Trends in Mission Operations Requirements and Technologies

- How should we prepare for 2020 and beyond? -

Dan Smith / GSFC
Stephen Horan / LaRC
Don Royer / JPL
Don Sullivan / ARC

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Why Invest in Ground Systems?

- Ground system advances have the potential of lowering development and operations costs, reducing schedules and enabling new operations concepts to increase science return.

- Many of the technologies exist today – but we need to be smart in how we apply them to our needs.

We need to identify those trends for which early study or development funding could increase the likelihood of their use and benefit to our future mission efforts.

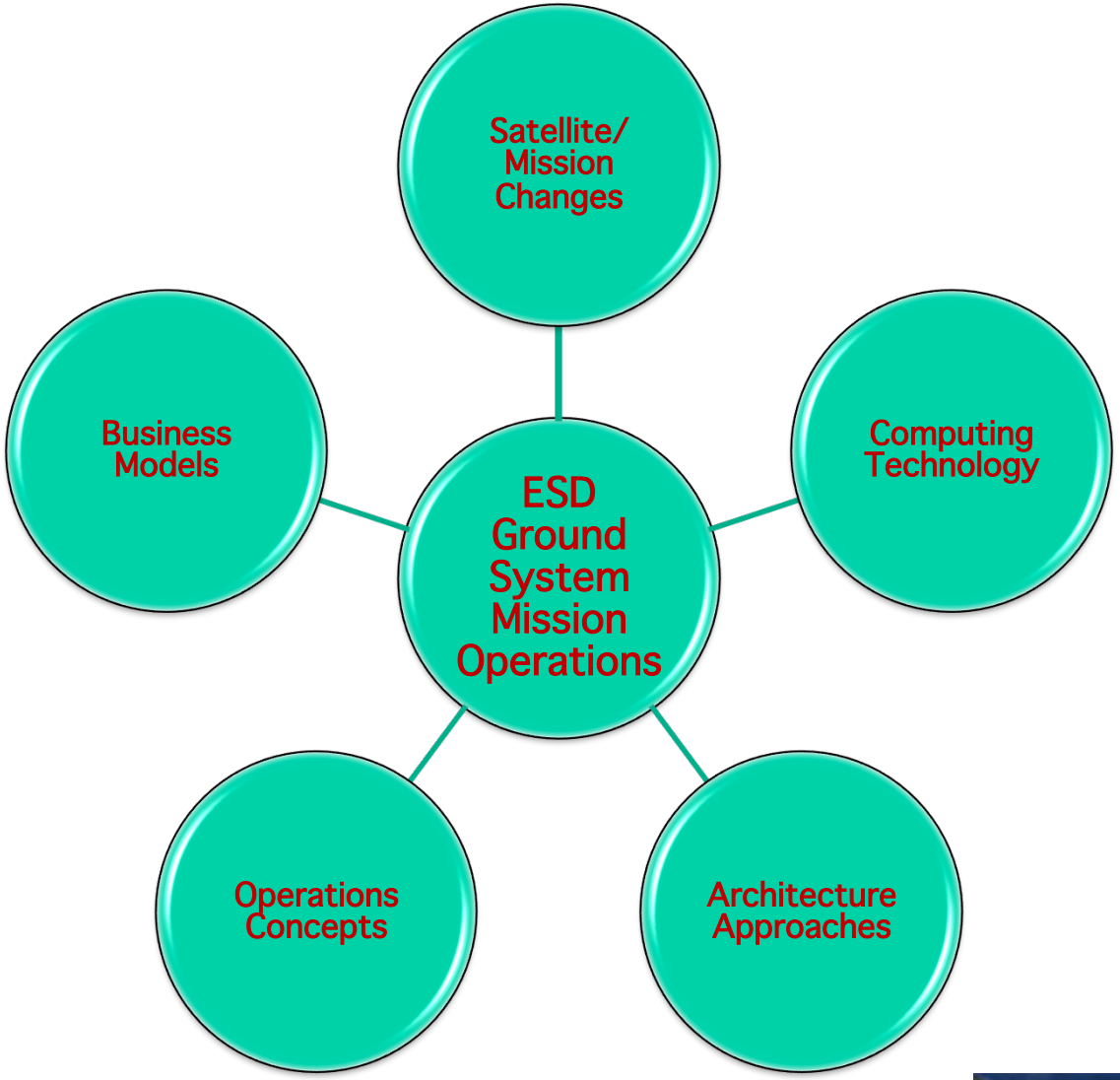
Background

Mission Operations is getting more visibility as a key mission cost element

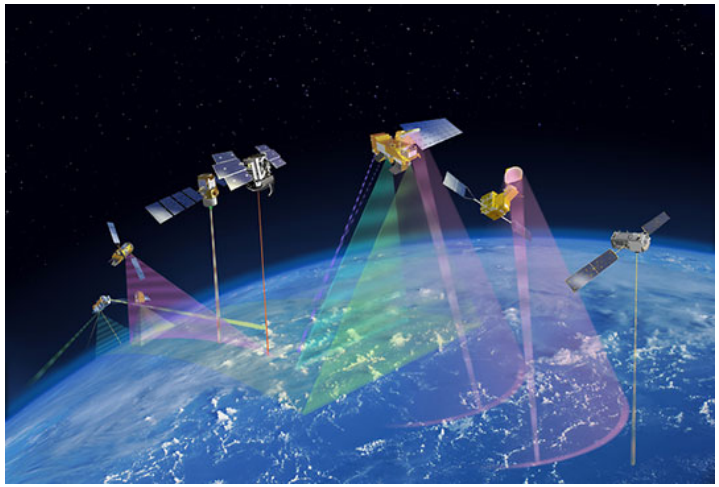
- From NASA Technology Roadmap, TA11. "Demand continues for ground systems which will plan more spacecraft activities with fewer commanding errors, provide scientists and engineers with more functionality, process and manage larger and more complex data more quickly, all while requiring fewer people to develop, deploy, operate and maintain them."
- NASA 2014 Mission Operations Technology Capabilities Assessment Team (TCAT) is bringing more visibility to mission operations at the NASA Agency-Level. NASA may now set goals for long-term cost reduction.
- European Space Agency has seen tremendous benefit from a "Common Core" of ground system software for use by all member countries and their spacecraft manufacturers.
- DoD 2014 Defense Authorization Act nearly requires common ground systems (as interpreted by DoD organizations). Could NASA be next? Would we be ready?
  : "SEC. 822. ASSESSMENT OF DEDICATED CONTROL SYSTEM BEFORE MILESTONE B APPROVAL OF MAJOR DEFENSE ACQUISITION PROGRAMS CONSTITUTING A SPACE PROGRAM. (a) In General.--As part of the certification required by section 2366b(a) of title 10, United States Code, before Milestone B approval of a space system, the milestone decision authority shall perform a business case analysis for any new or follow on satellite system using a dedicated control system instead of a shared control system

Smarter and lower costs ground data systems and operations result in lower overall mission costs and enable a greater emphasis on science.

There are multiple factors influencing future mission operations planning



Satellite/Mission Changes
- requirements are evolving -



- Spacecraft Design/Mission Architecture
  - Cubesats, smallsats – opening new science opportunities
  - ISS-hosted instruments, commercially hosted payloads
  - Geosync orbits with continual coverage and access
  - Fleets, constellations, exotic orbits
  - Satellite networking, collaborative science efforts
  - Data system and interface standardization – or not
  - On-board reconfiguration
  - What will next generation TDRSS look like?

- Data
  - Larger data volume, higher data rates (including optical)
  - Data from many sources – space, in-situ sensors, archives
  - Increase in on-board processing and analysis
  - Delay-tolerant networking, more satellite relays
  - Data provenance and traceability
  - Need for low-latency product generation and analysis (sensor to scientist and back)
  - Security at all levels

- Operational and Programmatic
  - Commercial hosted payloads
  - Rapid development and deployment
  - Onboard autonomous tasking
  - Refuel, repair, and replenishment strategies

Computing Technology Advances

- How many of today's buzzwords were even known 5 years ago? -

- Virtualization
- Cloud Technologies
  - Software as a service
  - Platforms as a service
- Software-Defined Networking
- Explosion of remote computing advances
  - How will we interact with our personal mobile devices in 10 years?
- Dozens of new COTS products to aid development
  - Simplified software distribution, update, and monitoring tools
  - Which ones will stand the test of time?
- New business models from mission control center COTS vendors leading to new product lines and options
- New space data standards by CCSDS, OMG, and OGC could either simplify or complicate development efforts. Which ones will stand the test of time?
- System simulation, modeling, big data, data mining, and data analytics as special discipline areas for mission health assessment enabling new operations approaches.
- Crowd Sourcing as an innovation/discovery approach
- Autonomy and automation tools evolving from other industries

Architecture Approaches

- New systems will use a combination of approaches. -

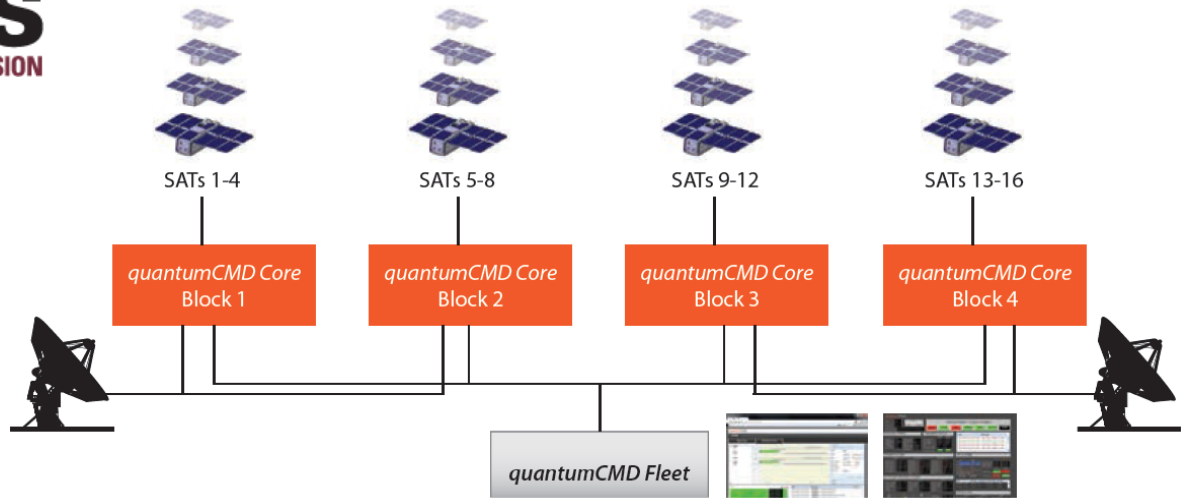
- One-off systems, with software reuse from past missions or low-cost COTS
- Multi-mission enterprise solutions
- Frameworks
- System of Frameworks
  (evolved from previous “System of Systems”)
- Service-Oriented or Service-Enabled Architectures
- Open System Architectures
- Mission Operations “Appliance”
- The “Internet of Things”
- Standards-Based Approaches (could have full international interoperability and even software sharing)
- Zero-Footprint Control Center
  - Maybe the satellite publishes its own website, keeps its operations software on-board
  - A cubesat group is working on the idea of texting service requests to their satellite and performing many traditional mission ops functions autonomously on-board

- Security impacts every architecture

Low-Cost Off-the-Shelf Ground Systems

- smallsats are forcing vendors to create new products and paradigms -

KRATOS
TECHNOLOGY & TRAINING DIVISION



2014: Everything Needed, All In One Box

- quantumCMD™ is the industry's first commercial-off-the-shelf (COTS), self-contained, pre-integrated appliance designed from the bottom up to meet the specific technical, mission, schedule and budget needs of small satellite operations

Operations Concepts
- The variety of approaches keeps growing. -

- Changing support needs
  - More autonomous spacecraft
  - Smarter ground system – it will call the expert if there is a proble
  - Fleet and constellation approaches
  - Manage the set of instruments – regardless of platform
  - Move towards data-driven and event-driven operations
  - Reduce sensor-to-scientist time
  - Lights-out operations whenever possible
  - Access to any data, any time

- Changing personnel roles
  - Have universities perform routine ops, NASA provides engineering, anomaly support, critical ops
  - Increase multi-mission cross training
  - Increase indiviudal roles – can one person be trained to do most functions?
  - Hosted payloads – we don't do the entire job

- Changing the envirionment
  - Increase move towards untethered mission support (home, mobile access)
  - Office-environment operations, use control center space for critical operations
  - Totally virtual control center
  - Service-oriented satellite functionality

Business Models

- Our technical and our business approaches impact each other. -

- "Traditional" – Each mission has sufficient funding to build its own ground system and provide its own dedicated operations team
- Low-cost one-off solutions for each mission. Reduced budget allocations.
  - Enabled by changes in COTS industry, considerable use of GOTS
- Local common enterprise.
  - Each new mission either is a simple add-on to current system or obtains a tailorable copy of the existing system.
  - Decisions are local – not dependent on cross-Center decisions
- "Landlord-Tenant" – Low cost facility for mission ops. Do not reinvent the wheel for each mission, share common resources. In place today for GSFC's smaller instrument operations efforts.
- Move towards ESD- or Center- or Agency- level of commonality or enterprise support
  - Consider specialties of each organization. Easy goal to request; hard goal to achieve
- Collaborate and cost-share with other organizations

- Drastically reduce mission funding for ground data systems and operations
  - This would create a forcing function for common solutions and shared expenses and support
  - This strategy being used today across Europe
- "Outsource" - Mission purchases operations support from outside group
  - Fee for service
  - Currently offered by NRL/Blossom Point , tried in the past by General Dynamics, others.
- Hosted payload – No NASA mission ops center, may have smaller science ops efforts or interact directly with science community

Putting it all together . . .

- Imagine the near future when . . .
  - Tested ground systems are assembled in months, not years
    - Days or even hours may even be possible
  - PIs and spacecraft/instrument component vendors can view status information and help diagnose problems remotely
  - Different missions collaborate with each other through the cloud to determine best science opportunities
  - Mission ops staffing is kept low or on-call; the software will call you if there are problems
  - A user can monitor dozens of small spacecraft and coordinate their activities. Individual satellites can easily be added or deleted from the mix
  - In addition to the spacecraft and on-orbit/in-situ instruments, we monitor the ground equipment and the data/product distribution progress; and we are aware of related activities on other missions

Scenario 1: Multi-Center, Multi-Satellite

- The basics:
  - GSFC manages of fleet of 40 smallsats providing full earth coverage at all times + 2 heritage satellites with 3 instruments each. Use GSFC's common open architecture software
  - JPL manages 3 large earth science satellites using their common software
  - Instrument operations split between ARC and LaRC.
- Data from the large fleet used in near real-time to task the larger satellites
  - Coordination across all 4 Centers done using new CCSDS data exchange services to access cloud-based storage (secure cloud for government use).
  - In-situ ground-based sensor data used to calibrate space sensors
- Common Software and Services
  - ARC coordinates activity planning using planning & scheduling system that is standard across the Agency
  - GSFC's Flight Dynamics facility interacts with the missions for navigation functions
  - Cross-Center ops team shares a common access security system
- Ops team staffing surges for launches – 8 satellites per launch.
  - Routine ops for satellites moved to another facility for launches (data lines reconfigured using software-defined networking)
  - 4 hours of core support per day (all Centers available) for routine ops, most activities fully automated

Fleet operations

Common software

Open systems

Collaborative science

Secure cloud storage

Service/Interface standards

Many data sources

Centers provide specific services

Software –Defined Networking

Summary of Findings

1. Simple suggestions like “just make one system for everyone to use” or “the latest technologies make the best system” or “now we need a new approach because of cubesats” miss the point that there are many many factors that together should affect our final mission operations and system design decisions.

2. We are in a period of tremendous pressures to reduce long-term mission operations costs at the same time that the industry itself is going through a period of signficant change. Many of our old practices and assumptions may no longer be ideal, but we can not simply discard our current infrastructure and capabilities – we must plan to leverage our heritage and move deliberately towards our new goals.

3. The high rate of change in both space data systems requirements and operations concepts, as well as the rate of change in technology available to help address the new challenges requires us to carefully plan our future mission support architectures.

4. Clearly, our future investments must help lead to new systems that are vetted from multiple perspectives, can themselves accommodate change easily, and can address the ever-widening range of mission support requirements. New systems will combine aspects of multiple existing approaches used in a more versatile open-system approach and leveraging appropriate new technolgies that are now available or still to be identified.

5. We must find ways to incentivize our missions and organizations to encourage the creation of our new flexible systems which infuse extensibility and efficiently meet the growing breadth of common needs across our new missions.

Acronyms

ARC	Ames Research Center
CCSDS	Consultative Committee for Space Data Systems (standards organization)
Co-I	Co-Investigator
COTS	Commercial Off-the-Shelf [software]
DoD	Department of Defense
ESD	Earth Science Division
ESTO	Earth Science Tehnology Office
GOTS	Government Off-the-Shelf [software]
GSFC	Goddard Space Flight Center
JPL	Jet Propulsion Laboratory
LaRC	Langley Research Center
MCC	Mission Control Center
NASA	National Aeronautics and Space Administration
OGC	Open Geospatial Consortium (standards organization)
OMG	Object Management Group (standards organization)
PI	Principal Investigator
TCAT	NASA's Technical Capabilities Assessment Team,
TDRSS	Tracking and Data Relay Satellite System