18th International Conference on Space Operations, Montreal, Canada, 26 - 30 May 2025.

SpaceOps-2025, ID # 160

The Virtualized Multi-Mission Operations Center (vMMOC): Goddard Space Flight Center's Solution for Future Spacecraft Operations

Chris Bomhardt

Right Ascension 231, LLC / NASA, chris.bomhardt@ra231.com

Abstract

The Virtualized Multi-Mission Operations Center (vMMOC) represents Goddard Space Flight Center's solution for spacecraft operations in the future. This paper examines the philosophy behind the vMMOC, which aims to provide common ground system components, tools, processes, and a shared staffing model across multiple missions to drastically reduce the cost of post-launch mission operations. The solution leverages modern technologies including virtualization, containerization, cloud-computing, shared services, and built-in IT security, leading to less costly ground system development. The shared staffing model across both flight operations and engineering provides the ability to add new missions without adding new staff. The vMMOC has successfully integrated several NASA missions including Fermi, Lunar Reconnaissance Orbiter, Advanced Composition Explorer (ACE), Wind, Magnetospheric Multiscale (MMS), and the Solar Dynamics Observatory (SDO), resulting in significantly lower sustained operations costs. The paper further discusses future directions for the vMMOC, including the evolution towards a cloud-native solution called Polaris, which will offer a collection of loosely coupled applications and services that, when integrated, provide a complete MOC and ground system solution for future missions.

Keywords: virtualization, multi-mission operations, cloud computing, spacecraft operations, shared services, ground systems

Acronyms/Abbreviations

Advanced Multi-Mission Operating System (AMMOS), Advanced Composition Explorer (ACE), Configuration Management Database (CMDB), data at rest (DAR), data in transit (DIT), Goddard Space Flight Center (GSFC), Mission Operations Center (MOC), Multi-Factor Authentication (MFA), Magnetospheric Multiscale (MMS), NASCOM Mission Backbone (NMB), software defined network (SDN), Solar Dynamics Observatory (SDO), Virtualized Multi-Mission Operations Center (vMMOC)

1. Introduction

The traditional model of spacecraft operations typically involves dedicated mission operations centers for each mission, resulting in significant redundancy in infrastructure, staffing, and services. This approach has proven to be costly and inefficient, particularly in an era of budget constraints and increasing mission complexity. The need for a more efficient and cost-effective approach to spacecraft operations has led to the development of the Virtualized Multi-Mission Operations Center (vMMOC) at Goddard Space Flight Center.

The vMMOC represents a paradigm shift in how spacecraft operations are conducted, moving from siloed, mission-specific operations centers to a shared, virtualized environment that serves multiple missions simultaneously. This paper presents the architecture, capabilities, and benefits of the vMMOC, as well as future directions for this innovative approach to spacecraft operations.

1.1 Background and Motivation

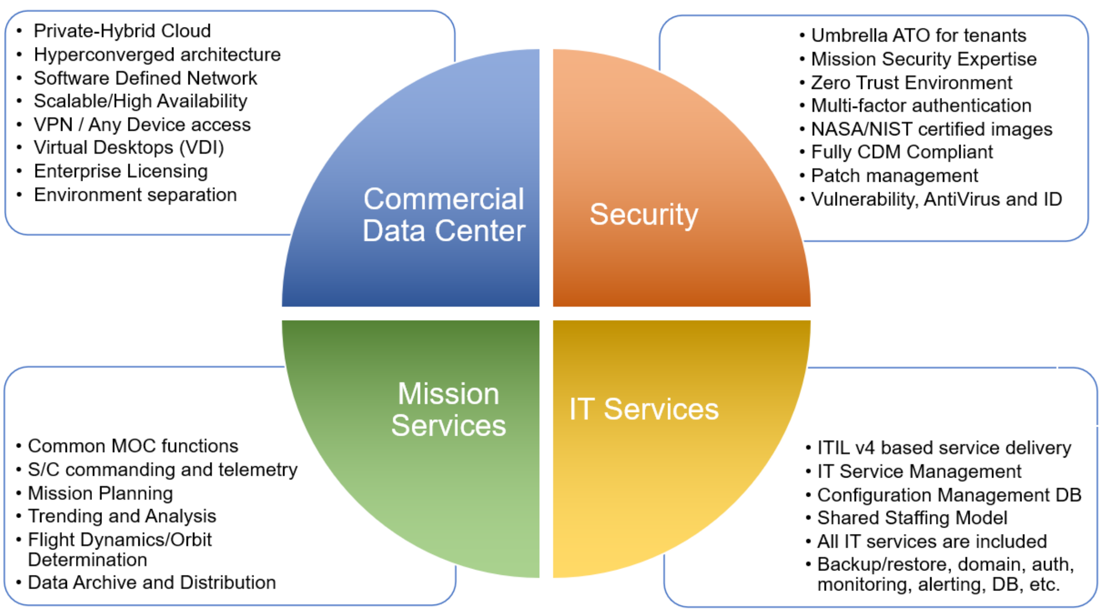
Traditional spacecraft operations centers are typically designed, built, and operated independently for each mission. This approach results in duplication of infrastructure, software, and personnel across missions, leading to inefficiencies and increased costs. The vMMOC was conceived as a solution to address these challenges by providing a shared platform that can support multiple missions simultaneously, leveraging common components and staff across missions.

1.2 Paper Organization

This paper is organized as follows: Section 2 describes the vMMOC architecture and its four main functional areas. Section 3 discusses the scalability of the vMMOC and provides examples of missions that have been migrated to this platform. Section 4 outlines future directions for the vMMOC, including the evolution towards a cloud-native solution called Polaris. Finally, Section 5 provides conclusions and recommendations for future work.

2. vMMOC Architecture and Functional Areas

The vMMOC was designed and built around a commercial IT services philosophy with a centralized organization providing functional services around four main areas: 1) Commercial Data Center; 2) IT Security; 3) IT Service Delivery; and 4) Mission Services.



2.1 Commercial Data Center Infrastructure

The vMMOC was built using a hyper-converged architecture with a software defined network (SDN). Hyper-converged architectures are typically used in commercial edge datacenters and consolidate compute, memory, and storage resources into large shared pools that can be partitioned in unlimited ways. This approach reduces bottlenecks to externally attached SANs and includes a software management layer that allows the entire cluster to be managed by a single pane of glass console, reducing the need for multiple management software consoles for SANs, hypervisors, storage, etc.

An SDN provides a single DMZ-based network based on a leaf-spine architecture that enhances North-South traffic flow and provides East-West segmentation. It also allows fail-over to the cloud without changing IP addresses. The SDN connects to the NASA Mission Backbone and can connect with any ground station or IP address in the world.

The vMMOC provides multiple separate networks for physical communication, development/testing, production, external access, and a separate network for backups and archiving. The system is designed with high availability and can lose up to 30% of physical nodes without negatively impacting operations, eliminating single points of failure.

We provide many core services typically found in a corporate IT environment such as:

- **VPN**: Secure connectivity with any device (NASA and Non-NASA) with host scanning and geolocation security.
- **Virtual Desktops (VDI)**: Secure access to NASA or USGS imaged Windows machines including PIV authentication.
- **Enterprise Licensing**: No need to purchase additional licenses for Windows or Red Hat OS.
- **Environment/Network Separation**: Fully supported development, test, and production systems that are logically separated, with multiple clusters at GSFC and White Sands to provide failover and meet geographic diversity requirements.

2.2 IT Security

The vMMOC was designed with security as a fundamental consideration from the beginning. Key security features include:

- **Umbrella Security**: All tenants of the vMMOC are covered under a system-wide Authorization-to-Operate and a shared System Security Plan. Mission-specific requirements and systems are included in a tailored section in the existing documentation.
- **Common ITSec Team**: A dedicated security team works across all missions, eliminating the need for mission-specific security staff. The team works closely with tenant flight teams and vMMOC engineering teams to ensure security is handled across missions in a unified manner.
- **Network Security**: All ports are locked by default, every packet that traverses the network is interrogated, and complete data at rest (DAR) and data in transport (DIT) encryption is implemented within the cluster.
- **Multi-Factor Authentication (MFA)**: Support for PIV and DUO MFA for NASA, non-NASA, and foreign national users.
- **Compliance**: The vMMOC is fully compliant with NASA Office of the CIO's Continuous Diagnostics and Monitoring requirements and adheres to all United States Department of Homeland Security reporting requirements. It is also fully NIST 800.53 Rev 5 compliant.

2.3 IT Service Delivery

The vMMOC provides two categories of IT services based on the ITILv4 framework: common IT functions and project support functions, along with shared staffing teams.

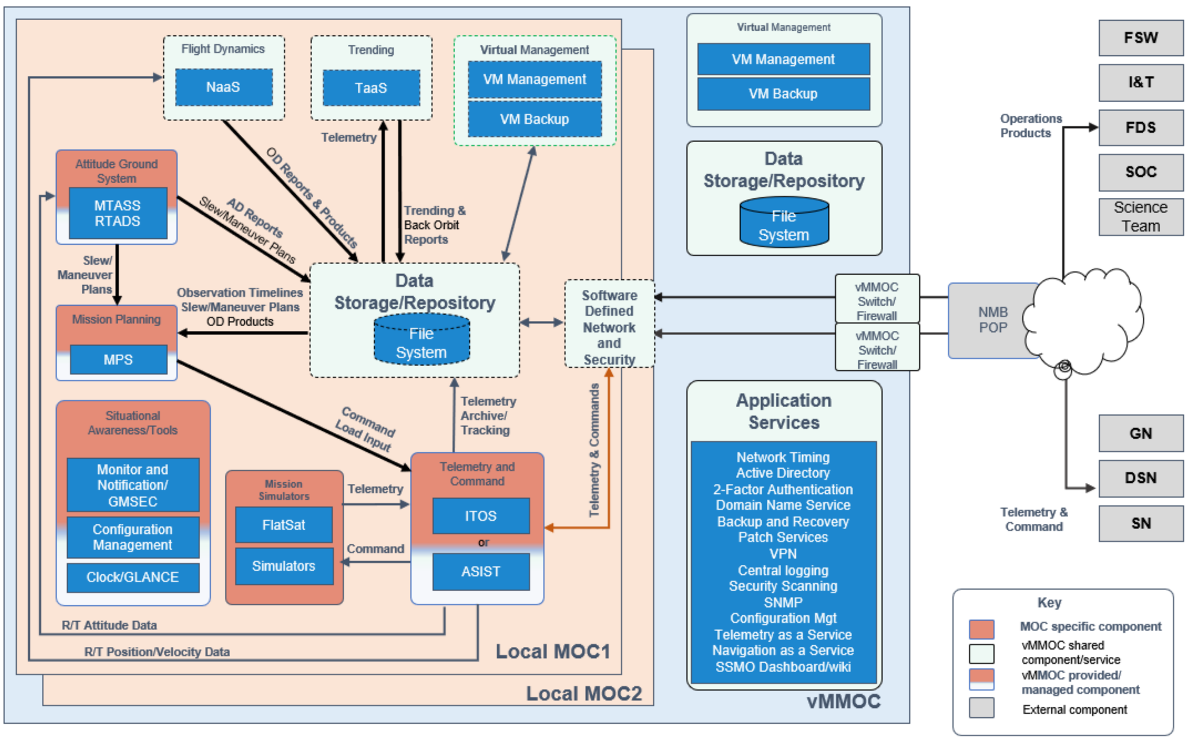
- **IT Services**: Core IT services expected in any corporate environment, such as backup/restore, domain/firewall/network management, system monitoring and alerting, HA database solutions, identity/LDAP/AD management, etc.
- **Support Services**: Including a Configuration Management Database, asset and document management repositories for documents and code, GitHub, Jira, Confluence, and ticketing systems for IT support.
- **Shared Staffing Model**: Dedicated teams for flight operations, mission planning and scheduling, ITSec, engineering, and architecture services. This allows resource pooling, particularly around IT support, reducing the need for expensive dedicated mission system administrators.

2.4 Mission Operations Services

The vMMOC provides core flight operations functions including:

- **Commanding and Telemetry**: ITOS, ASSIST, Yamcs, etc.
- **Mission Planning**: MPS, FlexPlan, with ongoing work with JPL/AMMOS to expand their Aerie product into a fully multi-spacecraft, multi-mission planning system hosted within the cloud.
- **Trending and Analysis**: Telemetry as a Service (TaaS) and a Situational Dashboard that are cloud-based.
- **Flight Dynamics**: Navigation-as-a-Service (NaaS), GMAT/GMAN

In contrast to the vMMOC approach, a typical 'legacy' mission architecture involves each mission having its own Mission Operations Center (MOC) instance that is logically separated from other missions, with separate development, test, and operations environments for that mission.



3. vMMOC Scalability and Mission Integration

3.1 Scalability Features

The vMMOC was designed to be scalable, highly available, and state of the art. There are over 800 virtual machines actively running at any time, with another 400 that are suspended and ready to be spun up when needed by flight teams. Scale is achieved by adding more physical nodes to the cluster or extending into the cloud. Multiple clusters exist in different buildings at GSFC, along with an extended cluster configuration at the White Sands Complex in New Mexico, achieving geographic diversity.

The health of the cluster and network is constantly monitored, with regular capacity planning sessions held with all tenants. All systems are thin provisioned at startup, and the system automatically allocates additional resources when predefined SLAs and KPIs are met to maintain system performance and response time. Eight SSMO missions have been added to the cluster in the last two years with no impact to each other or overall cluster downtime. Since beginning operations in 2017, the vMMOC has achieved over 99.999% availability for mission customers. A direct connection to AWS GovCloud provides additional scale and flexibility with workloads and data requirements.

3.2 Mission Integration Examples

Several NASA missions have been migrated from their siloed, bespoke ground system and MOC solutions to the vMMOC, including:

- Fermi
- Lunar Reconnaissance Orbiter (LRO)
- ACE
- Wind
- MMS
- SDO

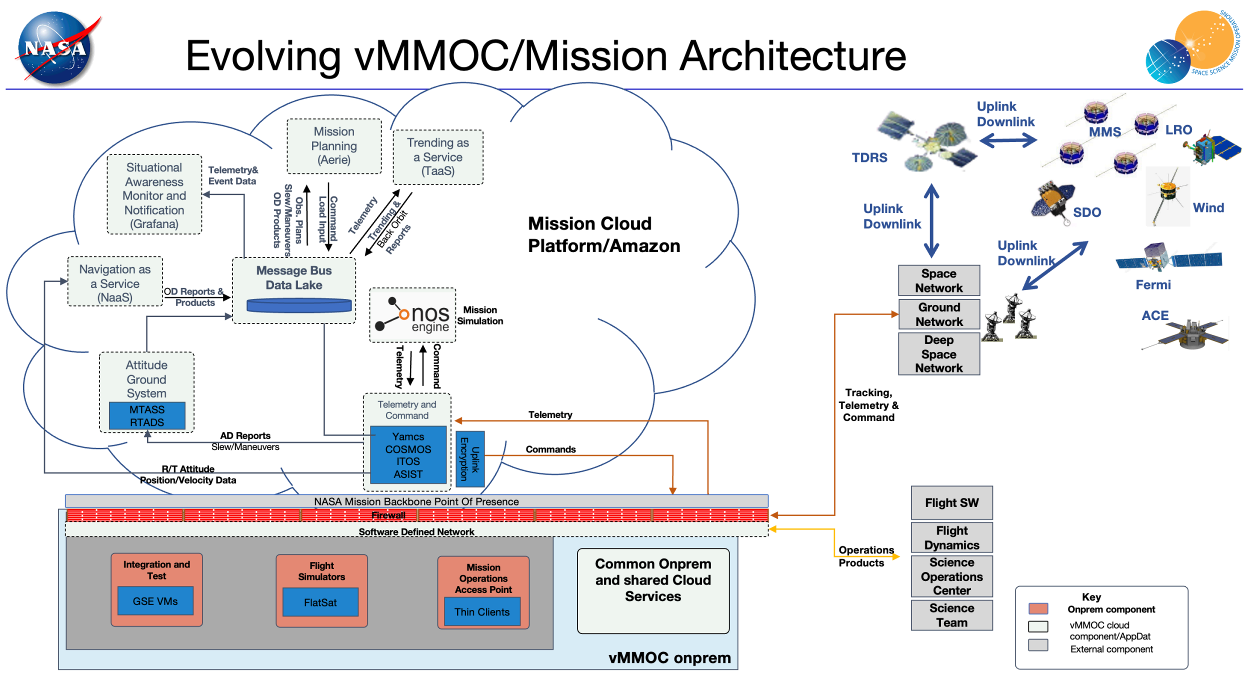
Each of these missions previously had their own datacenters, networks, and flight teams. They all followed the same migration path into the vMMOC, where they now share common services and flight teams, resulting in significantly lower sustained operations costs. Typical migrations were completed with three months for existing missions.

4. Future Directions: The Path to Polaris

4.1 Evolution to Cloud-Native Solutions

While there will always be requirements to maintain an on-premises (NASA-based) presence for certain missions due to legacy issues, purpose-built or proprietary hardware solutions, or security concerns, there is a clear need to move toward cloud-native solutions for future missions that are still in the proposal phase.

The vMMOC team is working to establish a baseline set of applications that can be used across missions, focusing on similarities rather than differences, and viewing risk as something to be managed rather than avoided. The architecture is evolving to be more cloud-centric, as illustrated below:



4.2 The Polaris Initiative

The goal of the Polaris initiative is to provide future missions with a next-generation baseline ground system comprised of best-in-class software and services. The plan is to leverage NASA/JPL's Advanced Multi-Mission Operating System (AMMOS) library and extend vMMOC into a cloud-native multi-mission ecosystem.

Polaris aims to provide a single, low-cost solution for new mission ground system and MOC requirements. While its primary focus will be on new missions, if implemented correctly, it can also serve as a cost-effective migration path for legacy missions. Polaris will be a collection of loosely coupled applications and services that, when integrated, provide a complete MOC and ground system solution. It will be:

Based on standards & specifications	Cloud native but portable
Modular	Cost competitive (known operations cost)
Extremely reliable	Readily deployable

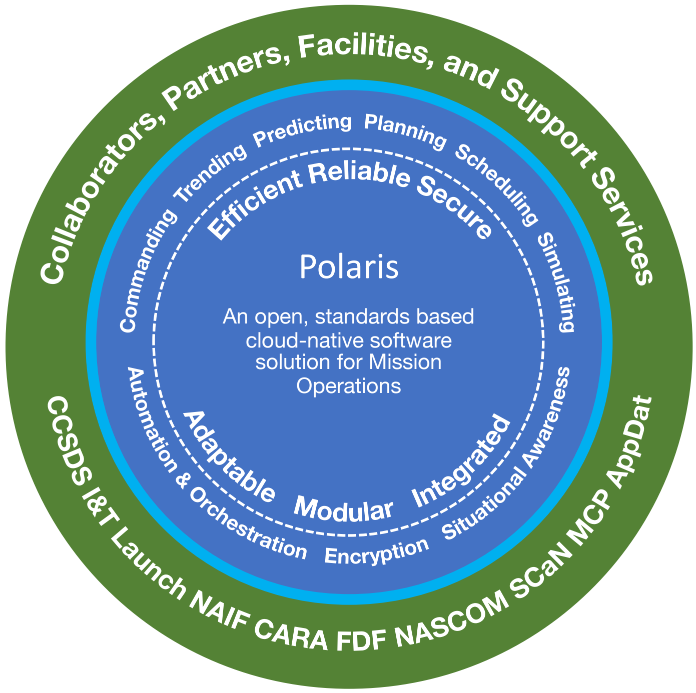
Standards Implementation: This approach balances prescriptive and suggestive standardization while strictly enforcing certain tools and standards (e.g., CCSDS, XTCE) while offering flexibility for missions to implement their own tools that meet requirements when necessary.

Modular Design: The architecture employs a loosely coupled framework where components can be interchanged seamlessly, similar to building blocks, maximizing adaptability for all stakeholders.

System Reliability: Reliability serves as a foundational requirement. This cloud-native architecture incorporates elasticity and redundancy principles to ensure consistent operation.

Vendor Independence: The system is designed to be cloud-native yet portable, operating effectively within any virtual private cloud or vendor environment without dependency on specific providers.

Operational Cost Transparency: The commitment is to publish accurate operations and sustainment costs based on extensive experience managing multi-hosted mission environments. This transparency addresses the historical tendency of government-funded missions to underestimate Phase E costs during the proposal process.



Polaris relies on and will be enabled by several key technologies and an overall philosophy focused on:

- **Cloud-native**: Open-source software and technologies such as containers, microservices, and service mesh to develop and deploy scalable applications on cloud computing platforms.
- **Data lake**: A centralized repository designed to store, process, and secure large amounts of structured, semi-structured, and unstructured data in its original form, used to train AI/ML.
- **Serverless**: A cloud computing application development and execution model that enables developers to build and run applications without provisioning or managing servers or backend infrastructure.
- **Event-Driven**: Asynchronous software model and architecture designed to capture, route, and process events or triggers between decoupled microservices.

5. Conclusion

The Virtualized Multi-Mission Operations Center (vMMOC) represents a significant advance in spacecraft operations, providing a shared, virtualized environment that can support multiple missions simultaneously. By leveraging common infrastructure, software, and staff across missions, the vMMOC has demonstrated substantial cost savings and operational efficiencies compared to traditional mission-specific operations centers.

The successful migration of multiple NASA missions to the vMMOC platform has validated this approach, with these missions now benefiting from shared services and staffing while maintaining mission-specific requirements and capabilities. The high availability and scalability of the vMMOC architecture ensure that new missions can be added without impacting existing operations or requiring significant additional resources.

Looking to the future, the evolution toward a cloud-native solution through the Polaris initiative promises to further enhance the capabilities and cost-effectiveness of the vMMOC approach. By embracing modern technologies such as containerization, microservices, and serverless computing, Polaris aims to provide a flexible, scalable, and efficient platform for future spacecraft operations.

Acknowledgements

James E. Clapsadle NASA, james.e.clapsadle@nasa.gov

Rich Burns NASA, rich.burns@nasa.gov