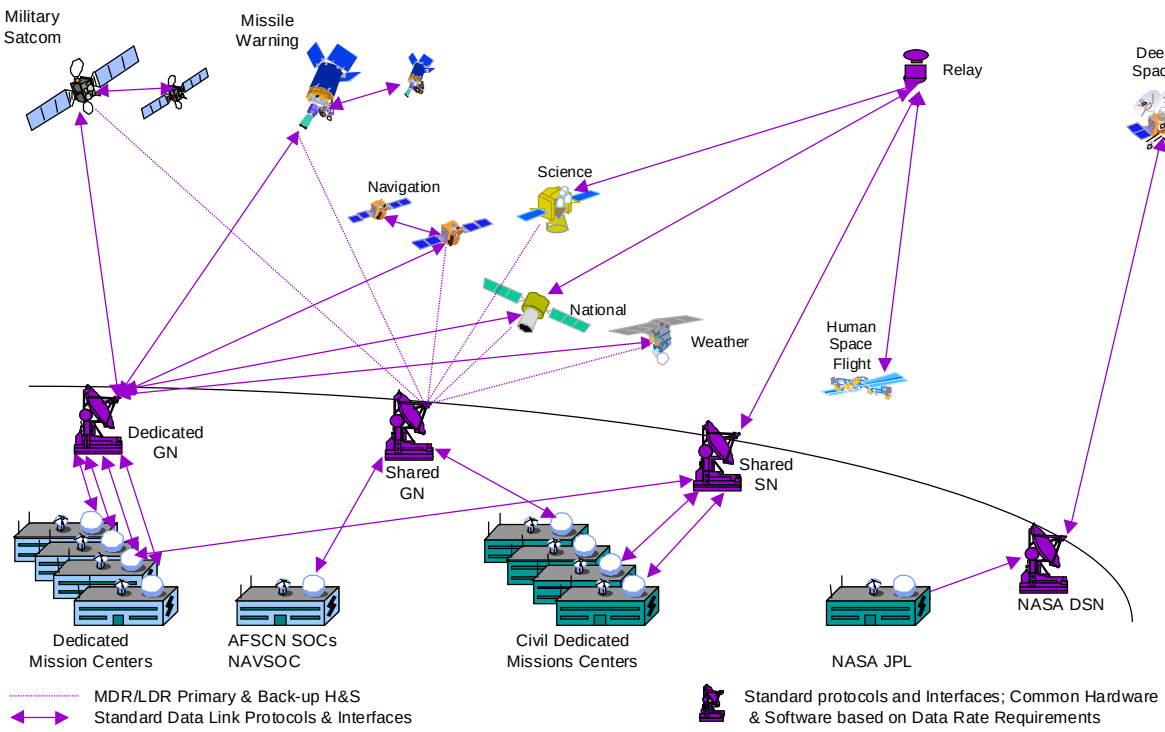
The Air Force is assembling a computer laboratory in which to investigate advanced concepts, including those for operational support of distributed satellite systems. Research includes:

- Satellite cluster management and control
- Fault detection software to correct satellite cluster anomalies
- Intelligent and collaborating software agents that replace traditional monolithic flight software and enable cross-satellite collaboration
- Advanced artificial intelligence techniques for efficient space and ground resource scheduling
- Reliable high-speed space-to-ground and space-to-space links to enable virtual satellite control and meet the high-volume data requirements therefrom
- Architectures that allow software to be easily migrated from the ground to the spacecraft after launch.

Selected project detail is tabulated in "Projected Applications," below.

Enabling Technologies *(Unconstrained)*

- Autonomous and adaptive algorithms for resource scheduling, mission planning, and mission execution
- Artificial/virtual intelligence (AI/VI), self-awareness, intuitiveness, automated recognition
- Human-machine interfaces and robotics
- Heterogeneous databases, software, integration, modeling and processing techniques
  - Advanced tools and algorithms for modeling and simulation (M&S)
- Satellite on-board data processing and storage
- Non-volatile random access memory
- Mass storage memory (including optical storage technologies)
- Laser/optical and/or microwave techniques for space-space, space-ground and space-air acquisition, tracking, and communications
- Radiation hardening and shielding of components
- Spacecraft laser and RF vulnerability mitigation techniques
- Precision time sources (10-ps timing accuracy) (atomic/laser clocks)
  - Network-centric communication synchronization techniques
- Plug-and-play hardware and software technologies
- Interoperability standards and protocols
- Encryption technologies
- Efficient solar cells and batteries (chemically or thermally generated electricity, such as thermionic power generation and thermo-electric conversion)
  - E.g., lithium ion/polymer hybrid batteries
  - Affordable solar cell materials and manufacturing
- Thermal management
  - Thermal distribution and control techniques
  - Cryocoolers
  - Other electronic cooling technologies
- Robust thruster design technology
- Advanced team training technologies.



Potential SatOps Architecture

Projected Applications

Capabilities and Characteristics	Project	Status	Agencies
Cooperative, autonomous, self-aware and self-healing; networked comms	• ***TechSat 21,*** experimental concepts for clusters of very low cost and weight microsatellites orbiting in close formation and potentially able to perform a variety of missions in and from space. Examples: – Microsatellite clusters that operate cooperatively to perform the function of a larger, single satellite – New concepts in space-based software intelligence to enable cluster-level C2, thereby allowing ground operations to task a cluster as an individual satellite and reduce SatOps complexity – New methods of space-time measurement and synchronization to manage the cluster and its microsat payloads.	Technology Concepts	Air Force
On-orbit servicing, rendezvous, proximity functioning capabilities	• ***Autonomous Space Transporter and Robotic Orbiter (ASTRO),*** the micro-shuttle vehicle of the ***Orbital Express*** – Autonomous space transporter and robotic orbiter concept to demonstrate feasibility of a servicing micro-vehicle permanently on orbit – Objective is a space vehicle that will conduct refueling and servicing operations autonomously, be able to access satellites at all orbital altitudes (LEO-to-GEO-to-Lagrangian points), and be able to perform significant plane changes – Development to include spacecraft-to-spacecraft interfaces to enable preplanned electronics upgrade, refueling, reconfiguration or resupply of consumables of one spacecraft by another.	Technology Concept (ATD Proposal)	DARPA
On-orbit servicing, multi-mission support	• ***Space Maneuver Vehicle (SMV)*** – High on-orbit maneuverability (>10,500 fps) for altitude and inclination changes – Standard payload bus for interchangeable ISR, space control and force enhancement missions – LEO/MEO station-keeping and rendezvous; GEO flyby – Flexible, moveable, recallable, runway-recoverable	Technology Concept	Air Force

GEO	Geosynchronous Earth orbit	GMTI	Ground moving target indication
ISR	Intelligence, Surveillance, and Reconnaissance	LEO	Low Earth orbit
MEO	Medium Earth Orbit	SAR	Synthetic aperture radar

Opportunities for Partnering

The Air Force Research Laboratory (AFRL) is a member of the Automation Technology for Space Operations Group (ATSOG), whose objective is to promote the insertion of automation technologies into space operations. ATSOG's membership includes all the NASA centers involved in space operations (manned and robotics) such as Johnson, Kennedy, Jet Propulsion Lab, Goddard and Ames, as well as the Naval Research Laboratory (NRL).

Potential collaborators for national security space operations include NASA/Johnson, the Jet Propulsion Laboratory (JPL), Aerospace Corporation (via the Air Force's Space and Missile Systems Center [SMC]), and the Naval Satellite Operations Center (NAVSOC).