111189 **N95-17604**

32009

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Renaissance Architecture for Ground Data Systems

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ABSTRACT

The Mission Operations and Data Systems Directorate (MO&DSD) has embarked on a new approach for developing and operating Ground Data Systems (GDS) for flight mission support. This approach is driven by the goals of minimizing cost and maximizing customer satisfaction. Achievement of these goals is realized through the use of a standard set of capabilities which can be modified to meet specific user needs. This approach, which is called the Renaissance architecture, stresses the engineering of integrated systems, based upon workstation/local area network (LAN)/fileserver technology and reusable hardware and software components called "building blocks." These building blocks are integrated with mission specific capabilities to build the GDS for each individual mission. The building block approach is key to the reduction of development costs and schedules. Also, the Renaissance approach allows the integration of GDS functions that were previously provided via separate multi-mission facilities. With the Renaissance architecture, the GDS can be developed and operated by the MO&DSD or all, or part, of the GDS can be operated by the user at their facility. Flexibility in operation configuration allows both selection of a cost-effective operations approach and the capability for customizing operations to user needs. Thus the focus of the MO&DSD is shifted from operating systems that we have built to building systems and, optionally, operations as separate services.

Renaissance is actually a continuous process. Both the building blocks and the system architecture will evolve as user needs and technology change. Providing GDS on a per user basis enables this continuous refinement of the development process and product and allows the MO&DSD to remain a customer-focused organization. This paper will present the activities and results of the MO&DSD initial efforts toward the establishment of the Renaissance approach for the development of GDS, with a particular focus on both the technical and process implications posed by Renaissance to the MO&DSD.

INTRODUCTION

The MO&DSD provides end-to-end mission support for National Aeronautics and Space Administration (NASA) low earth orbit scientific space flight projects. This support ranges from establishing the radio frequency (RF) link with the user spacecraft for data acquisition, tracking and spacecraft commanding to distribution of captured instrument data to scientific investigators. In meeting its charter over the last three decades, the MO&DSD developed significant expertise within its organizational elements in building and operating systems to meet requirements in these functional areas. As an example, flight dynamics support is provided by one MO&DSD Division. That Division builds and operates institutional, multi-mission systems to support flight missions. Other Divisions are responsible for other areas of support. In general, Division systems were housed in multi-mission facilities and based on large mainframe computer architectures, to provide efficient and cost-effective ground support operations for missions.

These MO&DSD systems and services reflect a technology environment where large computers provided the only viable system solutions, and a science environment that often advocated large and complex science objectives and correspondingly complex spacecraft. But now both the nature of the users and the technology environment have changed significantly. NASA science programs have embraced the "faster, better, cheaper" philosophy as a means of survival in the present fiscally constrained environment. Smaller spacecraft are being built with substantially reduced budgets and development schedules from those of their predecessors. At the same time, the modern computer technology trend is embodied in small, powerful workstations connected via a network in appropriate configurations to meet specific processing needs. This combination of smaller missions and flexible technology has created enormous opportunity for users and providers to find innovative ways of doing business.

BACKGROUND

Drivers for change within MO&DSD have come from numerous sources, both external and internal to the MO&DSD. Acknowledgment of these led the MO&DSD to actively and collectively seek new ways of serving its customers' needs. The drivers and initial analysis activities targeted at addressing the consequent challenges are discussed.

External Drivers for Change

The nature of the newer scientific missions and the prevailing technology have led to a desire and ability on the users part not just to receive data, but to actually operate all or part of the ground data system in order to meet the objectives of their missions. The MO&DSD past approach to mission operations with shared institutional systems does not possess the flexibility to meet such changes in customer needs. Chiefly, because this approach ties solutions for all users to a common technology, it also does not possess the resiliency to implement cheaper, streamlined systems for mission support where these are appropriate. In addition, customers have felt that dealing with several separate multi-mission facilities added complexity in dealing with MO&DSD for mission support. This is especially true for the smaller and simpler space flight projects that tended toward a more consolidated approach for mission and science planning and operations. Finally, with the dramatic reduction in the cost of computing power resulting from the evolution of data processing technology, the previous cost advantage of the multi-mission approach based upon mainframe computer architectures has evaporated. Flight project customers perceive the MO&DSD past approach to mission operations as not being the most cost-effective.

Internal Drivers for Change

Recent downsizings of mission budgets coupled with the availability of rapid technology advancements have led the organizational elements within MO&DSD to seek alternate solutions for development and operation of ground data systems within their functional areas. Utilization of workstation/LAN architectures, formalized software reuse, and adoption of commercial standards have all been successfully demonstrated within the Divisions for several years. For example, a paper published in the SPACEOPS 92 Proceedings entitled "SAMPEX Payload Operations Control Center Implementation" described the first development of a Payload Operations Control Center (POCC) based upon the Transportable POCC (TPOCC) architecture. These technology innovations have been beneficial and demonstrated significant cost savings. However, before Renaissance they remained generally localized within the various MO&DSD facilities. While there were benefits that accrued from collaboration across Division facilities, they had not yet gained supremacy as a standard way of accomplishing the MO&DSD mission.

Architecture Analysis Activities

Recognizing these drivers, the MO&DSD initiated activities to explore new, consolidated approaches for development and operation of GDS for flight mission support. The goals of minimizing cost, maximizing flexibility for meeting customer requirements, and reducing complexity were established for this effort. A study was commissioned to identify GDS architecture approaches that offer significant reductions in cost and development schedules as well as increased flexibility for meeting individual customer requirements in establishing mission support capabilities. The report recommended an architecture approach that addressed implementations from simple to complex missions through integration of support functions in a mission-specific instantiation. Implementations would employ reuse over multiple missions and incorporate effective standards for commercial product inclusion

An Architectural Steering Group (ASG) was established to evaluate the recommendations from the architecture study report and to determine if the scope of the study should be expanded to address space-to-ground and ground-to-ground communications mission support functions. The ASG also chose to commission two additional studies: to look at current and future Directorate operations concepts to assure that operations as well as development improvements would be realized in the new architecture. The ASG activities ultimately led to the identification of an architecture approach that stressed the engineering of integrated systems that encompassed the MO&DSD mission support functions of flight dynamics, spacecraft command and control, and data capture and distribution. These systems would be based on workstation/LAN/fileserver technology and reusable hardware and software components called building blocks. The name "Renaissance" was applied to this architecture approach. ("Renaissance" is an acronym that stands for Reusable Network Architecture for Interoperable Space Science, Analysis, Navigation, and Control Environments.) The ASG also determined that the institutional nature of communication services should not be changed, though in fact the technology of implementing these services will be improved as Renaissance evolves.

THE RENAISSANCE CONCEPT

The MO&DSD has embraced change through Renaissance on two fronts. First, is willing to view itself as a provider of both systems and services, rather than primarily a provider of services. Secondly, is the espousal of particular objectives to facilitate achievement of Renaissance.

MO&DSD Renaissance Services

Renaissance divides the domain of MO&DSD mission support capabilities into three areas: mission operations, science operations, and centers of expertise (see Figure 1).

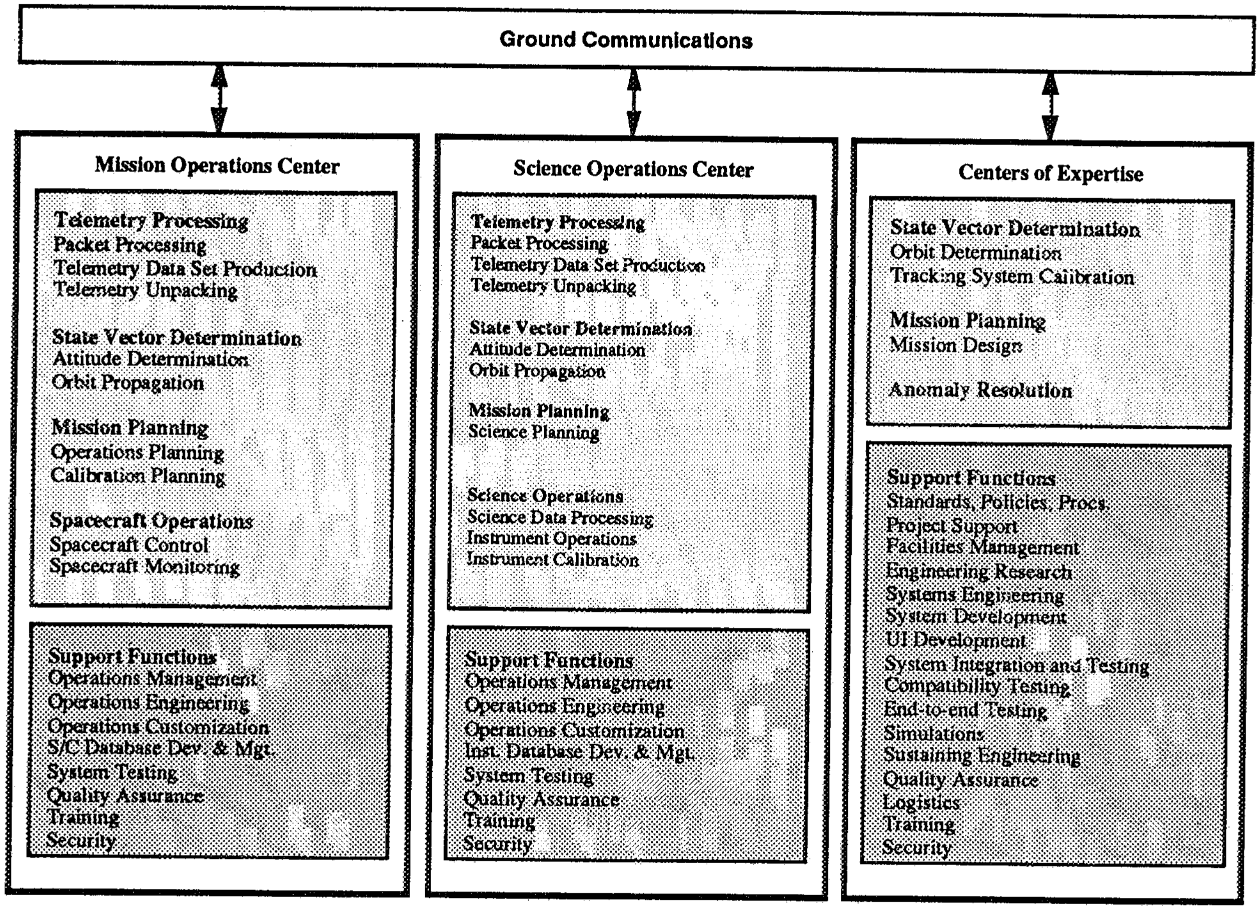

Figure 1. Renaissance Mission Support Domain

Mission operations are those functions that are integrated to operate the spacecraft to meet the specific requirements for that mission. Similarly, science operations are integrated to achieve the science objectives of a specific mission. The functional elements associated with mission and science operations are physically embodied within a Mission Operations Center (MOC) and a Science Operations Center (SOC), respectively, for each flight mission. Under the Renaissance concept, the MOC and the SOC could be integrated into a single center, collocated in a shared facility, or geographically dispersed. There is no requirement that either be located at the Goddard Space Flight Center (GSFC).

The third area of the MO&DSD domain, the Centers of Expertise (COE), comprise a permanent institutional infrastructure that contains the resources to support the set of flight missions over their entire life cycle. Obviously, the key resource within the COE is the personnel with the technical skills and experience in the development and operation of GDS. The balance of the COE resources include the tools, materials, and processes that are applied by the personnel to develop and operate the mission support functions.

Renaissance Objectives

The Renaissance architecture approach espouses three major objectives for achieving the goals of cost-effectiveness, flexibility, and simplicity for providing mission operations support to space flight project customers. Firstly, to assure that developed systems permit integrated operations in a stand-alone environment for unique mission support. Development and operation of mission-specific systems provides maximum flexibility for customizing the GDS to meet the user's particular requirements. The integration of mission support functions for command and control, flight dynamics and data processing also presents an opportunity for reducing the cost of ground system development through the elimination of redundant functions that had been replicated within each of the multi-mission systems, (e.g., telemetry unpacking). Developments, however, would not preclude recombining of functions into multi-mission facilities if this should prove cost-effective.

The second objective inherent with Renaissance is reuse of support capabilities. Here reuse means a systematic, planned approach for developing reusable components of ground data systems rather than reuse on an ad hoc basis. It implies well-defined interfaces and use of standards to implement systems, and an ability to insert new technology readily over time. The construction and use of these reusable components, or "building blocks", is the key to reducing the cost of ground system development. MO&DSD established a Renaissance Project Team to define those "building blocks".

The third significant objective associated with Renaissance is the projectized approach to GDS development and operation which is aimed at reducing the complexity associated with the present user interfaces. Previous mission support systems have of course been coordinated among MO&DSD Divisions, but subsystems were implemented in separate facilities and not functionally integrated. The new approach calls for completely integrated requirements and integrated testing. Establishment of a mission team, led by a Ground System Project Manager (GSPM), provides a focal point within the MO&DSD for matters relating to the development and operation of MO&DSD GDS. The team defines the mission system, and integrates reusable Renaissance "building blocks" with mission-unique building blocks that it develops. The team also assures that space flight project customer needs receive strong advocacy within the MO&DSD.

APPROACH TO ACHIEVING RENAISSANCE

The ASG selected the Advanced Composition Explorer (ACE) mission for the initial implementation of a Renaissance GDS. The mid-97 launch date was close enough to provide for a relatively quick demonstration of Renaissance without incurring the risks related to interruption of system developments that were already well under way [e.g., X-Ray Timing Explorer (XTE) and Tropical Rainfall Measuring Mission (TRMM)].

The challenge faced by the MO&DSD teams was to achieve the modular "building block" goals of Renaissance, while simultaneously meeting the near-term mission needs of the ACE Mission. Schedules, climate and budget would not allow for an extended period of time to prototype Renaissance concepts before instantiating them in a mission. Building blocks could not be created first, followed by mission-unique pieces. Parallel paths and integrated planning were required to achieve the ACE Mission.

However, this challenge was not as daunting as it might appear. Two factors created a climate for success: tight integration of the Renaissance and ACE implementation teams; and extensive availability of predecessor systems that meet Renaissance goals.

Implementation Teams

The Renaissance Project Team, a core group of highly capable engineers, was charged with Renaissance building block definition. Their charter was as follows:

- Identify building blocks through examination of ACE and other system (e.g., XTE) requirements to determine generic functionality.

- Identify predecessor systems and Commercial Off-the-Shelf (COTS) products that could meet the building block specifications.

- Identify standards and development processes useful in the Renaissance era.

- Develop plans for transitioning into the Renaissance approach.

- Work with the mission teams, initially the ACE team, to apply the Renaissance architecture.

This core team was augmented by additional MO&DSD engineers who served to provide input to their efforts and to review and critique the outcomes. In particular, those engineers charged with implementing the ACE Mission were early and constant participants in the Renaissance effort.

Predecessor Systems

Despite the use of the Renaissance name to capture a system concept within the MO&DSD, many predecessor efforts on other missions were aligned with the Renaissance concepts, and influential in molding its goals and giving confidence that the architecture would be successful. The Renaissance concept, in fact, was merely an acceleration and consolidation of various efforts that were already occurring naturally within the Directorate. Reliance on these efforts gave credence to the possibility of meeting both ACE and Renaissance goals within the aggressive schedule. Examples of forerunner efforts include:

- The TPOCC UNIX-based software that supports real-time spacecraft command and control and that, prior to Renaissance, was in use or planned for use for the Small Explorer missions (SAMPEX, FAST, SWAS), ISTP WIND, POLAR and SOHO, XTE and TRMM. The TPOCC brings a legacy of substantial software reuse as well as workstation and LAN-based processing.

- The VLSI-based Level Zero Processor (LZP) employed on the FAST mission. This system captures spacecraft science data and removes transmission artifacts before forwarding it to science investigators. It is integrated into the mission command and control facility, and as such is a predecessor to the Renaissance operations approach.

- The Packet Processor (PACOR) II distributed system, a multi-mission data capture and level zero processing system planned for use by SWAS, TRMM, XTE, HST and GRO. PACOR illustrates both system (hardware and software) reuse and distributed processing.

- The Generic Support System (GSS), a reusable system for attitude determination.

- The Generic Spacecraft Analyst Assistant (GenSAA), a tool that allows spacecraft analysts to create graphics and rule-based systems to assist in monitoring spacecraft health and safety, and other decision-based situations.

- The Generic Trend Analysis System (GTAS), a reusable spacecraft trending tool.

All of these systems support in some measure the Renaissance objectives of reusability and integrated, stand-alone systems. Figures 2 and 3 capture the extent to which these goals are met in missions prior to ACE.

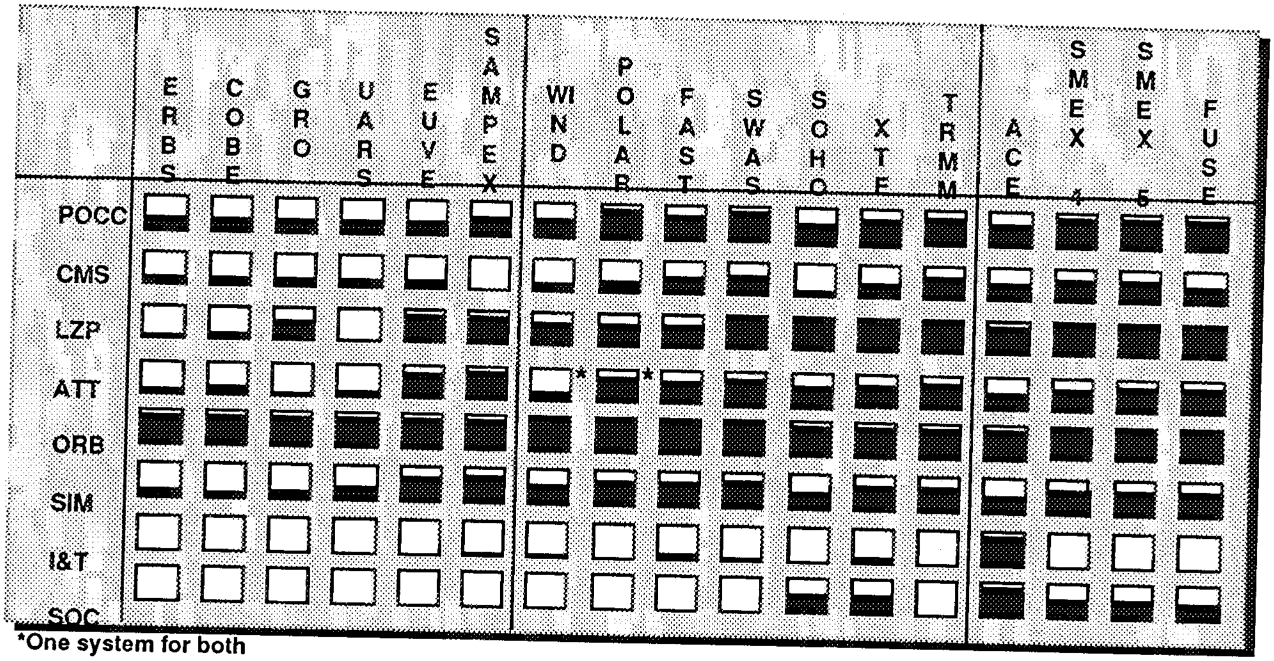

Figure 2. Percent Reuse

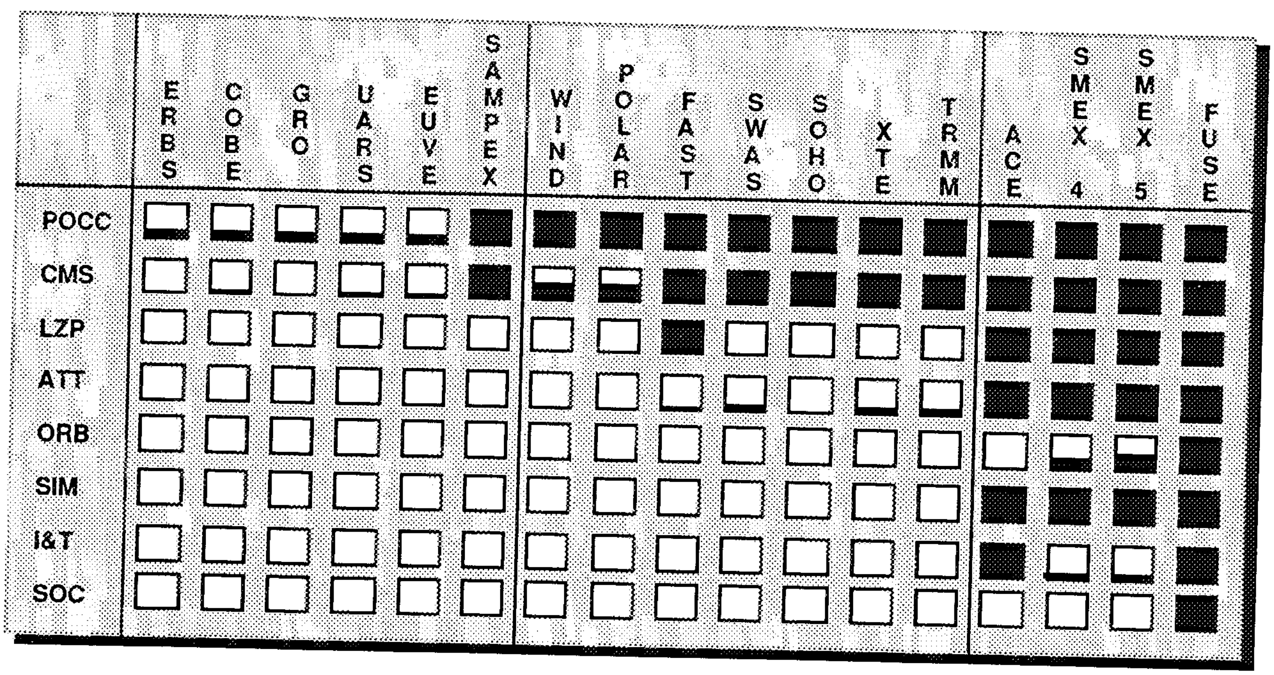

Figure 3. Percent Independent of Multi-Mission Facilities

ACHIEVEMENTS TO DATE

Early efforts have partitioned the Renaissance GDS into four sets of services. A Renaissance Project Team working group is defining functionality and building blocks for each set. The groupings are as follows:

- Spacecraft Communication Services (reconstruction of telemetry packets, command transmission, packet annotation, time correlation, and archiving).

- Spacecraft Data Distribution Services (real-time, quick-look and routine data delivery, data subsetting, output logging, and delivery validation).

- User Services (user interface, user tools and application builders, system configuration and monitoring, system security, system time synchronization, and data management).

- Application Services (spacecraft services such as telemetry monitoring, trend analysis, attitude support, command verification; planning and scheduling applications for spacecraft, science and network activity planning; and uplink applications such as real-time commanding and load generation).

Two additional working groups are assigned to issues that cross all Renaissance services:

- Architecture group, charged with defining the integrated architecture.

- Simulation and testing.

Many of the promised innovations of Renaissance are being realized within the context of the ACE ground system, including largely integrated operations, consolidation of functionality, incorporation of new technology and standards, and reliance on the legacy of past systems. Figure 4 illustrates the architecture proposed for ACE.

Integrated Operations

It is intended to incorporate real-time command and control, command and load generation, attitude determination and data capture and distribution within the ACE mission operations center. The only major MO&DSD ground system function that will still be treated within a separate facility for this mission is orbit determination and the ancillary production of maneuver planning aids. The ground station and SOC will remain separate from the MOC. (These facilities are not implemented by MO&DSD and are traditionally separated from MO&DSD facilities. Future directions will lead to the consolidation of MOC and SOC functions. See, for example, related paper in this conference, "A New Systems Engineering Approach to Streamlined Science and Mission Operations for the Far Ultraviolet Spectroscopic Explorer (FUSE)."

Consolidation of Functionality

In two significant arenas, functionality previously developed and performed within multiple facilities will be consolidated. Firstly, there will be a single front-end for frame synchronization, Reed-Solomon processing, virtual channel separation, and data quality annotation. This front-end will be located at the Deep Space Network (DSN) ground station (vs. former performance of portions of this function in three MO&DSD facilities). Data will be forwarded from there to the ACE MOC. This system will also allow data to be forwarded directly to the SOC for processing, if this proves desirable.

Secondly, a consolidated simulator that will meet the testing needs of all ground system functions is planned for development

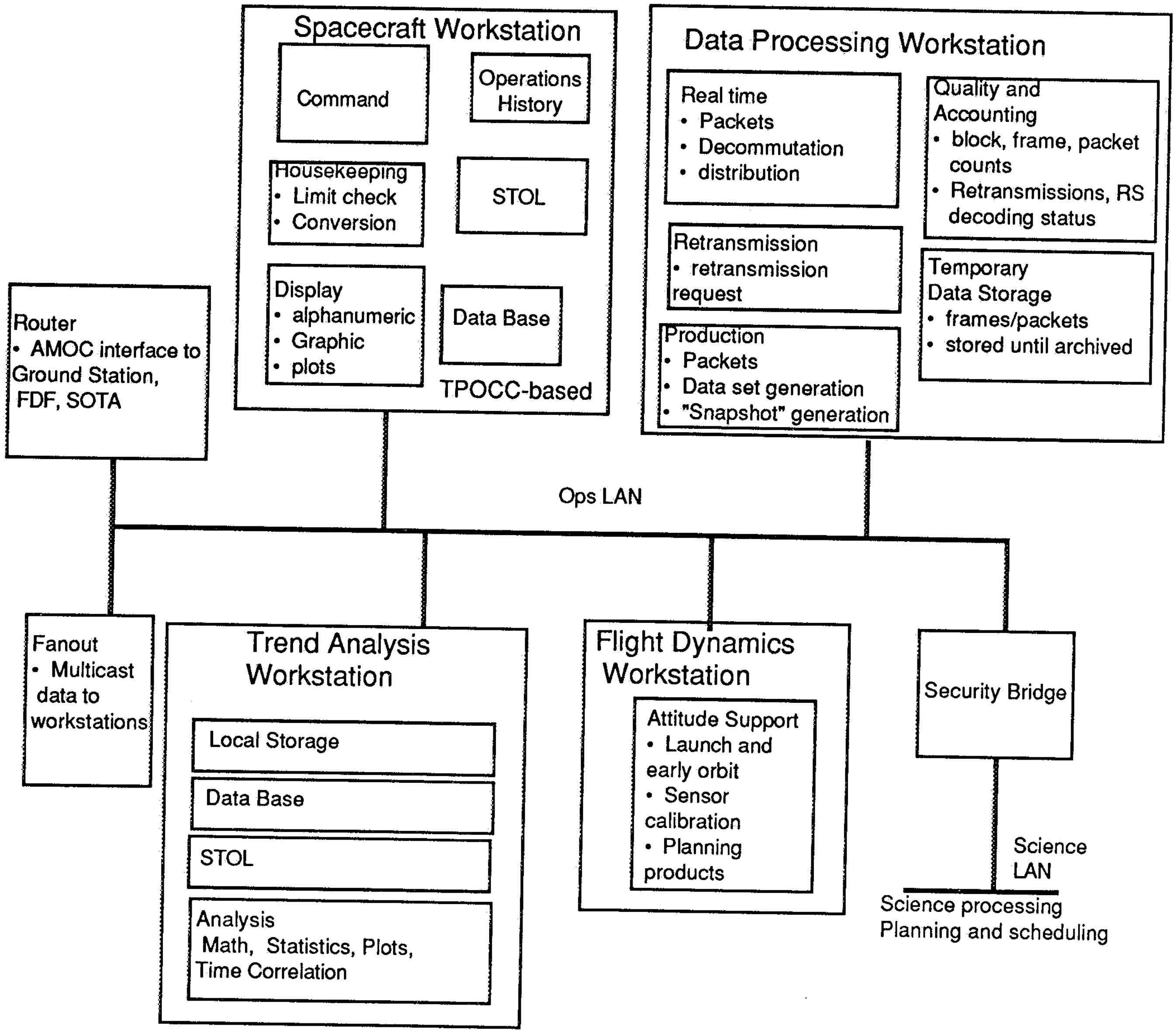

Figure 4. Renaissance Architecture for ACE MOC

Incorporation of Technology and Standards

A particular innovation within the ACE ground system is the use of the commercially available Transmission Control Protocol/Internet protocol (TCP/IP) protocol to transmit data from the ground station to the MOC. This allows replacement or encapsulation of the traditional 4800-bit NASA Communications (Nascom) blocks, and eliminates the need for custom systems to handle these blocks. Use of this protocol paves the way to ultimately reduce institutional cost for providing ground communications because of wide commercial availability and ability to eliminate Nascom blocks in the future.

The ACE ground data system will consist of a series of workstations supporting POSIX and communicating via a LAN. Software will be developed in ANSI C, C++ or Ada. While each workstation will have particular functionality assigned to it, the ability to move functions among workstations for load balancing or recovery from anomalies will be supported.

The ground system will also use X-windows and MOTIF as interface standards.

Predecessor Systems

The ACE ground system will depend heavily on building blocks, either implemented particularly to support ACE as the first mission, or derived from predecessor systems within MO&DSD. Table 1 lists ACE services and their derivation.

CONCLUSION

The consolidated Renaissance effort is less than a year old. Progress is substantial, however, due to an aggressive project team and integration of predecessor systems already aligned with Renaissance goals. Reliance on Renaissance products is allowing the MO&DSD to work with its customers in defining low-cost systems whose operations are tailored to the customers needs, for example, with the FUSE and the upcoming Small Explorer missions. Early results are promising, and the Directorate is committed to sustaining a management approach that will allow Renaissance goals to be achieved.

Table 1. Derivations of Renaissance Services for ACE

	Renaissance Building Blocks	Legacy Building Blocks	Mission Specific Building Blocks	Commerical Off-the-Shelf
User Services	•Interactive UI	•Event User Interface •Display •Report •STOL •HUD •Sim UI •LZP Ops •LZP QA	•MOC Init	•Window System •Network Mgmt
Application Services	•Mission Planning •Image Maintenance •RTADS •Commanding •Off-line ADS	•Gen Equation Processor •Maneuver Planning •GMT Sync •Contact Prediction •Config Monitor •State Manager	•Load Generation •Clock Correlation •Eqn Processor •Recorder Mgmt	
Data Services	•LZP Product Generation •LZP RT Proc •DSN Monitor Block Process •CMD Echo	•GMT Router Server •Event Logging •Telemetry Decom •Data Server •History	•Load Database	•File Server •DBMS
Space Comm	•Packet Services •Raw Data Logging		•Embedded. Frame Sync	•Comm Software •Multicast Server •Time Server

Nomenclature

ACE	Advanced Composition Explorer
ASG	Architectural Steering Group
COE	Centers of Expertise
COTS	Commercial Off-the-Shelf
DSN	Deep Space Network
FAST	Fast Auroral Snapshot Explorer
FUSE	Far Ultraviolet Spectroscopic Explorer
GDS	Ground Data Systems
GenSAA	Generic Spacecraft Analyst Assistant
GRO	Gamma Ray Observatory
GSFC	Goddard Space Flight Center
GSPM	Ground System Project Manager
GSS	Generic Support System
GTAS	Generic Trend Analysis System
HST	Hubble Space Telescope
ISTP	International Solar Terrestrial Physics
LAN	Local Area Network
LZP	Level Zero Processor
MO&DSD	Mission Operations and Data Systems Directorate
MOC	Mission Operations Center
NASA	National Aeronautics and Space Administration
Nascom	NASA Communication
PACOR	Packet Processor
POCC	Payload Operations Control Center
POLAR	Polar Plasma Laboratory
RENAISSANCE	Reusable Network Architecture for Interoperable Space Science
RF	Radio Frequency
SAMPEX	Solar Anomalous and Magnetospheric Explorer
SOC	Science Operations Center
SOHO	Solar Oscillator Heliospheric Observatory
SWAS	Submillimeter Wave Astronomy Satellite
TCP/IP	Transmission Control Protocol/Internet Protocol
TPOCC	Transportable Payload Operations Control Center
TRMM	Tropical Rainfall Measuring Mission
WIND	International Physics Laboratory
XTE	X-ray Timing Explorer