AEROSPACE REPORT NO.
ATR-2013-00118

Next Generation Enterprise NASA Earth Science Mission Control Center Architecture

April 30, 2013

Joanne H. Ostroy[1] and Bonnie Keillor Slaten[2]
[1]Integrated System Architecture Office, National Space Systems Engineering
[2]Science and Robotics Mission Directorate, NASA Programs Division

Prepared for:

NASA Earth Science Division
Goddard Space Flight Center
Greenbelt, MD 20771

Contract No. NNG11VN12T/3

Authorized by: Civil and Commercial Operations

AEROSPACE
Assuring Space Mission Success

AEROSPACE REPORT NO.
ATR-2013-00118

Next Generation Enterprise NASA Earth Science Mission Control Center Architecture

April 30, 2013

Joanne H. Ostroy[1] and Bonnie Keillor Slaten[2]
[1]Integrated System Architecture Office, National Space Systems Engineering
[2]Science and Robotics Mission Directorate, NASA Programs Division

Prepared for:

NASA Earth Science Division
Goddard Space Flight Center
Greenbelt, MD 20771

Contract No. NNG11VN12T/3

Authorized by: Civil and Commercial Operations

AEROSPACE REPORT NO.
ATR-2013-00118

Next Generation Enterprise NASA Earth Science Mission Control Center Architecture

April 30, 2013

Joanne H. Ostroy[1] and Bonnie Keillor Slaten[2]
[1]Integrated System Architecture Office, National Space Systems Engineering
[2]Science and Robotics Mission Directorate, NASA Programs Division

Prepared for:

NASA Earth Science Division
Goddard Space Flight Center
Greenbelt, MD 20771

Contract No. NNG11VN12T/3

Authorized by: Civil and Commercial Operations

AEROSPACE
Assuring Space Mission Success

Next Generation Enterprise NASA Earth Science Mission Control Center Architecture

Approved by:

Frank Donivan

Frank F. Donivan, Jr., Principal Director
Science and Robotic Missions Directorate
NASA Programs Division
Civil and Commercial Operations

SI0400(1, 4340, 40, KZ)

Acknowledgments

The study team would like to acknowledge the efforts of the NASA Advisory team in coordinating the site surveys and arranging for a number of people to be at our disposal for presentations and questions and providing essential feedback during the study execution.

Special thanks are due to P.J. Guske of the Jet Propulsion Laboratory, Dan Smith of Goddard Space Flight Center, and Steve Horan of Langley Research Center, as well as to Karen Moe of the Earth Science Technology Office for her guidance and to Barbara Grofic for her input to this study effort.

Contents

Figures

Tables

1. Executive Summary

The Aerospace Corporation (Aerospace) was tasked by the NASA Earth Sciences Division (ESD) to perform an Earth Science (ES) Mission Control Center (MCC) Architecture Study. The study had two objectives. The first was to capture the state-of-practice for both NASA MCCs and other operational MCCs. The second was to develop a next generation MCC enterprise architecture. This enterprise architecture accommodates the complexities of the missions and partners as well as unplanned life extensions of missions flying in the 2020 to 2030 time frame.

This study task statement broke the effort into three tasks. The first two were to survey to collect state-of-practice on NASA and non-NASA MCCs. The third task was to analyze the findings and define a next generation MCC enterprise architecture for NASA ESD. The first two tasks were documented in the combined Report 1, "Architecture and Operations of NASA and Non-NASA Earth Science Mission Control Centers." Report 1 documented the state-of-practice surveys of both the NASA and non-NASA MCCs, and summarized the findings. Report 2 documents the analysis of those findings and presents recommendations for next generation MCC enterprise architecture.

The present NASA Earth Science (ES) enterprise Mission Control Center (MCC) architecture is a collection of centers and independent MCCs that have physical connectivity but lack any interoperability. The composition of the ES community consists of diverse missions and partners both domestic and international. Each mission is fairly stove-piped in nature even though it may reuse software from other missions. There appears to be separate baselines for each mission MCC. It is not uncommon for missions to extend far beyond their planned life cycle. These unplanned extensions incurred costs which become large unfunded burdens. The goals for the next generation enterprise MCC architecture were developed to address these and other operational efficiency issues. Understanding the issues led to the following architectural goals:

- Lower operating costs:
- Accommodate changing and diverse missions and partners
- Maintain cyber security and protection

The next step was to determine which key architecture attributes could enable these goals. These attributes at a high level are mapped to the architectural goal it is meant to enable:

- Operational Automation (Lower operating costs)
  - Reduces operating costs
  - Flexibility of operations tempo
  - 24/7 to lights out
- Processing Virtualization (Lower operating costs)
  - Flexible movement of processing among IT resources. (Server/Client architecture, SOA, mobile code)
  - Common services (cloud storage, processes, collaboration)
  - Dynamic processing resource allocation

- Interoperability (Accommodate changing and diverse missions and partners)
  - Infrastructure standards and processes for coordination among partners, both domestic and international
    - Consultative Committee for Space Data Systems (CCSDS) standards for data and Command & Control & Telemetry (C2T)
  - Network connectivity for communications and transferring of information
    - Common Service Office/NASA Integrated Communication Service (CSO/NICS)
    - GMSEC
- Cyber Security and Protection (Maintain cyber security and protection)
  - Identification of cyber threats and architecture vulnerabilities and risks
  - Implementation of cyber security and protection into designs using secure coding standards
  - Technology refresh to help maintain cyber security and protection

Each of these attributes place capability requirements of performance as well as operational procedures on architectures. Various technologies were explored to meet the architectural goals. These included operational automation, processing virtualization using common services, hardware, and tools, as well as architectural constructs such as centralized and distributed MCC functionality. All of these technologies and architectural constructs are state of practice for MCCs and are viable options.

From the 30,000 ft. above look, there were two high level architecture candidates. The first being a distributed service oriented architecture (SOA), and the second being a centralized service oriented architecture. There are numerous implementation options depending on the direction one wants or needs to go in implementing a SOA. There are major cost and risk trades in implementing an enterprise wide SOA. The benefits in general are natural dynamic allocation of resources, single maintained baseline, and flexible expansions of the enterprise. External interfaces would be implemented using a loose coupling through standards at the level which is determined to be cost effective. SOA is not the only alternative, and a mixture of unique and SOA architectures is a trade space at the enterprise level. Figure 1 diagrams a distributed architecture where operational nodes, the MCCs, use common services or clients and operate independently.

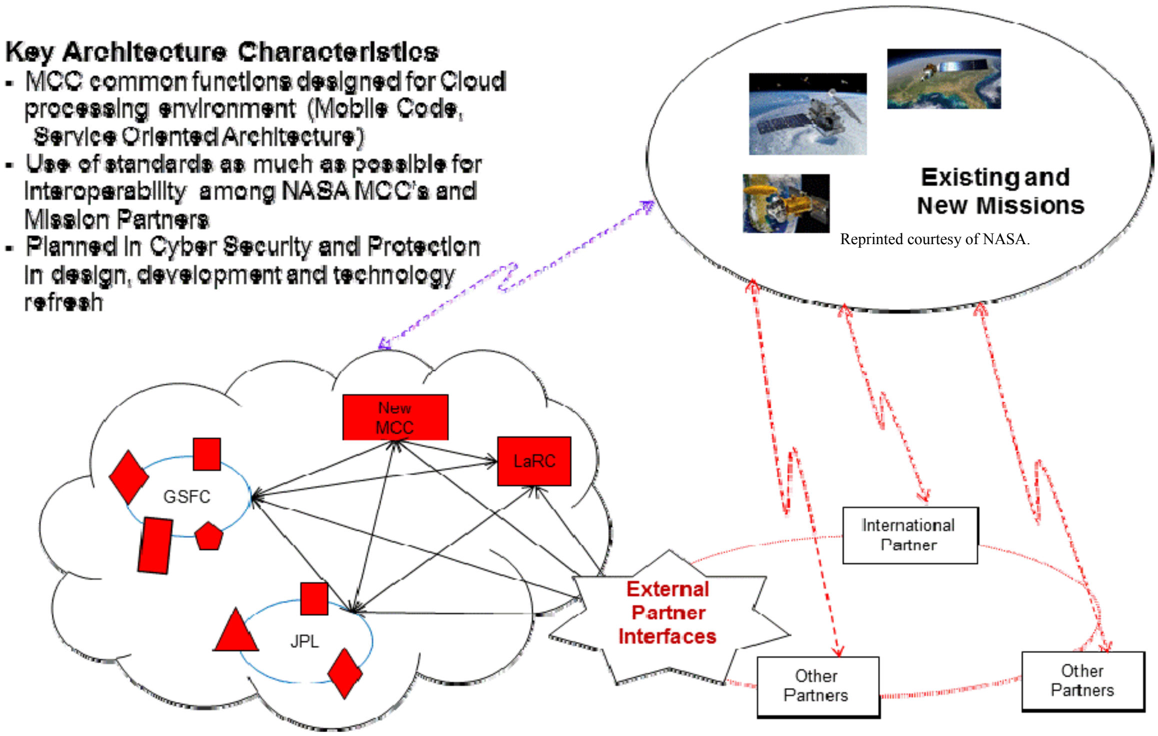


Figure 1. Distributed SOA enterprise architecture.

In contrast, a centralized MCC functional construct would look like Figure 2. This has all of the MCC functions being performed at a central operational node in support of all missions.

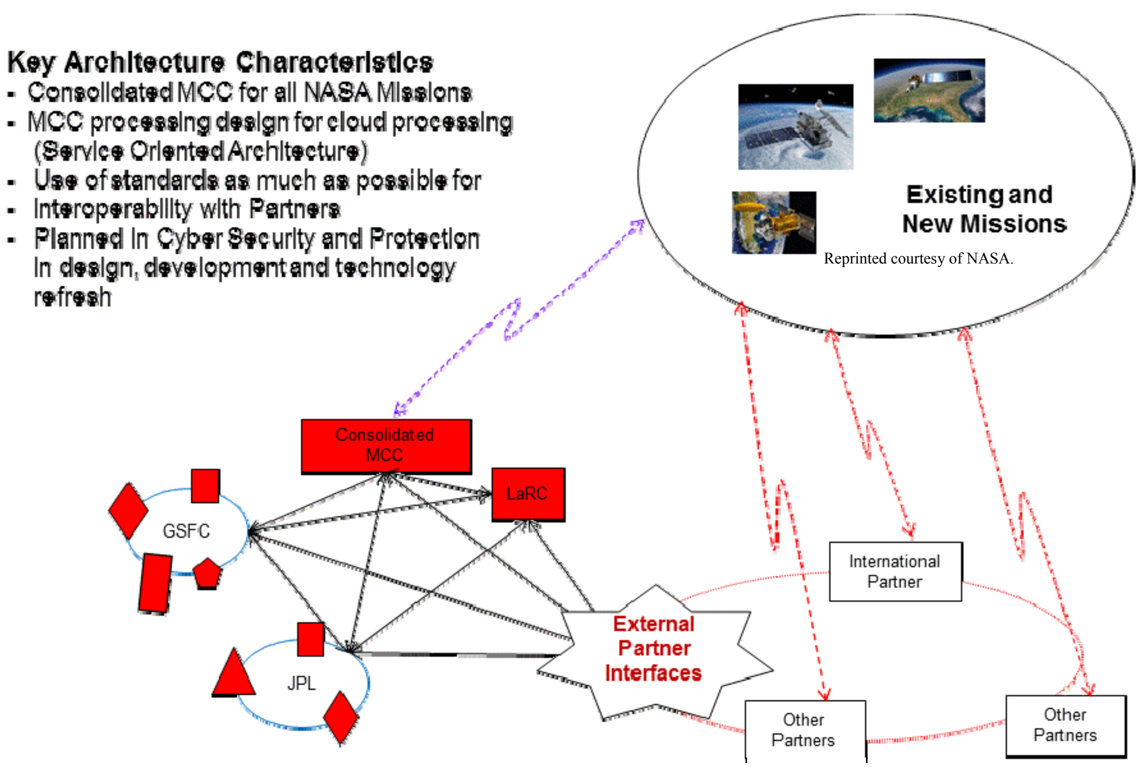


Figure 2. Consolidated MCC enterprise architecture.

The key characteristics of either option are listed in the upper left hand corner of Figures 1-1 and 1-2. Notice that at this high level, the key characteristics appear to be the same. The difference between the architectures lies in the allocation of functions and the extent of the coupling is usually accomplished through the use of standards. In the distributed option, all the MCC functions remain as common services or clients with each mission using a common baseline for their required MCC functionality. Operational nodes have a tighter coupling than a centralize construct, which may at first appear to be counter-intuitive. However, if one thinks about the operations of multiple independently operating nodes that need to maintain an enterprise situation, then the interchange among the individual nodes requirements will increase. In a consolidated MCC construct, situational awareness and maintaining the enterprise MCC situation lie in a single functional node. Therefore, individual mission nodes need only to report and respond to a single node. In the consolidated construct, the architecture has a consolidated facility providing all of the common MCC functionality and services for missions. There are many implications for each operational construct.

The costs/benefits and the driving attributes of each alternatives should be assessed in an Analyses of Alternatives (AoA). Those results needed to be incorporated into a future NASA ES enterprise MCC architecture yet to be determined. Additional details of existing and planned implementations of the NASA MCCs would also be needed to perform an AoA.

This does not imply that the amount of information gathered through the survey process was at all limited. In fact, given the time and effort required in collecting information, the results were quite extensive. Analyzing the findings from surveys of both the NASA and other MCCs yielded interesting results. Many MCCs have some of the key operational attributes; others are moving towards implementing them. The key findings from the surveys are summarized as follows:

- Major costs were involved in personnel staffing.
- All MCCs functions are required by all missions.
- Some missions have implemented automation into operations for cost savings.
- Several of the NASA MCCs and large centers are evolving naturally towards an enterprise type architecture. They incorporate some of the following attributes:
  - Reuse of common software processes and tools as much as possible
  - Use of common net-centric standards for interfaces
  - Use of common net-centric standards for data exchange
  - Use of Service Oriented Architecture (SOA) or server/client architecture
  - Use of virtual processing
  - Use of tech refresh for cyber protection issues.
  - Use of a physical network existing between missions
  - Use of a common middle layer providing services for interfacing, collaboration, exchanging of data, and layered security developed in GMSEC

Pockets of these needed attributes exist but missions are still basically stovepipe structured architectures and are not designed to utilize enterprise common services at an enterprise level. They appear to incorporate or reuse software from other programs, and modify it to meet their needs. This creates individual baselines that require additional maintenance:

- Software remains on separate baselines.
- Missions are not designed for interoperability so they can't naturally backup one another.
- Virtual processing is limited to hardware resources only within a mission domain.
- Existing services do not encompass the full MCC common functionality.

In general, there appears to be a natural migration path which could lead to a common MCC set of services and infrastructure. The basic NASA enterprise infrastructure is already in place but requires additional development to attain integrated operational interoperability. NASA has in place the NASA Integrated Services Network (NISN), which provides the network layer for interoperability. Goddard has developed the Goddard Mission Services Evolution Center (GMSEC), which includes middleware and a framework to provide for system automation, common services, and interoperations. These capabilities provide a great infrastructure upon which to build. Operational cost savings could be obtained through having natural backups and flexible resources used for extended mission life. The services for automation of MCC functions already exist to some extent at some of the NASA MCCs. Other agencies already have or are in the process of adopting versions of GMSEC as a framework for common MCC functionality. The Naval Research Laboratory (NRL) already has in place automated centralized operations, which provide many MCC functions today at their Blossom Point facility. This system utilizes the GMSEC framework as middleware to provide some of the common services necessary for automation. It is not meant to be a fully integrated operational enterprise. The Air Force also has been developing a Command and Control System - Consolidate (CCS-C), which also is looking to use GMSEC. Both the Navy and Air Force consolidated ground stations are capable of performing all of the core MCC functions. These constructs are very similar architectures and may suit the next generation ES enterprise MCC architecture well. There exists a natural inclination for these communities to work together to reduce developmental costs. This needs to be further explored.

Many NASA MCCs are already interconnected to a great extent since they utilize the Common Service Office/NASA Integrated Communication Service (CSO/NICS) infrastructure. Some sites have also moved to common hardware to maintain a single hardware baseline but these sites also utilize outdated and inefficient software architectures from the 1980s/1990s.

Processing Virtualization can add operational resilience and resource utility opportunities (e.g. cloud computing, Server/Client software, Service Oriented Architecture (SOA), resource balancing).

Portions of a future enterprise MCC architecture are already included in the vision of many of the individual NASA MCCs today. The problem lies in the lack of an overall enterprise vision which is not yet institutionalized throughout NASA. Having an integrated enterprise architecture construct in place can help keep centers and MCCs from developing similar enterprise type constructs. This lack of coordination can lead to duplication of work and maintenance of functionally duplicative baselines. In a recent GAO report on *Satellite Control, Long Term Planning and Adoption of Commercial Practices Could Improve DoD's Operations* the GAO's findings were that Commercial practices have the potential to increase the efficiency and decrease costs of DoD satellite control operations. These practices include: interoperability between satellite control operations networks; automation of routine satellite control operations functions; use of commercial off-the-shelf products instead of custom ones; and a "hybrid" network approach which allows a satellite operator to augment its network through another operator's complementary network.

2. Introduction

2.1 Purpose

The purpose of this study is to capture the state-of-practice of current NASA and other organization MCCs, and then to analyze the current Mission Control Center (MCC) state-of-practice to develop a notional high-level MCC enterprise architecture for the NASA Earth Observation fleet operating in the 2020-2030 timeframe. The study task statement broke the effort into three tasks. The first two tasks were to survey to collect state-of-practice on NASA and non-NASA MCCs. The third task was to analyze the findings and define a next generation MCC enterprise architecture for NASA ESD.

The first two tasks were documented in the combined Report 1, "Architecture and Operations of NASA and Non-NASA Earth Science Mission Control Centers." Report 1 documented the state-of-practice surveys of both the NASA and non-NASA MCCs, and summarized the findings. This report, Report 2, documents the analysis of those findings, and presents recommendations for a next generation MCC enterprise architecture.

2.2 Scope

The scope of this report is limited to addressing an enterprise architecture that includes only the findings from the surveys done during Report 1 and Subject Matter Expert (SME) inputs to develop the next generation MCC enterprise architecture. The study was a high level, best effort endeavor.

2.3 Background

Earth Science spacecraft require a mission control center in order to perform their missions. Presently, there is multiplicity of MCCs for various ES missions. NASA does not currently have an agency approach for an enterprise MCC architecture. Larger centers such as Goddard Space Flight Center have started to develop a framework structure that can be used as part of the infrastructure of an enterprise MCC architecture. Other ES missions have developed their own MCC without adhering to any of the infrastructure that NASA has and is being developed at Goddard. This causes the present enterprise MCC architecture to be very disjointed and inefficient. The one of a kind MCC does not allow for evolution as the mission enters into extended mission operations. These MCCs have developed duplicate functionality but the mission uniqueness must remain. NASA ESD is seeking new approaches that will allow lower costs for implementation and operation of future control centers.

NASA ESD is interested in defining a next generation MCC enterprise architecture and operational concepts that will facilitate future operations. Due to constrained budgets, future control center concepts could include lights-out operations or other innovative system architectures.

2.4 Methodology and Process

At the beginning of this study, a core set of ES MCC functions were defined. The surveys in Report 1 of the study identified which architectures presently exist at NASA and non-NASA MCCs. The first step was to evaluate the functionality of each MCC against the common MCC function list, thereby identifying completeness and gaps. Next generation enterprise MCC architecture goals and attributes were identified. The existing NASA MCCs were evaluated against the identified architectural goals and attributes to establish how the baseline measures up against these attributes. In Figure 3, steps in the darker goldenrod were accomplished while the dashed yellow steps remain to be done. The step

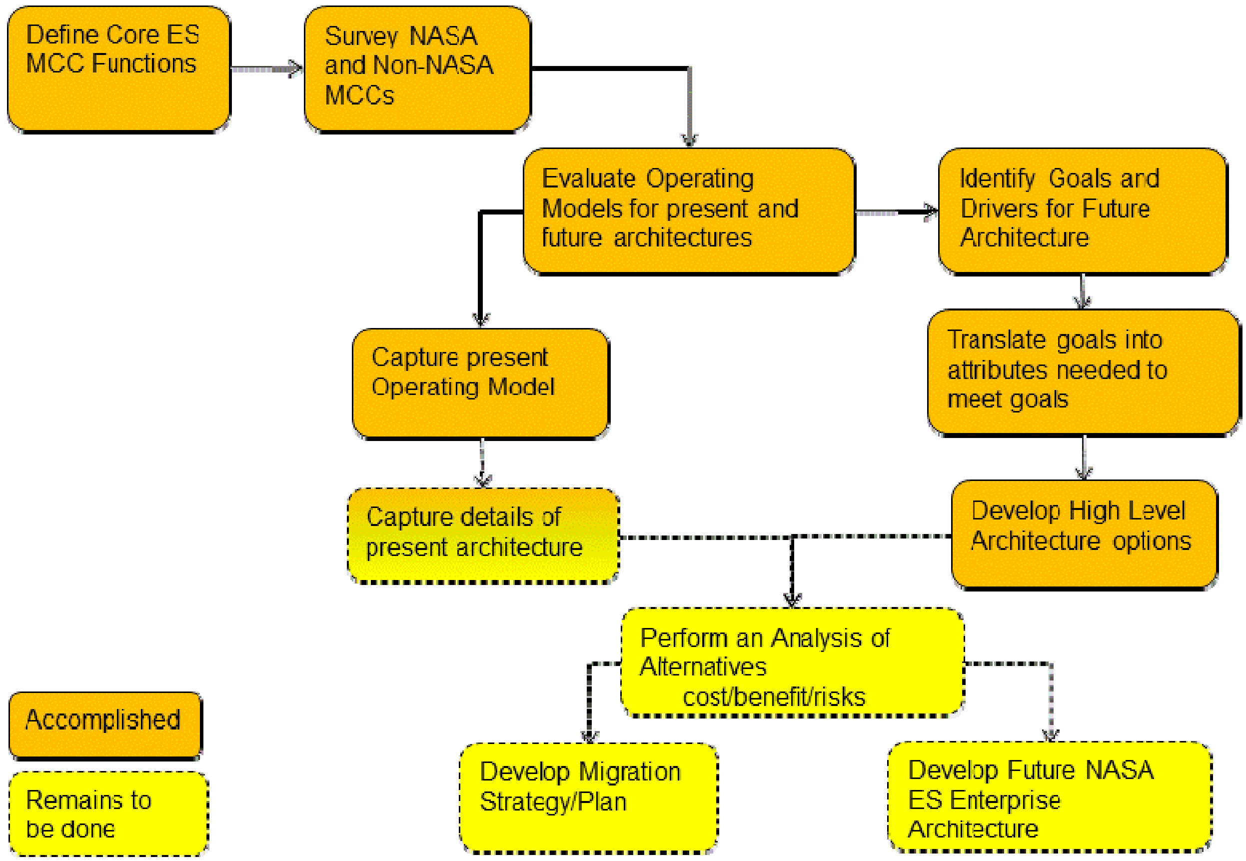


Figure 3. Architecture definition methodology.

involved in "Capture the details of present architecture" is partially yellow and partially goldenrod because future technical details are still needed to perform an AoA. The methodology used in developing the next generation enterprise architecture is illustrated in Figure 3.

3. Next Generation Earth Science (ES) Enterprise Mission Control Center (MCC) Architecture

3.1 Purpose of the Architecture

The main purpose of the next generation enterprise architecture is to make the MCC functionality of the ES enterprise more cost efficient and flexible. The core functions that were identified early in the study existed among all the surveyed MCCs. Duplicating functions at different MCCs is not cost effective not only from the developmental costs but also in the Operational and Maintenance (O&M) phases in a mission lifecycle. O&M costs appear to be the major costs to programs. Hence, reducing these costs could lead to significant long term cost savings.

3.2 Boundaries of the Architecture

The operational nodes of the architecture include all core functions of the MCC with the exception of: 1) the EOS Data and Operations System (EDOS), which acts as a buffer and storage for commands and spacecraft telemetry and mission data; 2) the space/ground communications, which provides the transmission to and from the spacecraft; and 3) the Science Data Processing, which is responsible for all mission data processes with the exception of perhaps Level 0 pre-processing. A representation of high level operations of nodal core functions within these boundaries is illustrated in Figure 4. Core MCC functions are designated in blue boxes and the external functions and architectural nodes are in yellow colored boxes with dashed outlines. Also included for completeness are the external auxiliary data sources, which are also identified in a yellow box with dashed outlines.

This only establishes the operational MCC functionality. How the functionality is implemented within the enterprise is the basis of the enterprise architecture.

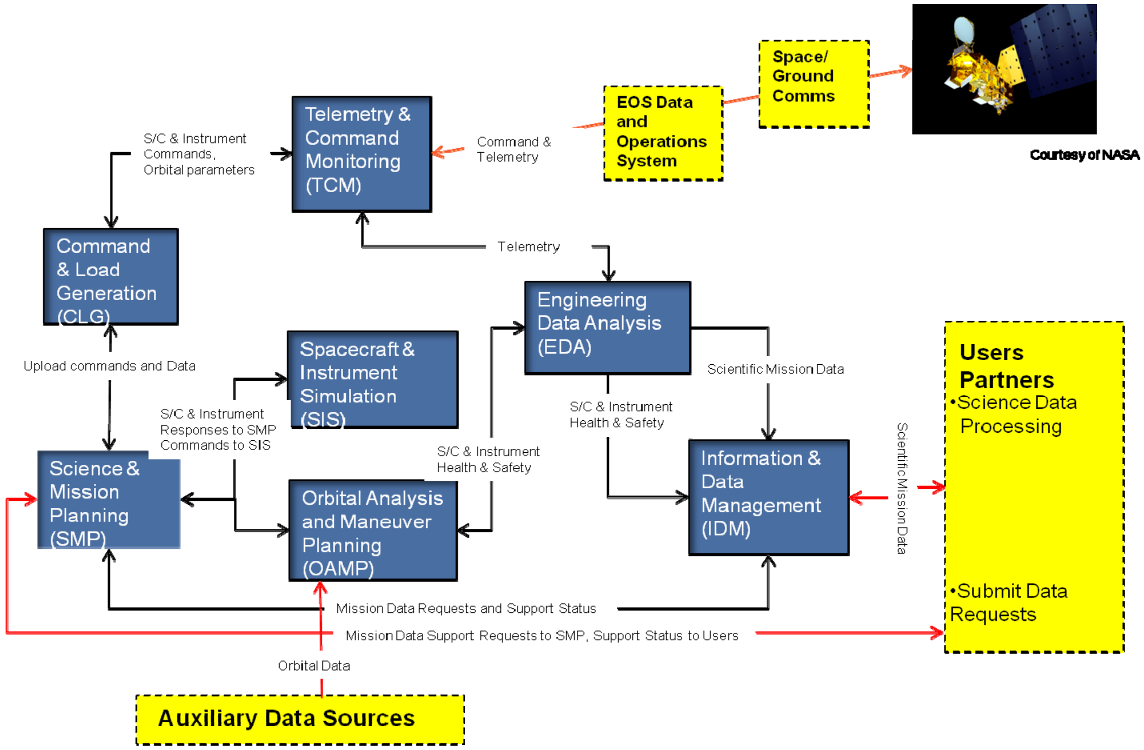


Figure 4. Boundaries of the MCC.

3.2.1 Constraints

The study was a five month quick look. The constraints that were identified included the limitation on the number of NASA MCCs surveyed, as well as the technical depth that these surveys were able to accomplish. These surveys were performed on a voluntary basis, and with only a single visit to each site. Each of the sites was cooperative but there was a lack of documentation provided on the technical details as well as cost information.

3.2.2 Goals and Attributes

Through the surveys, it was determined that there were only a few significant costs drivers. These included:

- Extended mission life beyond prime mission phase
- Unique missions and satellites support paradigm
- “Custom Services and tools” versus common services and tools
- Staffing is a major operating cost
- Cyber protection is a major unfunded cost driver

After analyzing the findings, the following goals were established for the next generation MCC enterprise architecture:

- Lower operating costs
- Accommodate changing and diverse missions and partners
- Varying MCC complexity
- Mission life uncertainty
- International and commercial partners
- Geographical dispersed
- Maintain cyber security and protection

The study looked at possible ways to meet these goals. The first objective was to lower operational costs. There are several approaches identified to obtaining lower costs. One is to reduce the required personnel for operations. Another is to reduce resources by optimizing resources use among all nodes. To optimize resource use, the operational load must be able to be reallocated among all resources by dynamic loading of work flow. This can be accomplished in several ways. One approach is the use of cloud computing, where all resources are basically in a cloud and are dynamically allocated as needs arise. This type of processing is often referred to as processing virtualization. Use of common services also reduces costs, in that it is total reuse of common functions and maintains a single baseline. Common services can be providing data, processes, tools, and services such as computing resources. This is the essence of a Service Oriented Architecture (SOA). One other option to reduce operational costs is consolidation to a single consolidated MCC, which provides MCC functionality for all missions and a single hardware and software baseline.

Each of these options has benefits as well as risks and constraints. Depending on the level of commonality and the operational complexity, different aspects work for the betterment or cause more than acceptable risk. For instance, if the computing loads are not significantly complex and dynamic in nature, using cloud computing can add unbearable complexity and overhead versus a simpler processing construct. Large complex dynamic processing architectures are better served using cloud computing than less complex processes.

Satellite functions are relatively less complex in nature and typically lean towards common services or consolidation. There have been several studies that have shown this exact conclusion. The construct of consolidation has been implemented for numerous years by other agencies. The Air Force has had this construct for many years since the late 1950's. Its integrated satellite command and control system is referred to as the Air Force Satellite Control Network (AFSCN). This original architecture was a series of similar nodes which supported satellite control for a variety of satellites. This architecture migrated towards a consolidated architecture with automated remote sites and a consolidated active site. One of the costs savings that the AFSCN implemented was automated remote sites. The Navy has also implemented a similar satellite command and control operational paradigm in their operations at Blossom Point. There the operations (mainly due to budget constraints) have been driven to an almost fully automated system, which includes automatic alarming and personnel notification. They have incorporated the middleware developed by Goddard Space Flight Center Goddard Mission Services Evolution Center (GMSEC) into their infrastructure to integrate legacy system systems and provide system-wide awareness and control with event-driven automation. GMSEC provides for system monitoring and provides a framework for technology insertion. Other agencies and satellite operations have also migrated towards common services such as in commercially available satellite command and control systems, which use the same common services for a multitude of satellites they support.

To accommodate changing diverse missions and partners, many systems have implemented their common services using XML descriptions to identify the mission uniqueness. They can adapt to almost any satellite and payload through the use of these descriptors without change to their baselines. None of these architectures described are truly SOA but they are moving towards SOA constructs. Presently, they lean towards centralized operationally consolidated architecture.

NASA ES satellites do not appear to have driving unique requirements that would prevent movement towards a similar architecture construct. The architecture functionality of all of these existing architectures is very adaptable to ES missions and would allow NASA to reap the cost savings benefits. Moving to a common baseline for MCC functionality throughout the future enterprise MCC architecture would allow for operational flexibility to support extended life missions with minimal additional costs, as well as provide sufficient backup with fewer assets. Presently, there are backup facilities for individual missions. This functionality could be incorporated into a virtual MCC functional enterprise, which would allow any MCC resource to process and support any ES mission. The interconnectivity required for the transfer of data, commands and telemetry and coordination are in place with the NASA CCGN. Goddard's GMSEC has the necessary middleware. Enterprise level functional common services for all of the ES MCC core functions do not presently exist. Goddard Space Flight Center as well as the JLP MCC supports multiple missions. Perhaps, with further technical understanding, one or either of these could easily evolve into the common baseline resulting in the following attributes:

- Lower operating costs
  - Reduce operational staffing through operations automation
  - Enable efficient resource utilization with processing virtualization
  - Reuse common services and tools using Service Orient Architectures (SOA)
  - Develop enterprise wide operational functional processes common services
- Accommodate changing and diverse missions and partners

- Utilize standards that enable common services and interoperability
- Provide for command, control, and data sharing
- Provide common network connectivity, communications, and collaboration

- Maintain cyber security and protection
  - Design in cyber security and protection early in the development
  - Plan for updates and refresh for currency

3.2.3 Core Functions

The core functions are defined in Table 1. The core functions list was analyzed for completeness against a typical operational scenario. Then the core functions were compared between existing MCC functions, and how the MCCs implemented the functionality of the core functions. The details of these correlations follow. Note: Not all of the MCCs surveyed are included in this report but are available upon demand.

Table 1. Core Functions

Function	Description
Science and Mission Planning (SMP)	The system of personnel, processes, procedures, and hardware/software that support the planning of science and mission activities. This includes ground software used to plan activities, as well as development, documentation, and maintenance of operating procedures.
Orbital Analysis and Maneuver Planning (OA&MP)	The system of personnel, processes, procedures, and hardware /software that supports the determination of spacecraft trajectory and position, and tracks the flight system. This may also be known as Navigation Operations by some NASA Centers. This system assesses position and velocity uncertainties and plans for changes in the spacecraft's trajectory, as required, e.g., trajectory analysis, orbit determination (OD), maneuver design analysis, target body orbit/ephemeris updates, mission change request analysis, etc. This includes development, documentation, and maintenance of software and operating procedures.
Command and Load Generation (C&LG)	The system of personnel, processes, procedures, and hardware /software that support the development and integration of the sequence of commands to control the space vehicle and its payload and/or instruments. This may also be known as Sequence Generation by some NASA Centers. This includes development, documentation, and maintenance of software and operating procedures. This also includes the flight rules (constraints) checking and testing of command sequences before being uploaded to the spacecraft.
Telemetry, Command and Monitoring (TC&M)	The system of personnel, processes, procedures, and hardware/software used to receive, process, and display telemetry, monitor real-time telemetry, format and transmit commands, and report the status and metrics of the tracking stations and ground network. This includes processing of telemetry into engineering units and may include the encryption of uplink, decryption of downlink, and/or Level 0 processing of science data.

Function	Description
Engineering Data Analysis (EDA)	The system of personnel, processes, procedures, and hardware /software used to analyze downlinked telemetry (real-time or stored) to determine spacecraft and instrument health and safety. Also includes models of spacecraft and instrument subsystems used for analysis and determination of maintenance activities.
Spacecraft and Instrument Simulation (S&IS)	The system of personnel, processes, procedures, and hardware/software used to simulate command loads before being uploaded to the flight system and/or simulate flight system behavior for major events or new operational modes. May include flight software simulators/test beds, and may be used in training activities.
Information and Data Management (I&DM)	The system of personnel, processes, procedures, and hardware/software used to ingest, store, query, and distribute information and mission data products. The system logs data downlinked from the spacecraft, archives engineering telemetry, logs command uplinked to the spacecraft, and is used to identify missing data (science or engineering) for re-downlink. This also includes data security and quality management, metadata management, and information technology (IT) infrastructure (storage, databases, web services, authentication services and networks), and may include merging of critical engineering data downlinked to multiple sites.

Figure 5 illustrates the exchange of data necessary between functions as well as identifying external nodes to and from the MCC node. The external functional nodes are drawn in lighter blue boxes. This illustration is MCC operational node focused and doesn't express the enterprise level influences. In later enterprise discussions, this functional grouping will be referred to as an MCC node.

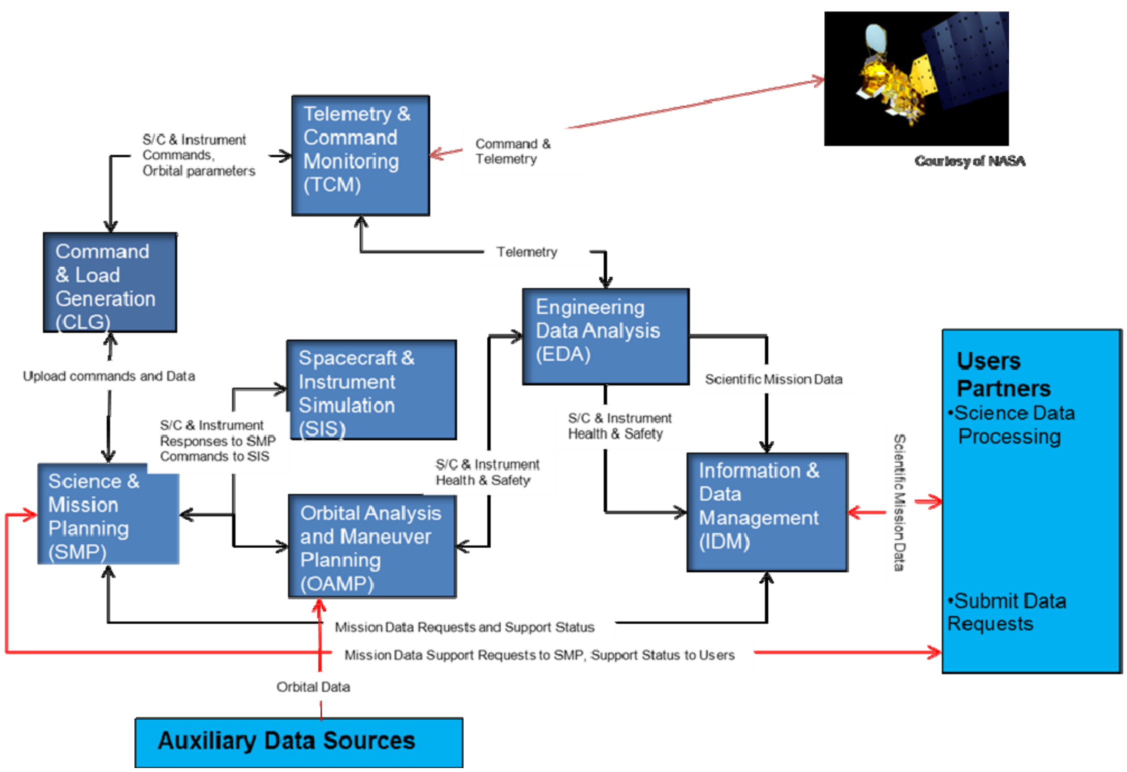


Figure 5. Operational functional view of MCC node.

Further analysis was performed to ensure that the core functions were adequate to represent a generic MCC node. An operational time flow was developed using the core functions and data exchanges for a typical operation. This flow is shown in Figure 6. This demonstrated that the core functions did provide all the functionality required for a typical operation.

This Operational Flow:

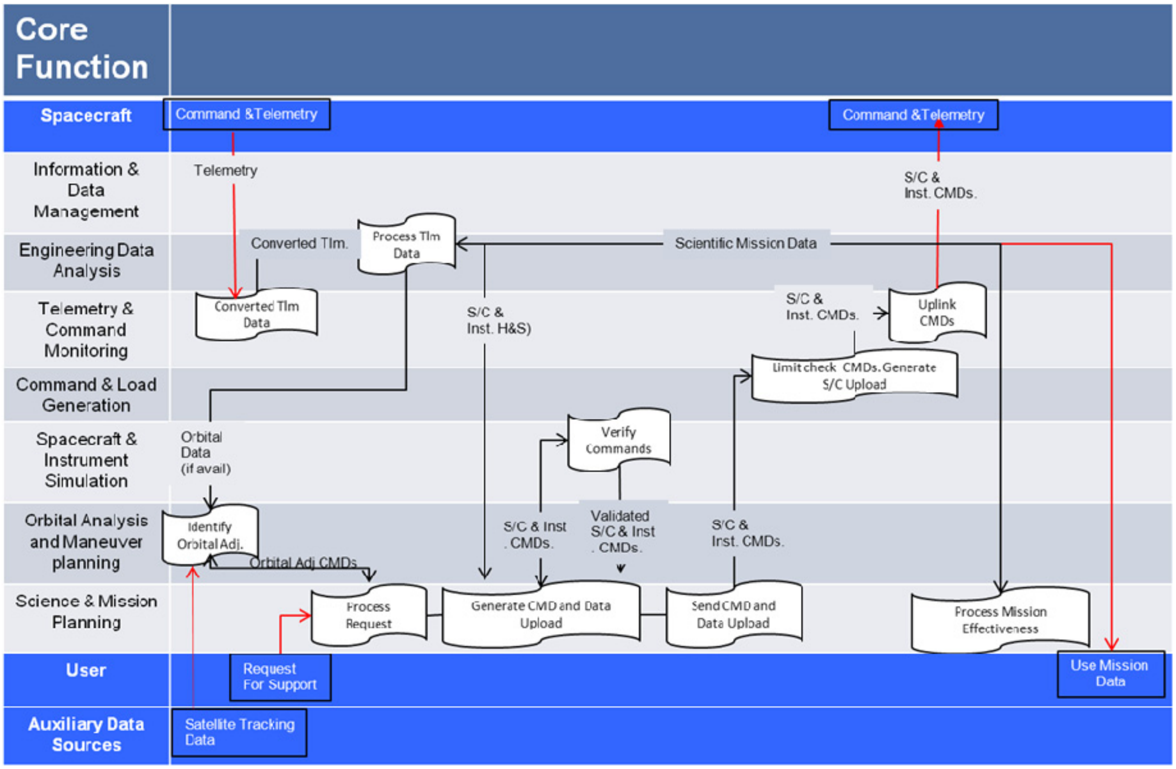


Figure 6. Operation timeline flow.

Additionally, these core functions were then mapped against existing NASA MCC functions to find consistency and common functionality. This mapping showed that the architectural implementations of these functions vary among the NASA MCCs but the common high level functions exist for all surveyed mission MCCs. In at least one case, the functionality is distributed among partners and so all the functionality of a core MCC is not the responsibility of NASA.

An example of this mapping of core functions against existing NASA MCC functionality was done on the Jet Propulsion Laboratory (JPL) Advanced Multi-Mission Operations System (AMMOS). There was also a strong correlation in functionality. This comparison is illustrated in the following Figure 7. The core functions are highlight in blue to show the correlation. AMMOS uses a basic operational model which is service oriented using common tool sets. The services that AMMOS provides are:

Mission planning	*(S&MP)*
Multi-Mission Resource Scheduling	*(S&MP)*
Observation Planning	*(S&MP)*
Sequence and Command Generation	*(C&LG)*
Sequence and Command Transmission	N/A

Data Archive	*(I&DM)*
Instrument Data Processing	N/A
Solar System Dynamics	*(OA&MP)*
Navigation and Mission Design	*(OA&MP)*
NAIF Data Processing	N/A
GDS Engineering Support	N/A
Data and Voice Communications and Security	N/A
Configuration Management	*(I&DM)*

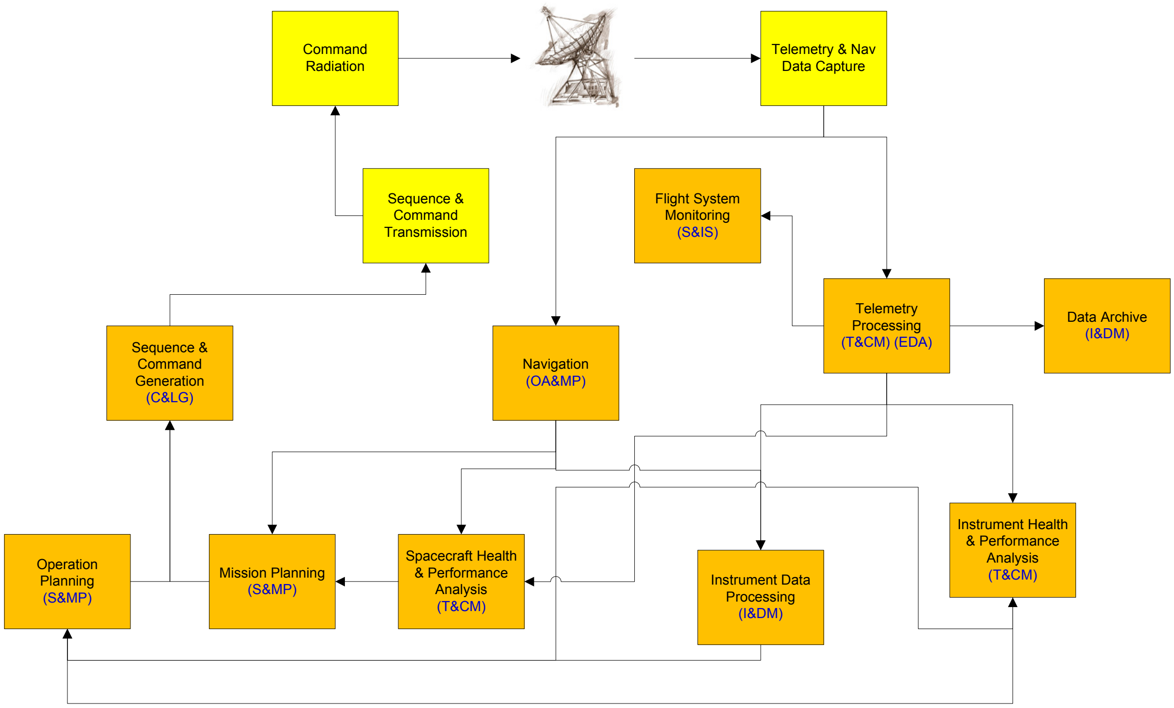
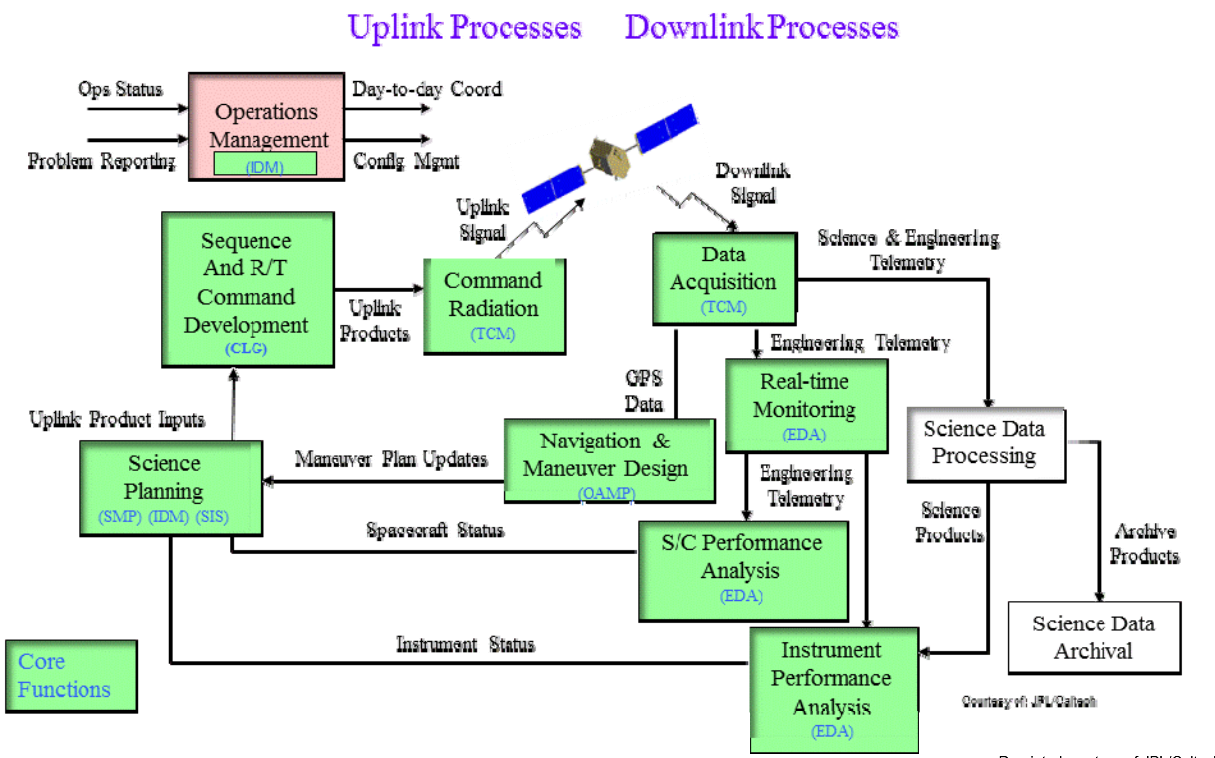


Figure 7. AMMOS functional decomposition (figure provided by AMMOX MCC).

A missing common service that the core MCC requires is the Telemetry, Command and Monitoring function, which is responsible for decomposing and multiplexing the telemetry and doing Level 0 processing on mission data. Another service that is in the core MCC functions but not a responsibility of AMMOS is Engineering Data Analysis, which maintains the health and status of the spacecraft as well as the instruments. Spacecraft and Instrument Simulation is the last core function that doesn't appear to be included in the list of AMMOS services, but could be imbedded in the Multi-Mission Resource Scheduling or some of the other services that should be reliant on this function.

The overall architecture is designed to handle many different missions with distributed users and partners. This is an inherent cost effective operating model, which should be considered as a potential starting point for the next generation enterprise MCC architecture. The specific applicability of these architectures at individual sites will require a more detailed review of the specific sites. Such a detailed review was not within the scope of this study. Further analysis is required to truly understand the amount that AMMOS services can directly be used in an enterprise MCC architecture.

Other JPL MCCs architectures are also distributed architecture constructs as is the case in of the Orbiting Carbon Observatory–2 (OCO-2). In Figure 8 the planned functions of the OCO-2 are represented with the core functions mapped to them. The core function acronyms are highlighted in the OCO-2 functional boxes in blue. There is not a one-to-one mapping. but the functions are fully mapped at a high level.



Reprinted courtesy of JPL/Caltech

Figure 8. Functional mapping between core and OCO-2 functions (figure provided by OCO-2 Program Office)

The functions of the OCO-2 are distributed between JPL, Orbital Sciences Corporation (OSC), and NASA Goddard Space Flight Center (GSFC). Core functions are duplicated at several sites as follows:

- *Science Planning (JPL)*
- *Mission Planning (JPL, OSC)*
- *Orbital Analysis and Maneuver Planning (OSC, JPL, GSFC)*
- *Drag Make-up Maneuvers (JPL)*
- *Inclination Adjustments (GSFC)*
- *Command and Load Generation (JPL, OSC)*
- *Tracking, Telemetry, Command and Monitoring (OSC, GSFC, JPL)*
- *Engineering Data Analysis*
- *Flight System (OSC)*
- *Instruments (JPL)*
- *Spacecraft and Instrument Simulation (TBD)*

- *Information and Data Management (JPL, OSC, GSFC)*
- *Anomaly Response (JPL, OSC, GSFC)*

The architecture appears to use a commercial command and control system from OSC for the spacecraft MCC. The instrumentation MCC functions are performed separately by JPL. Space to Ground communication is performed through GSFC. It appears that the Spacecraft and Instrument Simulation is TBD due to the division of spacecraft C^2 and the instruments C^2. This architecture utilizes a commercially available spacecraft C^2 system. The use of commercial products in next generation MCC enterprise architecture needs to be assessed as part of an AoA.

JPL Earth Science Mission Center (EMSC) provides all the functionality that the core functions require. Its architecture is self-contained or stovepiped. It is not a service oriented architecture and is not designed for large expansion to complex distributed architectures. The findings state that this system is able to handle small, non-complex missions but not necessarily the more complex missions. However, the set of core functions are designed for multiple missions' adaption and need to be assessed for exploitation towards core functions.

Goddard Space Flight Center has the Earth Science Mission Operations (ESMO), which manages flight operations and provided data capture and Level 0 processing for several of the NASA ES satellites. The design is setup for multi-mission support. ESMO proves the follow services to new missions:

- Spacecraft Operations
- Flight Operations Management
- High Rate Data Capture and Level 0 Science Data Processing
- Constellation Management.

At first glance, it appears to handle what is needed in an MCC.

Details of the existing NASA MCC nodes and state of the present enterprise architecture follow in Section 3.3.

3.3 Present ES Enterprise MCC Architecture

3.3.1 Overview of Present Enterprise Architecture

The present enterprise architecture is stovepiped with pockets of integration and interoperability. A high level pictorial of the current enterprise architecture is depicted in Figure 9.

The individual mission MCC nodes are represented by the differently shaped and colored objects representing basically independent missions with separate MCCs. This depiction is prevalent in the simplistic representation of GSFC and JPL. The individual missions may have commonality in reuse of software and some common tools but each operates as an independent MCC. There doesn't appear to be any interoperability between missions nor use of common baselines. Reused software is incorporated into mission unique baselines. There is interconnection between local architectures and the enterprise architecture; however there is very limited interoperability. GMSEC provides middleware services for MCCs that utilize it. However, the present services are limited to operational control and data transfers. The application layer is where common functional services would reside.

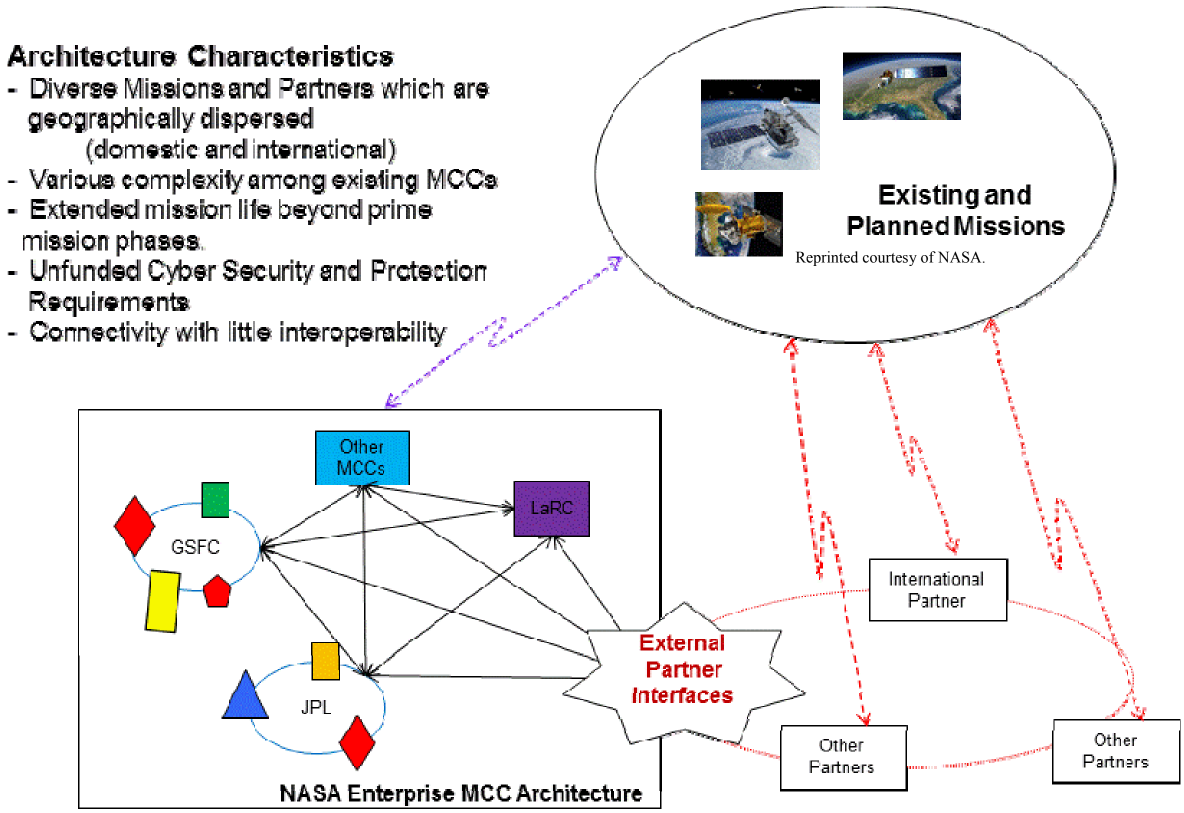


Figure 9. Present enterprise MCC architecture.

3.3.2 Operational Concept

An enterprise level operational concept does not exist among the present NASA MCCs. Each mission operates independently as a stovepipe. Different MCCs and centers also have different operational concepts. Some have single point MCC operations, while others such as JPL have some missions with a distributed MCC operational concept. There are basic operational concepts at the larger centers, which could provide the basis for the next generation MCC enterprise architecture. Within GSFC, there is Goddard Mission Service Evolution Center (GMSEC), which provides the middleware layer for integrated and interoperable architectures. GSFC also has Goddard Science and Engineering Network (SEN), a Local Area Network (LAN) similar and compatible with NISN Service Request (NSRs) that could be used to support a distributed architecture. SEN provides the transport layer for the center architecture and integrates into the NASA Wide Area Network (WAN). GSFC supports several missions that have their own MCC architecture structures. Within the missions at GSFC, there are sub-level architectures that also have attributes that could be expanded to apply at the enterprise level. The operational concept for GSFC is fragmented among the missions, but the evolutionary path is to develop a distributed common architecture with common services.

GSFC Science and Planetary Operations Control Center (SPOCC) offers a landlord/tenant operational model. This model provides flexibility in resource use and software development in supporting different missions with diverse requirements. SPOCC provides the access to common reusable software and facility resources tailorable to support diverse individual Satellite Operation Centers (SOCs). These provide cost efficient SOC developments and operations similar to a distributed architecture. However, the missions still run as stovepipes.

The Jet Propulsion Laboratory (JPL) controls the Advanced Multi-Mission Operations System (AMMOS). AMMOS operates as a business model that uses common operational functions held at a single software baseline. This provides a cost savings by removing duplication and multi-baselines. The internal operational concept is similar to a SOA but is limited due to the archaic stand-alone development of the 1980's/1990's. It does not have the interoperability to even move data to external systems.

JPL's Earth Science Mission Center (ESMC) operates in a limited distributed operation with functions distributed among several nodes. Some of the MCC functions exist at partner locations, as in the case of Jason-1. Jason-1 navigation and spacecraft analysis is done at CNES (France's national space agency). The operational concept includes partner participation. The enterprise architecture must have the flexibility to accommodate this type of functional split.

Key lessons learned from the surveys with respect to operational concept are:

- Several centers have small enterprise architectures that are both distributed and centralized in functionality. These could be used as starting points when evaluating the enterprise architecture.
- Several centers have or are leaning towards common services and tools. These also need to be evaluated, and can be applied to either a distributed or consolidated operational concept.
- Use of enterprise common functional services and tools will accommodate either the operational concept as well as distributed partner integration.
- The infrastructure to support either concept is also set in place with NISN and GMSEC. The enterprise common services and tools would provide the needed application layer.

3.3.3 Typical MCC Node

Within the present NASA MCC nodes, there is not a typical representation. However, there is a typical MCC functional node within a mission. The MCC nodes range from single stand alone nodes to fully functional nodes, where functions are distributed among internal and external system nodes.

The functional MCC typical node is represented by the common functions lists and diagramed in the Figure 10.

3.3.4 Infrastructure

The architecture involves not only these MCC functional nodes but also the infrastructure to provide for interoperability and net-centric operations. The infrastructure must also provide for the multiple and diverse functional allocations.

Infrastructure is usually defined in three functional layers: 1) the transport layer, which provides the basic physical connectivity; 2) the middleware layer, which provides the network services; and 3) the application layer, which provides for operational functional services.

Presently, NASA has their agency wide transport layer available in NISN, which provides a WAN among all NASA MCC. There also are LANs that can easily interface with NISN. GMSEC provides some of the common network services that enable easy integration and high level interoperability and security. The present infrastructure is lacking in the application layer, which provides the common services at an enterprise level.

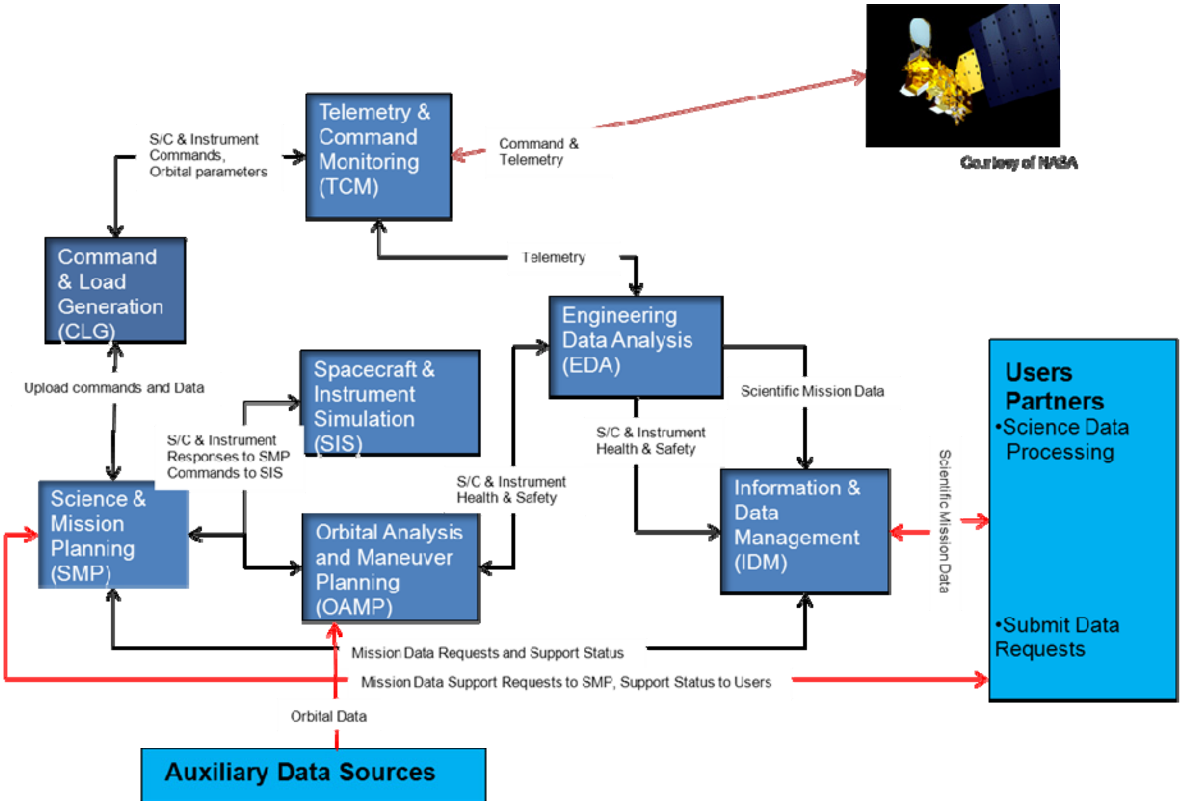


Figure 10. Typical functional MCC node.

These existing enterprise infrastructure components are very likely extendable to the next generation enterprise infrastructure, which should make a future integrated and interoperable architecture a relatively low risk. There are some application architectures that might be able to serve as the beginning of an enterprise application layer. Evaluation of the existing architectures at a very detailed level is needed to determine if they can be used as a migration to enterprise common services. This should be evaluated in an AoA.

A summary of the present missions and how they compare to the goals and attributes of a next generation ES enterprise MCC architecture is provided in the following Table 2.

3.4 Future ES Enterprise MCC Architecture Options

3.4.1 Overview of Future Architecture

The objective for a next generation MCC enterprise architecture is to provide a cost effective structure that supports all of the present and future operational needs. After analyzing the present MCCs and mission needs, it became intuitively obvious that a loosely coupled SOA would best meet the needs. The implementation and details can be divided into two distinctive organizational architectures: centralized and distributed. These two high level architectural constructs are described below.

A centralized construct will provide for the easiest operational concept in dynamic resource allocation and SOA common services. There would be a common infrastructure structure on the transport, middleware, and application layers. The baseline for the common services is kept at the enterprise level so that there are no additional operational costs for maintaining multiple baselines. This keeps

Table 2. Needed Attributes vs. Present NASA MCCs

ATTRIBUTES / NASA MCCs	Reduce operational staffing through operations automation	Enable efficient resource utilization with Processing Virtualization	Enable efficient resource utilization with Processing Virtualization	Reuse common services and tools using Service Orient Architectures (SOA)	Develop enterprise wide operational functional processes common services	Utilize standards enable Common Services and Interoperability
Langley Mission Control Center						
Cloud-Aerosol LIDAR and Infraared Pathfiinder Satellite Operations (CALIPSO)	Uses autonomous Failure Detection and Recovery. Remote control for ops	MOC is backed up in Texas. Distributed functionality.	Apparently tried to utilize other NASA assets but was unsuccessful. Virtualization UNKNOWN	UNKNOWN	UNKNOWN	Data transported between sites.
Jet Propulsion Laboraries						
Advanced Mult-Mission Operations System (AMMOS)	UNKNOWN	UNKNOWN	Software architecture is from 1980's/1990's.	Reuse but not a SOA design.	UNKNOWN	Common Library of tools, Common services for AMMOS customers to use, unclear if use of a common baseline, or services are incorporated into separate baselines?
Earth Science Mission Center (ESMC)	Highly automated which supports small to medium size mission in Earth orbit. Limited to handle complex missions	Distributed architecture. Doubtful if resource use is virtualized.	UNKNOWN	Appears to reuse common tools and functions but not verified as a SOA or details of reuse.	UNKNOWN	UNKNOWN
Orbiting Carbon Observatory (OCO-2)	Normal operations, not clear how much automation is planned	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN
Goddard Space Flight Center						
Earth Science Mission Operations (ESMO)	Working toward fully automated. Presently automated for data capture	Considering	Considering	Reuse and updates to older baseline 1990's	UNKNOWN	UNKNOWN
Global Precipitation Meaasurement (GPM)	Implemented automation using GMSEC	Looking at potential virtual machines to reduce costs	UNKNOWN	Heavy reuse of software but not clear on SOA	UNKNOWN	Looking to implement common standards for data sharing.
Science and Planetary Opoerations Control Cneter (SPOCC)	Objective is a standardized ground data system architecture. Remote controls. Landlord/tenant construct	Flexible resource allocation to meet mission needs. Provides virtual machine environments	Has capability to offer mission machine virtualization	Leverages cloud architecture. Provides reuse science and instrument operations, and mission operations.	UNKNOWN	Utilizes standards. Missions appear to be stovepipe MCCs.
Space Science Mission Operations Center (SSMO)	Uses automation as much as feasible but unclear what that means.	Appears to have separate baselines for the individual missions. UNKNOWN for virtualization	UNKNOWN	Reuse of processes for new missions, but not clear if common baselines are kept.	UNKNOWN	UNKNOWN
Goddard Mission Services Evolution Center (GMSEC)	Satellite mission operations center S.W framework. Middleware for net-centricity					

Configuration Management (CM) at a single point which also helps to control security and protection. This architecture is illustrated in Figure 11.

In Figure 11, operational mission nodes are denoted by the small individual shapes. They are all colored the same red because all use the C-MCC for MCC functions. Hence, their MCC functional requirements are met by the same baseline set of services.

One major issue with this concept is that it will still need to implement an operational mode to provide for functional distribution among partners and other stakeholders.

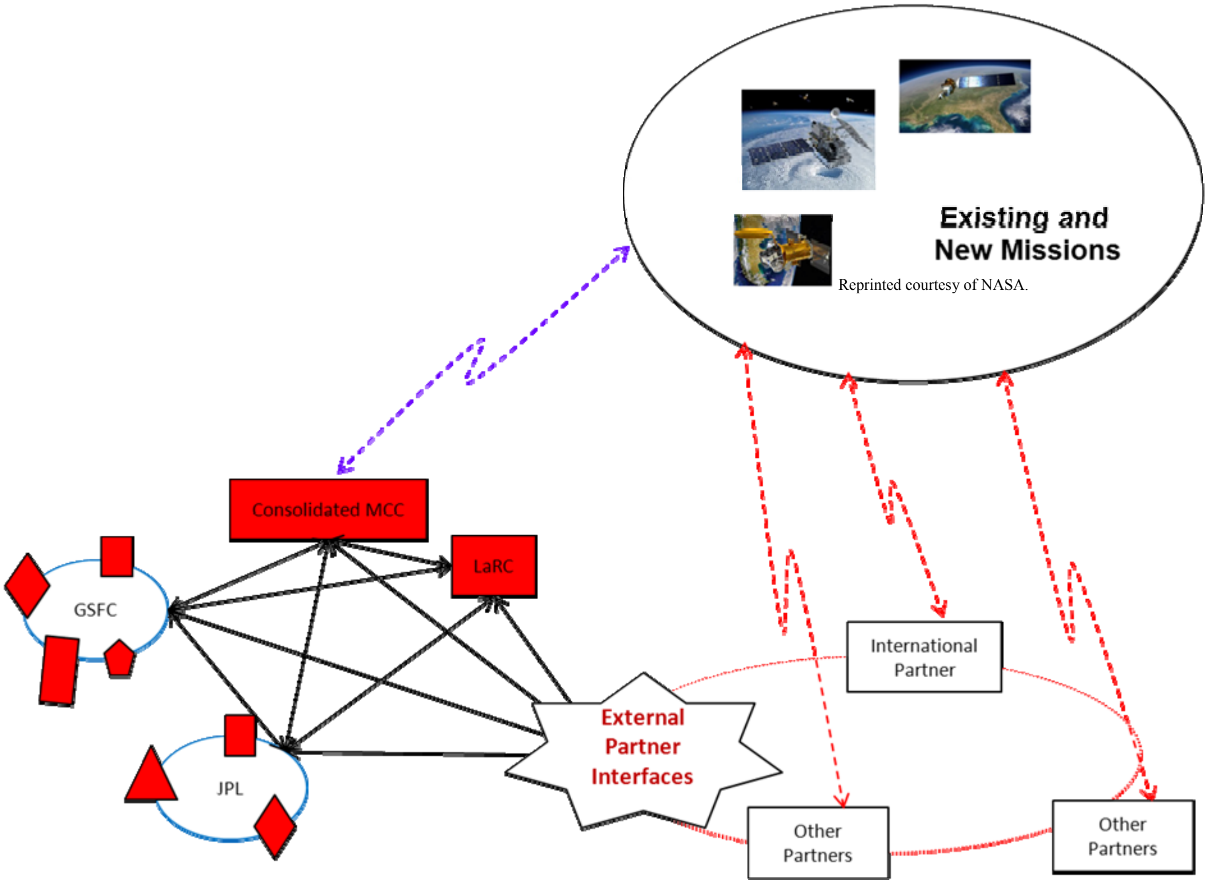


Figure 11. Centralized architecture.

The other top level architecture construct would be a distributed SOA with common services, which could be distributed or centralized at individual mission MCCs. The baseline for the common services is kept at the enterprise level so that there are no costs of maintaining multiple baselines. This keeps Configuration Management (CM) at a single point, which helps to control security and protection. The distributed nature of this construct accommodates all the present node configurations. The drawback is that now the MCC nodes are responsible for the MCC functionality, and there is no central control. This makes dynamic loading and allocation of resources a much more complex problem if implemented. Enterprise situational awareness (SA) is also slightly more complex since there is no entity that is monitoring the SA of the enterprise MCC functionality. However, the diversity of nodal MCC system implementations does provide for a certain amount of architectural resilience, especially if interoperability and dynamic resource allocation is doable and implemented.

The cloud drawing around the entire NASA MCC enterprise represents the ability for dynamic resource allocation similar to cloud processing. Operational nodes would be a part of the enterprise cloud.

The trades between these concepts need to be analyzed during an AoA, where there are sufficient details on present and future MCC requirements and operations.

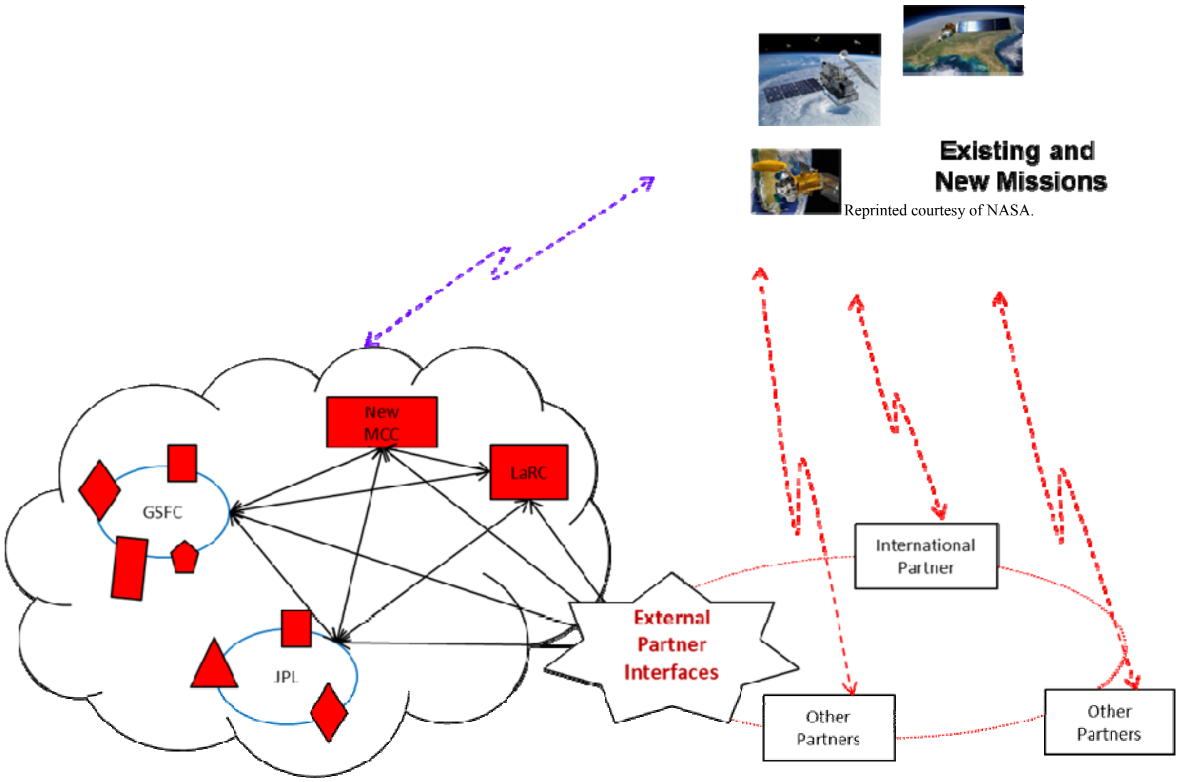


Figure 12.

3.4.2 Architectural trade spaces

There are several top level aspects that need to be evaluated during an AoA. These include but are not necessarily limited to the following:

- Boundaries of the enterprise
- Common Baselines in Hardware and Software
- SOA implementation of functions
- Standards used for interoperability
- Virtualization of resources H/W and S/W
- Centralization versus Distributed
- Collaboration and Sharing
- Operational Concept
- Present components or nodes, cost of migration

The extents that these attributes should be incorporated into architecture must be determined by the cost/benefit effectiveness of each attribute. There are pros and cons to each attribute. These are listed in Table 3.

Table 3. Architecture Attribute Trades

Archtecture Trades	Pros	Cons	Recommendation
Boundaries of the enterprise	Limiting the boundaries of an architecture limits the necessary occomodations the architecture has to consider.	The efficiency of the total operations are not included in the total trade space.	Maintain the boundaries of functionality of NASA in each mission MCC process. This may not include all of the core functions because they may be the responsibility of another partner.
Common Baselines in Hardware and Software	Having common baselines reduce developmental and operational O&M costs	Having a common baseline in H/W and S/W reduces resilience and flexibility. This imposes a cookie cutter approach which has never worked.	There is a logical balance between common baselines and funcatonally common baselines. In H/W, this doesn't necessary increase cost excessively. S/W having enterprise common services for those services which are truly common usually makes cost effective sense.
SOA implementation of functions	SOA makes the baseline a set of services which help to reduce duplication of functions.	Implementing a SOA requires not only a major restructure in most legacy systems but also additional network services. The Global Information Grid (GIG) has been struggling with this for years.	An AoA whill show what those are and if moving over to a SOA is in general cost effective. Implementing a SOA is only cost effective if services are needed at the enterprise level. There are costs to move to SOA. Bottomline is to move to SOA at the enterprise level that which is truly needed at the enterprise level.
Standards used for interoperability	Standards make interoperability issues such as interconnectivity and operability easy. Collaboration and data sharing become trivial. Net-centricity is implemented.	Standards can be inhibiting and costly for legacy systems to migrate to. Standards can not be levied on systems that are not under one's direct control or without signed Interface Control Documents (ICD). There are a multitude of standards available but eveyone doesn't use just one. Requires tailoring and can be costly if not correct.	Limiting the standards is generally the best approach. The analysis of what standards to use to minimize the impacts on legacy systems is also critical.
Virtualization of resources H/W and S/W	Allows for rapid resource balancing and allocation to meet enterprise level operational needs. Optimizes the resource useage.	Requires constant enterprsie monitoring and balancing to optimize the resources. Requires additional information assurance monitoring. Can increase security requirements and vulnerabilities.	Virtualization of S/W through common services or clients and mobile code enables extensive flexibility in the architecture construct. Local virtualization of H/W also probably makes sense since the control net is smaller than an enterprise of dispersed nodes. In a centralized construct, then both would allow for maximum resource useage.
Centralization versus Distributed	Centralized keeps control of configurations and allows for an easier implementation of virtualization in both H/W and S/W. Distributed constructs allow for resilience and natural dispersed backup if necessary.	Centralized construct will have a single center basically have all of ones eggs in one basket. The impact of the node failing makes the impact far reaching. However, centralized construct does not proclude backup operations. Distributed construct naturally limits the impact of one node failing.	Considering the present state of MCCs it appears that a distributed construct might be an easy migration. This could be a stepping milestone for a migration to a consolidated construct as well as a natural offramp point.
Collaboration and Sharing	Diverse partnership need collaboration and sharing to effectively perform the mission. It adds to the efficiency of the enterprise	Requires more infrastructure.	The infrastructure exists.
Operational Concept (Enterprise level)	The operational concept at the enterprise level keep operational plans and training simplier.	Too much constraint on the operational concepts at the enterprise level can be harmful to individual mission.	Enterprise level operational concept should limited to use of the enterprise common services and infrastructure as much as possible.

3.4.3 Operational Concept Options

The operational concepts for either proposed architecture construct are similar. The consolidated MCC concept must provide the same operational node for a distributed architecture. The following paragraph will describe the two types of operational modes of the consolidated architecture construct.

With a consolidated MCC, the operational concept will focus on using the Consolidated MCC (C-MCC) for all common MCC functions for those mission contained within NASA's domain. To accommodate external partner distribution of MCC functions, the C-MCC will use a common standard to exchange data, commands, and collaboration. The NASA MCC enterprise situational awareness (SA) will be implemented by the C-MCC and operational mission nodes that are kept abreast of the SA. Cyber security and protection will be monitored by the C-MCC, but provided by the network infrastructure and each operational mission node.

3.4.4 Future MCC Node Options

Consolidated architecture constructs will have the following characteristics:

1. Operations that do not involve distributed MCC functions distributed outside of NASA domain will be provided by a C-MCC.
2. The C-MCC will provide as needed common functions support to Mission Operational Centers (MOCs).
3. The C-MCC will operate in an autonomous operational mode with on-call support as needed.
4. Only a skeleton crew will be necessary to operate the C-MCC on an 8/5 basis.
5. The C-MCC will be capable of supporting new missions during their initial operations phase, which may require a phase to characterize the mission behavior through trending analysis. Once a mission is stable, it will be supported using automated operations.
6. C-MCC will provide for remote operational capability. This will be made available for those missions requiring intensive care and feeding operational support.
7. Missions requiring hand holding care will be responsible as a mission unique requirement to provide for these non-automated operations, and will operate remotely through this remote interface.
8. Communications, interoperability and enterprise situational awareness will use NASA's WAN infrastructure NISN and GMSEC.
9. Internal mission or center LANs will also incorporate GMSEC to provide enterprise level health and status to ensure enterprise situational awareness.
10. All common MCC functions and services will be implemented in a SOA at the C-MCC.
11. Common services will also be available as mobile distributed code, which will allow for dynamic processing virtualization. (TBD)
12. Interoperability between external foreign partners when functionality is distributed will be through the use Consultative Committee for Space Data Systems (CCSDS) standards for mission services (CCSDS 520.0-G-3).
13. Interoperability with external domestic partners, where MCC functionality is required to be distributed, will use GMSEC Application Programming Interface (API).

14. Enterprise situational awareness will be performed at the C-MCC. Potential resource reallocation will be the responsibility of the C-MCC with coordination with impacted MOCs. (TBD)

Distributed architecture constructs will have the following characteristics:

1. A single baseline of common MCC function services will be made available as needed to support Mission Operational Centers (MOCs).
2. The MCC functionality will be capable of operating in an autonomous operational mode with on-call support as needed.
3. Only a skeleton crew will be necessary to operate on an 8/5 bases.
4. Trending analysis will be made available for new mission to define the mission common operations.
5. Common services will provide for remote operational capability.
6. Communications, interoperability and enterprise situational awareness will use NASA's WAN infrastructure NISN and GMSEC.
7. Internal mission or center LANs will also incorporate GMSEC to provide enterprise level health and status to ensure enterprise situational awareness.
8. All common MCC functions services will be implemented in a SOA.
9. Common services shall also be available as mobile distributed code which will allow for dynamic processing virtualization. (TBD).
10. Interoperability between external foreign partners when functionality is distributed will be through the use Consultative Committee for Space Data Systems (CCSDS) standards for mission services (CCSDS 520.0-G-3).
11. Interoperability with external domestic partners, where MCC functionality is required to be distributed, will use GMSEC Application Programming Interface (API).
12. Enterprise situational awareness will be performed at the TBD. Potential resource reallocation will be the responsibility of the TBD with coordination with impacted MOCs. (TBD)
13. MOCs and NASA centers will provide enterprise situational awareness information.

3.4.5 Infrastructure Options

Based upon the surveys of the present NASA MCCs, the infrastructure is well on its way in development. It requires some additional capability, but most of the improvements need to be at the application layer and are dependent on the details of the existing applications and their structures.

The application layer for either architecture construct is very similar. There tends to be more emphasis on mobility of code or server/client relationships in the distributed architecture construct. The emphasis for the consolidated architecture construct is on interoperability in the infrastructure that could drive to more standards.

Distributed constructs allow for potentially greater resilience in the enterprise by having functionally equivalence without system duplication. Diversity in system implementation is what provides the increase in resilience. This does not preclude a centralized construct from implementing diversity in its systems, but will increase operational O&M costs.

Whether a distributed or consolidated construct is baselined, the application layer should migrate towards a SOA for those functions that have the most commonality.

3.5 Recommendations

At this point in time a definitive next generational NASA enterprise MCC architecture recommendation cannot be justified. However, either the consolidated or distributed architecture construct appears to be doable with a reasonable migration from present to the future. The main issue is establishing the way forward to ensure that missions and centers that are presently developing the needed capability to implement either architecture construct are on the same page so that diverse duplication is not being implemented.

A recommendation that can help to establish the end goal is to obtain the necessary details that will influence the parameters that have been identified as major factors in each of the architecture options. Once these necessary details are obtained, the recommendation is to perform an AoA to develop costs and risks assessments that will establish the most cost-effective, low-risk next generation NASA enterprise MCC architecture.

4. Acronyms

ACE	Advanced Composition Explorer
ACRIMSAT	Active Cavity Irradiance Monitor Satellite
AGS	Attitude Ground System
AIRS	Atmospheric Infrared Sounder
AMMOS	Advanced Multi-Mission Operations System
ASIST	Advanced Spacecraft Integration & System Test Software
BATC	Ball Aerospace & Technologies Corporation
CALIPSO	Cloud-Aerosol LIDAR and Infrared Pathfinder Satellite Operations
CARA	California Association for Research in Astronomy
CCSDS	Consultative Committee for Space Data Systems
CFDP	CCSDS File Delivery Protocol
CNES	Centre National d'Etudes Spatiales
CONAE	Argentina's Comisión Nacional de Actividates Espaciales
COTS	Commercial off-the-shelf
CSO	Communications Services Office
C^2	Command and Control
DAAC	Distributed Active Archive Center
DESDynI	Deformation Ecosystem Structure Dynamics of Ice
DoD	Department of Defense
DSN	Deep Space Network
EDOS	EOS Data and Operations System
EOS	Earth Observation System
ES	Earth Science
ESD	Earth Science Division
ESDIS	Earth Science Data and Information System
ESMC	Earth Science Mission Center
ESMO	Earth Science Mission Operations
ESTO	Earth Science Technology Office
FDIR	Failure Detection Isolation and Recovery
FDS	Flight Dynamics Subsystem
FEDS	Front End Data Systems
FOT	Flight Operations Team
FTE	Functional Technical Equivalents
GALEX	Galaxy Evolution Explorer
GCOM-W1	(Japanese satellite with no direct acronym translation) Water observation spacecraft
GEO	Geosynchronous Earth Orbit
GMSEC	Goddard Mission Services Evolution Center
GOTS	Government off-the-shelf
GPM	Global Precipitation Measurement
GRACE	Gravity Recovery and Climate Experiment
GSFC	Goddard Space Flight Center
HCI	Human Computer Interface
HEO	Highly-Eccentric Orbit
HVAC	Heating, Ventilation, and Air Conditioning
ICS	Interface Control Specification
IDS	Intrusion Detection
IOC	Instrument Operations Centers
IPAC	Infrared Processing and Analysis Center

IT	Information Technology
ITAR	International Traffic in Arms Regulations
ITOS	Integrated Test and Operations System
ITSEC	Information Technology Security Evaluation Criteria
JAXA	Japanese Aerospace and Exploration
JPL	Jet Propulsion Lab
LaRC	Langley Research Center
LASP	Laboratory for Atmospheric and Space Physics
LDCM	Landsat Data Continuity Mission
LEO	Low Earth Orbit
LIDAR	Light Detection And Ranging
LRO	Lunar Reconnaissance Orbiter
LSIMSS	LDCM Scalable Integrated Multi-Mission Support System
MCC	Mission Control Center
MOC	Mission Operations Center
MOM	Message Oriented Middleware
MOS	Mission Operations System
MPS	Mission Planning System
MSFC	Marshall Space Flight Center
MTASS	Multimission Three-Axis Stabilized Spacecraft
NAIF	Navigation Ancillary Information Facility
NEN	Near-Earth Network
NISN	NASA Integrated Services Network
NOAA	National Oceanographic and Atmospheric Administration
NSR	NISN Service Requests
OCO-2	Orbiting Carbon Observatory
ORS	Operationally Responsive Space
OS	Operating System
OSC	Orbital Science Corporation
PARASOL	(No Acronym) French-built Earth observing satellite
PI	Principal Investigator
QuikSCAT	Quick Scatterometer
RFI	Request for Information
RSO	Resident Space Object
RSPO	Robotics Systems Protective Office
RTADS	Real Time Attitude Determination System
S/C	Spacecraft
SAC-C	Third in a series of optical imaging satellites (Argentina)
SEN	Science Engineering Network
SDO	Solar Dynamics' Observatory
SLOC	Software Lines of Code
SMAP	Soil Moisture Active Passive
SN	Space Network
SOA	Service Oriented Architecture
SOC	Space Operations Center
SPICE	(No Acronym) JPL-created toolkit for planning and working with interplanetary data
SPOCC	Science and Planetary Operations Control Center
SSAI	Science Systems and Applications, Inc.
SSMO	Space Science Mission Operations
SSR	Solid State Recorder
SW	Software

SWOT	Surface Water and Ocean Topography
T&C	Telemetry and Commanding
TBD	To Be Determined
TDRSS	Tracking, Data, and Relay Satellite System
TOPEX/ Poseidon	(No Acronym) Surface topography mission
TRMM	Tropical Rainfall Mapping Mission
TTC&M	Tracking, Telemetry, Command and Monitoring
WIND	(No acronym) spacecraft built to explore solar wind
WISE	Wide-field Infrared Survey Explorer
XFDS	XMM Flight Dynamics System

5. References

1. Earth Science Mission Center Description, Donald Royer, Jet Propulsion Laboratory, October 1, 2011

2. *Wynn Watson,* Goddard Space Flight Center (GSFC), November 14, 2012

3. Personal notes from Bonnie Keillor Slaten from ESMO Project Overview by Wynn Watson, GSFC, November 14, 2012

4. Global Precipitation Measurement (GPM) Mission Operations Center (MOC), David McClure, MOC Development Lead, Tony Foster, GPM Ground System Manager, Goddard Space Flight Center (GSFC), November 14, 2012

5. Personal notes from Bonnie Keillor Slaten from GPM Mission Operations Center (MOC) by David McClure, GSFC, November 14, 2012

6. GPM Questions Answered for the NASA MCC Architecture Study, David McClure, MOC Development Lead, GSFC, November 14, 2012

7. Science and Planetary Operations Control Center (SPOCC) and Lunar Atmosphere Dust Experiment Explorer (LADEE) Science Operations Center (SOC), Jenifer Sager and Paul Swenson, Goddard Space Flight Center, November 14, 2012

8. Personal notes from Bonnie Keillor Slaten from Space Science Mission Operations (SSMO) Interview Questions, Ed Nace, GSFC, November 14, 2012

9. TOR-2012(1570)-11877e, Compatible Satellite C2 (Sat C2) Prototype Technical Overview and Demonstrations Briefing Charts, Tom Sullivan, Jan 27, 2012

10. Goddard Mission Services Evolution Center "GMSEC," Dan Smith, Goddard Space Flight Center, November 14, 2012

11. Ross, Jeanne W., Peter Weill and David C. Robertson, Enterprise Architecture as Strategy: Creating a Foundation for Business Execution, Harvard Business School Press, Boston, 2006.

12. Architecture and Operations of a NASA and Non-NASA Earth Science Mission Control Centers, prepared by Aerospace Civil and Commercial Operations, TBD

13. CSO-001, National Aeronautics and Space Administration (NASA) Communications Service Office (CSO) Services Document, October 2012, NASA CSO

14. Cloud Computing Strategy Memorandum, July 2012, Department of Defense (DOD) Chief Information Office (CIO).

15. Long-Term Planning and Adoption of Commercial Practices Could Improve DOD's Operations. GAO-13-315, Apr 18, 2013.